9 Power System Risks that Threaten Business Operations

White Paper

by Jean-Pierre Morand

Executive summary

Modern facility managers operate and maintain complex electrical distribution systems that represent the life blood of their site's operations. There is constant pressure to maintain operations in a safe, reliable, efficient, and sustainable manner. Unfortunately, the health of the site electrical system and the risks to its stability are often overlooked or are unknown. While electrical distribution equipment is typically reliable with long lifespans, unexpected and sudden failures can occur. This white paper describes nine commonly overlooked risks to electrical system availability and provides high level guidance on how to reduce or mitigate these risks

Introduction

For the modern site manager, there are many complex systems to oversee. Ultimately however, the fundamental responsibility of the site manager is to ensure uninterrupted operations so that business targets can be achieved. Whether it is manufacturing production, hospital healthcare services, safe airport operations, or commercial enterprise environments, the reliable and steady flow of electricity is critical. An unexpected shutdown of the electrical system, or parts thereof, can lead to significant costs in lost productivity, risks to health & safety, or even loss of life. Unfortunately, the health of the site electrical system and the risks to its stability are often overlooked or are unknown. While electrical distribution equipment is typically reliable with long lifespans, unexpected and sudden failures can still occur.

This white paper examines some commonly overlooked risks to electrical system availability. All the issues we discuss can be proactively identified and mitigated through an assessment of the electrical system by qualified personnel. Appropriate mitigation plans can be put in place to prevent them from resulting in system failures and from becoming risks again in the future. We will describe 9 risks in this paper including:

- Inadequate power system design
- Missing or outdated single line diagrams (SLDs)
- Inadequate protection coordination
- Lack of arc flash mitigation
- Lack of equipment training
- Insufficient power monitoring
- Insufficient maintenance practices
- Limited availability of spare parts
- Obsolete equipment

Risk #1 – Inadequate power system design

Electrical systems are rarely set up to perfection in order supply the needs of the site or to supply redundant power from different panels for critical loads. Poor electrical system designs can happen for several reasons. Electrical system designers can make decisions based on incomplete information or understanding of the interaction between operations and information technology. For older sites, problems usually arise over time as changes are made to the site and its operations without considering an update of the overall power system design. For example, if a redundant machine or system is installed but supplied from the same panel as the other. Then any issue with this panel will have an impact on the overall system. A review of the overall design would have help to identify this risk and a different supply would have been implemented to keep operation running.

A common outcome of inadequate power system design is to have critical site utilities such as air compressors, boilers, and chillers that are supplied by the same single electrical panel. In this case, even if there are redundant machines and systems, if anything happens to the section of the electrical system that supplies this one switchboard, the entire operations will shut down. These single points of failure may not always be obvious and may not be reflected in the as-built drawings particularly as the building ages and changes are made.

To benefit from system redundancy, the power system design needs to be reviewed regularly over time as the site changes. Being able to leverage machine redundancy at the power system level helps to improve uptime, reduce financial impact of electrical failures, and simplify maintenance operations that can be likely performed while keeping process and system running.

Risk #2 – Missing or outdated single line diagrams (SLDs)

Electrical systems can be highly complex and inter-dependent. Upstream events can have immediate downstream impacts while downstream events can also have upstream outcomes. Every time that qualified personnel engage with the electrical system for maintenance, upgrades, or other interventions, they will rely on drawings and single-line diagrams (SLDs) to inform their actions. However, these documents are sometimes missing, or they have not been updated after prior changes were made, and, therefore, do not reflect reality.

