EMGT 835 FIELD PROJECT:

Developing Business Case For
Electrical System Replacement

By

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Developing Business Case

For Electrical System Replacement Projects

EMGT 835 **Submitted by:**
Date: April 3, 2006 **Carles Miller**

Executive Summary

Generating plants in United States have 30 to 40-year-old electrical distribution equipment that is reaching the end of its useful life. The demand for electric power is expected to increase by about 25 percent, over the next ten years. Coal plants in the United States have begun major efforts to perform life extension projects of major equipment such as the turbines and generators. Also, over the next few years coal plants will began to install mandated air quality control equipment. For these types of projects to be successful, the electrical distribution equipment for coal plants will need to be evaluated.

Feasibility assessment will need to be performed to analyze alternatives ranging from replacing the existing electrical equipment with new equipment to continuing to perform maintenance on the aging equipment until failure occurs. This paper will discuss how to develop a Business Case for electrical system replacement projects, by performing a feasibility study. This paper will be a guide for using feasibility studies as the justification for electrical upgrade projects. The development of available options for rehabilitating the electrical equipment will also be discussed.

The paper will detail how to perform qualitative and quantitative assessments of existing electrical equipment, including details on evaluating the mechanical integrity of the

equipment, and discuss how to perform load flow, short circuit, and arc fault studies on existing equipment. This paper will discuss how to estimate proposed options, and how to use reliability analysis as an essential tool for developing economic justification and ranking the proposed options for electrical upgrade projects.

The concepts of reliable electrical systems, and the use of IEEE Std 493, "IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems" are detailed. The conversion of failure probability to risk cost will also be discussed. This paper will use a sample plant electrical distribution system to demonstrate the methods discussed in IEEE Standard 493.

The development of conceptual solutions and current trends of upgrading electrical systems will be evaluated in this paper. This includes discussion on preparing the estimates for proposed options of upgrading the electrical system. Finally, this paper will cover the implementation process including performing equipment risk ranking, and developing a generic phased approach for completing the upgrade program.

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1 Chapter 1 - Introduction

1.1 - Background

Generating plants in United States have 30 to 40-year-old electrical distribution equipment that is reaching the end of its useful life. Over the next ten years, the demand for electric power is expected to increase by about 25 percent. The North American Electric Reliability Council (NERC) has estimated the need for $56 billion in investment over the course of the next ten years to keep up with demand [QIU, 2003]. However, replacing existing coal fired generating plants because they are old is usually not practical, due to the large capital investment, environmental permitting, and public perception of coal plants. Therefore aging power plants will continue to operate well beyond a 40 year lifetime.

Coal plants in the United States have begun major efforts to perform life extension projects of major equipment such as the turbines, and generators. Also, over the next few years coal plants will began to install mandated air quality control equipment. For these types of projects to be successful, the electrical distribution equipment for coal plants will need to be evaluated.

The key to successfully managing electrical distribution modernization or life extension process is finding a solution that maximizes reliability and safety while minimizing costs. To accomplish this, a complete system assessment both technical and financial should be performed. This assessment should analyze the feasibility of alternatives ranging from replacing the existing equipment with new equipment to continuing to perform maintenance on the aging equipment until failure occurs.

The condition assessment provides a systematic approach for determining the present state of the facility, so that modification can be determined to ensure the quality of the electrical system performance. Performance depends on the reliability of the plant electrical system. Condition assessment is more critical to the coal plants due to their aging and their critical service as base-load units [Chau et al, 1998].

1.2 - Feasibility Study

To develop a Business Case for electrical system replacement projects, a feasibility study should be performed. The feasibility study outlines the justification for the project. The feasibility study should include an assessment of the existing electrical equipment. The feasibility study should also include a listing of the available options for rehabilitating the electrical equipment. The study should list the benefits and costs associated with each solution option, and recommend an option for approval.

Consulting engineers are usually requested by plant electrical engineers to perform a feasibility study for presentation to Senior Management and/or board of directors. Feasibility studies will be one of the first documents used in the Project Lifecycle and, once approved, will be used to formally define project. Below is a typical table of contents for an electrical system feasibility study:

Electrical System Feasibility Study Typical Table of Contents

1. Executive Summary

    Description Of The Study

    Conclusions And Recommendations

2. Introduction

    Background And History

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    Upcoming Changes To Electrical System

3. Equipment Assessments

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Sustainability

The executive summary and introduction sections of the electrical system feasibility study are standard to all reports. The executive summary should summarize all options, conclusions, and recommendations proposed in the study. The introduction should give a brief overview of the location, planned changes to electrical system, capacity of the electrical system, and methodologies and approach to performing the study. These sections of the feasibility study will not be covered in this paper.

This paper will cover how to perform Equipment Assessments, it will go into detail on evaluating the mechanical integrity of the equipment, and it will discuss how to perform load flow, short circuit, and arc fault studies on existing equipment. This paper will also discuss how to estimate proposed options, and how to use reliability analysis as an essential tool for developing economic justification and ranking the proposed options for electrical upgrade projects.

The implementation, assumptions and risks section of a feasibility study will also be covered in this report. This section of the feasibility study is an overview of the general approach to execute the proposed solution. The implementation section is where the method for initiating the project is defined, where a general plan for executing the project is defined, and where generic phases for completing the project is presented. This paper will discuss how to identify risk that may impede the proposed option from being able to be implemented as anticipated.

2 Chapter 2 – Literature Review

2.1 - Introduction

The nation's power plants and electricity transmission and distribution systems have yet to be upgraded. Much of the electrical infrastructure was installed in the 1950's and 1960's and is due for replacement. To better understand the nature and affects of the aging electrical system, "Risk Assessment of Power System Catastrophic Failures And Hidden Failure Monitoring & Control System", by Qun Qiu and published in December 2003 was reviewed. This paper discussed the risks of catastrophic failures caused by hidden failures of hardware or software components of the power system protection equipment. This paper is pointed toward failures in electrical transmission and distribution equipment. This paper is a great resource for technical information concerning failure rates of electrical system protective relaying.

"Upgrading and Enhancing the Generator Protection System by Making Use of Digital Systems", published in April 1998 by N. H. Chau, Juno Beach, Subhash C. Patel, and Jonathan D. Gardell was also reviewed. The paper discussed upgrading of power plant systems and equipment to achieve life extension, and the implementation of condition assessment studies. This paper focus on upgrading generation plant electrical systems and is a good reference for performing generator relay protection upgrades.

2.2 - Feasibility Study

In preparation for this paper literature such as, "ABB Life Assessment Study", by David Stanier, was reviewed. This paper describes the Asset Life Study concept and how to develop and perform such studies. This paper is more of a general overview and does not focus on power plant or electrical equipment.

"Industry Approach To Aging Assessment Updated" by David A. Horvath discusses performing aging assessment studies on nuclear power plant equipment for operation beyond design or qualified life. This paper is a great source for developing the frame work for an aging assessment program.

"How To Justify Equipment Improvements Using Life Cycle Costs & Reliability Principles" written in 2005, and "How To Use Reliability Engineering Principles For Business Issues" written in 1998 by Paul Barringer describes how performing good economic models, provide better long term assessments of a projects effectiveness. These papers explain Life Cycle Cost evaluations and their importance to project proposals. Mr. Barringer has wrote many papers on using reliability principles to justify equipment replacement, his papers are a great source for engineers needing to develop project justification.

2.3 - Reliability Feasibility

To understand the concepts of reliable electrical systems and to gather data on electrical system reliability, IEEE Std 493-1997, "IEEE Recommended Practice for the Design of

Reliable Industrial and Commercial Power Systems" was reviewed. IEEE 493 is a great reference standard and contains useful methodologies, and reliability data for modeling electrical system reliability.

To understand how to apply the data in IEEE Std 493-1997, "Elements Of A Power Systems Risk Analysis And Reliability Study", by Oliver K. Hung and William A. Gough, "Evaluating Aging Electrical Systems And Equipment", by J. E. Propst and T. Griffin were reviewed. Both of these papers demonstrate how to relate electrical reliability data, and equipment failure rates to life cycle cost. These papers are also a great guide for evaluating electrical systems.

2.4 - Selection Criteria

To better understand estimating techniques for developing conceptual project estimates, "Cost Estimating Simplified", published in 2003 by Nick Butcher and Linda Demmers was reviewed. This paper is a great tool for developing cost estimates for all types of projects. "Controlling Capital Costs Prior to Construction" by Don L. Short, II was also reviewed, and is another great guide for developing estimates.

Papers such as, "RS Means Consulting Technical White Paper On Cost Estimating" published by Phil Waier in September 2002, and "Justifying Upgrade Projects in Existing Mills", by Oliver K. Hung and Ben Klimache discuss how the decision to proceed with a project is usually made after feasibility studies have been performed. These papers are useful for plant engineers who need to implement plant improvement projects.

