EFFICIENT OUTAGE MAINTENANCE PRACTICES

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Abstract - Current market pressures and global competition have resulted in lower maintenance funding and extended maintenance intervals. Whereas many well-studied maintenance practices exist, there is a shortage of efficient methods to apply these practices. This paper shall present a cost-effective method to integrate time-based planned maintenance, predictive diagnostics and critically factors based on reliability-centered maintenance (RCM) guidelines. Three basic questions will be evaluated: Can we save money on our planned outages? Can we efficiently evaluate maintenance test reports, inspections, predictive maintenance, etc. to make a single decision? And last, can we get the maximum savings with the minimum effort? Input was obtained from a consortium of over 500 man-years of maintenance experience. This process identifies equipment that requires immediate service, while also identifying equipment that can have reduced levels of maintenance. The results can include a reduction in overall maintenance spending, while also redirecting funding to more efficient predictive diagnostics. Several case studies will be presented with the accompanying cost savings.

Index Terms — Outage Maintenance, Efficient Maintenance Practices, Performance Based Maintenance.

I. INTRODUCTION

Plant personnel are continually being faced with greater challenges to reduce maintenance costs while maintaining acceptable levels of reliability. Additional production needs have applied further pressure to actually improve reliability levels while simultaneously reducing maintenance costs. A recent publication of NFPA-70B [1] states, “As yet, most production managers look at maintenance as a necessary evil.” In recent times, this position is becoming more and more universal. To address the above needs, many manufacturers are designing in predictive instruments to identify insulation wear or are designing entire systems to minimize outage-based maintenance. Regardless of end-user needs to minimize maintenance and manufacturers efforts to accommodate this, there will always be unexpected outages, therefore during these unplanned outages, it would be beneficial to conduct some level of maintenance which would extend equipment life and/or improve equipment performance.

The current practice is to perform a set-procedure of steps in the process of maintaining all similar equipment. For example, manufacturers and industry standards have developed standardized work scopes for circuit breakers, relays, transformers, motor starters and the like. [2]. In addition, experienced plant personnel, as well as IEEE statistics [3] both conclude that extending or eliminating maintenance will eventually result in a catastrophic failure and the corresponding extended outage.

It has also been long recognized that the success or failure of any type of maintenance program will be in direct proportion to the planning which is extended in such programs [4]. In many cases, the resource depletion in the maintenance funding and maintenance personnel has cut into the effective planning of maintenance, which furthers results in the inefficient spending of already limited maintenance funds. Recent publications [5] have also emphasized the need for engineering support in areas such as:

a) Identifying and monitoring of maintenance performance parameters, especially failure precursors
b) Tracking and trending of parameters
c) Failure root cause analysis
d) Maintenance procedures development and control
e) Maintenance guidance and training

If maintenance activities continue to be reduced or minimized, then original equipment manufacturers (OEM’s) will need to apply greater levels of Maintainability Engineering in the original design of electrical distribution components. With regard to new equipment design, this has been defined as, “Maintainability Engineering is the science of minimizing the need for maintenance and minimizing the downtime if maintenance action is necessary [6].” Manufacturers can consider the above as a critical design criterion for future products, but existing installed equipment may not have had such an emphasis during the design phase.

II. PAST PRACTICES

Many current maintenance practices will address several aspects of equipment performance. The primary goal of most maintenance functions is to identify the equipment that requires immediate attention. This equipment will be labeled “Unsatisfactory” or “Near-Failure” with a recommended immediate corrective action plan. This equipment is usually given a top priority either prior to returning to use, or immediately following the receipt of the necessary replacement parts or components.

In general, the balance of all equipment is labeled as “Satisfactory” for continued use. At the same time, all electrical equipment would be expected to follow a normal distribution. The two groups of “unsatisfactory’ and “satisfactory”, with the normal distribution are both shown in Figure 1. The group of “unsatisfactory” equipment is illustrated in the “a’ area below, while the balance of the “satisfactory” equipment is shown in the “b” area below.

