Automating Emergency Power Supply System Testing in Hospitals

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Executive summary

The testing of emergency power supply systems (EPSS) in hospitals plays a critical role to ensure backup power is available when needed. Due to the shortcomings of manual testing, more hospitals are switching to automated EPSS test systems. This paper demonstrates how automated EPSS testing increases reliability due to the accurate monitoring and recording of test parameters, provides traceability in case of unanticipated problems with the EPS system or litigation, and helps reduce the staffing burden for such tests.

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Executive Summary

The testing of emergency power supply systems (EPSS) in hospitals plays a critical role to ensure backup power is available when needed. This testing is usually done weekly or monthly and depending on the jurisdiction, different regulatory bodies dictate the parameters of the test. Most commonly, diesel engines are used as prime movers for emergency power supply generators. While diesel engines are known for their reliability and fuel efficiency, it is critical that the testing is carried out within certain limits to make sure that the reliability is increased rather than decreased as a result of the testing.

Traditionally, EPSS testing has been carried out using stop watches and manual recording of test parameters. Manual test procedures are time-consuming and tie up a significant number of personnel.

Due to the shortcomings of manual testing, an increasing number of hospitals are switching to automated EPSS test systems. Automated EPSS testing increases reliability due to the accurate monitoring and recording of test parameters, it provides traceability in case of unanticipated problems with the EPS system or litigation, and it helps to reduce the staffing burden for such tests.

Introduction

Hospitals have emergency power supply systems (EPSS) that play a critical role in medical and healthcare facilities, where the continuity of electrical power is vital for patients' lives and safety. EPS systems are made up of one or more alternate power sources which can supply the healthcare facility with power during an interruption of the main utility-supplied power. Typically, alternate power sources are made up of one or more diesel or gas powered generators, sized to carry, at a minimum, any vital, critical and emergency loads. Power is transferred from the main utility supply to the alternate power sources using automatic transfer switches (ATS) whenever the main utility supply is interrupted. A facility may have one or several independent EPS systems.

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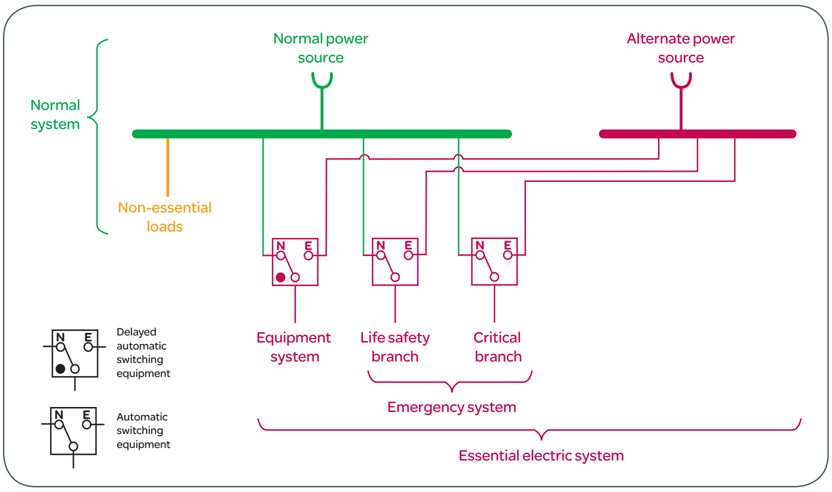
Depending on the jurisdiction of the facility, different regulatory requirements dictate how the EPS systems need to be maintained and tested.

Many countries mandate specific compliance standards for generator testing and some require formal reports for government agencies and for audit purposes. These compliance standards may be mandated by federal governments, local (state/provincial) governments, or by private organizations.

In the U.S., for example, hospitals are required to test their EPS systems at least 12 times a year, every 20 to 40 days, for 30 minutes at or above the manufacturer's recommended engine exhaust temperature or at a minimum load of 30% of the generators' nameplate rating. Also, maximum transfer times of less than 10 seconds are typically required.

Within a hospital electrical distribution network, the circuits can be divided between the normal non-essential circuits and the essential electrical system. The non-essential circuits do not require an alternate power source, but the essential electrical system does.

