Evaluating Your Electrical Distribution System

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Introduction

Virtually all industrial and commercial installations are powered via the local electrical utility. Power is provided at the point of common coupling (PCC) after which the client owns and operates its electrical distribution network. While the main electrical substation upstream of the PCC is maintained by the local utility, the reliable operation of client owned equipment (after the PCC) is the sole responsibility of the client. Most of the production equipment, which is responsible for producing the revenue and profit of the client, is powered by electricity, except in some rare instances whereby excess process steam or gas may be used. It is therefore self-evident that the reliability of the electrical distribution system within the client’s facility is of utmost concern. The cost of an unreliable electrical system is mostly due to lost production as well as high maintenance costs. The cost to repair or replace failed equipment is usually insignificant in comparison.

This paper will describe how to evaluate the reliability of your electrical distribution system so that informed decisions can be made to improve it. In order to make these decisions on improvement, a business case must be made to upper management in order to demonstrate how capital cost improvements such as the replacement of obsolete or aged components, installation of redundant power feeds to critical busses, updating of spare parts inventories, updating preventative maintenance procedures or the installation of predictive maintenance equipment will positively improve the bottom line. In order to demonstrate the improvement, techniques will be described to calculate the statistical probability of failure of critical components. By multiplying the probability of failure over a fixed time period by the potential loss of revenue and profit, a dollar value can be ascertained to support the business case.

Advantages of Electrical Reliability

Reliability is defined as the probability that an asset will perform its intended function over a fixed amount of time. In the electrical world, most components will either function at 100% capacity or fail (0%) such as breakers & cables. However, there are certain electrical components such as transformers, generators and motors that may partially function below its intended performance level. A 1000 HP motor that is only producing 800 HP due to bearing friction, rotor bar cracks or turn-turn shorts is considered a failed component, although it is still running. A transformer that is operating but at a reduced voltage level due to a tap changer mechanical failure or generating additional losses due to internal heating in the windings is considered a failed component although it is still transforming power downstream.

An electrical reliability evaluation looks at all possible failure modes of individual components and determines the best method to detect an impending failure in order to take proactive steps impending before the component results in an unplanned outage. This may take the form of better off-line testing methods, more frequent testing, and the addition of predictive maintenance technologies to trend and detect an impending failure or improving spare parts inventories. In addition, the analysis can statistically quantify the probability of failure of an electrical system at all nodes.

Therefore, besides reducing the probability of a loss of production during unplanned outages, electrical reliability can increase equipment performance, reduce quality losses, reduce rate losses, reduce maintenance costs and extend equipment life.
History of Electrical Reliability

There are three generations of electrical reliability philosophies as follows:

**Generation 1** is to run equipment to failure and then replace the equipment. This has the consequence of unplanned production outages which have a significantly greater impact on revenue and profitability than the cost of regular planned equipment maintenance to detect impending failures.

**Generation 2** is a time based maintenance plan which regularly shuts down equipment for testing and maintenance. This is inefficient as equipment that is running properly is taken out of production along with equipment that is not running properly or has an impending failure.

**Generation 3** is a condition based maintenance strategy. By installing on line or off line predictive maintenance technologies, equipment performance can be monitored and trended before a failure occurs. This strategy allows targeting of these assets only and thereby reduces overall maintenance costs.

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**Time**

**Condition**

- Onset of Failure
- Predictive Detection
- Skilled Inspection
- Beyond Operating Parameters (Functionally Defective)
- Performance Losses
- Equipment Failure

**Equipment Maintenance Windows**

- Predictive Window (Condition Based Maintenance)
- Maintenance Window (Time Based Maintenance)

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The Process – Electrical Reliability Analysis

The process of conducting an electrical reliability analysis is as follows;

A. Identify the critical processes that affect production, revenue and profit using ‘Value Stream Mapping’ and ACASS (Asset Criticality Analysis) to determine a priority list of criticality.

The process equipment that generates the most profit in a complex industrial plant can be prioritized using ‘Value Stream Mapping’.

In a fertilizer plant, various end products are produced. Some of these products are Anhydrous Ammonia, Ammonium Phosphate, Ammonium Sulfate, Nitrogen, and Urea. Each product line is usually segregated in different areas of the plant. A determination of the critical electrical equipment required to produce these products is determined. Some electrical equipment may be critical to multiple product lines and would have a higher priority.

An ACASS (Asset Criticality Analysis) is a spreadsheet that identifies seven or more criteria used to numerically rank the equipment. The numerical system is based on the client’s tolerance to risk. These criteria are;

1. Operational Severity
   How will failure affect the facility’s ability to meet mission requirements? It is a ranking based upon throughput reduction from ‘No Impact’ to ‘Full Impact’.

