Switchgear Design Impacts the Reliability of Backup Power Systems

by

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When a cascaded sequence of events led to the ultimate collapse of a highly interconnected power transmission system, the Northeastern “blackout” of 2003 demonstrated that the present utility infrastructure will not adequately support critical processes. And despite the fact that power-monitoring technology has been available to record the sequence of events down to millisecond resolution, the deployment of such technology was insufficient to construct a uniform explanation for the events.

Any control system is subject to malfunction due to the aging of components, improper maintenance or operator error. Built-in diagnostic and event re-construction technologies are the key elements of disaster recovery, as they quickly point to the root cause of the problem. Therefore, the first lesson learned is that the deployment of a sophisticated sequence of events recording system is an essential element of design where critical power is needed.

The second lesson learned is that standby generators with automatic transfer are indispensable. At first glance the function of automatic transfer equipment appears to be very simple. Programmable logic controllers and relays of various degrees of sophistication sense the quality of voltage, start standby generators and transfer the power. In reality the nature of the switchgear control scheme may become quite complex while no industry standard provides comprehensive design specifications.

Therefore, there is a large degree of variation in functionality between the products of various manufacturers. The burden of assuring proper functionality of equipment is laid upon the specifying engineer who communicates his requirements through performance specifications. A basic knowledge of the inner-workings of the switchgear is necessary for developing successful applications.

POWER SYSTEM TOPOLOGIES

The simplest system topology involves two sources of power such as a utility source and a generator source and does not involve load shedding. Double throw automatic transfer switches or circuit breaker transfer pairs are used in this application in an open transition configuration (figure 1). In this arrangement the transfer mechanism includes an electrical (and/ or mechanical) interlock such that the two sources can not be closed at the same time.

Closed transition power transfer, on the other hand, refers to paralleling of the two sources for a short period of time when returning the power from the alternate to the normal source. Under this condition where both sources of power are of acceptable quality, the two sources are closed into the common bus for a short time period before opening the circuit breaker on the alternate source.

The arrangement in figure 1 poses a fundamental reliability issue. The common bus on the load side of the transfer switch is a single point of failure and the loss of this bus will cause complete loss of power to the critical load. The arrangement in figure 2 partially resolves the reliability
problem by introducing the tie circuit breaker. A bus fault on the right half of the switchgear can be isolated by the automatic operation of the tie circuit breaker assuring that half of the loads will continue to be supplied.

Figure 3 illustrates a medium voltage design where more than one generator is required. This design utilizes generator paralleling, which is costly and increases the complexity of the control system. Figure 4 provides an alternative arrangement. Proponents of each system may argue that one system or the other is more beneficial when considering the avoidance of single points of failure and the overall reliability as calculated by classical methods.

However, in both of the above power systems (figure 3 and figure 4), the loss of a power transformer will cause complete loss of power to a portion of the facility. Transformer replacement could take weeks or months during which a large area will be in the dark. Therefore, a more fundamental argument can be made about whether power transfer should be made at medium voltage or at 480 V.

Some designers prefer the 480V automatic transfer option of figure 5. They argue that in this design, a complete loss of the medium voltage system and the power transformers will not interrupt the facility’s operation. The 480V diesel generators will supply the loads as long as fuel is available and until a mechanical or electrical breakdown occurs.

Further, load shedding may be introduced to remove the non-critical loads and reduce the total burden on the generators. The preference and experience of the consulting engineer and the facility owner plays a major role in selecting the system topology.

**WILL INDUSTRY STANDARDS HELP?**

Underwires Laboratories standard 1008 has typically been specified for legally required standby and emergency power systems – such as the systems used for the critical branch of power in hospitals. It is applicable for equipment up to 600 V and is written for the simple standalone transfer switches – such as the rocker arm design of the double throw transfer switch (figure 1).

However, where multiple generators and utility sources are involved in the transfer scheme, the relaying and control system become rather complex and UL 1008 falls short of providing the necessary functional specifications. And for medium voltage systems, UL 1008 does not provide any guidance at all. For these applications, a detailed understanding of switchgear equipment is necessary in order to develop successful applications. Aside from simplifying the inspection process on code-mandated emergency power systems, a question may arise as to what value the owner of the facility will receive by specifying UL 1008.

UL1008 is designed to be a self-contained standard for a switch assembly. It contains overload, endurance and interruption testing criteria in addition to all mechanical construction requirements. In a typical switchboard construction, however, these requirements are split up into the enclosure and bussing mechanical construction (UL 891) and the circuit breaker design requirements (UL 489). Where equipment is designed to switchgear standards, UL 1558 and ANSI C37.20 provide design and testing criteria for the structure and bussing while UL 1066 and ANSI C 37.13 and C37.16 provide the standards for circuit breaker design and listing.

The main distinguishing factor when comparing a transfer switch built to UL 1008 and a circuit breaker transfer pair built per UL 891 and UL 489 is the mechanical endurance requirements. Comparing the 2000 ampere endurance ratings in the standards we find:
- UL 1008 requires 500 operations at 200% of rated current, 500 operations at 100% of rated current and 2000 operations at no-load

- UL 489 requires 500 operations at 100% of rated current and 2000 operations at no-load

Clearly UL 1008 has more stringent requirements for the endurance testing. However, with advances in circuit breaker design and construction, some modern circuit breakers (such as Square D Masterpact NW) exceed the basic industry circuit breaker standards by large margins. Therefore, the advantages of specifying UL 1008 diminish where high endurance circuit breakers are employed. The key point of specification is the endurance of the devices, not UL 1008.