Electrical Systems for Hospitals



The essential electrical system includes circuits that support equipment or systems vital to the protection of life and safety (including patient-care related circuits like the intensive care unit or operating rooms as well as emergency lighting, alarm systems, battery chargers, and so on), and all the electrical infrastructure equipment needed to ensure that vital or life safety equipment power interruptions are kept to less than a maximum legislated duration.

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It is not uncommon for back-up generation to fail in the case of an emergency due to insufficient testing and maintenance. In fact, in some cases, nominal run tests can actually create problems within the gensets that can affect operation in a true emergency situation (like wet stacking, where unburnt fuel or carbon builds up in the exhaust system when generator run times are too short or the test is performed outside recommended operating parameters).

The challenge is that comprehensive manual tests are difficult to coordinate and it is equally hard to effectively measure results. There are major challenges for multiple stakeholders in the hospital, including medical personnel, facility personnel, and the hospital administration. In short, manual testing of EPS systems is costly and inefficient.

Why EPSS Testing is Critical

Interviews with hospital staff have identified the following EPSS stakeholders:

CEO, hospital administrators, executive management: Hospital directors and administrators are concerned about the three main issues as related to their electrical distribution system and electrical equipment: reliability, traceability, and liability. They want to ensure that hospital systems are as reliable as possible, to reduce any failures in the emergency system. They want to ensure they can show the events that lead up to any failure in case of litigation, and to protect the hospital from liability. They have to rely on the facility manager to ensure the system is reliable and that appropriate reports are being created, but generally don't have much insight into what is being done or whether it is sufficient.

Facility managers: Facility managers face substantial challenges in organizing EPSS testing. There are often regulatory and reporting requirements that must be met but which are difficult to truly measure or satisfy with a manual testing scheme. Staff is diverted from normal duties to conduct the test, so other activities are delayed or dropped. As well, there is a complex list of stakeholders and equipment that must be coordinated to actually conduct the test, and tests have to be set around the hospital schedule – often early in the morning so staff has to come in off-schedule, and tests can be cancelled summarily if an unexpected critical situation arises.

Besides that, doing manual EPSS tests creates a host of technical issues: the tests that can be run easily are often not a true test of how the generator will perform in an emergency situation. It is difficult to manually monitor EPSS load levels during the entire test. It is not possible to manually record precise timing of transfer switches and actual generator operating temperatures are often ignored, which could result in "wet-stacking". Additional trending and analysis requires data to be transferred manually to a PC.

Doctors / Surgeons: In hospitals, there is nothing more important than the care and preservation of life. Surgeons rely on electrical power in the operating room and cannot afford to be without it for even a moment. Today, most life-sustaining equipment is connected to an uninterruptable power source (UPS), but, the ride-through capability of UPSs is usually limited. Any loss of power to life-sustaining equipment such as ventilators could result in the death of patients. As such, the reliability of the hospital's EPSS is critical.

Nurses: Traditional manual EPSS testing creates a sharp increase in workload for nurses, because each time the test is held (often once a month or more), they must manually check on multiple critical patients or procedures before each test occurs; check with doctors to see if there is any risk to the patient or procedure from the test; and reset equipment alarms that are triggered by switching to back-up power (and back to utility power) during each test.

In addition to the hospital's internal requirements, more and more governments are legislating mandatory EPSS tests. Some of these regional legislated standards include:

- US: NFPA 99 & 110
- UK: HTM-06-01
- Canada: CSA Z32
- Australia / New Zealand: AS_NZS 3009
- European IEC standard: 60364-7-710

Major Outages Resulting from EPSS Failures

Despite the fact that there are legal requirement for EPSS testing, this does not prevent EPS system failures from occurring. The following are examples:

Hospital generator failure during power outage – December 2005, Dublin, Ireland: A power cut in Ennis town cut electricity supplies. Backup generators then failed in two hospitals, Ennis General and St Joseph's.

Inquiries into blackout and hospital generator failure – April 2010, Wellington, NZ: Separate investigations are under way to get to the bottom of the massive Wellington power cut and determine why a backup generator at Wellington Hospital failed – forcing patients to be sent elsewhere.