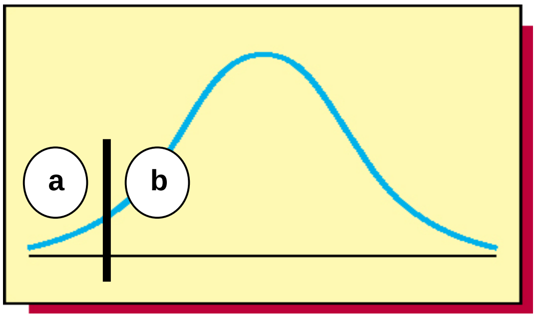

Figure 1: Normal Distribution of Expected Equipment Conditions

The process to determine the condition of equipment is based on either the manufacturers, or industry standard maintenance and testing practices [2]. In general, during a traditional outage, a similar workscope will be completed on all similar equipment. For example, the testing and maintenance procedure for circuit breakers will be completed on all circuit breakers, and the same for transformers, motor starters, etc.

III. RESEARCH

To begin to answer the question: "Can we save money on our planned outages?" we need to review areas of potential savings. One simple process to save money would be to reduce the level of maintenance on equipment, which is considered in "Excellent" or "Above Average" condition. As shown in Figure 1, traditional outage maintenance and testing practices only identify the other end of the spectrum, that is, the equipment in "unsatisfactory" condition. To review the potential for savings, a survey of professionals who provide traditional maintenance services in North America was conducted concerning low voltage circuit breakers. The survey evaluated the number of low voltage circuit breakers that are expected to require additional immediate service following a traditional maintenance cycle and equipment that could possibly have its maintenance cycle extended.

The results are as follows concerning the number of low voltage circuit breakers that are expected to require additional immediate service following a traditional maintenance cycle.

a) Number of respondents: 24
b) Total years of experience represented by the 24 respondents: 508 person-years
c) Mean of the expected number of LV circuit breakers that would require additional immediate service: 18.0 %

The frequency distribution of the results did correspond to a normal distribution.

This is an estimate of the "unsatisfactory" or "near failure" equipment requiring additional repairs. Once again, the potential for future savings results from the "other" equipment, that is, the percentage of the remaining 82% that can possibly be afforded a lower level of maintenance, or have the maintenance interval extended.

The above group of professionals was also questioned concerning the number of LV circuit breakers that could have had their maintenance cycle extended or provided a lesser level of maintenance. Of the twenty-four (24) total respondents, sixteen (16) provided a specific numerical response. The eight (8) who did not provide a specific numerical response indicated that additional information was required to provide a generalized answer.

a) Number of respondents: 16
b) Total years of experience represented by the 16 respondents: 333 person-years
c) Mean of the expected number of LV circuit breakers that could have had their maintenance cycle extended or afforded a lesser level of maintenance: 53.8 %

The data obtained form the above referenced research is summarized in Table 1.

Category	Number of Respondents	Years Experience	Results
Equipment requiring immediate service	24	508	18.0 %
Equipment that could have extended interval or lesser maintenance	16	333	53.8 %

Table 1: Professional Service Group Research of Equipment requiring Immediate Service versus and Extended Maintenance Interval

IV. SOLUTION CREATION

The type of low voltage circuit breaker studied for this analysis is low voltage power circuit breakers with spring charging mechanisms, since these types of circuit breakers are normally provided maintenance at certain intervals. This study does not include molded case circuit breakers (MCCBs). Molded case circuit breakers (MCCB) do not require extensive maintenance, beyond exercising and periodic thermographic surveys, therefore identifying MCCB circuit breakers, which can be afforded a lesser level of maintenance, would not generate any savings, when compared to low voltage power circuit breakers with spring charging mechanisms. Basically, exercising and thermographic surveys are the least possible maintenance that can be recommended for molded case circuit breakers.

