MANAGING ELECTRICAL EQUIPMENT PROTECTION AND MAINTENANCE

INTRODUCTION

Electrical equipment includes motors, generators, transformers, wires, cables, switchgear, batteries, light fixtures, arresters and electronic controllers. Electrical equipment components include insulating and support structures, like oil and air dielectrics, bushings and insulators. Deterioration of equipment is normal, but equipment failure can be avoided if an acceptable Electrical Preventative Maintenance Program (EPM) is adopted by senior management, Unchecked, the deterioration process can cause malfunction or electrical failure of critical equipment, which can lead to property loss and/or business interruption.

Whether electrical equipment is used for generating power, transmitting power or running machinery, its protection and maintenance must be managed. Managers decide what equipment and what protective devices and systems are installed, and how to maintain them.

Electricity is controlled by designing, installing, protecting and maintaining electrical equipment and components in ways that provide acceptable levels of reliability. Ideally, the result is a cost-effective, safe and reliable electrical system – one that is reasonably safeguarded to limit damage, injury and production interruptions.

Electrical codes address electrical installation features. They mandate rudimentary levels of protection for electrical systems and equipment. These codes are written to be adopted by governing bodies and written to be implemented as law. Installation codes do not prevent employing higher levels of protection to improve safety and reduce losses. If high loss potentials are not satisfactorily reduced by application of these codes, higher standards may be applied.

These codes rarely mandate specific maintenance tasks. They presume maintenance practices are adequate. Code users are expected to implement appropriate practices.

For some equipment, perhaps only code requirements need be followed. For most equipment, higher standards are needed. Programs for loss prevention and loss control require analyzing the unique and special conditions of systems and equipment, and applying appropriate loss prevention and loss control resources. A “one size fits all” approach to loss prevention and loss control either wastes valuable resources or neglects valuable actions.

Housekeeping, training, hazard evaluation, maintenance and many of the other 14 interlocking loss prevention and control programs identified in AXA XL Risk Consulting’s *OVERVIEW* have a role in safeguarding electrical installations. This Property Risk Consulting Guideline discusses issues needed to make electrical equipment protection and maintenance decisions within such programs.

The maintenance of industrial electrical systems and equipment is essentially a matter of economics. Maintenance costs can be placed in two basic categories: preventative/predictive maintenance or breakdown repairs. Money spent for preventative and predictive maintenance will be reflected as less money required for breakdown repairs. An effective maintenance program holds the sum of these two expenditures to a minimum. Figure 1 is a typical curve illustrating this principle.

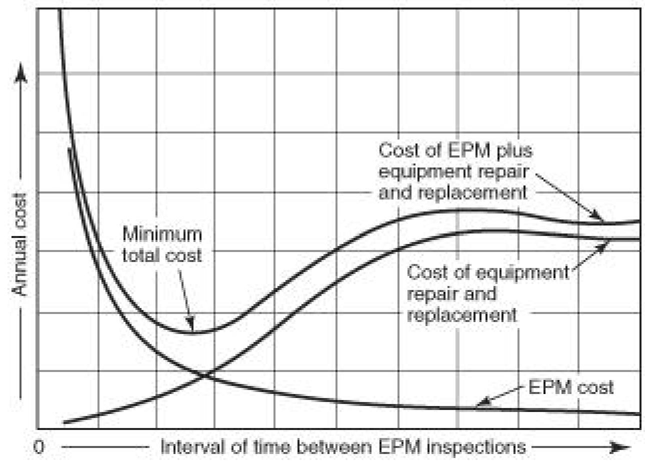

Figure 1 Effect of EPM Inspection Frequency on Overall Costs

The curve indicates that as the interval of time between EPM inspections increases, the cost of the EPM diminishes and the cost of breakdown repairs and replacement of failed equipment increases. The lowest total annual expense is realized by maintaining an inspection frequency that keeps the sum of repair/replacement and EPM costs at a minimum.

A well-administered EPM program reduces accidents, minimizes costly breakdowns and unplanned shutdowns of production equipment and can saves lives. An Electrical Preventative Maintenance (EPM) should be managed based on the importance of systems and equipment. This Property Risk Consulting Guideline describes a procedure for managing EPM using an informal ranking of equipment importance based on consequence of loss and modifications based on risk and experience. It further describes discretionary considerations appropriate to such a program. Figure 2 shows these procedures and the decisions that are part of this program. Although some of the discussion specifically addresses maintenance decisions, the concepts also apply to protection and other loss prevention and loss control decisions.

