MAXIMIZING THE RELIABILITY OF STANDBY POWER USED IN MISSION-CRITICAL APPLICATIONS

Identifying Equipment, Systems Design and Maintenance Procedures that Contribute to Dependable Emergency Power Systems

While standby power system reliability is a concern for any facility, it is especially important for mission-critical applications such as hospitals, data centers, telecommunications, government, municipal water and water treatment. Additionally, there are numerous organizations that rely on standby power systems for business continuity and to reduce exposure to monetary loss resulting from a utility outage.

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To maximize reliability, facility managers need to understand and consider the critical factors that go into specifying, installing and maintaining a standby power system. These factors can be grouped into five categories:

1. Generator set design and manufacturing quality
2. Generator set sizing and power system design
3. Commissioning and operator training
4. Maintenance and periodic testing
5. Code compliance

While no mechanical system can be expected to perform with 100 percent reliability over time, modern diesel and spark-ignited standby power systems come very close to this ideal – provided they are properly designed and maintained. In fact, power system component failure is a fairly rare event, whereas the vast majority of problems result from human error or neglect. This paper will examine the factors that contribute to power system reliability and suggest ways to maintain it at the highest possible level.

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What is "reliability"?

Before discussing ways to ensure better power system reliability, it is important to define the term. The Institute of Electrical and Electronics Engineers' (IEEE) Reliability Society defines reliability this way:

> *Reliability is a design engineering discipline which applies scientific knowledge to assure a product will perform its intended function for the required duration within a given environment. This includes designing in the ability to maintain, test, and support the product throughout its total life cycle. Reliability is best described as product performance over time.*

To a great extent, reliability can be designed into generator sets, transfer switches, switchgear and control systems to increase the likelihood that they function as intended. Of course, the other part of the definition relates to maintenance, testing and support – all human activities that must be carried out as part of an overall plan to maximize reliability.

Another way to look at reliability is to consider it from an economic point of view. In general, to get the highest reliability, facilities will incur greater costs for redundant equipment, advanced system design and more frequent maintenance.

For organizations that face life-safety risks or severe financial losses if their standby power system fails, it is often prudent to invest more to attain the highest possible measure of reliability. For example, this often means designing for N+1 redundancy in utility feeds, generator sets and UPS systems as recommended in the Uptime Institute's Tier IV design topology. While this redundant system design approach comes at a higher first-cost, power reliability and availability improve. N+1 redundancy also enables periodic equipment maintenance to be carried out without affecting the availability of the standby power system.

Actual measured availability of power systems in mission-critical data center applications ranged from 99.67 percent to more than 99.99 percent in a 2006 study by the Uptime Institute. At the higher end of the availability were systems with N+1 redundancy. However, the Uptime Institute noted in its study that actual availability was below the vaunted "Five Nines" (99.999 percent) sought by many mission-critical applications.

However, this higher cost must be weighed against the cost of power interruptions that disrupt manufacturing or business. Industry studies have found that the cost of downtime for a major corporation can range up to $6.5 million per hour. For certain businesses, it is clear that the additional investment in a more reliable power system will be a wise decision. In addition to financial considerations, the ability to maintain electric power to systems whose loss may impact human safety, such as ventilation systems, elevators and stairwell lighting, is also critical.

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Each organization has to determine the level of reliability it can afford, or, conversely, the amount of risk it can tolerate. And, while spending more money for redundancy to eliminate single points of failure generally increases reliability, it also increases complexity, which at some point may, itself, threaten reliability. After determining what level of reliability may be acceptable and affordable, an organization must turn to the selection of equipment and suppliers.

1. GENERATOR SET DESIGN

Engines – Diesel engines are some of the most reliable prime movers ever designed and are the most popular choice for standby power applications. For optimum reliability, look for engines that are designed specifically for power generation applications and not simply adapted from off-road heavy-equipment applications. Engines specifically designed to power generator sets have been optimized to start and assume full load in 10 seconds or less and run at a constant rpm (1,500 rpm or 1,800 rpm). Because they operate at a constant speed, generator set engines also have different turbochargers than typical off-road or on-road engines, have different combustion parameters and need to meet different emissions levels.

For the highest reliability, look for generator sets with engines that have some measure of reserve horsepower capacity at the alternator's nameplate kW rating and a low brake mean effective pressure (BMEP). ISO 8528-5 identifies larger engine displacement and lower BMEP as key factors in a generator set's ability to accept load without an undue drop in output voltage and frequency. Engine manufacturers vary in their approach to this issue. Therefore, when one-step load-acceptance is called for in mission-critical applications, select a manufacturer that can provide a generator-drive engine with the highest displacement and lowest BMEP relative to nameplate kW rating.