Concerning low voltage circuit breakers studied, a process was implemented using cause-and-effect diagrams to determine a method to identify the 53.8% of low voltage circuit breakers, which could be afforded a reduced level of maintenance, while ensuring that full outage-based maintenance is performed on the balance of all equipment. Cause-and-effect diagrams, also known as fishbone diagrams, were developed by Kauro Ishikawa of Tokyo University in 1943 and thus are often called Ishikawa Diagrams [7]. The assumption from the research is that this 53.8% could represent the equipment that is in "Excellent" or "Above Average" condition.

Brainstorming sessions were conducted and many potential options were identified. After many consolidations, the majority of possibilities were grouped into four primary functions. A summary of the fishbone

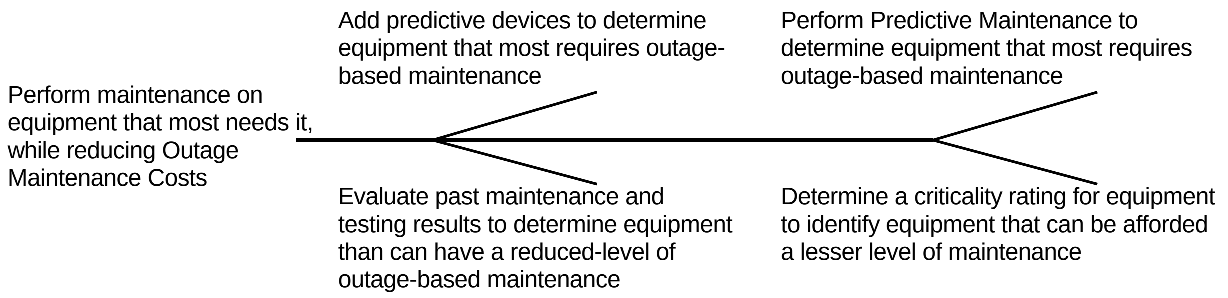

Figure 2: Fishbone Diagram to determine assets that need full maintenance while reducing outage maintenance costs

diagram, and these four primary functions are shown in Figure 2.

The first and second areas involve the addition of predictive devices to determine equipment that most requires outage-based maintenance, and the performance of such predictive maintenance to determine equipment that most requires outage-based maintenance. An example would be the addition of partial discharge continuous monitoring for medium voltage switchgear [8].

The second area involves the performance of predictive maintenance such as thermographic surveys that identify overheated electrical connections or deteriorated contacts primarily for low voltage systems. Thermography, which works very well for LV systems, does not apply to MV systems. First, thermographic inspections require direct line-of-sight of connections to determine heating and in many cases, active corona, associated with MV switchgear, does not generate intense heat that is detectable by a thermograph gun. In addition, modern MV switchgear may contain additional sheet steel panels therefore even visual inspections can be difficult to impossible to conduct in a cost-effective manner. The installation of "thermograph viewing windows" does improve both the capability of these inspections as well as provide for personnel safety since the windows eliminate the need to remove covers, or open doors on energized equipment, but again, this would pertain to LV switchgear, including MCCB applications. In general, the authors would recommend the two predictive solutions of continuous partial discharge detection for MV equipment and thermography, with viewing windows, for LV equipment.

The third area involves the review of past maintenance records, including both outage-based maintenance test sheets and past predictive maintenance results. Consistency standards would be required to ensure that all assets of a similar class are provided with the same evaluation, and provided a similar rating. Such standards have been developed for circuit breakers (MV and LV), MV Starters and transformers and were applied to the Case Studies to be discussed in this paper.

The forth area requires plant personnel input. A "criticality rating" is developed using similar inputs as applied in Reliability-Centered-Maintenance programs [10], but in no way attempts to match the detail of an RCM program. This is further discussed in the next section.