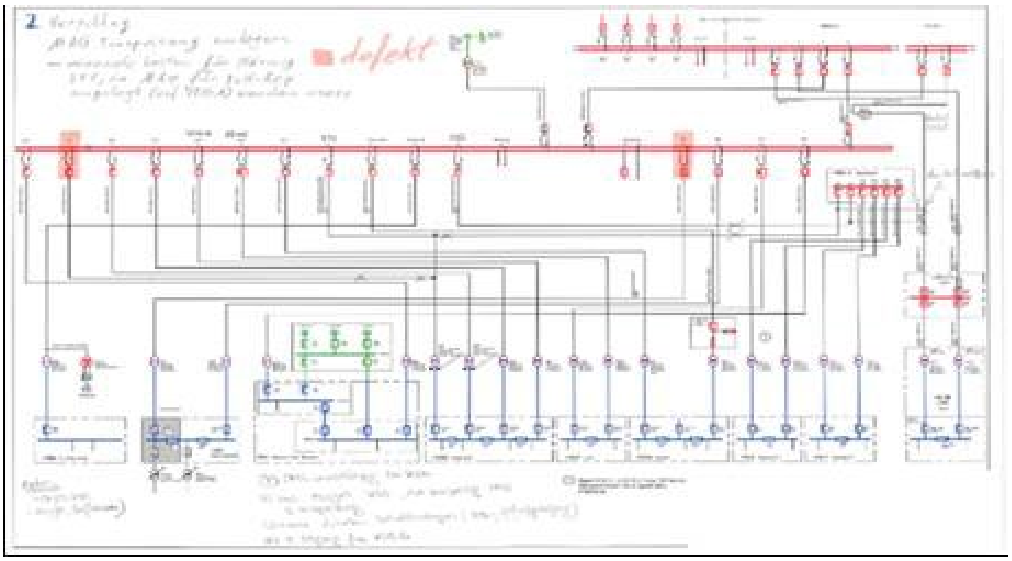

Figure 1

Example outdated paper-based SLD with handwritten notes

In Schneider Electric's experience, roughly 60% of facilities operate today with simple paper based SLDs (**Figure 1**). Most of these SLDs are not synchronized with the actual electrical system today because they haven't been regularly reviewed or maintained over time. We've also found that about 10-20% of sites have no SLDs at all. Sites with no or poorly managed electrical blueprints run a higher risk of experiencing critical safety incidents, service interruptions, longer mean time to diagnose and repair, as well as being in a state of non-compliance with local codes and standards.

Therefore, electrical distribution single-line diagrams must be kept up-to-date and posted in the site's electrical rooms and substations. This should include a site-wide high and medium voltage (HV, MV) single line diagram as well as more detailed low voltage (LV) single line diagrams. Both should be on display and up to date following any electrical distribution changes performed. Some vendors will offer a service to create, update, and/or even digitalize your SLDs. This digitalization makes it easier to maintain them and to use them as inputs to future technical studies. They also become the foundation for creating a live digital twin of your electrical system.

To learn more about these intelligent SLDs and their safety, efficiency, and cost-savings benefits, read Schneider Electric White Paper 520, "The Foundation of Electrical Digital Twins: Maintaining Accurate Single-line Diagrams (SLDs)".

Risk #3 – Inadequate protection coordination

Even if the power system is well designed to cover process and operation needs, poor protection coordination can still lead to an unplanned complete site shutdown. For example, consider the case where an electrical fault is not interrupted by a protective device that is just upstream from where the fault occurred. Instead, in this example, the fault is interrupted by a circuit breaker that happens to be far upstream from the location of the fault. In this case, several large sections of the electrical distribution that are supplied by this same circuit board would be shut down unnecessarily. This can even result in a cascading failure that shuts down other sections and even lead to shutting down the entire power system. After an event like that, it can be difficult, if not impossible, to find the source of the problem. This results in many hours of downtime before operations are restored.

Usually, a protection coordination study is performed before commissioning. The study is an analysis to determine the proper settings of protection relays and circuit breakers to reduce the impact of faults on power system availability, equipment lifespan, and worker safety. Inadequate protection coordination usually occurs when there is subsequent modification or extension of the power system. In many cases, the original study is not updated accordingly. To help maintain system resiliency, the protection coordination study needs to be revised periodically when changes are made to the power system or even at grid level (e.g., installation of a new HV/MV transformer or change in the grid's earthing system).