New engine manufacturing quality standards practiced by some companies have helped increase the mean time between failures (MTBF) on engine components by a significant factor. Manufacturing improvements have included significantly higher machining tolerances, better metallurgy, sophisticated quality control systems and improved inspection and testing. In addition, the best modern engines are computer-controlled – which not only improves performance, economy and reliability, but also limits the possibility that an operator may inadvertently alter the engine's performance characteristics. Each of these incremental design and manufacturing steps taken by several leading engine companies helps to assure power system operators that mechanical failure of the prime mover will be a very unlikely event.

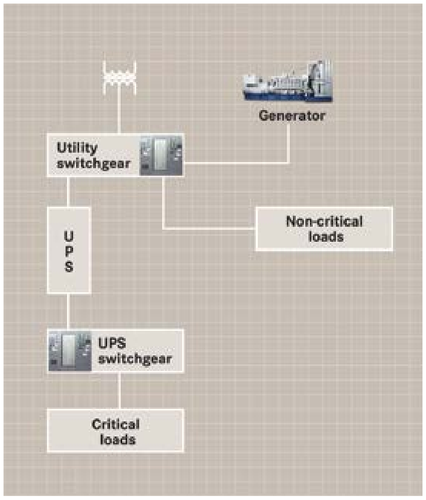

Figure 1. A typical Tier I design topology for a standby power system serving a few critical loads. Such a system has been shown to exhibit about 99.67% annual availability.

Alternators – As a major component in the standby power system, the ability of the alternator to supply its rated kVA and resist damage from transients is crucial to the reliability of any power system. While most major manufacturers utilize standard alternator protection schemes, more recent microprocessor-based controls take transient protection to a higher level. These introduce the feature of programmability into protective devices for over-current protection. For example, with modern molded-case circuit breakers (MCCB), the system designer can set the devices to activate very near the protection limits for the alternator. Older analog fault-protection methods had a lot of gray area, meaning that the protection points had to be quite conservative, leading to more fault occurrences than really necessary. The reliability of older thermal-magnetic breakers depended on the amount of regular exercise they received.

The type of alternator selected depends not only on the size of the electrical load it must supply, but also the types of loads. Factors to consider when specifying alternators for the most reliable power systems include temperature rise, fault tolerance and reactance issues, especially with large, nonlinear loads such as UPS systems and large motors.

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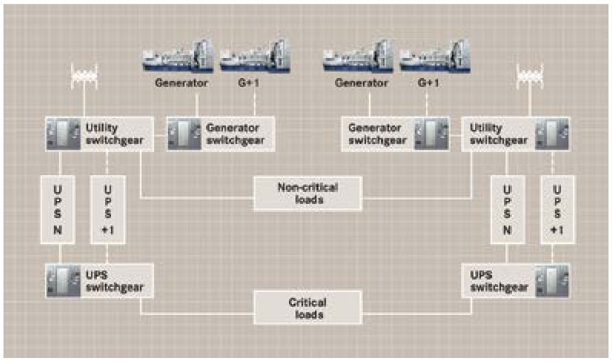

Figure 2. A standby power system with Tier IV design topology and full N+1 redundancy in utility supply, UPS systems and generator sets. This design has been shown to exhibit upwards of 99.99% annual availability.

2. GENERATOR SET SIZING AND SYSTEM DESIGN

Appropriately sizing a generator set for the specific application has a major impact on power system reliability. Some generator sets that are required to pick up a load equal or close to their nameplate rating may not perform as intended. While the generator set may start and run, it may not be able to assume the facility load in one step as required by NFPA 110, or it may take longer than the required 10 seconds for mission-critical or life-safety applications. Unless all critical loads are properly supplied within the 10 seconds as required by NFPA 110, the standby power system cannot be considered to be reliable for mission-critical applications. Consult the engine/generator set manufacturer during the planning stages to be sure the generator set will be capable of providing the expected transient load performance.

System design

Design considerations such as N+1 generator set redundancy, transfer switch selection, controls and ambient conditions play an enormous role in maximizing reliability.

// *N+1 system design* – The Uptime Institute has developed a Tier Classification of I – IV to describe the design topology of standby power systems used in mission-critical data center applications. Tier I topology (see Figure 1) represents a power system design with no redundancy – typical of most commercial standby power installations. In practice, according to the Uptime Institute, this design scheme results in approximately 99.67 percent availability annually.

