Ten Common Risks to Address When Managing Commercial and Industrial Electrical Systems

by Matan Marom

Executive summary

Facility electrical systems are the life blood that supports any functioning commercial, healthcare or industrial business. An unexpected partial or complete shutdown of the electrical system can lead to lost productivity and a wide range of health and safety issues. Unfortunately, the condition of site electrical systems is often overlooked. While most electrical equipment is robust and reliable, unforeseen failures can still occur. This white paper examines some commonly overlooked risks to electrical systems and offers recommendations for bolstering system reliability.

Introduction

Robust facility electrical systems act as an insurance policy that helps to ensure the successful operation of a plant, commercial building, service center or hospital. A proper audit of a building's electrical infrastructure can validate the integrity and safety of the system and can also reveal areas where energy consumption can be reduced, thereby reducing operating costs.

Since electrical system infrastructure is often invisible to most of the occupants of any building, it can deteriorate over time and, without warning, can lead to costly un-anticipated outages. This paper examines those aspects of the electrical system that could potentially pose problems down the road and offers recommendations for min-imizing unnecessary risks.

Figure 1

Power monitoring can offer clues to anomalies in the electrical system and indicate areas that will require repair or re-configuration.

Risk # 1: Design inadequacies

Electrical network design Inefficiencies

Electrical systems, when initially designed and installed, don't always perfectly align with the needs of the particular site in question. In the case of newly commissioned sites, the electrical system designers sometimes make decisions based on incomplete information. Or, in some cases, recommended changes fail to be communicated during the design and commissioning process, or the overall electrical system falls victim to over-design. In older sites, problems usually arise over time when non-electrical changes to the facility or facility operations aren't reflected in the electrical system design. The opposite can also happen: changes made to the electrical system don't take into consideration the surrounding operations.

When an electrical system design is sub-optimized, site equipment such as air compressors, boilers, and chillers, which may be redundant at the machine level, are not secured from an electrical point of view. For example, if all site utilities are supplied by the same electrical panel, an electrical malfunction upstream of that panel could, in effect, shut down the entire site.

Risk # 2: Incomplete documentation

Out-of-Date Single-Line Diagrams (SLD)

Electrical systems can be highly complex and interdependent. Just as upstream events can impact downstream performance, downstream events can also disrupt upstream power stability. When qualified technicians perform electrical system maintenance or upgrades, they rely on drawings and single-line diagrams to guide their actions. In some cases, these documents are either missing or incomplete. For example, a document may have been inappropriately updated after a prior change had been executed. When these circumstances present themselves, they often drive costly delays in electrical project work. The delays result in longer periods of down-time during interventions. In the worst-case scenario, safety is compromised. Uninformed decisions such as work performed on the wrong circuit breaker can result in unanticipated shut-down, injuries, or even death.

Electrical distribution single-line diagrams should be kept up-to-date and posted in the site's electrical rooms / substations. Within the confines of the appropriate substation, these displayed diagrams should include a site-wide medium voltage (MV) single-line diagram as well as more detailed low voltage (LV) single-line diagrams.

These drawings should be meticulously updated following any electrical distribution changes.

Risk # 3: Circuit protection gaps

Improper circuit protection setting or definition

A core component of electrical systems is circuit protection. The simplest example of circuit protection is a fuse in which a filament is designed to melt in the case of excessive amperage. Once the filament is melted, the flow of electricity is disrupted. Modern electrical systems utilize more sophisticated methods of circuit protection, but the end goal is the same: to protect against fault currents. In some cases, the circuit protection is not properly aligned or configured to handle the specific scenario. Consider an electrical device that operates at 30,000 amps of available fault current while the breaker servicing it is rated at 20,000 amps. In this scenario, if a fault occurs the equipment will explode. Such an explosion would almost certainly damage the electrical board and shut down the affected section of the electrical system. If human personnel are nearby at the time of the explosion, they could risk injury or death.

Risk # 4: Device coordination flaws

Lack of robust protective device coordination

Electrical systems are interconnected in such a way that events in one part of the system can affect every other part of the network. To account for the interconnected nature of these systems, designers install protective devices to isolate and manage electrical faults. In some cases, these protective devices can be inadequately coordinated. For example, consider the case where an electrical fault isn't tripped by a protective device that is appropriately downstream. Instead, the fault is tripped 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 particular circuit board would be shut down. In extreme cases, poor circuit breaker coordination can result in cascading failures that shut down an even wider section of the electrical system. If such an event occurs, it may take several hours before full operation can be restored.