These third and forth areas are items that can be evaluated and a professional decision made to consolidate the various inputs. In addition, following the development of a solution that integrates these processes, a test can be made to determine how valid are the results. The goal is a system that allows us to obtain greater differentiation between the normal distribution of equipment condition, and therefore determine the equipment that is in "Excellent" or "Above Average" condition. Ideally, we would identify equipment that matches the five areas illustrated in Figure 3. The equipment in areas "d" and "e" would be considered for a reduced level of maintenance.

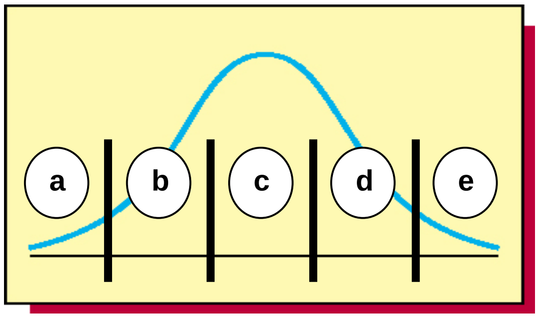

Figure 3: Normal Distribution of Expected Equipment Conditions

Figure 3 has the following labels:

a) Unsatisfactory
b) Below Average
c) Average
d) Above Average
e) Excellent

A system was developed that evaluated three items:

- Past maintenance testing results
- Current operating condition
- Environmental surroundings of the equipment

The above criterion was evaluated and applied a numerical score for each category. The three scores were weighted and summarized for a final score for each asset. The numerical score was translated to three equipment "labels" as follows:

a) "ST" – Equipment in need of short-term action or which should be selected for immediate maintenance during the next scheduled outage. This equipment is provided with "Full Maintenance" in addition to completion of any noted additional inspections or repairs.

b) "MT" – Equipment in normal condition, based on the time period since the last scheduled maintenance and which should be afforded a normal maintenance overhaul. This equipment is provided with "Full Maintenance" during the next scheduled outage.

c) "LT" – Equipment which is in above average condition and which could be afforded a lesser level of maintenance. This equipment is provided with "Operational Maintenance" during the next scheduled outage.

Operational maintenance has been determined by an expert review of traditional maintenance practices and a set of criteria was determined to evaluate the critical performance measures. An example of Full versus Operational Maintenance is included in the next section of this paper.

V. CASE STUDIES

Two case studies are illustrated which provide an indication of the results from the established program, which has been defined as a Performance-Based-Maintenance (PBM) program [9].

The first case study involves a large pulp and paper plant that traditionally provided full maintenance on 390 low voltage circuit breakers. The plant cycles through seven substations with each circuit breaker receiving full maintenance every three years.

The results were as follows:

a) "ST" – 42 LV Circuit Breakers (10.8 %)
b) "MT" – 142 LV Circuit Breakers (36.4 %)
c) "LT" – 206 LV Circuit Breakers (52.8 %)
Total 390 LV Circuit Breakers (100.0%)

The total savings was determined to be $ 29,087.50, to be captured during the next three years, since the equipment is cycled for maintenance every three years in this particular manufacturing plant.

It is interesting to note that the actual results, based on data analysis, in this case study for low voltage circuit breakers, was 52.8% of the circuit breakers are candidates for a reduced scope of maintenance. The survey research results indicated an expected 53.8%.

The second case study involves a department of a medium size petro-chemical plant. In this plant, four different types of electrical equipment were evaluated as shown in Table 2.

Two key observations are necessary. First, only three (3) MV Starters were evaluated and this is too small of a group for any statistically valid conclusions. It can also be noted that no MV Starters were identified as candidates for a reduced level of outage-based maintenance (No "LT" overall rankings). This may also hold for larger quantities since MV Starters do experience a high number of operations and therefore may always require full maintenance during planned outages.

The second observation is that, once again, we found close correlation between the actual tested results for low voltage circuit breakers and our research results. In this case study, our test data analysis and on-site observations indicated 57% as candidates for a reduced level of maintenance. (Research results being 53.8%).

