A Maintenance Optimization Success Story

A Case Study for Improved Reliability and Profit Generation

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Overview and Vision

Due to increasing competition in the industry, organizations are investigating ways to dramatically redefine ways of doing business. One specific focus of this investigation is to look at the entire maintenance process. This reengineering of the maintenance process is a critical first step in redesigning what the business process needs to be in order to gain and advantage over competitors and significantly improve performance.

One challenge is to reduce costs while improving reliability, availability and also capacity. The area of maintenance, for many companies, is the single, largest, controllable cost within an operating system. The goal for all of these companies should be to transform their maintenance process into a "proactive" environment, where they experience all of the benefits of having maximum control over their maintenance issues. New technologies and methodologies are available today to put into practice these challenges that will elevate them to "world class" levels.

One major midwest utility understood these challenges, and set about to achieve the vision. Specifically, the Substation Maintenance and Construction Group set a goal to reduce maintenance costs by 40% while simultaneously improving system reliability.

Basic Approach

Even though the utility had accepted the dramatic goals of cost reduction and improved reliability, they were also aware of the high percentage of unsuccessful attempts at maintenance reengineering. Although they had committed a substantial budget for their goal, they were cautious in their movement forward.

Their plan was to identify a small number of highly critical and expensive equipment, and to generate a small-scale plan around that equipment as a "proof-of-concept." If the proof-of-concept demonstrated adequate success, then the small plan would migrate to full-blown implementation.

But they still didn't know what this plan or program actually was, and they knew they would need some outside help to accomplish it. Their first step was to interview a number of recommended reengineering and maintenance optimization organizations. These organizations then presented their program for optimization for the small "proof-of-concept" system.

For maximum benefit and acceptance within executive management, they knew that the program must meet the following objectives:

- Highly visible
- Immediate demonstration of results
- Involves in-house personnel, with
- Rapid transfer of knowledge to staff

Selection of Consultants

As a result of a number of evaluation criteria, the Strategic Partner Team of Fluor Daniel, Power Services Division (FD) and Technical Diagnostic Services, Inc. (TDS) was selected to be the primary organization to perform the desired maintenance optimization plan.

FD and TDS designed the initial Maintenance Optimization Program, and then later added Asset Strategy Technologies, Inc. (EQL) to the team during the implementation and execution phases of the project.

One of the overwhelming reasons for selecting FD, TDS and EQL was that they were willing to back up their projection of results by proposing "cost sharing" alternatives. These alternatives included fee structures that were based on achieving results

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Maintenance Optimization Program

The Maintenance Optimization Program began in October, 1995 with a condition assessment of six critical substations. The major system components that were included in this assessment included breakers, power transformers, batteries, cables, capacitors and structures. In addition to the condition assessment, the program study also analyzed all current maintenance practices, maintenance frequencies, testing and maintenance technologies employed, and a comparison of that utility's practices with several others in the industry.

The major categories of maintenance reengineering identified in the resultant report included the following:

- Maintenance strategies
- The use of modern monitoring and condition assessment technologies
- The use of computerized maintenance management systems
- Integration of the entire maintenance optimization process with computer technology
- A look at the personnel "culture" and methods to promote team building and employee empowerment.

Maintenance Strategies

The existing maintenance strategies before optimization were a mix of preventive and corrective tasks. The corrective requirements often dominated the mix, making for a very "reactive" environment. While there was a good understanding and acknowledgement that better knowledge about the performance of the equipment was a desirable climate, it was nearly impossible to stop "putting out fires" to implement new predictive approaches.

Two events occurred nearly simultaneously to help demonstrate to the utility that the generation of maintenance strategies was critical to the success of the program:

- EQL conducted seminars to all of the key team members, from technician to executive, to get a clear understanding of reliability centered maintenance (RCM) methodologies. These seminars were brief (2 - 6 hours), and focused on the value and benefits instead of the detailed how-to type of information.
- EQL, FD and TDS performed an actual RCM analysis on the two most critical components, transformers and breakers.