Figure 2 shows a Tier IV topology that is recommended for mission-critical data center applications with the greatest need for power availability. With N+1 redundancy in utility feeds, standby generators and UPS systems, such a system is expected to deliver annual availability of approximately 99.99 percent.

A standby system with multiple generator sets (either paralleled or segregated by loads) improves reliability because the scheme increases the likelihood that at least most of the generator sets will start and run as intended. In a paralleled N+1 system design, typically all generator sets start when there is an interruption in utility service. With proper configuration of the switchgear, the "extra" generator set will shut down after a time if all the other generator sets start and run normally.

// *Transfer switches* – The selection of the transfer switch depends on the types of loads on the system. Choosing the right mode of operation (open, closed or programmed) for the application can go a long way to minimize the stress of load acceptance on the generator set. This is especially true in facilities with large motor loads or large nonlinear loads such as a UPS system, motors with variable-speed control or other electronic loads.

- *Control systems* – Controls have been among the fastest-evolving power system components. Both analog systems and microprocessor-based digital systems offer high reliability, and both continue to be manufactured and used, depending on the application. There is a good argument that the monitoring capability of digital systems enhances reliability of the total system by helping to identify issues before they become problems.

  Power systems that feature the flexibility inherent in open-protocol control systems and software ensure better compatibility and system integration – which leads to increased reliability. While certain proprietary control protocols may exhibit acceptable reliability as a stand-alone system, the likelihood of failure increases as these systems are interfaced with components from other manufacturers or software from third-party suppliers. Proprietary control systems also complicate testing and maintenance if there are compatibility issues between components and subsystems.

- *Ambient conditions* – The operating environment must be taken into consideration when designing and installing a standby power system. Power systems in coastal regions are likely to need more frequent maintenance and inspection due to salt air. In areas of the earthquake-prone western United States, power systems used for mission-critical applications need to be designed and built to meet the seismic standards of the International Building Code (IBC). Similarly, site altitude and temperatures are important factors in system specification and design that may affect generator set rating.

3. COMMISSIONING AND OPERATOR TRAINING

Proper commissioning is essential to the startup of a standby power system and ultimately is essential for the system's reliability, regardless of its size, type or industry. As power systems become more complex, the commissioning process becomes even more important to confirm that the entire system functions as designed.

The purpose of commissioning is to verify that all components in the power system are functioning as designed in the event of a power outage. In fact, it is during commissioning that most design or installation flaws are uncovered. The generator set must start and accept load, and all alarm functions need to be tested and verified. If the system does not function as required, then remedial measures need to be taken. Following a commissioning protocol such as ASHRAE 0-2005 and the manufacturer's guidelines will ensure that the commissioning process will be implemented in a coordinated manner.

The commissioning process is also an educational opportunity for system operators and maintenance personnel, and it sets a baseline for future operational analysis. Making a video of the initial training session is one way to help new personnel quickly adapt to the established operating and maintenance routine.

Proper training of operating personnel is essential for a reliable standby power system since human error or neglect is responsible for the majority of power system failures. Personnel training begins during the commissioning process and should cover system operation, record-keeping and periodic maintenance. Operators must be familiar with all the power system components, alarm conditions, operation and maintenance procedures. Special attention should be given to critical subsystems such as fuel storage and delivery, starting batteries, engine coolant heaters, and air flow in and out of the generator building or enclosure. Frequent retraining is also necessary, along with making sure that personnel maintain an operational history of the power system. Consult your generator set manufacturer about factory training opportunities available to customers.

Figure 3. Regular exercise and maintenance of the complete power system are very important factors in high reliability.

4. MAINTENANCE AND TESTING

Once a power system has been properly designed and commissioned, the most important factor in its long-term reliability is regular maintenance and system exercise. Some organizations undertake the maintenance themselves, while others opt for maintenance services direct from the generator set manufacturer or its distributor. See Figure 3.

Preventive maintenance of generator sets should include the following operations:

- Inspections
- Oil changes
- Cooling system service
- Fuel system service
- Testing starting batteries
- Regular engine exercise under load

It is important to establish a maintenance schedule that is based on the specific power application and the severity of the environment. For example, if the generator set is located in an extremely cold or hot climate, or is exposed to salt air, the generator set's manufacturer can help develop appropriate measures to deal with these special needs.

Like regular maintenance, periodic testing is required by code in mission-critical applications. It is best to exercise a generator set under the actual facility load it will be expected to supply in emergency conditions. When operated with the actual building load, the entire power system is tested – including the automatic transfer switches and switchgear.