Blackout and generator failure at Major Adelaide hospital – April 2009, Adelaide, Australia:
A blackout and failure of backup generators caused an emergency for Flinders Medical Centre.

Power Failure Leaves Hospital in Darkness – May 2010, Zimbabwe: The Avenues Clinic had to transfer some critical patients as their generators could not power the whole hospital. They had to quickly rush some of Caesarean patients to another clinic because the major generator at the hospital was not working and the smaller one used for emergency purposes did not supply the whole hospital.

Patient on Life Support Dies During Power Loss – September 1999, Rhode Island: Lack of ventilator support caused the death of a critical patient when a utility transformer exploded and the hospital's emergency power system failed.

Fire Destroys Main Circuit Breaker Causing 42 Day Power Outage – March 2000, Florida: Fire in electrical vault destroyed emergency power system resulting in operating procedures to be completed by flashlight, patient evacuations and total shutdown of facility.

Blackout Impacts Services – August 2003, New York: Several hospitals cancelled surgeries, closed units, and operated without air conditioning or computers when generators failed during the Northeastern blackout.

Faulty Internal Switch Impacts Generator – November 2004, Minnesota: A faulty internal switch limited generator power causing a patient to be transferred and cancellation of surgeries.

Generator Fails after Power Outage – August 2006, Indiana: During a power outage, an overheated generator forced the evacuation of 3 long-term critical care patients.

Backup Generator Fails – April 2007, Florida: A fan for the main generator failed during an outage resulting in total darkness and the transfer of 5 patients.

Hospital Loses Power after Transfer Switch Failed – August 2007, Texas: An automatic transfer switch failed during an outage resulting in a patient wing being without power for an hour.

Joint Commission Investigates Hospital after Power Failure – January 2008, California: During the transfer back from emergency power to main utility, a circuit breaker tripped causing the hospital to lose power.

New Emergency Power System Fails to Operate as Required – February 2008, California:
A 6-month-old emergency power system did not kick in for 20 minutes causing fire department personnel to deploy temporary power.

Downed Wire Leaves Hospital in the Dark – July 2008, Maryland: Hospital's backup generators failed to operate as planned causing critical patients to be transferred to other local hospitals.

Hospital Evacuated When Power Fails During Storm – July 2008, Illinois: Nearly 50 patients were without power and 11 patients were evacuated when a generator failed during a power outage.

Hospital Backup System Slow to Respond – December 2008, Alabama: Backup power did not respond due to a faulty circuit breaker impacting emergency room, patient tower and main surgical wing.

Financial Risk of EPSS Failure During a Blackout

It is very difficult to accurately quantify the financial risk associated with an EPSS failure during a utility outage. Here are a few statistics that quantify the true costs of systems downtime[1]:

Industry Sector	Revenue/Hour	Revenue/Employee-Hour
Energy	$2,817,846	$569.20
Telecommunications	2,066,245	186.98
Manufacturing	1,610,654	134.24
Financial Institutions	1,495,134	1,079.89
Information Technology	1,344,461	184.03
Insurance	1,202,444	370.92
Retail	1,107,274	244.37
Pharmaceuticals	1,082,252	167.53
Banking	996,802	130.52
Food / Beverage Processing	804,192	153.10
Consumer Products	785,719	127.98
Chemicals	704,101	194.53
Transportation	668,586	107.78
Utilities	643,250	380.94
Healthcare	636,030	142.58
Metals / Natural Resources	580,588	153.11
Professional Services	532,510	99.59
Electronics	477,366	74.48
Construction and Engineering	389,601	216.18
Media	340,432	119.74
Hospitality and Travel	330,654	38.62
Average	$1,010,536	$202.55

The above statistics are focused on IT systems and do not take into account the impact of potential deaths caused by emergency power supply failures. But, it is clear that the cost of EPSS failures involving death would be a lot higher.