"Life Cycle Costing Manual: For the Federal Energy Management Program" published in 1995 by Sieglinder K. Fuller and Stephen R. Peterson detail the steps in preparing life cycle assessments and evaluating the options of feasibility studies. This manual is a great template for performing life cycle studies on new capital projects.

"A Review Of Appraisal Methodologies Of Feasibility Studies Done By Public Private Partnership In Road Project Development" written in 2001 by Katalin Tánczos and Gi Seog Kong also review the economic techniques for evaluating option of feasibility studies. This paper does not relate to performing feasibility studies on electrical projects. It was reviewed to gain an understanding of how the selection process for choosing options in feasibility studies. Other literature reviewed on this topic was, "A Life Cycle Cost Summary" written by H. Paul Barringer, in May 2003, as mentioned earlier Mr. Barringer is a great reference for relating reliability data to feasibility studies.

2.5 - Implementation Approach

During the implementation stage projects move from investment decision to project planning. During this stage a detailed implementation program and time-schedule must be included with the description of assumptions and possible risks. "Technical Risks And Mitigation Measures In Combustion Turbine Project Development", written by Dale Grace, and John Scheibel in 2001 explain how to evaluate risk of a project. This paper focuses on risk mitigation in large projects some of the methods discussed are useful for capital improvement projects.

"CPM Scheduling Will Work For Your Project" by Don L. Short, II describes how to perform critical path scheduling. This paper is a good guide for performing critical path scheduling.

"Avoid Failed Projects: Prevention Is Better Than Cure", by Duncan_Haughey discusses setting expectations and defining deliverables on projects before the projects start. Mr. Haughey's paper details how to avoid pitfalls that will lead to failed projects. This paper is a good reference for those getting started in project management.

3 Chapter 3 –Methodology and Definitions

3.1 - Methodology

This paper will use a sample plant electrical distribution system to demonstrate the methods discussed in this paper. It will be assumed that sample plant electrical distribution system has been will maintained and is 30 years old. For this report it is assumed the plant is planning to install new air quality control equipment. The assumed increase in demand on the electrical system will be approximately 8000kVA of load.

The reliability data used to evaluate the electrical system will be from IEEE Standard 493. The load flow, short circuit, and arc flash studies discussed in this report will assume that the three phase system, is in a steady state mode, with constant frequency.

3.2 - Definitions

Annual Risk - The calculated financial losses of production due to an electrical system failure divided by the frequency Mean Time Between Failure (MTBF) of the failure.

Availability - A ratio that describes the percentage of time a component or system can perform their required function.

Component - A piece of electrical or mechanical equipment, a line or circuit, or a section of a line or circuit, or a group of items that is viewed as an entity for the purpose of reliability evaluation.

Failure - The termination of the ability of an item to perform a required function.

Failure rate - The mean number of failures of a component per unit exposure time.

Forced downtime - The average time per year a system is unavailable in between failures and expressed in hours per year.

Lambda (λ) - The inverse of the mean exposure time between consecutive failures. Lambda is typically expressed in either years per failure or millions of hours per failure.

MTBF - The mean exposure time between consecutive failures of a component or system. The mean time between failures is usually expressed in either failures per year or failures per million hours. For some applications, measurement of Mean Time Between Repairs (MTBR) rather than mean time between failures may provide more statistically correct information.

MTTR - The Mean Time To Repair a failed component. For a system, it is the total amount of time it is unavailable in between failures and is expressed in hours in both cases.

Point - Any place or location within the electrical system. The name or designation for a point is always the same as the name of the zone that the point is located within.

Reliability - An indication of the ability of a component or system to perform its intended function during a specified time.

System - A group of components connected or associated in a fixed configuration to perform a specified function of distributing power.

Zone - A segment of a power distribution system in which a fault at any location within the segment or zone would have the common impact of causing the first upstream protective device to isolate the system.

4 Chapter 4 – Feasibility Study

4.1 -Initiation

The purpose of Project Initiation is to begin to define the overall parameters of the study and establish the appropriate method for collecting data to complete the project. During the initiation phase a detailed scope of work should be defined, understood and accepted by the stakeholders. During this phase an initial Project Plan is developed, and contains the Scope of Work, Schedule, Deliverables, and Cost for performing the study. The approved documents will ensure a consistent understanding of the project, and will set expectations and identify resources necessary to complete the study.

A formal review and sign off plan for reviewing drafts of the study and other deliverables should be developed. Review and feed back from the client should be encouraged, this will aid in validating the study and allows the assessor to move on to the next process in confidence.

During interviews, the assessor should gather information on availability of spare parts, system operation, future plans for system growth, and should collect equipment rating data. The assessor of the system should be knowledgeable of the equipment and should follow establish procedures for assessing the electrical equipment.

4.2 -Mechanical Integrity

The next step in gathering data for developing a business case for electrical system replacement projects is a mechanical integrity assessment. The mechanical integrity selection should begin with review of maintenance procedures, maintenance records, and interviews with maintenance and operations personnel. Routine maintenance such as oil changing, lubrication, contact refurbishment, and verification of contact engagement should be performed on a routine basis.

During the actual inspection of the electrical equipment, the assessor should look for maintenance neglects and for evidence related to equipment deterioration. Deterioration due to corrosion should also be checked. Maintenance neglects is usually the result of oversight, lack of knowledge of the equipment, or pressures to keep the equipment, and the plant in operation.

During the inspection of the equipment there may be several switchrooms or substations at the plant. The assessor should collect the following information; condition of the location, manufacturer and type of equipment, year of manufacture, date of installation, voltage rating, current rating, fault rating, details of any modifications or repairs, and type of electrical protection.

The following sections will discuss the typical maintenance practices and failure modes for major equipment that make up a plant electrical system. NFPA 70B Recommended Practice for Electrical Equipment Maintenance details typical preventive maintenance procedures that the facility should be performing. IEEE Standard 493 Design of Reliable Industrial and Commercial Power Systems, contains a summary of equipment reliability data. If the plant does not have sufficient failure mode data of their electrical system, IEEE 493 contains industry average failure mode data gained by performing industry surveys.

The assessor of the system should be knowledgeable of NFPA 70B, IEEE 493, and the type of electrical equipment at the facility.

4.2.1 -Transformers

Transformers located in power plants are large oil insulated power transformers, medium and low voltage station service transformers, and small power distribution transformers. Station service transformers may be oiled filled or dry type. Small power distribution transformers are typically dry type.

Transformers usually fail due to deterioration of the electrical insulation, deterioration of the electrical connections, and exterior corrosion. Insulation breaks down over time, due to aging and by heat generated by the operation of the transformers. Oil filled transformers, can have deterioration of the oil insulation system due to heat. Moisture contamination will cause deterioration of the insulation in dry type transformers. Also transformers can fail due to loose connections of tap connections, winding termination points and bushing connections. Harsh ambient conditions can corrode transformer tanks, cooling fins, and attached accessories such as control panels and conservator tanks.

Most of the above failure modes progress slowly over time. To help predict failures tests such as infrared thermography, oil testing insulation power factor testing, and partial discharge testing should be performed. The test data should be trended to identify failure patterns.

4.2.2 -Switchgear

Switchgear failures are caused by high resistance at bolted connections, control and protective relay failure, and corrosion due to installation in harsh environments. Also, switchgear will develop mechanical problems that will cause operational difficulties include racking mechanism failure, shutter assembly, and insulation barrier failure.

The most serious of the deficiencies is loose connections causing high resistance and heat build up at the connection. This type of failure can result in equipment burndown if not corrected. The assessor should check the plants Infrared Thermography and Ultrasonic testing procedure to assure that it is adequate. If the plant is not performing such testing on an annual basis, the assessor should make the recommendation that the testing be performed for safe long term reliable operation of the equipment.

4.2.3 -Power Circuit Breakers

Circuit breakers failure modes include binding in the operating mechanism, control circuitry failure, development of high resistance in the power connections, exterior corrosion, and deterioration of the electrical insulation. Perhaps the most serious and most dangerous are binding of the operating mechanism and control circuitry failure. These problems can result in a circuit breaker that will not open or close as required.

The assessor should check maintenance records to determine if serious deficiencies have been recorded and if they are frequent, such deficiencies include:

- main contacts not returning to full open
- pivot arms sticking
- tripping mechanisms sticking
- breaker not able to be electrically operated
- broken arc chutes
- puffers broken and not operating
- broken parts in arc chutes
- arc contacts broken
- silver platting on bus deteriorating
- loose bus connections

These types of deficiencies can cause faults on equipment and/or can allow high arcing currents and an arc blast to develop during a fault condition. These deficiencies will also cause the clearing time of breakers to be extended during a fault. The unintentional delay, caused by these deficiencies during a fault condition, can result in catastrophic damage to equipment, serious injury to personnel and cause loss of generation for several months.

4.2.4 -Relays and Meters

Electro-mechanical relays usually malfunction by initiating tripping too slowly or by not tripping when called to operate. The leading cause of this type of failure is the tripping mechanism being restricted mechanically. These failures are due to contamination by dirt, moisture, foreign matter, burnt contacts and/or loose connections. Microprocessor based relays usually fail due to loose connections.