Concerning the difference between Full Maintenance and Operational Maintenance, an example is provided concerning the Oil-Filled Transformers shown above and the associated savings. Similar differences exist concerning Full and Operational Maintenance for the other electrical assets.

An example of reducing the level of maintenance for oil-filled distribution transformers could be a detailed external inspection with bleeding and reapplying a new nitrogen blanket to the recommended level. This can be defined as Operational Maintenance. This would be in contrast to Full Maintenance that would include the above, plus winding insulation resistance testing (megger), turns-ratio testing (TTR) and winding power factor testing. In either case, a dissolved-gas analysis (DGA) and standard dielectric testing of the transformer oil would be recommended on a periodic basis.

If we review the transformer data in Table 2, we have 16 of the 32 units receiving full maintenance at 10 man-hours each, or a total of 160 man-hours for the 16 receiving full maintenance. The remaining 16 qualified for operational maintenance at 3 man-hours per transformer, or a total of 48 man-hours for the 16 receiving operational maintenance. The total man-hours with the performance-based-maintenance program are equal to 208 (160 + 48). This is a savings of 112 man-hours versus performing full maintenance on all 32 transformers, since it would require 320 man-hours to complete full maintenance on all 32 units (10 man-hours each). The 112 man-hours of savings represent the 35% savings for the transformer units as shown in Table 2.

The data, summarized in Table 2, indicates the overall savings for all assets analyzed in man-hours was 37.5%.

TABLE 2
MAN-HOUR SAVINGS FOR PLANT WITH VARIOUS EQUIPMENT TYPES

Equipment Type (Units Evaluated)	Base Man-hours (All devices provided Full Maintenance	PBM Man-hours (MT & ST get Full Maint.; LT gets Operational Maint.	PBM Resultant Man-Hours Savings	PBM % Man-hours Savings
MV Breakers (18)	57.6	44.4 (11 on LT = 61%)	13.2	22.9%
MV Starters (3)	9.6	9.6 (0 on LT = 0%)	0	0.0%
LV Breakers (21)	67.2	37.8 (12 on LT = 57%)	29.4	43.8%
Oil Transformers (32)	320.0	208.0 (16 on LT = 50%)	112.0	35.0%
Totals	454.4 man-hours	283.8 man-hours	170.6	37.5%

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VI. ADDITIONAL CONSIDERATIONS

The above solution, called Performance-Based-Maintenance (PBM), satisfies the goal of identifying equipment that can be afforded a reduced level of maintenance, both from the research completed and confirmed by actual case studies.

The second approach in the fishbone diagram indicates the need to identify a criticality rating for each piece of equipment to ensure that only equipment with a lower critically rating can become candidates for the lesser level of outage-based maintenance. This would ensure that any extremely critical equipment would be given full outage-based maintenance, even if all other past data indicates this piece of equipment as a candidate for lesser maintenance.

It is well understood that a detailed study to determine a Reliability Centered Maintenance Program [10] would be the most beneficial approach, but the authors, and many end-users, have found that such programs will require tremendous financial and personnel resources, and that the benefit versus cost must be reviewed, as well as the resources required to implement the results of such a detailed RCM study [11]. The goal of this program is to obtain the best possible information in the most cost-effective manner possible. For this reason, the recommended program to determine the criticality rating is for several knowledgeable plant personnel to perform the following:

1) Identify ten (10) to twenty (20) highly critical assets and ten (10) to twenty (20) lesser critical assets.
2) Use the criteria below, or a similar criteria, to assign a rating of 1 to 5 for each of the categories shown.
3) Review the final results and adjust the criteria individual weighing to ensure that the appropriate critical and non-critical assets are properly ranked.
4) Apply the final process to quickly and efficiently evaluate the balance of all the assets.
5) Sample 10% to 20% of the final results to ensure that results correlate to actual criticality of the subject equipment.