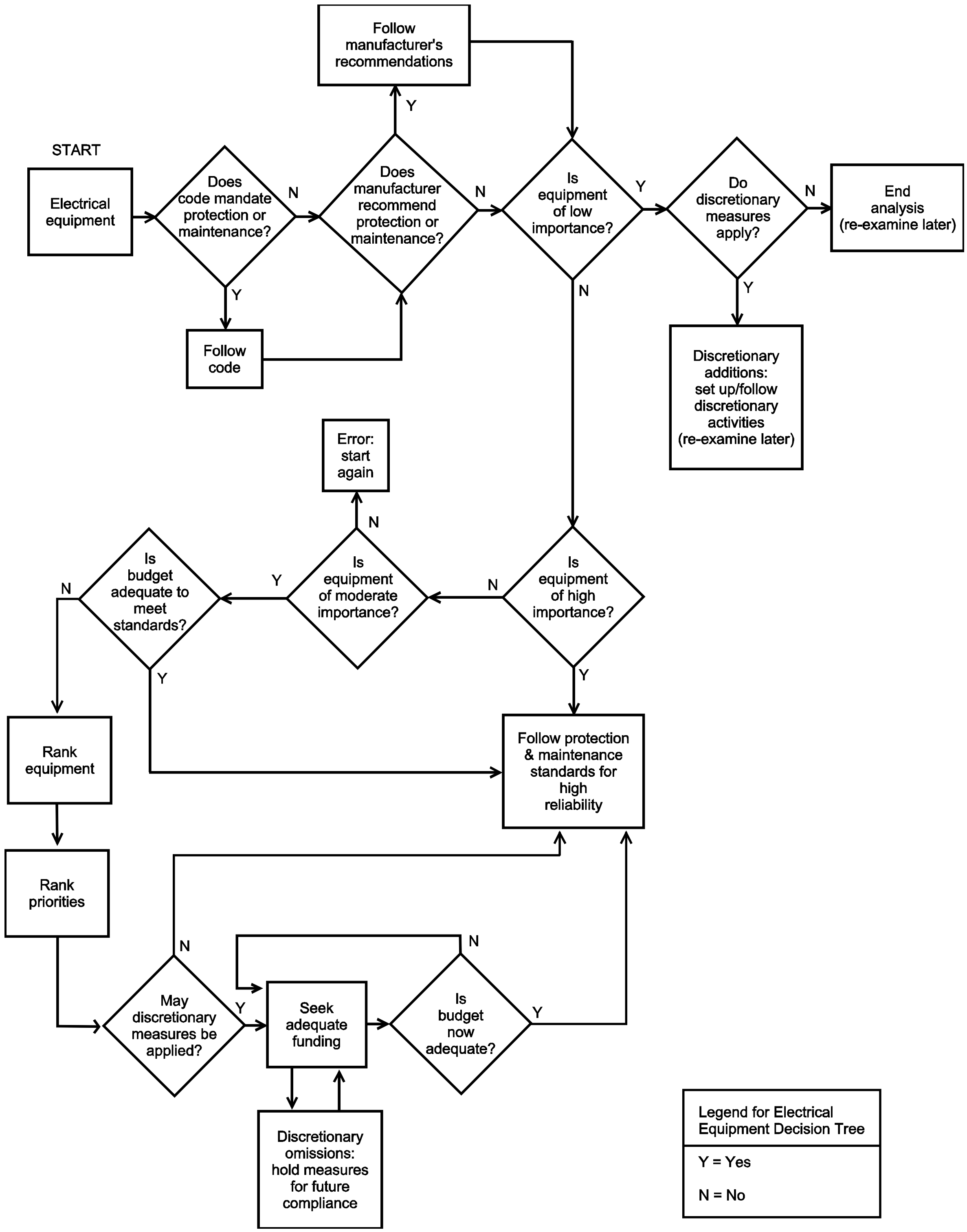

Figure 2. Electrical Equipment Decision Tree.

POSITION

General Requirements

Incorporate code-mandated and manufacturer-recommended protection features and maintenance practices into electrical equipment loss prevention and loss control programs. Where no electrical code is mandated by the local jurisdiction, adopt NFPA 70 (NEC), NFPA 70B, and NFPA 70E.