Electro-mechanical relays should be tested yearly. Microprocessor based relays should be set up on a regular testing schedule every 2 to 3 years. Protective relays should be functionally checked by using primary injection testing, or other manufacture recommended testing, and test voltage to assure that relay is functioning properly. All protection, metering, input, and output functions should be checked on the relays.

Relays should be checked for gasket failures, gasket failures will allow dust inside of the case, this may cause relay misoperation.

4.2.5 -Motor Control Centers Switch Boards and Panel Boards

Motor Control Centers (MCC), switch boards and panel boards includes: the enclosure, installed circuit breakers, main connection cubicle, installation pad, ground connection, and all installed control circuits.

Common failures of this type of equipment include molded case breaker failures, these breakers usually fail in service and do not trip when required. Another serious failure mode of molded case breaker's is failing when operators open or close the breakers. When this occurs the breakers may explode.

Other common failures are: contacts becoming welded together during operation, high resistance cable connections and bus connectors. Common causes for the equipment deterioration are dirt, moisture, and loose connections.

4.3 -System Studies

To assess electrical systems for expansion projects load flow studies, and short circuit studies must be performed. The purpose of these studies is to assure that the electrical system has the capacity to safely accommodate new loads. These studies will also verify that existing equipment is correctly applied within the manufactures ratings. Properly rated electrical equipment minimizes the damage done to the equipment and personnel during a fault on the system. There are numerous software packages available to perform load flow studies, and short circuit studies, for this report, SKM-Power Tools for Windows (PTW) suite of software packages is used.

Other studies that are useful in assessing electrical equipment are reliability analysis and arc flash analysis. Section 4.3.3 of this report will discuss how to use figures and methods found in IEEE 493 to calculate system reliability and failure rates. Section 4.4.1 will discuss how to convert these failure rates to risk cost to help justify electrical system reliability improvement projects. This helps power plant managers to invest money in a planned fashion rather than waiting for a failure to occur and then using the failure to justify the repair cost [Hung et al, 2000].

This report will not go into detail on arc flash analysis, but, it is worth mentioning that industrial electrical systems need to comply with the latest OSHA and NFPA standards, concerning arc flash protection. Noncompliance can have costly legal, economic, and sociological impact. OSHA 1910.132(d) requires that Flash Hazard Analysis be performed for work within flash protection boundaries. The result of the Analysis must document the risk to the worker in calories per centimeters squared. Power plant operators must know the amount of ARC Flash Energy exposure to its workers.

4.3.1 -Load Flow

The assessor should perform load-flow studies for normal and abnormal system configurations, for the existing electrical system and for the proposed changes to the electrical system. The intent of these studies is to determine electrical loading of main feeders, transformers, and bus voltage under different operating conditions and to study the effects of changes to the electrical system. For the sample plant it is assumed that 8000kVA of new load will need to be added to the electrical system 5000kVA of this load will be 4000V motor load and the remaining 3000kVA of load will be 480V loads. The largest proposed load addition will be a 3500HP, 4000V motor.

PTW is used to calculate Load Flow, Voltage Drop and Motor Starting studies. The software calculates the voltage drop on each feeder, the voltage at each bus, and the power flow in all branch and feeder circuits. It also calculates losses in each branch and total system power losses. Appendix D contains summary reports for the sample plant's load flow studies.

If the existing plant configuration or the proposed addition of new equipment exceeds the electrical equipment full load ratings the equipment must be retrofitted or replaced to add the new loads.

4.3.2 -Short Circuit

Short circuit studies are used to verify that equipment withstand ratings are capable of handling the system available fault current. Switchgear, motor control centers, safety switches, panel boards, motor starters, and bus bar must be capable of withstanding available fault currents.

PTW is used to perform studies based on the ANSI/IEEE C37 standard for circuit breakers, switchgear, substations, and fuses. ANSI Standard C37.13 is used for calculating the fault duty at low voltage buses, whereas ANSI Standard C37.5 and C37.010 are used for calculating the fault duty on medium and high voltage buses. The existing plant is studied with all loads connected to the system this yields the highest available fault current, and is used to verify that the existing plant equipment is rated properly. A study is then performed to determine what the new available fault current will be with the new equipment added.

If the studies determine that the available short circuit current exceeds the equipment ratings, the equipment must be retrofitted or replaced. Appendix E contains summary reports for the sample plant's short circuit studies.

4.3.3 -Reliability

The "series and parallel" reliability methodology is a recommended methodology found in IEEE 493 this method will be used in this report to demonstrate how to determine the reliability of electrical power systems. To use the "series and parallel" method the electrical system is sectioned into series and parallel zones, or reliability blocks. By doing this the reliability of a complex system such as an electrical system becomes easy to determine. This method is easy for the assessor to communicate the reliability of the system to other disciplines, clients, and managers who will approve projects.

The reliability of the system depends on the reliability and maintainability of the components that make up the system. After the system has been sectioned into zones the failure rates and Mean Time To Repair MTTR for each component must be assigned to each component and calculated for the entire system. Some plants have an excellent data base of failure modes and repair times. Also some vendors have this data available. If the plant or vendor data is readily available it should be used to construct the reliability model. If this data is not readily available, IEEE Std 493 has compiled a database of equipment and system reliability data that is based on extensive surveys over many years.

The failure rate per year (λ) is given by $\lambda = \frac{1}{MTBF}$ (equation 1).

Component Reliability (R) for one year is given by $R = e^{-(\lambda)8760}$ (equation 2).

Series components of the system are modeled by the following equations and should be modeled as shown in Figure 2. r_n is Mean Time To Repair (MTTR)

$\lambda_S = \lambda_1 + \lambda_2 + \lambda_3$ (equation 3)

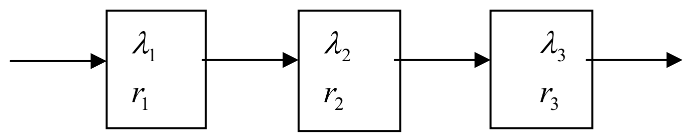

Figure 2

$r_S = \frac{\lambda_1 \times r_1 + \lambda_2 \times r_2}{\lambda_1 + \lambda_2}$ (equation 4)

Parallel components of the system are modeled by the following equations and should be modeled as shown below.

$\lambda_P = \frac{\lambda_1 \times \lambda_2}{\frac{r_1 + r_2}{8760}}$ (equation 5)

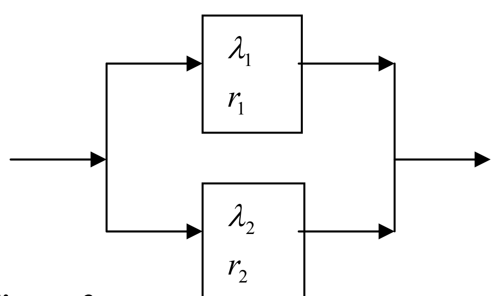

Figure 3

$r_P = \frac{r_1 \times r_2}{r_1 + r_2}$ (equation 6)

Figure 4 and Figure 5 below demonstrate how to use the “series and parallel” zone method to determine reliability.