In the case of the Pendleton Memorial Methodist Hospital in New Orleans, Louisiana, two lawsuits were filed against the hospital and its corporate parent, Universal Health Services of Pennsylvania, for the deaths of Althea LaCoste and Lorraine Edwards in the days after Hurricane Katrina because their disaster plans left the emergency power system vulnerable to flooding. The Louisiana Supreme Court rejected defense efforts to put the case on the medical malpractice track, a path that would have capped the family's potential damages at $500,000. Louisiana law does not cap damages for general negligence claims.[2]

Obviously, fully accurate numbers regarding the costs of liability are very hard to find because most settlement amount are being kept confidential. It is fair to say, however, that each incident is easily in the millions of dollars when loss of life occurs.

[1] APC Learning, "The Problem with Power", website content; cited source Network Computing, March 5, 2001 (http://www.apc.com/power/problems.cfm)

[2] Barrows, B. Article on nola.com website, "Pendleton Memorial Methodist Hospital negligence claim at issue in trial", published January 12, 2010 (http://www.nola.com/hurricane/index.ssf/2010/01/pendleton_memorial_methodist_h.html)

Preventable Adverse (Sentinel) Events

A Joint Commission study done for the years 1995 through 2010 has broken down preventable adverse events in US hospitals resulting in death or permanent loss of function as follows[3]:

Total number of sentinel events reviewed by the Joint Commission since 1995 = **6782**

Type of Sentinel Event	#	%
Wrong-site surgery	908	13.4%
Suicide	804	11.9%
Op/post-op complication	734	10.8%
Delay in treatment	580	8.6%
Medication error	547	8.1%
Patient fall	436	6.4%
Unintended retention of foreign body**	360	5.3%
Assault/rape/homicide	256	3.8%
Perinatal death/loss of function	209	3.1%
Patient death/injury in restraints	201	3.0%
Transfusion error	146	2.2%
Infection-related event	145	2.1%
Medical equipment-related	135	2.0%
> Fire	102	1.5%
Anesthesia-related event	100	1.5%
Patient elopement	99	1.5%
Maternal death	94	1.4%
> Ventilator death/injury	62	0.9%
Abduction	32	0.5%
> Utility systems-related event	25	0.4%
Infant discharge to wrong family	8	0.1%
*** Other less frequent types	799	11.8%
TOTAL	**6782**	

**Unintended retention of a foreign object was added to the definition of reviewable events June 2005. This data represents events reviewed since that date, not 1995-2009.

Three identified sentinel events – fire, ventilator death/injury and utility system-related events – can potentially be caused by failure or problems with the electrical distribution infrastructure in a hospital. By improving the reliability of the EPS system, the financial risks from these events can be reduced.

[3] The Joint Commission, Sentinel Event Statistics, March 31, 2010

Improper Testing Can Cause Reliability to Decrease

Most hospitals rely on diesel engines for backup power. Diesel engines are known for their reliability, fuel efficiency, and longevity. Also, they are able to deliver most of their rated power on a continuous basis.

However, simply testing a diesel engine does not guarantee an improvement in reliability. When tested or used incorrectly or outside their intended operating range, diesel engines can suffer damage such as "wet-stacking", internal glazing of the cylinder bore or carbon buildup. This is due to prolonged periods of running at low loads, when the engine is left idling during the test, or if the engine is oversized for the application.

Running an engine under low loads causes low cylinder pressures and consequent poor piston ring sealing since this relies on the gas pressure to force them against the oil film on the bores to form the seal. Low cylinder pressures cause poor combustion and resulting low combustion pressures and temperatures.

This poor combustion leads to soot formation and unburnt fuel residue which clogs and gums piston rings, causing a further drop in sealing efficiency and exacerbating the initial low pressure. Glazing occurs when hot combustion gases blow past the now poorly-sealing piston rings, causing the lubricating oil on the cylinder walls to 'flash burn', creating an enamel-like glaze which smoothes the bore and removes the effect of the intricate pattern of honing marks machined into the bore surface which are there to hold oil and return it to the crankcase via the scraper ring[4].

Also, unburnt fuel can pass into the exhaust side of the turbocharger and on into the exhaust system. This condition is referred to as "wet-stacking" and is detectable when there is black ooze around the exhaust pipe connections and around the turbocharger. Continuous white exhaust from the stack when under a constant load is also an indication that all the fuel is not being burned.