Adopt or customize a set of protection and maintenance standards following a thorough review of available, published standards. Further references to the “standard” or to “standards” in this Property Risk Consulting Guideline refer to these customized, adopted protection and maintenance standards. These standards are design goals which apply beyond the limited scope of code-mandated and manufacturer-recommended items. Continually update these standards as new information becomes available. In developing these standards, combine the following:

- Institute of Electrical and Electronics Engineers (IEEE), i.e. IEEE 56, 67, 242, 432, 450, 515, 625, and 1188
- InterNational Electrical Testing Association (NETA)
- National Fire Protection Association (NFPA) The primary NFPA reference on electrical equipment maintenance is NFPA 70B. Other NFPA standards referring to electrical equipment maintenance include NFPA 12, 16, 20, 25, 30, 34, 70, 70E, 72, 79, 92, 99, 99B, 110 and 850.
- AXA XL Risk Consulting guidance published in Property Risk Consulting Guidelines sections discussing electrical protection and maintenance. Selected guidelines are referenced at the end of this document.
- Items developed through hazard identification and evaluation programs discussed in *OVERVIEW*.

Included in the standards will be electrical protection and maintenance activities that are most effective when implemented so as to cover an entire electrical system. Three examples are surge protection, electrical coordination studies, and infrared or thermographic surveys. These protection and maintenance activities broadly impact loss prevention and loss control when used with system-based implementation methods. Authorize expenditures for such activities in protection and maintenance programs. See PRC.1.3.1, PRC.5.0.3, PRC.5.0.4, and PRC.5.2.2.

Certain electrical equipment maintenance activities are directly involved in maintaining loss prevention and loss control systems. Three examples are the maintenance of electrically powered alarm systems, actuation systems and condition-monitoring systems. Authorize expenditures for these activities in maintenance programs.

As part of hazard evaluations, examine the purpose and use of all electrical equipment and systems; the degree that production or operations depend on them; and the consequences of their loss, including possible losses to surrounding property, to profits and to contingent operations. Examine the possibility of electricity being a source of ignition and leading to fire spread. Evaluate surroundings, including atmospheres exposing and exposed by each unit. Classify electrical equipment in terms of importance. As a starting point, establish three categories, one each for low, moderate and high importance. Equipment in the low importance category may be excluded from equipment-specific loss prevention and loss control activities. The remaining equipment (equipment in the moderate and high importance categories) is considered **important equipment** and normally does require equipment-specific loss prevention and loss control actions. Define the three primary importance categories as follows:

Low Importance — Equipment has low importance if its failure or loss creates only minor inconvenience and does not significantly jeopardize people, property or profits. Equipment has low importance if it does not present a significant fire or electrical threat, and does not significantly affect the rate or quality of production.

High Importance — Equipment meeting any of the following criteria has high importance:

- “Critical components” and components of “critical systems.” (See Discussion.)

- Components of “emergency systems.” (See Discussion.)
- Components of “legally required standby systems.” (See Discussion.)
- Stationary battery installations if their reliability is important to loss prevention and loss control, such as those in control-circuit power supplies for circuit breakers, those in glass furnace cooling systems, and those in alarm systems.
- Electrical equipment creating a high potential loss to property, to profits or both. Equipment requiring such consideration normally includes:
  - Production-dependent equipment that will take more than 2 weeks to replace.
  - Equipment posing a fire hazard and that can spread fire damage to high-valued contents, to buildings or to other structures.
  - Equipment that is unique or obsolete.
- Electrical equipment having a unique potential for generating a corrosive atmosphere, polluting the environment or contaminating a surrounding occupancy. See PRC.5.0.3, PRC.5.4.5, and PRC.5.4.5.1.
- New equipment for which operating experience has not yet been established and for which benchmarks are recommended for future maintenance purposes.
- Important equipment remaining in use beyond 80% of its expected service life.
- Important equipment used in a severe duty application.
- Transformers meeting the criteria for high importance units identified in PRC.5.9.0.1.

Moderate Importance — All other electrical equipment has moderate importance.

For equipment having high importance, authorize protection and maintenance programs to incorporate all actions and features of the selected standards. Take all practical measures needed to protect and maintain equipment and operations at optimal levels of reliability.