Risk # 5: Arc flash threat

Substandard arc flash protection

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 most often caused by accidental contact. Other common causes include equipment which is underrated for the available short circuit current, cracking of insulation, deterioration or corrosion of equipment, and vermin infiltration. The arc flash ionizes air at 35,000 degrees Fahrenheit (19,427° Celsius) which can severely burn skin within fractions of a second across several feet. 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 onsite personnel, arc flash events are costly. Costs include medical fees to treat burns, worker's compensation, legal fees, lost production due to cleanup and repair, damages to equipment and process, and regulatory fines. To protect against an arc flash incident, assessments should be performed that determine a worker's potential exposure to arc flash energy. These assessments should make recommendations surrounding injury prevention best practices, safe work practices, and the appropriate levels of personal protective equipment (PPE) to be worn. A proper assessment should undergo the following steps:

1. Collect system and installation data
2. Determine system modes of operation
3. Determine bolted fault current
4. Calculate arc fault current
5. Identify protective device characteristics and arc duration
6. Select working distances
7. Calculate incident energy
8. Calculate flash protection boundary
9. Determine PPE (risk hazard) category
10. Generate and apply labeling to equipment that shows the PPE category

Figure 2

Example of proper arc flash labeling information.

The United States regulates arc flash prevention through standards and requirements such as NFPA 70 E and OSHA and IEEE. Some countries do not require this level of assessment. As a result, it is common not to have the arc flash threat properly assessed and identified and which puts personnel at a higher risk of injury. Consider a scenario where an electrical operator is servicing a piece of equipment but he is not wearing the appropriate PPE for the associated arc flash category. If an arc flash occurs, he will be subjected to severe injury or death.

Risk # 6: Inadequate training

Substandard electrical equipment training

Electrical systems harness a tremendous amount of power. Therefore, each time an untrained operator interacts with an electrical system, the risk of errors and the consequences of those errors are compounded. Unexpected shut down, sub-par performance, compromised reliability and human health and safety are all realistic consequences. The threat presented by inadequate training is also exacerbated as a result of increased workplace employee turnover. As the more experienced workers retire, a younger, less seasoned workforce takes over.

For these reasons, appropriate assessment of personnel competencies and adequate training is extremely important for the safe and effective operation of electrical equipment. Proper training should include the following:

- General theoretical education surrounding electrical risks
- Specific practical training on equipment that is to be operated and maintained
- Regular formal certification or validation of competencies, depending on job responsibility.

Traditional classroom training is often difficult to coordinate and can be off-putting to certain types of learners. As a result, this important education step can be overlooked or inadequately managed. However, more modern training methods are available that allow site managers to more easily assess competencies and increase employee knowledge and awareness:

- eLearning webinars
- Individualized online content
- Software
- Simulations
- Virtual reality
- Augmented reality

In all cases, the goal of modern training is to more closely align the learning context to the work context. In this way, a higher level of skills and knowledge will be transferred as the educations is 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 # 7: Insufficient system monitoring

Lack of electrical system monitoring

The best way to avoid a problem is to address it before it happens. However, many electrical system issues are not simple to identify. These are invisible issues such as sags, transients, and harmonics that can only be uncovered through measurement and proactive monitoring. Left unchecked, these types of “power quality” issues can lead to equipment malfunction, downtime, and damage.

Monitoring systems are designed to assess the current state of electrical equipment and to provide a history of abnormal occurrences and trends involving equipment key performance indicators. Typical equipment and conditions to be monitored include:

- Transformers: loading statistics and temperatures
- Circuit breakers: open/close status, trip status, loading statistics
- Capacitor bank / Power factor correction unit: temperatures, alarms
- Busbar: temperatures
- Generator: loading statistics, temperatures, alarms
- Automatic Transfer Switch (ATS): position status, alarms, watchdog (a system that determines and tests whether protection functions are working).

By detecting abnormal trends, the monitoring system may help avoid equipment failure, reduce recovery time if a failure occurs, and reduce the cost of equipment corrective maintenance. A monitoring system can also provide historical data of energy consumption, equipment conditions, and power quality.

An effective power monitoring system takes into consideration the site’s process and management targets and performs a gap analysis of existing monitoring system and communication device capabilities. Power monitoring systems can benefit users in the following ways:

- **Visibility to real-time monitoring data from any workstation or even from handheld devices** - The types of data to be viewed includes numeric values, status indicators, gauges and trends, all with intuitive graphical navigation. The monitoring system can be configured to automatically provide meaningful and actionable monthly reports.
- **Performance of virtual meter calculation** - When all the meters are accessible in one unique system, this allows the site to perform virtual meter calculation, which is not possible if the components of the virtual load are in two different systems.
- **Trend analysis** – Power monitoring systems can be used to study trends, to uncover energy waste, or to identify unused capacity as well as verify efficiency improvements (e.g., easy-to-read Power Usage Effectiveness), and allows for the allocation of costs to buildings, departments, or processes.
- **Issue identification** – The monitoring system can diagnose costly power quality problems such as sags, transients and harmonics that can cause device malfunction, downtime and damage. The system could protect the site electrical system by immediately identifying the root cause of power quality issues, rapidly communicating critical conditions before they escalate, confirming device tolerances, and supplying information to coordinate backup power systems.
- **Capacity planning** - The power monitoring system information can contribute to power distribution system capacity design specifications - 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 that can reveal hidden capacity and increase forecast accuracy, helping the site to "right size" the electrical infrastructure thereby deferring some of the capital expenditure.

Risk # 8: Insufficient maintenance

Neglected electrical system maintenance

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 this 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. Proper electrical equipment field maintenance can benefit site owners in the following ways:

- **Increased safety: Protecting people, equipment and goods**

  One of a plant manager's most crucial responsibilities is to ensure the sustainable development of their business and adherence to international standards for environment, health, and safety. Plant managers are obligated to adopt all available technical and economic measures to minimize the risk of accidental events, such as those that harm personnel or destroy assets, or which compromise the business. Some electrical distribution system components such as circuit breakers and fuse-contactors are specifically designed to minimize the risk and severity of accidents or process breakdowns.

- **Availability enhancement: Maximizing service continuity**

  Maintenance maximizes uptime and is often conducted during off-peak business periods, thereby mitigating its impact on operations with less disruption to normal activities. It takes less time to perform proactive maintenance than to undergo emergency repair (immediate corrective). A preventive or condition-based maintenance approach can avoid the risk of emergency shutdown, where the consequences of even a short hour-long production delay can be enormous.

- **Aging asset performance: CapEx optimization**

  Site managers want their electrical distribution equipment to run safely for longer periods of time with maximum availability. Stress accelerates equipment wear (aging), shortening endurance. When wear is under control (within functional limits), endurance is secured or even extended and capital equipment acquisition cost (CapEx) is reduced.

- **Operational cost efficiency: OpEx optimization**

  When emergency shut down situations occur, spare parts have to be purchased at a premium. Proper maintenance practices can cut these costs by reducing faults within complex parts and by deploying efficient on-site spare parts management.

A prudent approach for maintaining electrical equipment is to develop a tailored maintenance plan that takes into consideration both equipment types and level of criticality of the equipment in question. Such a tailored plan ensures that:

- The overall maintenance cost is kept low
- The proper maintenance is applied for each item of equipment

- Equipment downtime is kept to a minimum

An important point to consider when planning electrical equipment maintenance procedures is the difference between manufacturer maintenance and end-user maintenance. Oftentimes, site managers will conduct end-user maintenance while neglecting manufacturer maintenance. This is easy to do since manufacturer maintenance intervals are generally several years apart. A proposed maintenance program should take each piece of equipment in an electrical system into consideration and create a maintenance schedule based on the equipment stress, reliability, and criticality. Such a program should include the right mix of end user and manufacturer maintenance.

Table 1

Sample of a detailed 10-year maintenance program.

Device Location		Device Designation	Device Type	Brand	Range	Type	Rating	Reliability Level	Stress Level	Criticality Level	2017				2018				2019				2020				2021				202		
Building / Room	Board										MANUFACTURER OPM	MANUFACTURER OCM-E	MANUFACTURER OCM-A	MANUFACTURER OAD	MANUFACTURER OPM	MANUFACTURER OCM-E	MANUFACTURER OCM-A	MANUFACTURER OAD	MANUFACTURER OPM	MANUFACTURER OCM-E	MANUFACTURER OCM-A	MANUFACTURER OAD	MANUFACTURER OPM	MANUFACTURER OCM-E	MANUFACTURER OCM-A	MANUFACTURER OAD	MANUFACTURER OPM	MANUFACTURER OCM-E	MANUFACTURER OCM-A	MANUFACTURER OAD	MANUFACTURER OPM	MANUFACTURER OCM-E	OCM-
HV Substation	HV Main SWGR	HV_Cubicle_Incoming 1	MV Circuit Breaker Cubicle	Schneider Electric	SM6-24	DM1-A		1	3	1			X	X				X				X			X	X				X			
HV Substation	HV Main SWGR	HV_Cubicle_Incoming 2	MV Circuit Breaker Cubicle	Schneider Electric	SM6-24	DM1-A		2	3	2		X																X					
HV Substation	HV Main SWGR	HV_Cubicle_Incoming 3	MV Circuit Breaker Cubicle	Schneider Electric	SM6-24	DM1-A		3	3	3	X																				X		
HV Substation		Power TX_TR1	Transformer	Hammond				1	3	1		X		X				X				X		X		X				X			
HV Substation		Power TX_TR1	Transformer	Hammond				2	3	2		X																X					
HV Substation		Power TX_TR1	Transformer	Hammond				3	3	3	X																				X		
Main Electrical Room	SWBD A	LV_CB_SWBD A Main	LV Circuit breaker	Siemens	Sentron 3WL	WLII 3200	3200	1	3	1			X	X				X				X			X	X				X			
Main Electrical Room	SWBD B	LV_CB_SWBD B Main	LV Circuit breaker	Siemens	Sentron 3WL	WLII 3200	3200	2	3	2		X																X					
Main Electrical Room	SWBD C	LV_CB_SWBD C Main	LV Circuit breaker	Siemens	Sentron 3WL	WLI 1600	1600	3	3	3	X																				X		
Electrical Room A	DP 1	LV_SW-DP 1 Main	LV Switch	-	Conmutador BT			1	3	1	X												X										
Electrical Room A	DP2	LV_SW-DP 2 Main	LV Switch	-	Conmutador BT			2	3	2	X																X						
Electrical Room A	DP3	LV_SW-DP 3 Main	LV Switch	-	Conmutador BT			3	3	3	X																				X		