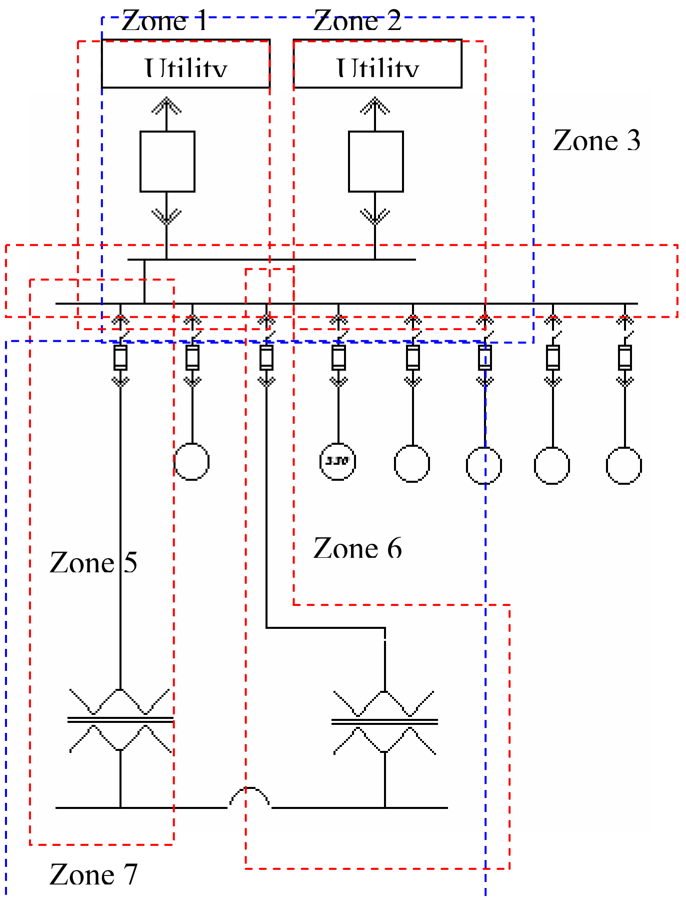

Figure 4

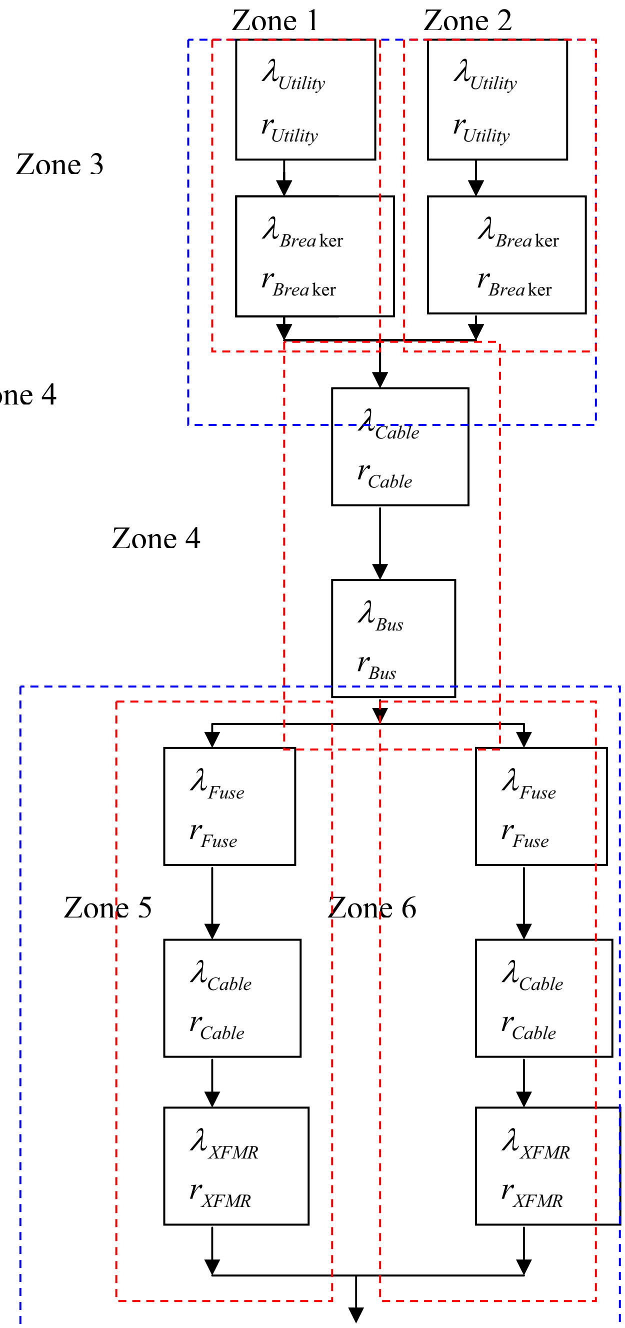

Figure 5

Using data from IEEE Std 493 we will apply the following values to the model.

$\lambda_{Utility} = 0.537000$ $\qquad r_{Utility} = 5.7$

$\lambda_{Breaker} = 0.017600$ $\qquad r_{Breaker} = 10.6$

$\lambda_{Cable} = 0.006170$ $r_{Cable} = 95.5$

$\lambda_{Bus} = 0.001129$ $r_{Bus} = 128.0$

$\lambda_{Fuse} = 0.006100$ $r_{Fuse} = 2.8$

$\lambda_{XFMR} = 0.005900$ $r_{Xfmr} = 356.0$

Using equation 3 and equation 4 the values for the series components are:

$\lambda_{Zone}\, 1 = 0.5546$ $r_{Zone}\, 1 = 5.8$

$\lambda_{Zone}\, 2 = 0.5546$ $r_{Zone}\, 2 = 5.8$

$\lambda_{Zone}\, 4 = 0.007299$ $r_{Zone}\, 4 = 18.7$

$\lambda_{Zone}\, 5 = 0.0296$ $r_{Zone}\, 5 = 77.8$

$\lambda_{Zone}\, 6 = 0.0296$ $r_{Zone}\, 6 = 77.8$

Use equation 5 and equation 6 to combine Zone 1 and Zone 2 results in Zone 3. Repeat the calculations to combine Zone 5 and Zone 6 result in Zone 7.

$\lambda_{Zone}\, 3 = 0.000408$ $r_{Zone}\, 3 = 2.9$

$\lambda_{Zone}\, 7 = 0.000016$ $r_{Zone}\, 7 = 38.9$

To calculate the failure rate and MTTR for the combined system equation 3 and equation 4 are used to combine Zone 3, Zone 4 and Zone 5 in series.

$\lambda_{System} = 0.007707$ $r_{System} = 17.9$

From the failure rate and MTTR are the reliability (R) and the Mean Time Between Failures (MTBF) can be calculated. Using equation 1 to solve for MTBF yields 129.7 years.

The reliability of the system can be solved by equation 2. For the example the λ is in terms of per year, so equation 2 is modified to $R = e^{-(\lambda)}$. The reliability of the system is 0.9923.

The MTBF for this example is a 129.7 years, redundancy calculations frequently lead to reliability numbers that are outside the realm of reason. In reality, even redundancy of components still leaves a chance that the parallel system will fail from a common-mode. Examples of this include common electrical connections, common alarm wiring, or the environment. These common modes can be represented by placing a component in series with the system [Propst et al, 2000]. A common failure mode of older systems is control wire failure, inputting data from IEEE Std 493 for control wire failure yields a MTBF of 17.6 years and a MTTR of 2.4 hours.

4.4 - Selection Criteria

The decision of upgrading the system, should take into consideration the complexity, maintainability, reliability, and affordability of the options being studied. Qualitative Analysis should be performed on the data gathered during the mechanical integrity phase of the assessment, to determine if the electrical equipment is acceptable as is or equipment upgrading is needed. Section 4.4.1 below gives guidance on evaluating the equipment based on the Qualitative Analysis.

If it is determined that the system needs to be upgraded options should be developed and cost estimates prepared for the options and a Quantitative Analysis performed on the proposed options.

When preparing the assessment study the deliverable shall include an executive summary giving a summary of the mechanical integrity of the system, a description of the options evaluated, and the recommendations of the assessment study. The assessment study report should also include backup information used to formulate the recommendations. Organize the study to clearly show the results of the analysis, how the option selected meets the functional requirements for the future plant requirements. Provide tables and data to show the results of the reliability cost analysis for each of the options studied.

4.4.1 - Qualitative Analysis

The mechanical integrity discussed in Section 4.2 provides means of performing a subjective analysis of the current condition of the system. If the current system exceeds the equipment short circuit ratings, full load rating, is obsolete, spare parts are unavailable, or the condition of the equipment has deteriorated to where it is unsafe to operate the equipment, the equipment should be upgraded.

Major electrical equipment such as transformers, switchgear, motor control centers, and switchboards follow the reliability bath tub curve shown in Figure 6 below. The bath tub curve should be used to help identify if the equipment is near the end of its useful life.

The "Burn-In-Phase" represents the infant mortality area of the curve, failures in this area of the curve are usually caused by substandard components used in the equipment and/or defects in construction techniques used when the equipment is installed. During this period equipment failure rates are high but the failures decrease rapidly.

The "Manufactures Life" is the area of the curve where failures that occur are predictable, and maintenance cost is low. In this area of the curve spare parts are readily available, and refurbishing the equipment is cost effective.

The "Reliable Life Phase" is the area of the curve where the equipment as relatively constant failure rate, but randomly occurring failures due to defects and stresses may start to appear. Stress failures include exceeding the equipment short circuit rating, exceeding full load ratings, and environmental stresses that may be placed on the equipment.

The "Wear Out Phase" is the area of the curve where the failure rate begins to increase due to equipment parts wearing out. In this area of the curve it takes less stress for equipment to fail. In this area maintenance cost increases and outages could be significant due to the availability of spare parts.