When electrical equipment loss prevention and loss control standards cannot be totally followed, identify the relative importance of electrical equipment ranked moderately important. Base this initial ranking on consequence of loss. This ranking of moderately important equipment may be modified by risk and experience, as discussed later. When necessary and with due caution, less than standard protection and maintenance may be possible **at the low end of this middle range** if there are no special requirements identified later in this section. Such deviations from the standard may be permitted on a temporary basis. Keep in mind, the greater the deviation from the standard and the longer the deviation exists, the greater the chances for unexpected loss. Authorize protection and maintenance actions commensurate with the importance of equipment.

- Determine appropriate loss prevention and loss control needs for each unit of equipment based on established standards. Determine costs of compliance for each protective system or device if it, by itself, can prevent or reduce losses. Determine costs of compliance for each maintenance task, whether inspection, testing or servicing. Compare costs to the resources available.
- Implement loss prevention and loss control measures in a cost-effective manner. Authorize expenditures for cost-effective electrical equipment protection and maintenance practices based on priorities set by these rankings. Direct expenditures to those items that will best prevent or control losses.
- Permit deviations from standard only at the low end of the moderate importance range, and only when necessary because of temporary budgetary limitations.
- Seek adequate funding for future loss prevention and loss control needs. Eliminate deviations from the standard as quickly as possible.

Special Requirements

Transformers

Inspections of transformers should be made on a regular basis. The frequency of inspections should be based on the importance of the transformer, the operating environment, and the severity of the loading conditions. For transformers of high and moderate importance, and for those of low importance where discretionary considerations apply, follow the advice in PRC.5.9.4. Maintain important transformers in accordance with PRC.5.9.1. Maintain fluid testing programs to satisfy the criteria specified in PRC.5.4.5. Arrange and protect important transformers in accordance with PRC.5.9.2 and PRC.5.9.3.

Motors and Motor Control Equipment

Inspections of motors and motor control equipment should be made on a regular basis. As a general rule, motor control equipment should be inspected and serviced at the same time as the motors. Protect and maintain high and moderate importance motors, and motors of low importance where discretionary considerations apply.

Uninterruptible Power Supply (UPS) Systems

UPS systems are usually provided to preserve the power supply to critical equipment and represent a sizeable investment Protect and maintain high importance stationary battery installations in accordance with PRC.5.6.1 and PRC.5.7.4.

DISCUSSION

For all electrical equipment, regardless of its use, a decision must be made as to what constitutes effective protection. Perhaps a fuse provides adequate protection. Or, a transformer vault and fixed water spray protection may also be needed.

Similarly, a decision must be made as to what constitutes effective maintenance. Making repairs or replacing equipment following its breakdown may be sufficient for some equipment, but not for most. Where planned maintenance is needed, what activities are needed and on what schedule?

Beyond scheduled inspections and servicing, what tests are needed? What condition monitoring is needed? Even the maintenance of electrical equipment used for maintenance tests is managed this way.

Effective maintenance might require de-energizing and removing equipment. This could be necessary for tests, component replacement or scheduled retrofit. Effective maintenance could require condition monitoring along with frequent supplemental, comprehensive, off-line testing. For some equipment, visual inspections by a specially trained technician along with some specific servicing activity might be all that is needed. For others, visual inspections by operators might be sufficient. For minor equipment, corrective maintenance based only on performance failures might be warranted. For an effective maintenance program, the decision to be made is not only what tasks to do, but also, when and how often to repeat them.

Making effective electrical equipment loss prevention and protection decisions requires knowing the hazards, knowing effective loss prevention and loss control actions, and knowing costs and benefits associated with each action. Other factors include: codes, standards and manufacturers' recommendations; ranking of equipment importance; risk and experience; and discretionary factors. These are discussed later.

Terminology

For this Property Risk Consulting Guideline, four terms are defined. The source for each definition is shown in parenthesis following the term; however, the definition may have been paraphrased. The following definitions apply:

Critical Components And Systems (AXA XL Risk Consulting's *OVERVIEW*) - Components and systems installed to prevent catastrophic loss. If critical components or critical systems malfunction or are taken out of service, the process or operation must be shut down to remain safe. Many protective systems installed for loss prevention and loss control are critical systems. These include automatic sprinkler systems, position limiting systems, vibration alarm and trip systems, and combustion control systems. Many electrically-powered actuation systems are critical systems. Another example of a critical system is a stationary battery dc power system supplying control-circuit power to operate circuit breakers.