The result of presenting these two events together was tremendous. The utility members could relate RCM to the equipment that they knew the best, and they had RCM samples on that equipment from specialists in the business.

These strategies started the team to constantly think about and address the following key areas of all of their equipment:

- What are the "right" things to do, on a consistent basis, to keep the equipment running better and longer?
- What tasks are we currently doing that seem to have little value, that can be eliminated?
- Are there some technologies better than others at providing the condition assessment information that we need.
  - good condition assessment information is critical when it comes to building confidence toward eliminating maintenance tasks that have been being done for many years.
- What monitoring instrumentation would be cost beneficial to install or acquire?
  - for remote substations, which may be located 100+ miles from the technical service center, transportation and personnel costs are extremely important factors when it comes to on-line or automatic monitoring to reduce normal costs.
- What are the best "frequencies" that these tasks should be performed in order to arrive at the maximum benefit?

Monitoring Instrumentation Identified
(New and Improved)

As a result of the strategies developed for the transformers and breakers, a number of on-line monitoring and diagnostic equipment was identified. In some cases, the information was already available but wasn't correlated properly to diagnose degradation or failure of the equipment. The new monitoring instrumentation that was implemented for the proof-of-concept project were:

- LTC Temperature monitors
- Transformer Gas monitors
- Nitrogen pressure monitors

- Breaker energy dissipation monitors

Existing instrumentation that was included for enhanced use and correlation were:

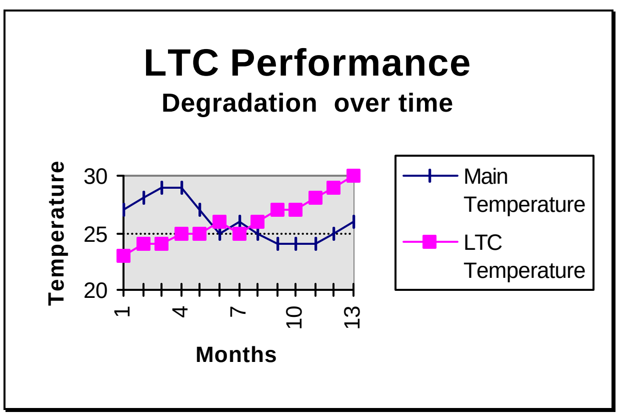
- Transformer load monitors

Descriptions of some of that instrumentation, reasons for implementing and results of correlation are listed below.

Transformer Load Tap Changer Contacts

Failures with load tap changers are common and have a serious impact on transformer cost and operation. They have a history of operating almost continuously in order to maintain the proper voltage to the consumer. As contacts wear or build up carbon, arcing occurs which increases the surrounding temperatures.

In the past, regular inspections were scheduled to investigate the condition of the contacts, but this requires that the equipment be taken out of service. These inspections could be eliminated with a good trend of the operating temperatures of the oil in the LTC compartment, correlated with the oil temperature in the main compartment and transformer loading conditions.



An instrument was installed that continuously monitors these temperatures. The benefits include longer duration between inspections, and improved diagnostics during operation and correlation to loading factors.

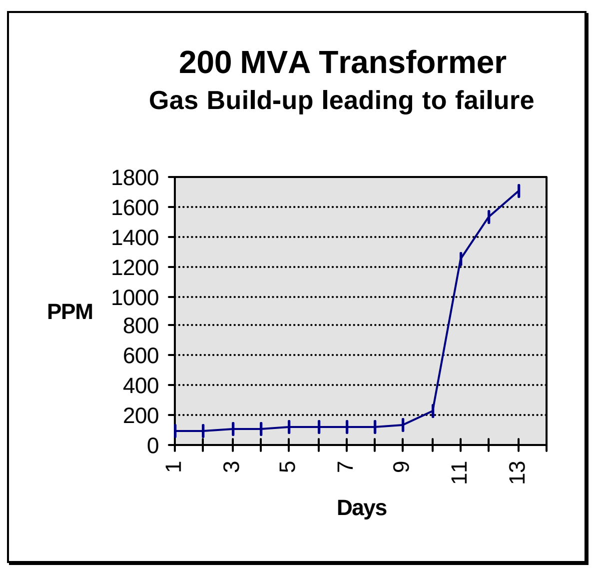
There have been several occurrences where this monitoring has discovered LTC problems, that if left uncorrected, would have led to serious transformer problems. The LTC in these cases was a $12K replacement, which potentially prevented several hundred thousand dollars in failures.