The second other significant requirement of UL 1008 is the mechanical interlocking requirements, which is a useful feature for the open transition transfer of two sources. However, outside of the simple double source transfer-switch (figure 1), other switchgear arrangements make mechanical interlocking impossible. Electrical interlocks have successfully been employed in all applications for many years. Either method of interlocking (mechanical or electrical) prevents the accidental paralleling of the two sources.

**MODERN CONTROL SYSTEMS**

Automatic transfer can be designed using electromechanical relay logic or programmable logic controllers (PLC). However, PLCs are universally used in modern systems for 5 critical reasons:

1. Ease of trouble shooting
2. Ease of modifying the functionality of the transfer logic
3. Integration with power monitoring and control system to annunciate the status of the circuit breaker and power sources
4. Self-check and diagnostic logic can be easily programmed
5. Forensic re-construction of events can be easily programmed

Modern Industrial grade PLC equipment is robust and has a proven reliability record in tough environments. However, these devices are dependent on the availability of control power, which must be supplied from the most reliable source within the facility. Uninterruptible power supply (UPS) equipment, DC battery sources and various simple transfer schemes can and should be utilized to increase the reliability of the control power supply.

Control power must ride through all power anomalies such that the PLC can record the sequence of operations of the equipment even if the main power transfer is not successful. The sequence of events can be used in identifying the weak links in the transfer system and pinpoint the cause of transfer malfunction. Therefore, the reliability of the control power supply must be higher than the overall reliability of the power transfer system itself.

**WHEN THINGS GO WRONG**

Any well-designed system is subject to malfunction due to aging of components, lack of (or improper) maintenance and operator error. If the system does not operate as intended, the operator must be able to quickly determine the root cause of the problem. However, this task may prove very difficult when we consider the multitude of inputs and outputs in the control system.
The solution is in the implementation of sequence of events recording logic. Figure 6 illustrates the basic building blocks of an automatic transfer and table 1 lists the basic inputs and outputs that connect to the PLC. The list in table 1 will grow as the number of sources is increased and as generator paralleling and closed transition transfer is introduced. However, components 1 through 5 are found in all transfer systems.

When a change of state occurs in an input or an output (on to off or vice versa), the diagnostic system must time-stamp the event and keep a record of it. PLC clocks typically track time to millisecond resolution, which is sufficient for recording most power system disturbances. This information will be held in a logic table in a manner that is most efficient for PLC programming.

However, such raw data is not very useful to the system operators. And the limitations of PLC memory require the data to be uploaded to a computer for processing and storage. Therefore, a complete sequence of events recording system is composed of:

1. PLC inputs and outputs, time stamped to 1 ms resolution
2. Short term storage of data in PLC memory
3. Communication system to transfer data to a central computer
4. Necessary computer programming to upload the data and store it in a reliable storage medium
5. User friendly application program to display the information and assist the operator in trouble shooting the system

The core technology of the diagnostic system is in collecting accurate data of sufficient resolution (item 1) and in the data analysis and evaluation (item 5).

**IMPROVING SYSTEM RELIABILITY**

For low voltage and open transition automatic transfer involving two power sources, UL 1008 provides robust stand-alone transfer switches. Such switches have been tested for their ability to operate under load for a large number of operations and incorporate effective interlocking mechanisms. The benefit of UL 1008 is that it simplifies the governmental inspection process for emergency and legally required standby systems. The authorities having jurisdiction may consider the UL 1008 label as evidence that the transfer switch is appropriately designed for life-safety related processes.

However, as the system becomes more complex with multiple sources of power and with the introduction of tie circuit breakers (and with all applications at medium voltage), the basic UL 1008 standard does not address the reliability requirements. Of particular concern are the design of the control system and the protective relaying functions.

Some modern circuit breakers surpass the endurance requirements in the industry standards. Therefore, the key specification item is the circuit breaker endurance. Mechanical interlocking can be specified for open transition transfer on simple systems where the switchgear arrangement makes it physically possible.

Any well-designed transfer system must employ a diagnostic tool such that the operators can quickly identify the cause of a system malfunction. Such a diagnostic tool is developed using sequence of events recording logic. The sequence of events can pinpoint the specific cause of system malfunction, pointing to specific component malfunction or operator intervention error.
An effective sequence of events recording system employs a PLC technology that can time stamp events to 1 millisecond resolution. Deployment of such systems will enhance the total uptime of the facility and improve power availability.

Figure 1: Simplest Topology, Automatic Transfer Switch

Figure 2: Addition of the Tie Circuit Breaker Improves System Reliability
Figure 3: Power Transfer System with Generator Paralleling at Medium Voltage level
Figure 4: Medium Voltage Power Transfer System that does not Require Generator Paralleling
Figure 5: Power Transfer at 480V. Critical loads are supplied even if a complete loss of the medium voltage system and the power transformers occurs.
Figure 6: The Building Blocks of Automatic Transfer
TABLE 1: PLC Inputs

<table>
<thead>
<tr>
<th>No.</th>
<th>Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Circuit breaker status (auxiliary contacts)</td>
</tr>
<tr>
<td>2</td>
<td>Overcurrent alarm switch (low voltage circuit breakers) or overcurrent relay contacts (medium voltage circuit breakers).</td>
</tr>
<tr>
<td>3</td>
<td>Drawout status indication (cell switch)</td>
</tr>
<tr>
<td>4</td>
<td>Voltage quality status (undervoltage and phase failure relay)</td>
</tr>
<tr>
<td>5</td>
<td>Various manual status switches</td>
</tr>
<tr>
<td>6</td>
<td>Generator protection relays</td>
</tr>
<tr>
<td>7</td>
<td>Reverse current relays for closed transition transfer</td>
</tr>
</tbody>
</table>