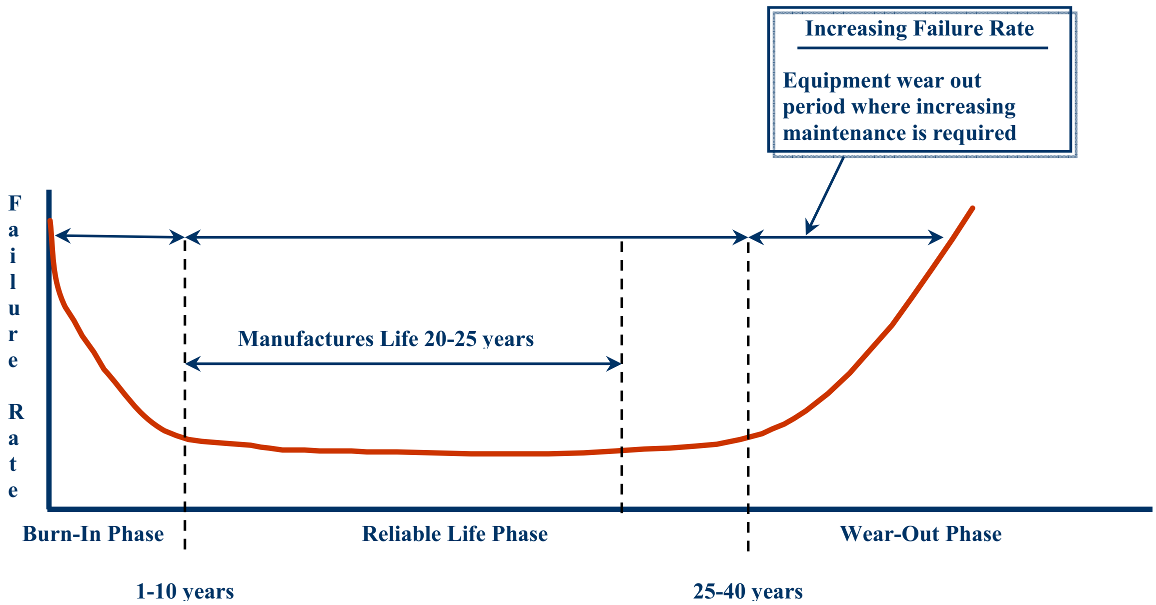

Figure 6: Reliability Bath Tube Curve

4.4.2 - Conceptual Development

After the electrical system has been assessed and the deficiencies defined, a minimum of three separate and distinct conceptual solutions for upgrading the electrical system need to be developed, and presented to the client. The conceptual solutions should provide preliminary oneline diagrams, site plans, calculations, +/- 30% cost estimate, and outline in detail the conceptual solutions.

Based on the results of the assessment one or more of the following will need to be done: continued maintenance, replacement, refurbishment, retrofit of equipment, and adjustments in operating environments and practices that reduce stresses, environmental and operational stress monitoring, inspection, surveillance, and trending [Horvath 2000].

When developing the conceptual solutions the current trends of upgrading electrical systems Replacement, Refurbishment, and/or Retrofitting the electrical system should be evaluated and incorporated into the conceptual solutions.

The Replacement solution should be considered when the integrity analysis determines that system expansion or reconfiguration will increase power demand or available short circuit current above the manufacturer's rating, the replacement of electrical equipment with new higher rated, and latest technology equipment should be performed. This increases safety, reliability, and decreases maintenance cost of the electrical system.

Issues that must be addressed when considering total replacement are:

- Downtime to remove the old and install the new equipment
- Site modifications to accept the new equipment
- Relocation of power and control cables

When analysis determines that system expansion will not exceed system load or manufacturer's ratings and spare parts are readily available this option should be considered. The advantage is downtime is kept to a minimum, and structural modifications or additions may not be necessary.

Disadvantages include:

- No increase in safety levels
- No new technology

- No increased system or load capabilities
- Questionable reliability
- Problems will reappear
- Marginal extension of service life
- Lack of replacement part availability with little cost improvement
- Postponement of the inevitable - possibility of failure relatively high

When analysis determines that only certain components are deficient such as breakers replacing the breaker interrupter assembly with Vacuum or SF-6 interrupter assemblies can be performed. This option will provide minimum down time, with minimal site modifications. However, performing the retrofit with interrupters designed to fit into the old interrupter frame, care must be used by the retrofitter to assure the new mechanism has the appropriate closing stroke, and force for opening and closing.

Disadvantages include:

- No increase in safety levels
- No increased system or load capabilities
- Questionable reliability
- If not properly retrofitted problems with stroke of breaker
- Marginal extension of service life

When the conceptual solutions are developed, they must take into consideration the current NFPA, OSHA, and IEEE standards for electrical system. The decisions of which solution is chosen should be based on the following:

- Safety
- Reliability
- Opportunities for increased system or load capacity
- Site modification, installation, and downtime costs
- Future maintenance and training requirements
- Availability and cost of replacement parts

4.4.3 - Conceptual Estimate

The Conceptual Estimate is a rough-order-of-magnitude cost estimate usually in the range of +/- 30% accuracy. The Conceptual Estimate will be used to evaluate the different options being considered. To prepare the estimate electrical one-line diagrams, electrical load list, equipment location plans, and electrical equipment list are developed for each option considered. The estimate includes cable size, cable lengths, raceway lengths, and estimated man hours for installing the equipment. The conceptual estimate is a detailed line item estimate itemized to include estimated quantities for all major equipment and work required for the options developed.

Pricing for the conceptual estimate is based on historical data gathered from bid tabulations of recently completed or currently under construction jobs, from budgetary bids from equipment vendors and subcontractors, and from data from data bases such as

RS Means. Contingency is included in conceptual estimates for uncertainties such site improvements, exact equipment locations, and other risk.

4.4.4 - Quantitative Analysis

After developing proposed options and estimates for the options of upgrading the electrical system, the options are analyzed using data from the reliability modeling performed in Section 4.3.3. The data allows the reliability, maintainability, and monetary results of each option to be compared based on probability of failure. The cost impact due to loss of production associated with the failure of the electrical system is determined and then calculated on an annual basis, the annualized cost aides in monetarily comparing options.

To convert failure probability to risk cost the Decision Tree method of analyzing reliability options will be used. The Decision Tree method is a good tool for assessing failure uncertainty in terms that management can understand. Decision trees are helpful for engineers and accountants to find a common ground for discussing mutual problems.

When considering upgrading electrical systems engineers are concerned with chances for failure, and management is usually concerned with expected monetary results from an outcome of a project. Performing the decision tree method of evaluating upgrade options provides a tool for factual discussion of proposed projects for engineers, managers, and accountants.

To prepare the decision tree model the plants availability must be determined or assumptions for availability of the plant must be agreed upon. Availability of the plant is the percentage of time the plant is not in a scheduled outage. The gross revenue of sell of electricity on a Mega Watt Hour (MWH) must be determined. Also, the cost of a forced outage must also be determined. The cost of the forced outage includes the cost of purchasing electricity, the cost of replacement parts, and the cost of man hours required to return the plant to the production levels before the outage occurred. For our sample plant it is assumed that the plant is available 92% of the year, net revenue is $40/MWH, and downtime cost is $80 MWH.

The next step is to calculate the expected net revenue value the existing plant will generate with no forced outages. The sample plant is capable of generating 285MWH, 92% of the year, at a net revenue $40/MWH.

Condition Value = 250MWH x 0.92 x 8760Hrs/year x $40/MWH = $91,874,900

The condition value is multiplied by the electrical system reliability, as determined by the method in Section 4.3.3 of this report. This calculated value is the Expected Condition value or the expected revenue the plant can earn with the current failure rate of the electrical system, for our sample plant the reliability is 0.9637.

Expected Value = $91,874,900 x 0.9637 = $88,539,800

Next the cost of a major failure of the plant electrical system is determined. A major failure would include such things as power transformer failure, switchgear failure, or other major equipment failure. Major failure cost is the downtime cost multiplied by the MTTR and MWH output of the plant, MTTR for the sample plant is 1128 hours.

Major Failure Cost = downtime cost x MTTR x MWH

= $80MWH x 1128Hrs x 285MWH = $25,718,400

The Major Failure Cost is then annualized by multiplying the value by 1 – R, this the Annual Expected Failure Cost. This is the yearly cost of a failure of the electrical system and includes cost of equipment, lost cost of production, and man-hours to repair system.

Annual Expected Failure Cost = Major Failure Cost x (1 – 0.9637)

= $25,718,400 x 0.0363 = $933,578

These Expected Values are the expected returns and expected failure cost for doing nothing. If the electrical system is near the end of its useful life, the probability of the full cost of a major failure on the system increases. The steps should be repeated for each reliability option proposed, the cost of doing nothing compared to the cost of the proposed options.

To calculate the Benefit or Avoided Risk of the option the Expected Return of the current system is subtracted from the Expected Return of the option being considered.

Benefit = Expected Return Option - Expected Return Current System

= $90,108,259 - $87,744,392 = $2,363,867

To calculate a payback period the Totaled Installed Cost for the option is divided by the Benefit for the option.

Payback = Totaled Installed Cost/Benefit

= $15,857,462/$2,363,867 = 6.7 years

The results of the Quantitative Analysis are summarized in a table as demonstrated in Figure 7. This table summarizes the reliability data, the reliability cost data, and the cost of each option. This table is a summary of the primary reasons why the selected option is chosen over the other options identified.