Emergency Systems (NEC) - Emergency systems are those systems legally required and so classed by municipal, state, federal, or other codes, or by any governmental agency having jurisdiction. Emergency systems consist of circuits and equipment intended to supply, distribute and control electricity for illumination, power or both, to required facilities when the normal electrical supply or system is interrupted. Emergency systems may provide power for such functions as ventilation where essential to maintain life, fire detection and alarm systems, elevators, fire pumps, public safety communications systems, and industrial processes where current interruption would produce serious life safety or health hazards.

Legally Required Standby Systems (NEC) - Legally required standby systems are standby systems required by law and so classed by municipal, state, federal, or other codes or by any governmental agency having jurisdiction. These systems are intended to automatically supply power to selected loads (other than those classed as emergency systems) in the event of failure of the normal source. Legally required standby systems are installed to serve loads, such as heating and refrigeration systems, communications systems, ventilation and smoke removal systems, sewerage disposal, lighting systems, and industrial processes, that, when stopped during any interruption of the normal electrical supply, could create hazards or hamper rescue or fire-fighting operations.

Optional Standby Systems (NEC) - Optional standby systems are permanently installed systems intended to protect public or private facilities or property where life safety does not depend on the performance of the system. Optional standby systems are intended to supply on-site generated power to selected loads either automatically or manually, and are typically installed to provide an alternate source of electric power to serve loads such as heating and refrigeration systems, data processing and communications systems, and industrial processes that, when stopped during any power outage, could cause discomfort, serious interruption of the process, damage to the product or process, or the like.

Codes, Manufacturers' Recommendations and Independent Standards

Most electrical codes establish a basic level of safety and protection. They are not highly functional as tools for a thorough property loss prevention and control program.

The NEC has been adopted by many jurisdictions. Where adopted, this code prescribes legal requirements for electrical installations within the community. Where no electrical code is mandated by a governmental jurisdiction, the NEC may be chosen as the regulation for compliance. Management of any facility may demand compliance with the NEC as a basis for accepting equipment and system installations.

The NEC declares it offers a means to safeguard against electrical hazards where electrical equipment is properly maintained. However, the NEC is an inadequate tool for identifying what is needed in an electrical equipment maintenance program. In fact, it sometimes refers to electrical equipment cleaning, repairing, troubleshooting and testing as though these activities are distinct from maintenance activities. Further, it is silent on most maintenance activities. Only with selected systems, e.g., legally required standby systems, does it give specific, limited guidance for basic levels of maintenance.

The Code of Federal Regulations, 40 CFR Part 761, is another code that aids property loss prevention and control. It, too, contains provisions mandating protection and maintenance. However, it was developed primarily for reasons of public safety and health, and, like the NEC, has limited value in property loss prevention and control programs.

Some manufacturers limit what they recommend for maintenance to avoid the appearance of requiring more maintenance than their competitors. Some even push “maintenance-free” as a competitive tool. Typically, what they recommend is inadequate for controlling the equipment aging process and avoiding unexpected breakdown.

Thus, codes and manufacturers’ recommendations provide only minimum levels of loss prevention and loss control. They do not fully address unique equipment arrangements and production uses. Well protected properties require much more.

By providing selective instrumentation, controls, protection and maintenance beyond the basics, high loss potentials can be reduced. These actions require on-site reviews to analyze the importance of the equipment, and require the application of independently-derived loss prevention and loss control techniques, especially, standards developed by professional organizations for the purpose of controlling hazards and minimizing business losses.

As stated in the AXA XL Risk Consulting position, a well protected facility will adopt or customize protection and maintenance standards following a thorough review of all available standards and guidelines. Input from a hazard evaluation and analysis is necessary. By developing a “company standard” in this fashion, protection and maintenance goals are defined, and losses are prevented or controlled.

Equipment Importance

As a maintenance philosophy, breakdown maintenance is not acceptable for well protected facilities. But some electrical equipment is not important to the continued operation of a facility. It may not require maintenance actions at the same level as required of other equipment. Corrective maintenance may be sufficient for equipment serving only a negligible portion of productivity; creating only minor inconvenience by its loss; and not significantly jeopardizing people, property or profits. For this minor electrical equipment, upon specific management review and concurrence, the lack of ongoing maintenance until there is a complaint, or until repair or equipment replacement is necessary may be acceptable. Similarly, the only protection required for such equipment may be that which is required by code, such as a fuse to provide overcurrent protection.