2. Safety Severity (add the three subsections)
   This is a summation of Personal Injury Potential, Fire or Explosion Potential and Safety during Maintenance.

3. Environment Severity (add the two subsections)
   This is a summation of the probability of air emissions or chemical spills in the event of equipment failure.

4. Single Point Failure
   Is there a way to minimize loss caused by failure? This can vary from no-loss of production from a failure due to available backup sources of power, to full loss of production until the equipment can be repaired or replaced.

5. Maintainability
   Maintainability is a characteristic of design and installation, expressed as the probability that an item will be retained in or restored to a specified condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources. The maintainability is a product of ‘Serviceability’ and ‘Supportability’.
6. Reliability

Use the last two previous year’s maintenance data to determine the number of breakdowns or routine tasks performed on each asset. A number is assigned based on frequency of breakdowns.

7. Spares and Lead Time

Spares on hand and the time required to repair parts or obtain replacement parts in an emergency. This can vary from hours to months.

B. Build a fault tree and reliability block diagram of the electrical distribution network from the utility substation (PCC) down to the process motors.

A fault tree diagram shows graphically, using ‘And’ and ‘Or’ gates, how all of the components are connected from the power source (utility substation or generator) all the way down to the electrical process equipment (Motor).

C. Using Failure Mode and Effects Analysis (FMEA), determine the various failure modes of each component, the current methodology of detecting these failure modes, and recommend improved methods to detect the failure.

An FMEA looks at all of the components powering an electrical process such as generators, cables, busses, switchgear, breakers, relays, VFDs, Soft Starters and motors. A risk assessment is determined for severity, probability of occurrence and method of detection by a subjective ranking of 1 to 10.

Recommended improvements in these three criteria are then evaluated to reduce the component’s risk assessment. This may be through a comprehensive preventative maintenance program (PM) and/or by on-line or off line predictive maintenance technologies (PdM).

D. Using Weibull statistical analysis, calculate the probability of loss of production at the process motors as currently exists. This can be over the next 1, 3, 5, 10 and 15 years.

From the fault tree diagram, each component is assigned an MTBF (Mean Time Before Failure) based on component age and statistical probability of failure over time. The statistical probabilities are obtained from IEEE-493 ‘Design of Reliable Industrial and Commercial Power Systems’ which provides typical MTBF and MTTR (Mean Time to Repair) values for each type of electrical component. More accurate MTBF values can be obtained from manufacturers and can also be adjusted to a particular system based on component loading and operating temperatures. This requires conducting a load flow analysis of the client’s electrical distribution system.

Once each component is assigned an MTBF and age, the total reliability of the process motor’s reliability can be ascertained over a per-determined future time period using Weibull statistical analysis.
E. Provide recommended changes to the system which may include but not limited to:
   » Power redundancy to the process motors (ties to other busses, standby generators, automatic transfer schemes).
   » Backup DC power with UPS for critical process control.
   » Replace obsolete or aged components.
   » Reduce power flow through critical components (PF correction and harmonic filtering).
   » Reduce switching and lightning transients (Arrestors and Snubber circuits).
   » Reduce motor stresses via soft starting or VFD drives where practical.

F. Using Weibull statistical analysis, re-calculate the probability of loss of production at the critical process motors with the above recommendations. This can be over the next 1, 3, 5, 10 and 15 years.

G. Recommend preventative maintenance or predictive maintenance technologies (on or off-line) to monitor the health of critical components and to detect impending failures before they affect production.

Weibull analysis only provides a statistical probability of failure of a critical process motor over a set time period of 1, 3, 5 years or longer. This analysis does not predict exactly when power to a specific motor will fail with any great degree of certainty.

To reduce the probability of an undetected failure mode occurring during production, the client’s preventative maintenance program and component testing methodologies must be reviewed and recommendations for improvement made. This may be in the form of increased component testing frequency or testing methodologies.

In addition to improved preventative maintenance, predictive maintenance technologies (PdM) may be recommended that will provide real time monitoring of equipment performance and which can be monitored for trending. A few such technologies currently on the market are on-line dissolved gas analysis of transformers, furan analysis of insulating oils, on-line partial discharge monitoring of cable terminations and on-line motor signature analysis.

H. Provide recommendations to reduce downtime in the event of an unexpected failure of a component (MTTR) by evaluating the critical spares inventory as well as have an effective job plan in place to replace the component as efficiently as possible.

The above processes (A-G) identify critical process motors, failure modes of components and provides a baseline probability of failure of the electrical distribution system at the critical process motor. To evaluate the cost of failure, downtime in the form of MTTR (Mean Time to Repair) must be assessed.