Transformer Combustible Gas Build-up

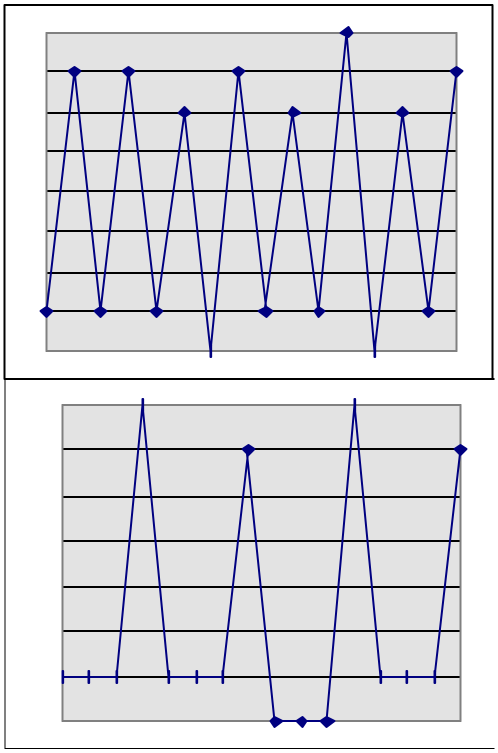
There are a number of gases that are generated in a transformer, and there are multiple reasons that this occurs. Insulation breakdown, internal degradation and overload are just some of the reasons. In any case, high levels of combustible gas may produce an explosion which would result in lost revenue, replacement, collateral damage and oil clean-up probably in excess of $1M.

A total combustible gas instrument was installed to continuously record and trend this gas build-up to replace periodic manual sampling of the oil and laboratory analysis. The benefits include a tremendous improvement in the time response of obtaining gas information (often several months), and providing the utility with the time necessary to take emergency action if gasification becomes a problem.

This instrument already helped prevent a catastrophic failure within the first month of the proof-of-concept project. One of the transformers built up combustible gas from 137 ppm to over 1500 ppm in a matter of two days. The transformer was removed from service and replaced. The unit was later detanked and diagnosed with an insulation breakdown which would have surely led to an explosion.



Transformer Nitrogen Pressure Loss



Many transformers are maintained with a nitrogen blanket at a slight positive pressure, fed from a nitrogen bottle at the side of the transformer. This keeps the gas mixture from being explosive and prevents implosion when oil temperatures drop in the main compartment.

Infrequent replacements of the nitrogen bottle are normal. Frequent replacements may indicate a leak in the system, and emergency replacements are usually due to structural failure or a careless hunter. In any case, nitrogen bottle replacements are a nuisance and costly when associated with remote locations.

A continuous nitrogen pressure monitor was installed on all proof-of-concept transformers. The benefits include improved maintenance planning, enabling scheduling for the bottle replacement to occur concurrently with other visits to the substation, as well as correlation with transformer load to identify leaks above the normal replenishment frequency.

Breaker Energy Dissipation Monitors

A new instrument associated with the continuous measurement of energy dissipation (I^2T) was installed at five oil circuit breakers. The instrument provides valuable information about the performance of the breaker and specifically about the condition of the contacts over a long period of time.