Configuration	failures/yr. (λ)	R (RELIABILITY)	MTBF	EXPECTED COND. VALUE	Failure Cost/yr.	Increased Profitability	Total Installed Cost
Current System	0.0370	0.9637	27.03	$87,744,392	($934,123)		
OPTION 1	0.0210	0.9792	47.61	$90,075,118	($33,142)	$2,330,726	$17,621,302
OPTION 2	0.0189	0.9813	52.90	$90,278,104	($19,606)	$2,533,712	$19,504,680
OPTION 3	0.0187	0.9814	53.35	$90,301,442	($10,572)	$2,557,050	$15,678,078

Figure 7: Reliability Summary

4.5 - Implementation Approach

After the appropriate option is selected, the planning for conducting the equipment upgrade is conducted. The equipment to be upgraded needs to be ranked by the urgency for upgrading the equipment; this will help prioritize the upgrade program. A quantitative risk assessment process may need to be conducted to help prioritize what equipment should be first. Also, the schedule of planned outages needs to be considered during this planning phase.

4.5.1 – Equipment Risk Ranking

Developing a Risk Ranking Matrix is an effective means of identifying the equipment that has the highest probability of having a significant failure, and determining which equipment is the highest priority for upgrading, Figure 8 is an example of a risk matrix.

	Likelihood				
Severity	**Frequent**	**Probable**	**Occasional**	**Remote**	**Improbable**
Catastrophic	HIGH	HIGH	HIGH	MODERATE	MODERATE
Critical	HIGH	HIGH	MODERATE	MODERATE	LOW
Marginal	HIGH	MODERATE	MODERATE	LOW	LOW
Negligible	MODERATE	LOW	LOW	LOW	LOW

Figure 8: Risk Matrix

The risk ranking matrix has the range of severity on the y-axis and likelihood on the x-axes. The combination of a severity and likelihood range gives a "High", "Moderate", or "Low" risk ranking. Equipment showed by prioritized based on there risk ranking, equipment with a high risk ranking may need to be scheduled for replacement before the next scheduled outage, and means for protecting against an event should be used. Below are the definitions of the severity and likelihood ranges:

A Catastrophic event could result in serious personnel injury including death, loss exceeding $1M, or irreversible severe environmental damage that violates law or regulation.

A Critical event could result in permanent partial disability, injuries or occupational illness that may result in hospitalization, loss exceeding $200K but less than $1M, or reversible environmental damage causing a violation of law or regulation.

A Marginal event could result in injury or occupational illness resulting in one or more lost work days(s), loss exceeding $10K but less than $200K, or mitigatible environmental damage without violation of law or regulation where restoration activities can be accomplished.

A Negligible event could result in injury or illness not resulting in a lost work day, loss exceeding $2K but less than $10K, or minimal environmental damage not violating law or regulation.

A Frequent occurrence is a continuously experienced failure. Equipment with a failure rate of 10^{-1} or higher is considered to fail frequently.

A Probable occurrence is a failure that will occur several times in the life of the equipment. Equipment with a failure rates between 10^{-1} and 10^{-2} is considered to have a probable chance of failure.

An Occasional occurrence is failure that is likely to occur some time in the life of the equipment. Equipment with a failure rates between 10^{-2} and 10^{-3} is considered to have an occasional chance of failure.

A Remote occurrence is an unlikely but possible to occur failure in the life of the equipment. Equipment with a failure rates between 10^{-3} and 10^{-6} is considered to have a probable chance of failure.

An Improbable occurrence is so unlikely, it can be assumed occurrence may not be experienced. Equipment with a failure rate of 10^{-6} or less is considered to be improbable of failure.

4.5.2 - Upgrade Plan

Once the equipment has been prioritized for upgrade, generic phases and activities required to complete the upgrade program can be identified. If the condition and risk ranking of the equipment does not mandate immediate action the phases of the upgrade need to be scheduled to coincide with planned plant shutdowns and outages.

During this phase of the study equipment with long lead times need to be identified, and a procurement plan developed for ordering long lead equipment. Also, work that can be done before an outage should be identified. A generic man-hour loading schedule should be developed for each of the generic phases of the project. Also, during this phase of the study any project risk should be identified and a contingency plan developed for mitigating the risk.

Some typical risk could be limited site space, this could cause a problem for staging equipment or for installing new equipment before demolition of old equipment. Limited time frame for installing equipment during an outage is another risk that should be considered. Another typical risk is the escalating prices for major electrical equipment. Also, construction contracting method should be considered for the different phases of the project, if the phase of the project will require close coordination between the plant operations and the relocation of equipment, or power and control equipment a time and material contracting strategy should be considered

5 Chapter 5 – Summary and Conclusion

Power generating companies our currently upgrading there aging assets for continued safe and economic operation for the next 30 years and beyond. These companies will not only need to assess the condition of their turbines and generators, but they will also need to proactively assess their electrical systems.

The electrical equipment in many of the generating plants were installed 70's, early 80's, and some as for back as the mid 50's and 60's. Currently the request for studies on these systems are sporadic but with the need to add equipment for upcoming air quality control regulations the request for electrical system assessments and feasibility studies will increase.

It is important to remember that if the equipment in electrical system exceeds the equipment short circuit ratings, full load rating, is obsolete, spare parts are unavailable, or the condition of the equipment has deteriorated to where it is unsafe to operate the equipment, the equipment should be upgraded.

The risk assessment process discussed in this paper will help identify electrical equipment that have the potential for catastrophic failure. The risk assessment will aide in determining when, what and where actions should be taken to upgrade the electrical system and to enhance the reliability and safety of operating the system.

This paper has discussed methodologies that have been developed and refined over the last ten years for effectively assessing electrical equipment, and ranking the risk of electrical equipment. Over the past ten years there has been many papers written, and standards developed to simplify modeling techniques for assessing the reliability of industrial electrical system.

These reliability modeling techniques are currently not widely used in the power generation industry, it is hopeful that this paper, and research by others will increase the use of these reliability techniques in assessing and justifying electrical system upgrade projects.

6 Chapter 6 – Suggestions for Future Research

Additional work and research is required to gain a better understanding of the methods of predicting catastrophic failures in electrical power systems. With the aging electrical infrastructure and the push to operate this infrastructure beyond the design life of the equipment understanding and predicting failures will become a very sought after expertise.

The use of Fault Tree Analysis, Failure Modes and Effects Analysis (FMEA), and Reliability Centered Maintenance (RCM) techniques are not new to general industry but are not widely used in the power generation industry. It is pertinent that the use of these reliability tools be studied to aide in risk assessment, identifying specific failure causes, and functional failure modes.

Also further work is needed in identifying and controlling hidden failures in electrical equipment. A better understanding of these topics and the topics covered in this paper will help the consultant to better asset plant engineers, managers, and other decision-makers prioritize and match available resources with the many needs of the aging electrical systems.

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Appendices

Sample Mechanical Integrity Forms

ELECTRICAL SWITCHGEAR–ASSOCIATED EQUIPMENT INSPECTION REPORT

Plant ______________________ Date ______________________

Location ______________________ Serial No. ______________________

Mfr. ______________________ Year Installed ______________________

Rating: Volts ______________________ Bus Capacity Amperes ______________________

Type: Switchboard ❑ Indoor Metal Clad ❑ Outdoor Metal Clad ❑

Annual Inspection (Disregard items that do not apply.)

Date					
Inspector's Initials					
Switchboards					
Clean					
Check Wiring					
Inspect Panel Insulation					
Exposed Bus and Connections					
Clean and Check Porcelain					
Check Insulators for Cracks or Chips					
Check and Tighten Connections					
Inspect Potheads for Leaks					
Check for Environmental Hazards					
Test Insulation (Megohms)					
Metal Clad Enclosures					
Clean					
Check for Openings That Permit Dirt, Moisture and Rodent Entrance — Repair					
Check Hardware for Rust or Corrosion					
Paint Condition					
Check Heaters and Ventilators					
Metal Clad Bus and Connections					
Clean Insulators and Supports					
Check and Tighten Connections					
Check for Corona Tracking					
Inspect Potheads for Leaks					
Test Insulation (Megohms)					

Date					
Inspector's Initials					
Disconnect Switches					
Check Contact Surfaces					
Check Insulation Condition					
Lubricate per Mfr.'s Instructions					
Test Operate					
Fuses and Holders					
Check Contact Surfaces					
Lubricate per Mfr.'s Instructions					
Meters and Instruments					
Check Operation					
Test Meters per Eng. Std.					
Test Relays per Mfr.'s Instructions					
Interlocks and Safety					
Check for Proper Operations					
Check Lightning Arresters					
Check Ground Detectors					
Check Equipment Grounds					
Station Battery					
Periodic Routine Maintenance is performed					

Remarks (note action taken when indicated by inspection or tests):

____

____

Recommendations:

____

____

____

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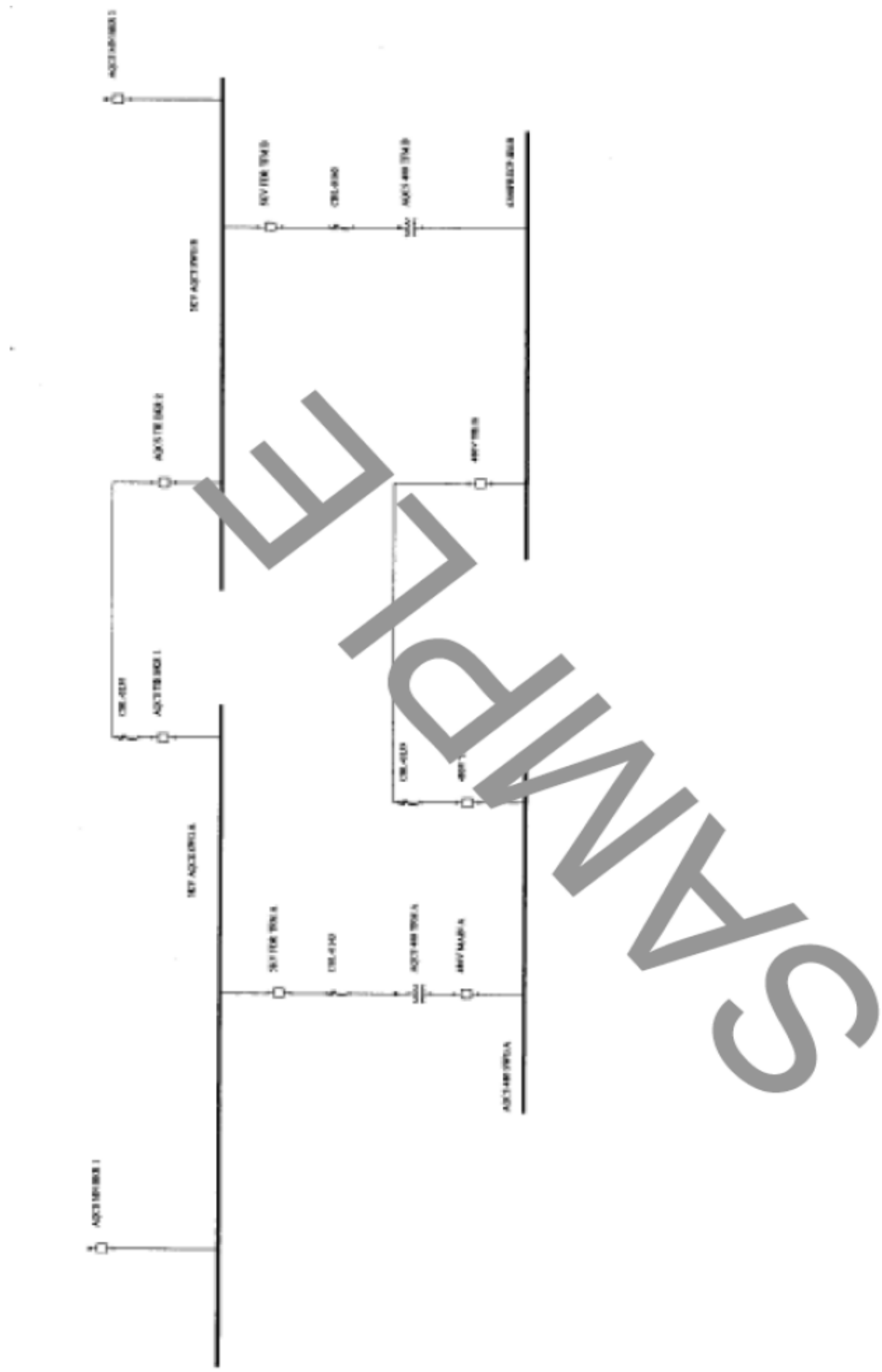
Sample Onelines



Sample One-Line Diagram

Sample Cost Estimate

Conceptual Estimate for Installation Cost of Upgrade

		Unit Price		Extended Price		
Description	Qty	Const. Unit	Materials	Materials	Labor	Labor & Mat'l
Equipment & Material						
Unit 1, 21KV GENERATOR BREAKER	1	Each	$600,000	$600,000	$182,000	$782,000
Unit 1, Generator Breaker Foundation	10	cubic yd.	$350	$3,500	$3,640	$7,140
Unit 1, 21KV ISO-PHASE BUS	1	Each	$450,000	$450,000	$312,000	$762,000
Unit 1, 21-4.16kV, 30/40/50MVA Auxiliary Transformer	2	Each	$500,000	$1,000,000	$109,200	$1,109,200
Unit 1, Transformer Foundation	230	cubic yd.	$350	$80,500	$83,720	$164,220
Unit 1 SU XFMR TO SWITCHGEAR 5KV 750 Single Core Cable	1.5	1000 feet	$20,000	$30,000	$5,850	$35,850
Unit 1 4.16kV Bus 1A & 1B Switchgear	1	Each	$960,000	$960,000	$26,000	$986,000
Emergency Diesel Generator 1000kW with auto sync/auto transfer	1	Each	$260,000	$260,000	$10,400	$270,400
Unit 1 480V Emergency MCC	1	Each	$75,000	$75,000	$7,800	$82,800
Unit 1 5KV Tray Cable	8	1000 feet	$15,000	$120,000	$31,200	$151,200
Unit 1 Unit Substation 1A	1	Each	$265,000	$265,000	$20,020	$285,020
Unit 1 Unit Substation 1B	1	Each	$265,000	$265,000	$20,020	$285,020
Unit 1 600V Tray Cable	1.5	1000 feet	$27,000	$40,500	$3,900	$44,400
Unit 1 600V 12AWG Control Cable	3	1000 feet	$900	$2,700	$7,800	$10,500
Unit 1 300V Instrument Cable OSBL	2	1000 feet	$1,200	$2,400	$7,800	$10,200
DEMO Unit 1, 21KV ISO-PHASE BUS for Tie In of New Gen BKR	1	Each	$0	$0	$156,000	$156,000
DEMO Unit 1, Auxiliary Transformer	1	Each	$0	$0	$36,400	$36,400
DEMO Unit 1 SU XFMR TO SWITCHGEAR 5KV 750 Single Core Cable	1.5	1000 feet	$0	$0	$7,800	$7,800
DEMO Unit 1 4.16kV Bus 1A & 1B Switchgear	1	Each	$0	$0	$26,000	$26,000
DEMO Emergency Diesel Generator 1000kW	1	Each	$0	$0	$15,600	$15,600
Total Extended Prices				$4,154,600	$1,169,350	$5,323,950
Construction Equipment, i.e. Cranes, Scaffolding						$1,064,790
Indirects, i.e. Engineering, Project Management, Startup Management						$2,129,580
Contingency						$2,555,496
Base Cost (+/- 30%)						**$11,073,816**

Sample Estimate

Sample Load Flow Reports

Configuration	Rated MVA	Rated FLA	Load Flow MVA	Load Flow Amps	Voltage Drap %	PASS/FAIL
XFMR 1A	40	1924	22.7	1135	6.3	PASS
XFMR 1A with additional transformer fans	50	2405	22.7	1135	6.3	PASS
XFMR 1A ID Fan Starting with additional transformer fans	50	2405	43.5	2955	19.1	PASS
XFMR 1B with additional transformer fans	**50**	**2405**	**54.9**	**2739**	10.9	**FAIL**
XFMR 1B ID Fan Starting with additional transformer fans	**50**	**2405**	**64.8**	**2739**	**22.3**	**FAIL**
XFMR 1NEW	40	1924	22.8	1135	5.7	PASS
XFMR 1NEW ID Fan Start on secondary	40	1924	36	2365	14.3	PASS

Sample Load Flow Summary Report

Sample Short Circuit Reports

Equipment	Volt (V)	Rated Interrupting Amps (kA)	Connected Load Interrupting Amps (kA)	Connected Load Bolted Fault Amps (kA)	Interrupting 3P X/R ratio	PASS/FAIL
7KV SWGR2A	7200	63	37.2	43.8	12	PASS
7KV SWGR2B	7200	63	37.3	44	12	PASS
4KV SWGR1A	**4160**	**30**	**31.5**	**37.5**	**16**	**FAIL**
LIG SWGR 1	**4160**	**30**	29.5	**34.8**	**16**	**FAIL**
CRUSH SWGR	4160	30	17.9	20.2	12	PASS
4KV SWBR1B	**4160**	**30**	**30.9**	**35.8**	**16**	**FAIL**
4KV SWGR2A	**4160**	**30**	**36.7**	**50.1**	**16**	**FAIL**
4KV BUS2AA	**4160**	**30**	26.1	**33.3**	**16**	**FAIL**
4KV SWGR2B	**4160**	**30**	**36.9**	**50.3**	**16**	**FAIL**
4KV BUS2BB	**4160**	**30**	26.7	**34.2**	**16**	**FAIL**
PRECP SB1A	480	65	19.2	19.2	12	PASS
SUB 1A	480	65	48.4	48.4	12	PASS
RCLAIM MCC	480	65	20.7	20.7	12	PASS
TR HOP MCC	480	65	31.9	31.9	12	PASS
CRUSH MCC	480	65	17	17	12	PASS
PRECP SB1B	480	65	19.4	19.4	12	PASS
SUB 1B	480	65	43.3	43.3	12	PASS
SUB 2A1	480	65	49.7	49.7	12	PASS
SUB 2A1	**480**	**23**	**49.6**	**49.6**	**16**	**FAIL**
SUB 2A2	480	65	56.7	56.7	12	PASS
SUB 2A2	**480**	**23**	**43**	**43**	**16**	**FAIL**
SUB 2AA-1	480	65	32.4	32.4	12	PASS
SUB 2AA1	480	23	17.5	17.5	12	PASS
SUB 2A3	480	65	46.8	46.8	12	PASS
SUB 2A3	480	23	21.3	21.3	12	PASS
SUB 2A3	480	23	22.8	22.8	12	PASS