At the opposite extreme, operations might be 100% dependent on electrical equipment for which corrective actions, such as unplanned equipment replacement or retrofit, might be difficult and require a great amount of time. Or, valuable assets might be jeopardized by the loss of electrical equipment used in critical, emergency and standby systems. Or the mode of equipment failure can cause conditions that spread damage. The equipment in these examples requires high reliability and avoidance of unexpected breakdown. This can require high levels of protection and maintenance-intensity. Even special tests and condition monitoring might be important to loss prevention and control. Spares might be useful to minimize the consequences of loss. Special protective systems might be needed to limit the spread of damage.

Most electrical equipment requires protection and maintenance activities between these extremes. Ranking techniques may be used to make management decisions concerning the handling of these activities. Some ranking systems are based on the severity of potential accidents. Others are based on considerations of accident frequency and accident consequences. Ranking systems can be simple or complex, depending on the perceived need.

Maintenance servicing priorities can be set based on importance categories and the relative consequence of equipment loss, modified by risk and experience. Actions can be set based on standards; cost of maintenance, which includes costs of maintenance equipment and labor costs for the time involved; discretionary factors; and other maintenance resource considerations.

Cost of maintenance is influenced by equipment and system design, and by equipment placement. For example, if two transformers present the same consequence of loss, and if they are 100% identical in all features except that one is atop a 40-ft (12-m) pole and the other is at ground level, the difficulty in performing maintenance on the elevated unit results in a higher cost of maintenance per unit. If this equipment is at the low end of the importance ranking, budgetary considerations may necessitate temporarily delaying standard maintenance for the elevated unit.

Thus, the effects on business operations from the loss of electrical equipment can be negligible, catastrophic or something in between. The impact depends on various considerations including unit cost, the availability of replacement units, system flexibility and exposures. Only minimum levels of protection are provided by code compliance. Increased protection is warranted on other than low importance units, those that have loss scenarios suggesting a more significant impact on business operations. Thus, evaluating the importance of electrical equipment is a necessary step in determining protection and maintenance needs.

More on Consequence of Loss

To determine the importance of a unit, it is necessary to analyze the loss potential. That is, "What can happen to it?" and "What will happen without it?" The total safety and loss potential should be considered. The maximum financial consequence for existing conditions should be explored. Business financial recovery methods do not lessen these loss potentials. The equipment type, size, use, location (arrangement and position) and protective devices directly influence the nature and severity of the unit's loss. Only probing uncovers the true importance of the unit.

Loss potential from equipment is measured by evaluating and estimating:

- The extent of property loss, including that from fire, heat, smoke, water, contamination and corrosion; associated demolition, removal, cleaning and repair costs; the original purchase and installation costs of damaged property and current estimated purchase and installation costs. Is this property difficult to repair? Is identical equipment available? Will undamaged auxiliary equipment also have to be replaced? Will new instrumentation or controls be needed? Will the unit's location or size make replacement difficult and necessitate building alterations?
- The nature and duration of production interruption; the dependent upstream, downstream and contingent operations (a one-line diagram will help to identify these consequences); the degree of loss for each, whether slow-down or stoppage, and associated restoration times. What length of time will be needed to replace or rebuild the property? Are spare parts or standby units available? Can production be resumed by use of temporary electrical setups, alternate suppliers or alternate production methods?

Management might initially decide that the only necessary loss control measure for a small, easily replaceable dry type transformer is to separate the unit from combustible storage. A small, nonflammable fluid-insulated transformer might be regarded as needing only barriers and ventilation. But if the use of these transformers is deemed to be highly important, additional loss prevention and loss control measures, including additional maintenance, could be warranted. As loss potentials increase, additional preventive and protective measures are justified. The need for these additional strategies only becomes apparent once the importance of the unit is determined.

Trade-offs can exist between the cost of maintenance and the cost of protection. For example, the long-term cost of maintaining certain equipment might be higher than the long-term cost of replacing or retrofitting it with better-constructed equipment requiring much less maintenance. Or, if new equipment is selected based solely on a low purchase price, management may soon find that operating this equipment demands high-intensity maintenance, and the long-term cost, over its full service life, will be much greater.

At some point, the importance of a unit may justify obtaining spare units or spare parts for on-site storage. Or it may justify redesigning a distribution system, such as by installing parallel on-line or easily-connected backup units to add flexibility to the distribution system. Once any of these are done, production output should be less dependent on individual unit, and the consequences of its loss should decrease. The resulting lower consequence of loss reduces the unit's importance.