Breaker operation has been infrequent at all five oil circuit breakers, and therefore the only information that has been gained is that these particular breakers are performing very well and are not experiencing restrike or arcing difficulties. The benefit is an increased level of confidence and a reduction of unnecessary maintenance inspections.

Transformer Load Monitors

Interestingly, the utility was already obtaining transformer load for their operations center, but they weren't using this parameter for any trending or diagnostic correlation to any other parameters. The project identified the following degradation or failure situations where this parameter could be useful:

- overload and life reduction
- temperature trending over time
- nitrogen behavior
- LTC operation behavior
- LTC responsiveness and adjustment requirements

The above graph depicts two separate load tap changers over the same period of time at relatively the same load levels. The top LTC performs roughly twice as many "steps" as the bottom LTC, and therefore is expected to wear out twice as fast. With this knowledge, proper adjustments can extend the life of the top LTC to more closely resemble the life of the bottom LTC.

Implementation of CMMS

Prior to the optimization program, the utility's maintenance planning functions were primarily manual and using self-generated database applications. Some historical information could be retrieved, but basically it was related entirely to the maintenance task that was performed. There was absolutely no information associating the task with the equipment conditions leading up to the maintenance requirement. It would have been extremely difficult to generate a "proactive" maintenance plan based on this documentation.

It was determined that a low end, computerized maintenance management system (CMMS) would be implemented for the proof-of-concept program. The CMMS selected was Datastream's MP2 for Windows.

There were several goals of the CMMS effort, including :

- Improve scheduling and coordination of maintenance tasks at each substation
- Improve the administrative control associated with a work planning function
- Improve the documentation of work performed and costs associated with maintenance
- Use the CMMS to statistically help determine general equipment problems (i.e. numbers of problems for equipment types, parts replacements, labor requirements, etc.)
- Use the CMMS to formalize the new "maintenance process" in a way that everyone could understand and adhere to the process.

Integration of the Maintenance Process

Maintenance Strategy
+
Equipment Condition Assessment
+
Maintenance Execution
+
CMMS

When the maintenance optimization program was being designed, there were a large number of utilities that were doing individual pieces of the total plan, but not one had a totally integrated process.

This program was designed specifically with the understanding that all of the aspects of the optimization plan *must* migrate toward being fully functional and integrated.

The EQL TAPS™ (stands for Total Asset Performance Solution™) was the only system of its kind that could satisfy that criteria.

The unique features of EQL TAPS™ that made it appropriate for this program were:

- RCM Strategy Plus™ software integrated with the CMMS
- Total Productive Maintenance (TPM) methodologies integrated with both the RCM strategies and CMMS
- Easy implementation of expert diagnostic rules
- Integration of the equipment condition assessment technologies with the CMMS, generating automatic work orders from the on-line monitoring based on expert diagnostic rules

This integration has created a dramatically streamlined process that allows the "Reliability Engineer" to view technical information associated with any monitored equipment, and then transmit a "work order" to the maintenance planner for execution.

It also creates an environment where any member of the team (manager, engineer, technician, planner, statistician, etc.) has access to all of the information.

This effort does the following things:

- concentrates the planner's time for scheduling and administrating the process
- concentrates the reliability engineer's time to assess technical issues,
- makes expert diagnostic features available to "not-so-expert" technicians, and
- greatly reduces the time of everyone in the process as a result of improved coordination

Summary of the Proof-of-Concept Design

The following is a summary of the maintenance optimization program as it was developed and implemented for the proof-of-concept project.

1. Performed a preliminary study to determine which substations and substation equipment should be included in the proof-of-concept project.

2. Developed RCM analyses on a number of the critical substation components, including transformers and breakers.

3. Provided seminars and training to all team members concerning maintenance optimization methods, RCM, TPM, condition assessment, computerized maintenance management, and the integration of the entire process.