Risk # 9: Spare parts inventory

Insufficient electrical system spare parts inventory

Every piece of equipment has an associated risk of failure, this is known as its "failure rate." Typical electrical systems consist of components characterized by various ages, duty cycles, and service lives. Because of this, the spare parts availability of critical equipment can vary based on equipment age and commercial presence.

When a piece of critical electrical equipment requires repair, the availability of that particular facility's power depends on repair time. If the right spare parts aren't readily available, an unplanned downtime occurrence which would otherwise last hours can instead last days while spare parts are procured or a full replacement is required. Therefore, by adopting a spare parts stock policy, along with efficient inventory management, the repair time of devices can be significantly reduced and electrical system reliability 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 # 10: Obsolete equipment

Equipment is out-of-date

Perhaps one of most significant risks to unplanned downtime is the continued duty cycle of equipment that is obsolete, that is, equipment that has outlasted its planned service life (as designated by the original equipment manufacturer). This equipment is no longer commercially available. Spare parts are no longer sold. In most cases, this type of equipment is old and has been in use for a very long period of time.

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 we warn out, pieces can be deteriorated, and components may be consumed. 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. Any one of those issues can accumulate and lead to a cascading failure of the equipment and can have upstream and downstream effects on the overall electrical system. Failure will result in downtime and, in extreme cases, can lead to injury.

In most cases, obsolete equipment that is kept in operation is not supported by adequate spare parts inventory. In these cases, equipment failure is followed by significant delays in the repair time while the site waits for the electrical system to come back online.

Beyond the risk of failure, obsolete equipment requires a more demanding and costly maintenance schedule, which negatively impacts the site's process and management targets, and decreases the overall availability of the electrical system.

To protect against these risks, a modernization plan should be established that manages equipment end-of-service life in an efficient manner. This will require planning for obsolescence by replacing/retrofitting equipment and by adjusting the electrical architecture when major components are replaced. Installed base information will need to be gathered and equipment obsolescence status will need to be identified down to the component level. Next, the various pieces of equipment in the electrical system will need to be categorized based on stress, reliability, and criticality parameters. Then, levels of priority can be established for either retrofit or replacement.

Conclusion

Many of the risks to electrical system performance and reliability are due to an expectation that electrical equipment is continuously robust and reliable. While modern electrical equipment is indeed quite reliable and risks are low, the impact of electrical issues can be severe. Risks include complete and continued shutdown of the electrical system and the site's operations and can also extend to human injury and death in the most extreme cases.

Fortunately, all the risks outlined in this paper are controllable through simple proactive measures. Many of these measures can be outsourced to qualified service providers and professional assessments can provide other tangential benefits such as energy savings and decreased long-term OpEx. Managing these risks through training, technical assessments, maintenance, monitoring, and modernization planning is a key responsibility of the site manager. Engaging in these activities will ensure that the electrical installation is modernized, thereby enabling peak performance and avoiding the risk of either obsolete equipment or threats to human safety.

About the author

Matan Marom is global manager of consulting services at Schneider Electric. He holds a Master of Science from Syracuse University, United States and a Master of Business Administration (MBA) from North Carolina State University, United States. In addition to his current position globally managing the electrical distribution consulting services portfolio, Matan has broad experience in consulting, strategy, and marketing in the industrial automation and energy efficiency industries.