Risk and Experience

Risk analyses may be of value to management when making loss prevention and loss control decisions. Risk may be used to set or modify the protection and maintenance priorities described earlier. As defined in PRC.1.3.0.2, risk is the product of probability of loss and consequence of loss.

By examining a business and its operations, loss prevention and control professionals can develop information to show the financial consequence of loss for each equipment failure. This consequence of loss is a "what-if" calculation that fundamentally portrays a reasonably accurate estimate of loss potential. Multiplying this number by the probability of loss identifies the risk. Risk can then be ranked to set priorities.

However, electrical system and equipment characteristics can affect the accuracy of probability factors, and thus of risk. Where inadequate attention is given to these issues, probabilities can deviate by orders of magnitude because of the unique conditions that apply to this equipment. Multiplying a reasonably accurate consequence of loss by such a number can destroy the degree of accuracy previously available. Uncertainty is heightened.

Setting the probability of an occurrence for an electrical breakdown or failure of a selected group first requires defining the occurrence to be measured. Then, the frequency or number of such occurrences can be measured. The process of determining the frequency is objective. It identifies the likelihood of an occurrence within a population or group.

When applying this probability to a specifically named unit within the population, the number loses some of its objectivity. A decision that one named unit within the population has the same likelihood of failure as the typical unit in the group is subjective because risk profiles are not perfect, and uncertainties exist. Stresses experienced by the named unit will differ from those experienced by others in the group. Application of risk and probabilities is most meaningful for large groups where there is a spread of risk, and thus, less uncertainty.

Some of the highly interrelated issues to consider when using population probabilities for named units are as follows:

- **Definitions.** What is failure and how is it caused? What is the purpose of the analysis? Is the purpose of the analysis consistent with the use of the data? Is the population consistent? Is the named unit representative of the entire population? Are exposures the same?
- **Validity of Data.** How valid is published historical data? Are all events reported? Are all the influences on the stated probabilities known? Because no two electrical systems are alike, it is unlikely that a named electrical system will have the same characteristics as the average in a large group of similar systems. What one "expert" applies as objective data for risk evaluations, another might call a guess.
- **Initial Conditions.** Does the equipment have the same "starting point"? For new or existing equipment, what is its history? If a serviced aged machine has a single turn-to-turn fault in one winding, a fault will develop slowly; the probability of failure for that machine is much greater than the probability of failure for identical machines without such a fault.
- **Events**. Of the universe of occurrences used to measure failure probabilities, are causes the same? Are all root causes for all outcomes identified? Is protection against those occurrences and outcomes the same? All electrical systems have different exposures. Not all have the same exposure to surges, temperature variations, contamination, environment, protective devices or maintenance schedules. One common influence on failure rates is the frequency of system overvoltages; the greater the number of overvoltages in a system, the greater the stress on system components. Another is maintenance; for much equipment, lack of maintenance increases the probability of failure. Are failure probabilities for the device the same as those existing in the database? A stated probability of failure should not ignore the likelihood of failure caused by vandalism or entry by rodents if those problems exist in the unit being analyzed. The likelihood of failure is proportional to likelihood of events. However, electrical protection can reduce the likelihood of failure. As an example, systems and equipment with surge protection are less likely to experience failures caused by surges than those without such protection. Proponents of risk analysis who believe surge protection limits consequences, rather than reduces probabilities, lack an understanding of electrical characteristics. As another example to show how a universe of events may not reflect local conditions, the likelihood of finding an improperly closed valve is greater at a facility where a

certain maintenance technician has a propensity to accidentally leave valves shut. Probability from a “universal” database does not adequately reflect such a situation. Be wary of historical probabilities published elsewhere, and local probabilities developed under different physical conditions. If there are differences between prevailing and database conditions, different probabilities exist.