4. Implemented CMMS, with appropriate training and data conversion where appropriate and available.

5. Implemented EQL TAPS™ as the Total Asset Performance System™ and integration platform for all aspects of the optimization plan.

6. Installed on-line monitoring instrumentation on 5 major size transformers and 5 oil circuit breakers, to include:
   - combustible gas monitors
   - LTC temperature monitors
   - nitrogen pressure monitors
   - OCB I^2T monitors

7. Upgraded SCADA equipment to be able to bring all of the above sensor parameters into a central maintenance and diagnostic computer system

8. Generated equipment condition assessment and expert diagnostic rules for all of the monitored equipment.

9. Integrated condition assessment with the CMMS for automatic generation of work orders.

10. Trained utility personnel in all aspects of the program and design so that they would possess the requisite skills and knowledge so that they could improve or continue to build on the system with minimal involvement from the consultants.

Summary and Lessons Learned

The biggest surprise of the project is that results have exceeded early expectations, and benefits will continue to roll in for the long term with very little additional investment.

Initial management buy-in was difficult, but no longer. The next section will describe briefly some of the expansion projects that are underway as a result of the results obtained to date.

To summarize some of the lessons learned:

- The key to good results is an excellent strategy. The results of the program seems to grow exponentially with the effort expended in the early RCM strategy development phase.
- Get broad buy-in on the maintenance strategy at all levels. Increased buy-in improves the success of execution. Better buy-in is achieved if everyone understands the process and is offered some opportunity of involvement on the strategy development phase.
- Good RCM strategy development software allows faster development, and faster development allows faster execution.
- Implement RCM strategies as soon as they become available. Don't wait to implement several at the same time, as this delays the potential results.
- Don’t force-feed computer literacy. Few of the technician had strong computer skills, and forced initial training produced immediate negative behavior. Instead, designate a few highly qualified personnel to support the entire team, and let a few early successes drive the involvement.

  When a few of the individuals came out looking like stars, it didn’t take long for human curiosity and personal pride to kick in. All of the others then wanted to learn and use the system to get some of the same or better results. The subsequent training was positively received, and the atmosphere remained harmonious.

- Keep the diagnostics and expert rules simple. If it takes a master scientist to build the expert rule, it probably takes a master scientist to use it. When it was kept simple, everyone used it and results multiplied.
- A good CMMS is the one that gets used, not the one that has the most features. Keep it simple.
- Don't forget that old business adage:

  Integrate, Integrate, Integrate

  An integrated system is far superior to a stand-alone one anytime.

Summary of Proof-of Concept Results

In just a few shorts months following implementation of the proof-of-concept effort, the following results have been achieved.

Description	Savings
Prevented catastrophic failure of a 200 MVA transformer by	Explosion prevention (@ $1M)

installing gas monitoring equipment	
Prevented unplanned outage and fluctuating voltage to customers by installing differential temperature monitoring equipment	Prevented unplanned outage to customers
Prevented call in to change nitrogen bottles at nineteen locations by installing nitrogen bottle pressure monitors	Prevented 19 emergency responses
Prevented 30 MVA transformer failure with temperature monitoring equipment	Transformer replacement (@ $350K)
Eliminated unnecessary maintenance by implementing RCM strategies	3,000 non-exempt labor hours
Prevented 2^{nd} 30 MVA transformer failure with temperature monitoring equipment	Transformer replacement (@ $350K)
Prevented LTC failure with temperature monitoring equipment	Prevented unplanned outage to major industrial customer
Discovered transformer bushing problem in time to position mobile unit on line and prevent unplanned outage to major industrial customer	Prevented unplanned outage to major industrial customer
Discovered OCB switches hot	Prevented 10 hour outage to customers
Discovered transformer switches hot	Prevented unplanned outage
Discovered bad LTC reversing switches	Prevented unplanned outage

Where are we going now?

The results of this project have exceeded early expectations, and as a result it has been relatively easy to obtain approval for growth.