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Operating a generator set under no-load conditions can adversely affect its long-term reliability if the generator cannot get up to an exhaust temperature of approximately 650 degrees F before the test is over. It is very important that both the engine and generator reach this minimum operating temperature in order to drive off any accumulated moisture that may have condensed in the system. Under heavy load, diesel engines come up to operating temperature in a matter of minutes, whereas, without load, they may not reach operating temperature even after prolonged operation.

Most manufacturers recommend that generator sets be exercised periodically, loaded to at least 30 percent of rated capacity. If it is not practical to test with the actual facility load, permanent load banks should be considered in the initial power system design, or a maintenance contract should be considered with a service professional that can bring in a portable load bank to properly load the genset during the exercise period.

At least once a year, all facilities should exercise the power system under the actual facility load and full-emergency conditions to verify that the system will start, run and accept the rated load. Running for up to several hours under these conditions helps to test all the system components. (It should be noted that total operating time for testing may be limited by local authorities for the purpose of reducing exhaust emissions released into the air.)

Besides verifying that the generator set will start and run, periodic exercise has the benefit of heating up diesel fuel and eliminating accumulated condensation in the fuel tank. Since clogged fuel filters and fuel contamination are among the leading causes of power system malfunctions, the cycling and refreshing of fuel is an important step in ensuring overall system reliability.

5. CODE COMPLIANCE

There are a number of industry and governmental codes that address standby generator set and power system reliability issues. Some affect the manufacture of power systems, and some affect their installation, maintenance and operation. Compliance with all the appropriate codes will increase reliability. Codes addressing or impacting power system reliability have been established by the following organizations:

- *NFPA (National Fire Protection Association)* – Section 110 addresses the standards for performance for a standby power system and recommends monthly maintenance and periodic testing.

- *IEEE (Institute of Electrical and Electronics Engineers)* – Defines reliability and addresses protocols for improving it through analysis and testing.

- *NEC (National Electrical Code)* – Also known as NFPA 70, the NEC has become the de facto standard set of electrical requirements throughout North America. NEC Section 700 sets standards for commissioning of generator sets and sets operational parameters.

- *JCAHO (Joint Commission on Accreditation of Healthcare Organizations)* – Recommends minimum standards for standby power systems for healthcare organizations, including record-keeping, maintenance and periodic testing under load conditions to ensure reliability.

- *UL (Underwriters Laboratories, Inc.)* – A national testing and rating organization. Compliance with the organization's UL 2200 code is designed to ensure that standby power systems are safe. UL 1008 is a rating for automatic transfer switches that verifies the switch will operate reliably for at least 3,000 operations – a number that is not likely to be exceeded for many years.

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- *IBC (International Building Code)* – Sets seismic standards for generator sets installed in geographic areas prone to earthquakes to ensure reliable operation after a seismic event.

- *ISO (International Organization for Standardization)* – This organization's ISO 9000 family of standards helps power system manufacturers develop quality control systems. ISO 8528 sets standards for load acceptance and transient response.

- *EPA (U.S. Environmental Protection Agency)* – Sets standards for emissions from many sources, including emissions from standby power systems.

- *Local air quality codes* – Recent air quality laws enacted in the South Coast region of California are restricting some generator sets to running a maximum of 30 minutes per month. This practice may affect the long-term reliability of standby power systems by reducing the frequency of power system testing and possibly damaging generator sets by not allowing them to reach minimum operating temperature. Where local codes discourage proper generator set exercise due to air quality concerns, consult your generator set's manufacturer for recommended exercise procedures.

Conclusion

Standby generator sets are very reliable machines with normal availability in excess of 98 percent on an annual basis. However, the generator set is only one component in a standby power system, and reliability needs to be considered in terms of the total system design.

In addition, close coordination between the facility manager and all the power system equipment and building automation system (BAS) suppliers during design, installation and commissioning is vital for maximizing reliability. This coordination is necessary to identify potential failure modes and develop solutions before problems occur.

By considering these factors along with the generator set manufacturer's recommendations, managers of mission-critical facilities can be assured of the highest possible reliability of their standby power systems.

MTU Onsite Energy is part of the Rolls-Royce Group. It provides diesel and gas-based power system solutions: from mission-critical to standby power to continuous power, heating and cooling. MTU Onsite Energy power systems are based on diesel engines with up to 3,250 kilowatts power output (kWe) and gas engines up to 2,530 kWe.

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