Hard carbon also forms from poor combustion and this is highly abrasive and scrapes the honing marks on the bores leading to bore polishing, which then leads to increased oil consumption (blue smoking) and yet further loss of pressure, since the oil film trapped in the honing marks is intended to maintain the piston seal and pressures.

Unburnt fuel then also leaks past the piston rings and contaminates the lubricating oil. Poor combustion causes the injectors to become clogged with soot, causing further deterioration in combustion and black smoking.

The problem is increased further with the formation of acids in the engine oil caused by condensed water and combustion by-products which would normally boil off at higher temperatures. This acidic build-up in the lubricating oil causes slow but ultimately damaging wear to bearing surfaces.

[4] Cox Engineering, "Bore glazing and polishing in diesel engines: A technical explanation", website content (http://coxengineering.co.uk/bore.aspx)

This cycle of degradation means that the engine soon becomes irreversibly damaged and may not start at all and will no longer be able to reach full power when required.

Under-loaded running inevitably causes not only white smoke from unburnt fuel but over time will be joined by blue smoke of burnt lubricating oil leaking past the damaged piston rings, and black smoke caused by damaged injectors. This pollution is unacceptable to the authorities and neighbors.

Once glazing or carbon build-up has occurred, it can only be cured by stripping down the engine and re-boring the cylinder bores, machining new honing marks and stripping, cleaning and de-coking combustion chambers, fuel injector nozzles and valves. If detected in the early stages, running an engine at maximum load to raise the internal pressures and temperatures allows the piston rings to scrape glaze off the bores and allows carbon buildup to be burnt off. However, if glazing has progressed to the stage where the piston rings have seized into their grooves, this will not have any effect.

The situation can be prevented by carefully selecting the generator set in accordance with manufacturers' printed guidelines. Diesel engines should be sized to run at least 30 - 40% of their maximum rated load, but should also provide a 20% reserve margin to allow for growth and better stability.

For emergency-only sets which are islanded, the emergency load is often only about one quarter of the set's standby rating, with the apparent over-size being needed to be able to meet starting loads and minimize starting voltage drop. Hence the available load is not usually enough for load testing and again engine damage will result if this is used as the weekly or monthly test load. This situation can be dealt with by hiring in a load bank for regular testing, or installing a permanent load bank. Both these options cost money in terms of engine wear and fuel use but are better than the alternative of under-loading the engine. For remote locations, a salt-water rheostat can be readily constructed.

Often the best solution in these cases will be to convert the set to parallel running and feed power into the grid, if available, once a month on load test, and or enrolling the set in utility reserve service type schemes, thereby gaining revenue from the fuel burnt.[5, 6]

This cycle of degradation means that the engine soon becomes irreversibly damaged and may not start at all and will no longer be able to reach full power when required.

[5] Diesel generator. (2010, June 7). In Wikipedia, the free encyclopedia. Retrieved June 21, 2010, from http://en.wikipedia.org/wiki/Diesel_generator

[6] Wet stacking. (2010, June 18). In Wikipedia, the free encyclopedia. Retrieved June 21, 2010, from http://en.wikipedia.org/wiki/Wet_stacking

Advantages of Automated EPSS Testing

The ultimate goal of EPSS testing is to increase the overall reliability of the system and to reduce the odds of failure under emergency situations. Automated testing and monitoring helps identify EPSS problems during testing rather than during emergency situations. By pointing out problem areas during tests, the system's overall mean time between failures (MTBF) can be improved.

It is crucial to ensure that any testing or EPSS operation is performed within the intended operating parameters as described above. This can be achieved by continuously monitoring the EPS system 24 x 7 and electronically measuring and recording all relevant ATS, genset and related parameters, such as transfer times, engine loading, engine temperature, exhaust gas temperature, and oil pressure.