The program is currently targeted for expansion to include all substations within the next two years.

In addition, the following new program initiatives have been started:

- Development of maintenance procedures
- Development of a maintenance training program
- Enhanced TPM initiatives and ways to improve employee involvement. ✍

Mr. Desi G. Dundics, P.E. (Co-Author)

Mr. Desi Dundics is President and Founder of Equipment Links, Inc. (EQL). EQL is a leading integration and consulting company in the field of asset management and equipment condition assessment. Recent products that have been developed by EQL and available to the commercial industry include:

RCM Strategy Plus™
EQL TAPS™ as a Total Asset Performance Solution™
EQL AMMO™, as an Asset Management tool for Maintenance Optimization™

Mr. Dundics has over 22 years of experience in the nuclear, utility, and general industry with particular emphasis in the areas of equipment reliability and plant operations.

Mr. Dundics graduated with honors from the U.S. Naval Academy in 1975. While serving in the U.S. Navy, served in the nuclear surface force and qualified as Chief Engineer for Navy Nuclear Propulsion Plants, performed a number of engineering related duties, and served on the staff of Nuclear Mobile Training Team (MTT). After the Navy, Mr. Dundics worked with NUS corporation managing on-site start-up and operations contracts, Gilbert Commonwealth as an Instrumentation and Controls Engineer, and was an integral member of the U.S. Navy's Advanced Research and Development Team as consultant in the development on a state-of-the-art integrated condition assessment technology.

Mr. Dundics is a registered Professional Engineer, a member of the American Nuclear Society, American Society for Mechanical Engineers, SMRP, and has held positions on the board of Regional High Technology Councils.

Mr. John J. Lapicola, P.E. (Co-Author)

Mr. John Lapicola is President and founder of Technical Diagnostic Services, Inc. (TDS). TDS is a leading electrical and instrumentation testing and maintenance, and technical consulting company. TDS resulted from a management buyout of AVO Multi-Amp Services. Corp. which was a leading provider of the same services for over 25 years.

Mr. Lapicola has over 25 years of experience in the nuclear industry with particular emphasis in the areas of testing, startup and plant operations.

Formerly, Mr. Lapicola served as President of AVO Multi-Amp Services Corp. and President of AVO Technical Services, Limited. Mr. Lapicola was also Director of the AVO Multi-Amp Institute, America's leading provider of electrical maintenance training.

Mr. Lapicola graduated with distinction from the U.S. Naval Academy in 1968, received his Master's of Science degree in Engineering Mechanics from the Naval Post Graduate School in 1969, and qualified Engineer of Navy Nuclear Propulsion Plants while serving in the nuclear submarine force.

While with Combustion Engineering, Mr. Lapicola served as Nuclear Startup Engineer at Millstone 2 and site consultant for the startup of Arkansas Nuclear One Power Plant. He later joined Automation Industries as Operations Manager for their nuclear services department.

Mr. Lapicola is a registered Professional Engineer, a member of the American Nuclear Society, IEEE, American Technical Educational Association, ASTD, and is on the Steering Committee of the American Standards Training Institute.

Mr. William H. Bush (Co-Author)

Mr. William H. Bush is Manager of Substation and Transmission Maintenance and Construction at the Dayton Power and Light Company (DP&L). DP&L operates and maintains 170 substations and 1,600 miles of transmission lines throughout 24 counties in West Central Ohio.

Mr. Bush has 39 years of experience in the construction and maintenance of electric substations, transmission lines, gas facilities and fossil fuel generating stations. He was Construction Manager on five 600 MW fossil fuel units built and operated by DP&L.

Mr. Bush is responsible for the maintenance and construction activities for the substation and transmission facilities. These responsibilities include the implementation of new methodologies and technologies to improve system reliability while reducing maintenance costs. The Maintenance Optimization Program presented here is an example of reengineering the maintenance process that meets the goals of improved reliability at reduced costs.