Risk #4 – Lack of arc flash mitigation

An arc flash is caused when a conductive object bridges the insulation gap between two energized parts (or an energized part and ground) in energized electrical equipment. An arc flash is mostly caused by accidental contact but may also be a result of equipment being underrated for the available short circuit current, having cracked/compromised insulation, being corroded, vermin infiltration, and other reasons. The arc flash ionizes air at more than 19000 Celsius degrees which can severely burn skin within fractions of a second across more than one meter distance from the source. The high temperature and resulting explosion can vaporize surrounding metals and set fire to nearby combustible materials. Beyond the risk to health and safety of site personnel, arc flash events can carry considerable costs including:

- medical
- worker's compensation
- legal
- lost productivity due to cleanup and repair
- damages to equipment and process
- regulatory fines

To help mitigate arc flash risk, it is important to perform an investigation that assesses a worker's potential exposure to arc flash energy. That is conducted for the purposes of injury prevention, determination of safe work practices, and appropriate levels of personal protective equipment (PPE). The general process of conducting such an assessment follows these steps:

- Collect power system and installation data
- Determine system modes of operation
- Determine bolted fault current
- Calculate arc fault current
- Find protective device characteristic and arc duration
- Select working distances
- Calculate incident energy
- Calculate flash protection boundary
- Determine PPE (risk hazard) category
- Generate and apply labeling to equipment that shows the PPE category


Arc Flash Information

Category 0 — Use this information in accordance with applicable OSHA standards, NFPA 70E, and other required safe electrical work practices.

18 inches Flash Protection Boundary
1.2 cal/cm^2 Max Incident Energy at 18" Working Distance
Category 0 PPE Category (Per NFPA 70E-2012)

480 V Shock hazard when cover is open
42 inches Limited Approach
12 inches Restricted Approach
1 inch Prohibited Approach
} Per NFPA 70E-2012

Eqpt Name: LP8 | Q2C: 12345678 | Date: 10/26/11

Values produced by a Schneider Electric engineering analysis.
Any system modification, adjustment of protective device settings, or failure to properly maintain equipment will invalidate this label.
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The United States regulates arc flash prevention through requirements such as NFPA 70 E, OSHA and IEEE standards. Other countries generally do not require this type of assessment and, therefore, it is common not to have the risk of arc flash potential at a specific piece of equipment properly assessed and identified. As a result, personnel are exposed to risk.

Executing an Arc Flash Incident Energy Analysis helps identify the PPE requirement and equipment labelling to warn operators. It also helps to identify active and passive mitigation solutions such as arc flash optic sensors, remote operations, etc.

Risk #5 – Lack of equipment training

Electrical systems provide a tremendous amount of power. For that reason, every time that an operator interacts with the electrical system, they are exposing themselves to significant levels of risk. Mistakes can result in injury or death. Beyond that, the way that personnel operate and manage the site's electrical system can lead to unexpected shut down or result in longer-term effects on performance, reliability, and safety. Therefore, proper and sufficient training is a critical element of any site's operations and maintenance program. Unfortunately, when organizations are resource con-strained, training often falls to the wayside as a priority. Inadequate training is also exacerbated by a trend towards increased turnover and a less experienced workforce. For those reasons, appropriate assessment of personnel competencies and adequate training is extremely important for the safe and effective operation of electrical equipment. This includes:

- theoretical training on electrical risks
- specific practical training on equipment that is to be operated and maintained
- ongoing, regular training of all methods of procedure (MOPs) and emergency operating procedures (EOPs)
- regular formal certification or ongoing validation of competencies, depending on responsibility

Training is often seen as a classroom exercise with a teacher or trainer in which attendees listen and attempt to assimilate the teacher's knowledge through lectures and theoretical exercises. Because this approach tends to be tedious, training is often overlooked or inadequately managed. However, the modern training that are available today allow site managers to assess competencies more easily and to use assimilation mechanisms to build on existing experience and structures consistently and gradually. Training can be delivered in a variety of ways including:

- eLearning webinars
- individualized online content
- software
- digital simulations
- virtual reality
- augmented reality

In all cases, the goal of modern training is to make the learning context closer to the real-world work context. In this way, a greater amount of skill and knowledge will be transferred because they are directly applicable to the work at hand. This is especially important for electrical system safety training, where untrained or unsafe behaviors carry severe risks.

Risk #6 – Insufficient power monitoring

Many issues that arise in electrical systems (including many of the issues raised in this paper), are not easy to spot. They tend to be invisible. For example, power transients such as sags, swells, and harmonic distortion can only be uncovered through measurement and proactive monitoring. Left unchecked, these types of "power quality" issues can lead to device malfunction, overconsumption, downtime, equipment damage and fire.