Air and fuel are other critical elements for the reliable operation of the prime mover. It is essential that a proper maintenance scheduled be followed. A system that includes dual redundant fuel lines and filters is a significant benefit in mission-critical applications where long runtimes must be supported. This is so that fuel lines and filters can be isolated and changed while the engine remains running. Proactive monitoring of these filters is done with differential pressure indicators. They show the pressure difference across a filter or between two fuel lines during engine operation. When applied to air filters, these proactive monitoring devices are known as air-restrict indicators. They provide an indication of the need to replace a dry-type intake air filter while the engine is running.[7] Both pressure drop indicators can be electronically monitored by the EPSS test automation system for long term trending and analysis, but also for alarming while the generator is running, be it for a test or for emergency operation.

Battery health monitoring is another important factor, which can affect the ability for the engine to start. Simply checking the terminal voltage of the batteries is not sufficient to monitor their ability to deliver adequate cranking power. As batteries age, their internal resistance to current flow can increase, and the only reliable test method is to measure the output voltage under load. This test can also be performed by an automated EPSS test system.

Having electronic records of the parameters discussed above makes it possible to analyze long-term trends using sophisticated computerized reporting methodologies. For example, a very gradual increase in transfer times (over the period of a year or more) may suggest that maintenance is required. Or, an abnormal drop in battery voltage during engine cranking may indicate that it is time to replace the batteries.

Some of these trends may be very subtle and gradual, and often cannot be detected by manual data collection methods.

[7] Wyatt, R. "Fundamental Principles of Generators for Information Technology". Published 2010, Schneider Electric (http://www.apcmedia.com/salestools/SADE-5TNRPC_R1_EN.pdf)

Also, by continuously monitoring the EPS system, alarms can be triggered if the system is operated outside its intended parameters for prolonged periods of time to avoid reliability threats such as wet stacking, clogged fuel filters or tired batteries.

Automated testing and monitoring helps identify EPSS problems during testing rather than during emergency situations.

Further, transfer switches and circuit breakers require exercising and mechanical maintenance at regular intervals to assure they operate as intended. Having precise electronic records of the exact times when these devices have been exercised makes it easy to determine when they are due for their next exercising operation.

In the US, for example, hospitals are required to follow NFPA 99 and 110, which prescribe that EPS systems have to be tested at least 12 times a year, every 20 to 40 days, for a minimum of 30 minutes at the manufacturer's recommended exhaust gas temperature or at a minimum load of 30% of the genset's rating. An automated EPSS test solution makes it straight forward to prove conformance to legislative test procedures and requirements.

In Europe IEC 60364-7-710 prescribes that changeover devices are to be functionally tested every 12 months. Genset combustion engines are to be tested monthly until rated running temperature is achieved with an additional 60-minute annual endurance test. In all cases at least 50% to 100% of the rated power shall be applied.

At the same time, hospitals are required to keep precise maintenance and test records for presentation to regulating authorities, or for traceability to determine what happened in the system after improperly functioning or system failure. In the case of system failure, despite proper testing, it is imperative to have access to detailed electronic data which facilitates sequence of event or cause and effect studies.

Conclusion

Hospital CEOs, administrators and executive management are most concerned about reliability, traceability, and liability, and emergency power supply systems are essential to appropriately manage these concerns. Unfortunately, the reliability of the diesel generators commonly used for backup power can be compromised if they are operated outside of their intended operating range, and consequently, may fail to operate or start when needed in case of a utility power failure. To avoid EPSS failure, it is crucial that diesel engines used for emergency backup power in hospitals get tested and exercised at regular intervals within the parameters dictated by regulatory bodies and engine manufacturers.

However traditional manual test procedures have been shown to be error prone, time-consuming and inefficient from a staffing perspective.

As a result, more and more hospitals are switching to automated EPSS test solutions. By installing an electronic system that continuously monitors and records EPSS-related parameters, it is easy to prove regulatory compliance, and have precise electronic records available for traceability and trouble shooting in case of an unanticipated failure. In addition, electronic records can be used for long-term EPSS trend analysis. Subtle long-term trends in parameters such as ATS transfer-times, differential fuel pressure, engine-start battery voltage, etc. can be used as flags for required maintenance.

Automated testing and monitoring helps point out problems during testing rather than during an outage. As such, the system's overall mean time between failures (MTBF) can be improved, giving patients, staff and administrators peace of mind, so they can rest assured that the EPS system is ready to power the hospital whenever required.

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