Sample Short Circuit Summary Report

Sample Reliability Calculations

Current System

AUXILIARY SYSTEM UNIT 1	failures/yr. (λ)	downtime/failure (r)		
UTILITY	0.537000	5.7		
MAIN XFMR 1	0.015300	1179.0		
AUX XFMR 1	0.015300	1179.0		
AUX XFMR 1 CABLE	0.000333	25.0		
MAIN BREAKER 1A	0.003600	109.0		
SWITCGEAR BUS 1A	0.001129	28.0		
FEEDER BREAKER	0.003600	109.0		
FEEDER CABLE	0.000333	25.0		
480V XFMR	0.005900	297.4		
480V MAIN BREAKER	0.003000	5.0		
480V SWITCHGEAR	0.000802	27.0		
480V FEEDER BREAKER	0.003000	5.0		
SERIES	0.036997	1128.0		
			R (RELIABILITY)	MTBF
SYSTEM TOTAL (EXCELLENT PM)	0.036997	1128.0	0.9637	27.0
SYSTEM TOTAL (POOR PM))	0.055496		0.9460	18.0

OUTCOME NO UPGRADE	PROB OF OCCURANCE	COND. VALUE	EXPECTED COND. VALUE
RUN	0.9637	$92,020,800	$88,678,515
DOWN	0.0363	($25,718,557)	($934,123)
		NET	$87,744,392

OPTION 1

AUXILIARY SYSTEM UNIT 1	failures/yr. (l)	downtime/failure (r)		failures/yr. (l)	downtime/failure (r)
UTILITY	0.537000	5.7			
MAIN XFMR 1	0.015300	1179.0			
SERIES	0.552300	38.2			
ISO PHASE BUS	0.000125	128.0			
SERIES	0.552425	38.2	SERIES	0.552425	38.2
AUX XFMR 1	0.015300	1179.0	AUX XFMR 1	0.015300	1179.0
AUX XFMR 1 CABLE	0.000333	25.0	AUX XFMR 1 CABLE	0.000333	25.0
MAIN BREAKER 1A	0.003600	109.0	MAIN BREAKER 1A	0.003600	109.0
SWITCGEAR BUS 1A	0.001129	28.0	SWITCGEAR BUS 1A	0.001129	28.0
FEEDER BREAKER	0.003600	109.0	FEEDER BREAKER	0.003600	109.0
FEEDER CABLE	0.000333	25.0	FEEDER CABLE	0.000333	25.0
MAIN BREAKER	0.003600	109.0	MAIN BREAKER	0.003600	109.0
SWITCGEAR BUS	0.001129	28.0	SWITCGEAR BUS	0.001129	28.0
FEEDER BREAKER	0.003600	109.0	FEEDER BREAKER	0.003600	109.0
FEEDER CABLE	0.000333	25.0	FEEDER CABLE	0.000333	25.0
480V XFMR	0.005900	297.4	480V XFMR	0.005900	297.4
480V MAIN BREAKER	0.003000	5.0	480V MAIN BREAKER	0.003000	5.0
480V SWITCHGEAR	0.000802	27.0	480V SWITCHGEAR	0.000802	27.0
480V FEEDER BREAKER	0.003000	5.0	480V FEEDER BREAKER	0.003000	5.0
SERIES	0.598084	69.8	SERIES	0.598084	69.8
PARALLEL	0.005703	34.9			
	0.015300	1179.0			
	0.021003	868.4			

			R (RELIABILITY)	MTBF
SYSTEM TOTAL (EXCELLENT PM)	0.021003	868.4	0.9792	47.6
SYSTEM TOTAL (POOR PM))	0.031504		0.9690	31.7

OUTCOME UPGRADE	PROB OF OCCURANCE	COND. VALUE	EXPECTED COND. VALUE
RUN	0.9792	$92,020,800	$90,108,259
DOWN	0.0208	($9,899,202)	($205,743)
		NET	$89,902,516

OPTION 2

AUXILIARY SYSTEM UNIT 1	failures/yr. (l)	downtime/failure (r)		failures/yr. (l)	downtime/failure (r)
UTILITY	0.537000	5.7	UTILITY	0.537000	5.7
230KV BREAKER	0.003600	109.0	230kV BREAKER	0.003600	109.0
69kV Overhead Line	0.007500	17.5	69kV Overhead Line	0.007500	17.5
69KV XFMR 1	0.015300	1179.0	69kV XFMR 1	0.015300	1179.0
MAIN BREAKER	0.003600	109.0	MAIN BREAKER	0.003600	109.0
SWITCGEAR BUS	0.001129	28.0	SWITCGEAR BUS	0.001129	28.0
FEEDER BREAKER	0.003600	109.0	FEEDER BREAKER	0.003600	109.0
FEEDER CABLE	0.000333	25.0	FEEDER CABLE	0.000333	25.0
480V XFMR	0.005900	297.4	480V XFMR	0.005900	297.4
480V MAIN BREAKER	0.003000	5.0	480V MAIN BREAKER	0.003000	5.0
480V SWITCHGEAR	0.000802	27.0	480V SWITCHGEAR	0.000802	27.0
480V FEEDER BREAKER	0.003000	5.0	480V FEEDER BREAKER	0.003000	5.0
SERIES	0.584764	41.4	SERIES	0.584764	41.4
PARALLEL	0.003235	20.7			
	0.015300	1179.0			
	0.018535	976.8			

			R (RELIABILITY)	MTBF
SYSTEM TOTAL (EXCELLENT PM)	0.018535	976.8	0.9816	54.0
SYSTEM TOTAL (POOR PM))	0.027803		0.9726	36.0

OUTCOME UPGRADE	PROB OF OCCURANCE	COND. VALUE	EXPECTED COND. VALUE
RUN	0.9816	$92,020,800	$90,330,880
DOWN	0.0184	($11,135,818)	($204,504)
		NET	$90,126,375

OPTION 3

AUXILIARY SYSTEM UNIT 1	failures/yr. (l)	downtime/failure (r)		failures/yr. (l)	downtime/failure (r)
UTILITY	0.537000	5.7			
MAIN XFMR 1	0.015300	1179.0			
SERIES	0.552300	38.2			
PARALLEL	0.000000	0.0			
ISO PHASE BUS	0.000125	128.0			
SERIES	0.000125	128.0	UTILITY	0.537000	5.7
AUX XFMR	0.015300	1179.0	SU XFMR 1	0.015300	1179.0
AUX XFMR CABLE	0.000333	25.0	SU XFMR 1 CABLE	0.000333	25.0
MAIN BREAKER	0.003600	109.0	MAIN BREAKER	0.003600	109.0
SWITCGEAR BUS	0.001129	28.0	SWITCGEAR BUS	0.001129	28.0
FEEDER BREAKER	0.003600	109.0	FEEDER BREAKER	0.003600	109.0
FEEDER CABLE	0.000333	25.0	FEEDER CABLE	0.000333	25.0
480V XFMR	0.005900	297.4	480V XFMR	0.005900	297.4
480V MAIN BREAKER	0.003000	5.0	480V MAIN BREAKER	0.003000	5.0
480V SWITCHGEAR	0.000802	27.0	480V SWITCHGEAR	0.000802	27.0
480V FEEDER BREAKER	0.003000	5.0	480V FEEDER BREAKER	0.003000	5.0
SERIES	0.037122	557.5	SERIES	0.573997	41.3
PARALLEL	0.001456	38.5			
	0.015300	1179.0			
	0.016756	1079.9			

	failures/yr.	downtime/failure	R (RELIABILITY)	MTBF
SYSTEM TOTAL (EXCELLENT PM)	0.016756	1079.9	0.9834	59.7
SYSTEM TOTAL (POOR PM))	0.025135		0.9752	39.8

OUTCOME UPGRADE	PROB OF OCCURANCE	COND. VALUE	EXPECTED COND. VALUE
RUN	0.9834	$92,020,800	$90,491,702
DOWN	0.0166	($12,310,455)	($204,561)
		NET	$90,287,141