In addition, the lack of remote visibility of the power system asset status is increasing the time it takes to find the root cause of incidents. This increases stress and risk to operations teams that are acting in an emergency fashion given the likely high cost of system downtime.

The main objectives of an electrical power monitoring system (EPMS) are to continuously monitor the current state of electrical equipment and to provide a history of abnormal occurrences and abnormal trends of equipment key performance indicators. Typical conditions to monitor (by equipment type) include:

- Transformer: loading, temperature, etc.
- Circuit breaker: open/close, tripped, loading, watchdog, etc.
- Capacitor bank / Power factor correction unit: temperature, alarms, etc.
- Busbar: temperature, etc.
- Generator: loading, temperature, alarms, etc.
- Automatic Transfer Switch: position, alarms, watchdog, etc

By detecting abnormal trends in the key performance indicators of the electrical equipment, the monitoring system may help avoid equipment failure, reduce recovery time if a failure does occur, and reduce the cost of equipment corrective maintenance. A monitoring system can also provide historical data of energy consumption, equipment conditions, and overall power quality.

An effective power monitoring system considers the specific requirements of the site's process and management targets. An effective EPMS should also provide awareness when devices are not communicating with the software. An EPMS will ultimately provide a range of benefits:

- Real-time monitoring to view the status of the electrical system from any workstation. It can be used to view numeric values, status indicators, gauges and trends, all with intuitive graphical navigations. The monitoring system could be set up to automatically provide meaningful and actionable monthly reports.
- It can be used to study trends, to reveal energy waste, or unused capacity as well as verify efficiency improvements (easy-to-read Power Usage Effectiveness), and allocate costs to buildings, departments, or processes.
- It helps reduce downtime after a failure as site team will be able to do a root cause analysis faster and be more efficient in executing operations to restore service.
- It will help diagnose costly power quality problems such as sags, swells, and harmonic distortion that can cause device malfunction, downtime, and damage.

Additional benefits can be realized by using the information from the power monitoring system to design the right power distribution system capacity - one that meets but does not exceed the needs of any new plant, retrofit, or expansion. The system can be used to generate load profiles to reveal hidden capacity and increase forecast accuracy, helping the site "right size" the electrical infrastructure to defer capital expenditure.

Risk #7 – Insufficient maintenance practices

Proper maintenance is clearly an important part of managing any complex machine or system. In turn, improper or insufficient maintenance leads to an increased likelihood of breakdown and failure as well as a reduced service life. The components of modern electrical systems are designed to provide high quality, high reliability, and robust performance across a wide range of operating conditions. For that reason, electrical components are often overlooked and neglected as part of site-wide maintenance operations. While modern electrical systems don't require the same level of maintenance as older systems, they are still complex devices with moving parts and require routine maintenance to ensure their efficiency and reliability over time. Benefits of field maintenance on electrical equipment falls into four categories:

Increased safety: protecting people, equipment, and goods

One of a plant manager's most key responsibilities is to ensure the sustainable development of their business. Plant managers are obligated to adopt all available measures technically and economically available to them to minimize the risk of unwanted events, such as those that harm personnel, assets, or the business, while following international standards for environment, health, and safety.

A group of electrical distribution equipment is designed to minimize the risk and severity of accidents or process breakdowns, such as circuit breakers, fuse-contactors, etc. Prioritizing regular, on-going maintenance helps ensure that role is fulfilled.

Increased availability: maximizing service continuity

Maintenance maximizes uptime and is commonly conducted on scheduled outages during off-peak business periods, thereby mitigating its impact on operations with less disruption to activities, and less stress is generated.

It takes less time to perform proactive maintenance than emergency repair, while mitigating the risk of emergency shutdown, where the consequences of a production shutdown can be enormous.

Improved asset lifespan: CapEx optimization

Considering the significant costs of equipment acquisition (CapEx), site managers want their electrical distribution equipment to run safely for longer with maximum availability. Stress accelerates equipment wear (aging), shortening endurance. When wear is under control (within functional limits) endurance is secured or even extended.