This approach considers nine inputs, within three groupings, to determine the criticality rating in an efficient manner. In addition, a weighing factor is applied to each of the nine inputs. These weighing factors can be adjusted as discussed below, based on plant needs and concerns.

A rating of 1, 2, 3, 4 or 5 is required for the following nine parameters. The weightings shown are for illustration only and plant personnel should determine or modify the final set.

Safety: Potential *injury* to:
- Operating Personnel (weight of 3 x rating)
- Maintenance Personnel (weight of 2 x rating)
- Other Personnel (weight of 2 x rating)

Environment: Potential *hazard* to:
- Internal Plant Environment (weight of 2 x rating)
- External Plant Environment (weight of 2 x rating)
- Local Working Environment (weight of 1 x rating)

Production: Potential *loss* of:
- All production/process (weight of 3 x rating)
- Some (<50%) production (weight of 2 x rating)
- Product Quality (weight of 3 x rating)

The above criteria, and especially the weights applied to each rating, would be adjusted based on input from knowledgeable plant personnel. For example, the product quality might be increased in relation to other weights, but all weights must total 20. Also keep in mind that the dollar-value of the asset is normally proportional to the affect the asset will have on production, therefore higher dollar-valued assets should be normally awarded higher ratings in the Production Category. If there exists highly valued assets which are critical to the function of the plant, but are not directly integrated into any of the three categories above, the Production, or other ratings should be adjusted to accommodate for either higher valued assets, or assets which have a very long-lead time for repair or replacement.

As referenced above, the total of the weights must equal twenty (20). The above-illustrated scenario indicates the following split of this total of 20 weighting points.

Safety:	7
Environment:	5
Production:	8
Total	20

For sites with a higher emphasis on production, due to improved safety and environmental plant systems, the spit may become:

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Safety:	4
Environment:	4
Production:	12
Total	20

The Performance-Based-Program can be implemented without the criticality rating, but it is recommended for a complete and proper analysis.

VII. CONCLUSIONS

To answer our original questions:

Can we save money on our planned outages? Yes, our research, confirmed by actual case studies, has identified that equipment in either “excellent” or “above-average” condition can be identified in accordance with available engineering judgment, and those assets be provided a lesser level of outage-based maintenance. The savings result from reduced man-hours costs to complete the maintenance. Feedback from plant engineering and maintenance personnel also confirmed these findings. Most plant management personnel will only budget an additional 10% to 15% of funding for repairs, which are identified during planned-outage maintenance. These plant personnel have indicated they knew that not all of their assets required full-maintenance, but there was no efficient system to help differentiate the assets. A developed Performance-Based-Maintenance type program does not randomly select equipment for less maintenance but uses several inputs to ensure the best possible engineering judgment. As with all engineering judgments concerning equipment life, none are infallible, but this process does provide an engineered-based decision model.

Can we efficiently evaluate maintenance test reports, inspections, predictive maintenance, etc. to make a single decision? Yes, a similarly developed program summaries both test report results, current inspections and can include input from predictive maintenance to determine a final designation of either "ST" requiring short-term repairs and full maintenance; "MT" requiring mid-term maintenance and standard full-maintenance during outages; and lastly, "LT" requiring longer-term maintenance or a lesser level of maintenance during the next outage.

And last, can we get the maximum savings with the minimum effort? Yes, including an efficient criterion to also evaluate the criticality rating of each asset to ensure that only less critical assets are provided with a lesser level of outage-based maintenance. In some cases, a plant may desire to only apply such a program between future planned outages, when full maintenance is performed to all assets. This would still result in a savings, but just one-half the original magnitude.

This program has been successfully applied and will required continue applications and monitoring, with future corrections, as deemed necessary to this or similarly developed programs.

VIII. ACKNOWLEDGEMENTS

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X. VITA

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