- **Design.** Is the selected group or population composed of the same equipment? Equipment constructed to different design specifications experiences different electrical stress, even with “identical” electrical exposures. Increasing stress increases the likelihood of failure. The likelihood of failure is inversely proportional to safety factors built into construction features to reduce stress. Only equipment having identical construction features can be lumped into a given failure probability, assuming the stress and history of units is identical. Although the likelihood of failure carries less uncertainty with identically-designed units, even then, quality control issues and manufacturing defects influence failure rates. Failure probabilities determined by failure rates of equipment populations having different electrical stresses, different constructions, or other differences, have greater uncertainty.
- **System Characteristics.** Is the arrangement of equipment the same? Even identical devices on two different parts of an electrical system experience different electrical stress when operating. A facility located at a high elevation, whose electric supply comes from the end of a heavily-loaded utility distribution system, in contrast with neighbors at lower elevations and located closer to generating sources, can experience an increased number of surges, increased energy in these surges, lower system voltages with accompanying higher system currents, increased equipment heating stress, and a greater number and severity of power quality and interruption incidents. Even identical equipment will most likely have different failure probabilities if used in different systems and with different arrangements.
- **Use and Duty Factors.** Was the equipment from which the database was developed exposed to the same operating conditions as will be the equipment to which the probability is applied? A simple example of this concern is evidenced by the fact that the operating life of a circuit breaker is inversely related to the number and severity of the faults it interrupts.
- **Age of Equipment.** The likelihood of equipment failure is a function of its age. What is the age of equipment included in the population? Is age a variable or constant in the database? New equipment and equipment nearing the end of its service life has a higher likelihood of failure than middle-aged equipment. Some authorities build such factors into their standards by specifying increased maintenance frequencies in the first two years and late in a unit’s life.
- **Complexity and Assumptions.** Are probabilities sufficiently refined to examine all possible outcomes and all possible alternatives? Assume a decision must be made concerning performance of four maintenance tasks that can increase the service life of a machine. The alternatives include: doing none, doing any one, doing any two, doing any three and doing all four. There are 16 possible alternatives. With “n” tasks being considered, there are 2n possible alternatives. Each alternative can lead to a different expected life span, and a different probability of failure. Further, the different costs for the 2n alternatives, must be addressed when making effective loss prevention and loss control decisions. Without simplifications and shortcuts, analysis becomes unwieldy. With simplifications and shortcuts, the analysis becomes less accurate. Use of computers can help is such analyses, but still, the amount of information can be formidable. Analysis of 500 units, with each having a possibility of performing 0 to 5 maintenance tasks, requires analyzing 16,000 combinations of actions.
- **Uncertainty.** Uncertainty in outcome, complicated by different levels of failure, and uncertainty in failure frequency make probabilistic risk assessment controversial.

All electrical equipment left in service without ongoing maintenance will eventually, unexpectedly fail. Most electrical equipment has a life span somewhere between 5 and 40 yr. The certainty of unexpected failure during this time approaches 100%. But as shown, aging or life span is only one factor in failure probabilities. State-of-the-art maintenance greatly reduces unexpected failures. Maintenance manages the aging process.

These issues should not be ignored. Misapplication of risk distorts the importance of electrical equipment maintenance, loss prevention and loss control actions. Risk may be ranked to make management decisions for loss prevention and control programs, but uncertainties should be understood and quantified. More specific details are beyond the scope of this document.

Discretionary Factors

Management of protection and maintenance programs must be allowed the option of making certain discretionary decisions. These may be based on cost-benefit considerations, experience or other relevant factors. These decisions should be periodically reviewed for reconfirmation.

If a small motor is of negligible importance, but some maintenance action is needed for a nearby motor located in same room, there may be some cost benefit to performing minor maintenance on the small motor. The added cost of this small motor maintenance might be extremely small because of the nearby work. A decision to include the small unit in the maintenance program is cost-effective if this minor added maintenance cost over the life of the unit is shown to be less than the cost of more-frequently replacing the unit due to the lack of maintenance. Such comparisons can be made based on the present worth of expenses for both eventualities, essentially taken to perpetuity. A discretionary decision to include the small motor in the maintenance program may be reasonable for the special circumstances.

Alternately, when considering actions for equipment in the low end of the moderate importance range, decisions to temporarily perform only breakdown repair or replacement may be made. In the example given earlier about two transformers, one atop a pole and one at ground level, decisions may be made to temporarily not service the difficult-to-reach unit based on its higher maintenance cost, caused by the difficulty of performing this service. However, efforts should be made to avoid budgetary restrictions in the next budget cycle, and to allow resumption of standard maintenance for important equipment.

The use discretionary decisions to limit or temporarily omit specific loss prevention and loss control should be applied only to electrical equipment ranked at the low end of the moderate importance range. Subsequent budgets should be increased as needed to permit future resumption of the missed actions for this important equipment. Properly applied in this fashion, discretionary factors may be used in loss prevention and loss control programs.