Improved cost efficiency: OpEx optimization

Without maintenance, emergency shut down situations can happen that cause:

- Spare parts to be purchased at a premium. Maintenance can cut these costs by reducing faults within complex parts and using efficient on-site spare parts management.
- Labor to be purchased at a premium.
- Process downtime costs (no production, ramp-down/up production, loss of product, etc.).

A good approach to maintaining electrical equipment is to develop a tailored maintenance plan that takes into consideration the equipment types and level of criticality of the equipment. This type of tailored plan ensures that the overall maintenance cost is kept optimal, the right maintenance is applied for each item of equipment and its downtime is kept to a minimum.

An important point to consider when planning maintenance procedures on electrical equipment is the difference between routine and manufacturer maintenance. Routine maintenance consists of an overall check of equipment condition, lubrication, and operation. It can be performed by qualified maintenance service providers or site's qualified technicians per manufacturer's instructions. Manufacturer maintenance, on the other hand, is performed by the equipment manufacturer's specialists with specialized equipment and tools used for diagnosing equipment problems. This will often involve an internal inspection of the equipment.

Oftentimes, site managers will conduct routine maintenance while neglecting manufacturer maintenance. This is especially easy to do since manufacturer maintenance intervals are generally several years apart. This tends to create a false sense of security wherein the maintenance needs of electrical equipment are not being met and the risk of failure and long-term breakdown increase dramatically. A proposed maintenance program should take each piece of equipment in an electrical system under consideration and create a maintenance schedule based on the equipment criticality that includes the right mix of routine and manufacturer maintenance.

Sample of a detailed time-based maintenance program containing the list of asset and the different maintenance activities to be performed over years.

Device Location												2018				2019				2020			
Local	Switchboard	Device	Device type	Brand	Range	Type	Rating	ES	OS	GS	Obsolete	END-USER	MANUFACTURER	DIAGNOSIS	MODERNIZATION	END-USER	MANUFACTURER	DIAGNOSIS	MODERNIZATION	END-USER	MANUFACTURER	DIAGNOSIS	MODERNIZATION
MV Switchroom A	Main MV SWB	SWBA-Incomer 1	MV Switch Cubicle	Merlin Gerin	VM6	IM		2	3	2	Yes	X	X	X		X	X	X		X	X	X	
MV Switchroom A	Main MV SWB	SWBA-Incomer 2	MV Switch Cubicle	Merlin Gerin	VM6	IM		2	3	2	Yes	X	X	X		X	X	X		X	X	X	
MV Switchroom A	Main MV SWB	Busbar SWB A	Busbar	-	-	-	-	1	1	1	No	X				X				X			
MV Switchroom A	Main MV SWB	SWBA-Feeder to TRA	MV Fuse Switch Cubicle	Merlin Gerin	VM6	QM		2	2	2	Yes	X	X	X		X	X	X					x
MV Switchroom A	Main MV SWB	MV Fuse TRA	MV Fuses	Merlin Gerin	Solefuse	-	43	2	2	2	Yes	X		X		X	X	X					x
MV Switchroom A	Main MV SWB	SWBA-Feeder to TRB	MV Fuse Switch Cubicle	Merlin Gerin	VM6	QM		2	2	2	Yes	X	X	X		X	X	X					x
MV Switchroom A	Main MV SWB	MV Fuse TRB	MV Fuses	Merlin Gerin	Solefuse	-	43	2	2	2	Yes	X		X		X	X	X					x
MV Switchroom A	LV SWB A	LV-SWB-A-Main Incomer	LV Circuit Breaker	Schneider Electric	Masterpact NW	NW12	1200	1	2	2	No	X	X	X		X				X	X		
MV Switchroom A	LV SWB A	LV-SWB-A-MCC03 Comp.	LV Circuit Breaker	Schneider Electric	Masterpact M	M08	800	3	1	1	Yes				x	X				X			
MV Switchroom A	LV SWB A	LV-SWB-A-Mobile genset	LV Switch Disconnector	Schneider Electric	Masterpact NW	NW12HA	1200	3	3	3	No	X								X			

Maintenance programs can be further enhanced by taking advantage of device management software (e.g., BMS, EPMS, etc.) along with environmental monitoring systems that track room ambient temperature and humidity levels. These management software platforms increasingly offer analytical tools that make it possible to have a conditions-based maintenance program. This can reduce the amount of maintenance that is performed for newer and healthy assets while proactively initiating corrective maintenance before failure occurs.