This can be obtained from IEEE-493 but is best determined through consultations with the client and analysis of the spare parts inventory and job planning. By quantifying the MTBF and MTTR, the production cost in lost revenue and profit can be determined for each critical process motor.
Financial Benefits of Enhanced Reliability

Although improved electrical reliability would seem to be in everyone’s best interest, a business case must be made in order to implement the above recommendations for improved electrical reliability. Although the electrical reliability can now be statistically quantified and weak points in the distribution system clearly identified, many plant managers are reluctant to spend large funds on capital projects when the system has run reliably for many years. How does one make the case?

Overall Equipment Effectiveness (OEE) is defined as Equipment Availability x (100-rate loss) x (100-quality loss). Equipment Availability is defined as uptime/planned production time = run time / (total time – scheduled downtime). It is also defined by MTBF/(MTBF+MTTR) in a continuous operation with no scheduled downtime.

Therefore, increasing OEE by either:

A. Increasing equipment availability
B. Reducing rate loss.
C. Reducing quality loss.

An example focusing on improving equipment availability follows:

A production motor that, if failed, contributes to a loss of revenue of $25,000 per hour. If the combined reliability for that critical motor using component MTBF, component age and component loading results in a probability of failure within the next five years of 75% (via Weibull Analysis) and the MTTR is 7 days (168 hours), then the loss of revenue can be calculated as:

75% x 168hrs x $25,000 = $3,150,000 over five years (as the failure can happen anytime during the five years)

If the electrical reliability of this motor can be improved so that the probability of failure is reduced to 25% over the next five years and the MTTR reduced to 4 days (96 hours), then the loss of revenue reduces to:

25% x 96 x $25,000 = $600,000 over five years

This represents a ‘gain’ in revenue of $2,550,000 over five years.

If the gross profit related to this gain in revenue is 20%, then the gain in profit is:

20% x $2,550,000 = $510,000 over five years or $102,000 per year

The capital cost to achieve this improvement in reliability can then be amortized over five years to determine the net cost benefit to the company.
Conclusion

Although electrical reliability, in the broadest sense, is an established goal for all stakeholders, an electrical reliability analysis of a client’s electrical system can quantify the improvements in reliability both statistically through the processes described above as well as in financial terms. Once a business case can be made showing that capital cost improvements in the electrical system can provide financial benefits for a company over a selected time period ranging from short term (1-3 years), medium term (3 – 10 years) or long term (over 10 years), a financially sound decision for facility planning can be reached.

It is of paramount importance that the electrical reliability of a distribution system be one of the cornerstones of electrical distribution design at the outset, along with meeting electrical code and safety requirements. However, once an optimal design has been implemented, factors such as aging of components, changing operating conditions and maintenance can affect the system reliability so it is recommended that an Electrical Reliability Analysis be conducted on a client’s system at regular intervals.
Electrical Reliability

Reliability requirements for facilities vary based on their criticality to the organization. Unplanned outages can cost millions of dollars in damages, directly and indirectly. Further, it impacts the performance and compensation of a facility’s engineers, operators and plant managers. Although poorly understood among stakeholders, electrical system reliability is directly tied to productivity and operating cost.

Improving electrical reliability doesn’t have to be a guessing game. Magna IV Engineering can empower you to make informed decisions through a comprehensive analysis of your power system. We employ a bottom-up approach to determine areas that can be improved to reduce potential downtime, safety issues, and environmental risks.

When considering reliability services, it is paramount to consider all three pillars of electrical reliability: engineering design, day-to-day operations and overall electrical maintenance.

Benefits

» Reduced...
» Unplanned Outages
» Liability
» Maintenance Cost
» Outage Duration

» Minimized...
» Equipment Damage
» Loss of Production
» Environmental Risks
» Improved Safety

Our Process

» Site Visit
» Asset Criticality Assessment
» Evaluate Facility’s Reliability Programs
» Conduct Analysis for Potential Failures
» Fault Tree Analysis
» Failure Mode Event Analysis
» Cause & Effect Analysis
» Sequence of Events Analysis
» Ishikawa/Fishbone Analysis
» Reliability Block Diagram
» Weibull Analysis

Solutions

» Reduce asset criticality
» Early detection & monitoring
» Performance trending critical parameters
» Improve preventative maintenance program
» Predictive maintenance program (condition based)

Magna IV Engineering extensively uses industry standards, guidelines and recommendations (IEEE Std 493, NFPA 70B, NETA –MTS, etc.) while conducting a study.

Our team is well aware of the operating cost constraints faced by facilities. We can generate recommendations based on criticality, cost and timeline. This will allow clients to prioritize and implement recommended solutions.

All reliability studies by Magna IV Engineering include short-, medium-, and long-term recommendations, as well as capital cost estimates.