Risk #8 – Limited availability of spare

Every piece of equipment has an associated risk of failure, this is known as its "failure rate." While we can minimize risk by choosing high-quality electrical distribution equipment and performing regular maintenance on it, that risk can never be eliminated. Oftentimes, the electrical systems at a site consist of components that have various ages, duty cycles and service lives. Because of this, the spare parts availability of critical equipment can vary based on the state of commercialization as listed below:

Commercialized	Commercialization period - Supply of spare parts guaranteed
Spare parts available	End of commercialization - Spare parts available for limited time
Obsolete	Final cancellation - No spare parts available

When there is an electrical equipment failure that requires repair, the availability of power supply depends on repair time. If the right spare parts aren't readily available, an unplanned downtime which would otherwise last hours can instead last days while spare parts are procured, or a full replacement is required. Therefore, by adopting a spares and spare parts stock policy, along with efficient inventory management, the repair time of devices would significantly be reduced. Subsequently, the electrical system reliability will be increased.

When spare parts are no longer available (obsolete equipment) the only solution to extend equipment service life is to carry out intense maintenance while planning for modernization.

Risk #9 – Obsolete equipment

Perhaps one of the biggest and most influential risks to unplanned downtime is the continued duty cycle of equipment that is obsolete. Obsolete equipment is equipment that is considered past its planned service life by its original manufacturer. This equipment and its spare parts are no longer sold or supported. In most cases, this type of equipment is very old and has been in use for a very long period, given the average longevity of electrical infrastructure. Even in such cases where obsolete equipment has been meticulously maintained and is operating in a low stress environment with adequate spare parts on hand, there are still significant risk to operating equipment that is past its service life.

Mechanical linkages may be worn out, components are deteriorated, and perhaps used up (e.g., batteries). The equipment will no longer operate at peak efficiency and may be prone to fluctuations in power quality, thermal issues, and operating characteristics that may be out of specification. This will result in equipment failure, downtime, and in extreme cases, can lead to injury.

Beyond the risk of failure, obsolete equipment will require greater maintenance demands, will lack modern features that may be beneficial to the site's process and management targets, and will also decrease the overall availability of the electrical system.

To protect against the risk of obsolete equipment, a modernization plan should be established that aims to manage equipment end-of-service life and obsolescence by replacing/retrofitting equipment and to improve installation performance by modifying the electrical architecture. The first step is to develop an understanding of installed base information and equipment obsolescence status down to the component level. The next step is to categorize equipment based on its stress, reliability requirement, and criticality into levels of priority for either retrofit or replacement. An added benefit of modernization planning is that it will inform on possible architecture modifications that can greatly improve the reliability and performance of the electrical system.

Conclusion

As we have seen, many of the risks to an electrical system's performance and reliability are due to an expectation that electrical equipment is robust and reliable. While that's true for the design of electrical equipment and to the low demands required of electrical systems in terms of maintenance and management, this can also lead the site manager to overlook risks. While these risks are low, the impacts of electrical issues can be severe. Risks include complete and continued shutdown of the electrical system and the site's operations but can also extend to injury and even death to site personnel.

Fortunately, all the risks that have been outlined in this white paper are manageable and avoidable through simple proactive measures. Many of these measures can be outsourced to qualified service providers that can perform site assessment to quantify these risks and even provide other tangential benefits including energy savings and decreased Opex costs in the long-term. Engaging in these activities will help ensure that the electrical installation is modernized to avoid the risks of obsolete equipment, that it performs at peak reliability and availability, and that above all, it is safe for the health and well-being of site operator and personnel.

About the author

Jean-Pierre Morand is the consulting offer manager supporting the development of world-wide consistent site assessment and system studies. Owner of a master's degree in Electrical Engineering, he started as power system engineer in France running system studies for Buildings, Data Centers, Hospitals, Water and Wastewater. He then supports the deployment of multi-site assessment program over 35 countries before taking the position of consulting offer manager. He has 15+ years of experience in power systems.