XA0054505

CANDU PLANT MAINTENANCE - RECENT DEVELOPMENTS

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Abstract

CANDU units have long been recognized for their exceptional safety and reliability. Continuing development in the maintenance area has played a key role in achieving this performance level. For over two decades, safety system availability has been monitored closely and system maintenance programs adjusted accordingly to maintain high levels of performance. But as the plants approach mid life in a more competitive environment and component aging becomes a concern, new methods and techniques are necessary. As a result, recent developments are moving the maintenance program largely from a corrective and preventive approach to predictive and condition based maintenance. The application of these techniques is also being extended to safety related systems. These recent developments include use of reliability centred methods to define system maintenance requirements and strategies. This approach has been implemented on a number of systems at Canadian CANDU plants with positive results. The pilot projects demonstrated that the overall maintenance effort remained relatively constant while the system performance improved. It was also possible to schedule some of the redundant component maintenance during plant operation without adverse impact on system availability. The probabilistic safety assessment was found to be useful in determining the safety implications of component outages. These new maintenance strategies are now making use of predictive and condition based maintenance techniques to anticipate equipment breakdown and schedule preventive maintenance as the need arises rather than time based. Some of these techniques include valve diagnostics, vibration monitoring, oil analysis, thermography. Of course, these tools and techniques must form part of an overall maintenance management system to ensure that maintenance becomes a living program. To facilitate this process and contain costs, new information technology tools are being introduced to provide system engineers with current system performance trends as well as historical records. This paper discusses the experience gained in CANDU plants with the application of these maintenance tools and the results achieved to date. New technologies being developed by Atomic Energy of Canada Limited for CANDU plants will also be discussed.

1. INTRODUCTION

With the increasing pressure to reduce costs and improve capacity factors, development of a systematic approach to defining maintenance and inspection requirements is a strategy frequently adopted by utilities. The experience in Canada is no different. Originally the maintenance programs established at Canadian CANDU plants were largely based on manufacturer's recommendations and experience at similar plants. The program consisted primarily of time based preventive maintenance developed from manufacturers recommendations as well as experience feedback from other plants. Updates and optimization of the program was largely based on operating experience and lessons learned from plant events or problems. Often, increasing the frequency of overhauls was the solution to equipment problems. This strategy led to a growing volume of preventive maintenance work with little optimization. In the early 1990's increasing unit incapability due to equipment problems and concerns related to safety related system availability led to a reassessment of the maintenance programs and the development of a maintenance model which promoted a systematic process to identify maintenance, surveillance and inspection requirements.

2. MAINTENANCE DECISIONS AND APPLICABLE TOOLS/METHODS AND CONSTRAINTS

In 1993, Ontario Hydro nuclear plants initiated a program to optimize the maintenance program using a reliability centered maintenance methodology. The same basic approach was used by each plant although the degree of detail varied mainly in the analysis phase. Each plant conducted pilot projects to assess the benefits of the approach and then extended the approach to other systems. The process currently in use at the Bruce site consists of the following steps:

1) Starting from a complete list of plant systems, a subset of 20 systems were identified for the first phase of the project. These systems were critical to plant safety as well production. Examples of systems included in the original list are the reactor shut down system, the heat transport system, reactor moderator system, emergency boiler cooling. The importance of the system was established based on an assessment of the system impact on the plant key effectiveness of safety, reliability and cost based on the following considerations:

    - Importance to plant safety and reliability
    - System reliability/availability
    - Maintenance resource requirement
    - Maintenance complexity

2) For each system on the list, the system boundary and sub systems were established. This boundary is important because it delineates the components which must be considered in the analysis and ensures that all support systems such as air, power supplies and service water are taken into consideration. The system design, operating and maintenance historical information was collected for the analysis.

3) The system functions were then identified for each sub system. A functional failure analysis identified the functional failures which could impact on the system fulfilling it's primary role. The components associated with these failures were then identified along with their dominant failure mechanisms. The probabilistic safety analysis was used where the system was modeled to ensure all critical functions and components important to safety were included.

4) Based on the potential and actual failure mechanisms an effective preventive task was established. External experience from other plants, vendor information and regulatory requirements were taken into consideration in arriving at an improved program. For each component, the strategy consisted of one or a combination of the following strategies:

    - Condition Monitoring & Diagnostics

- Time Based maintenance
- Periodic Overhaul
- Component replacement
- Surveillance and testing
- Visual inspections
- Design change
- Run to Failure

5) The recommended program was then compared with the program in existence at the time and the program adjusted accordingly. The revised system surveillance and maintenance requirements were then incorporated into the station documentation for execution. Changes to plant maintenance call ups were revised or updated, the operator routines were redefined and the maintenance procedures updated. Each analysis was documented in a maintenance basis document.

Optimization of the maintenance program using this process requires expertise in the following three main areas:

- Experience with the process of systematically analyzing systems, system functions, failure mechanisms and developing effective strategies.

- A good overall understanding of the system design intent, safety design requirements, system operation

- Experience with maintenance and surveillance of plant components including the technology available for plant maintenance.

The level of effort required varied from system to system dependent on complexity and the quality of information. The detail analysis portion of the process on average required about 6-8 person-weeks of effort and the implementation of the program required about the same level of effort. Using a streamlined analysis process and an expert panel review , the level of effort was down to a few days.

Implementation of this overall program led to the following changes in component and system surveillance and maintenance:

- In many cases, the system surveillance carried out by operators during routine plant rounds were modified. Overall a 20% increase in operator surveillance workload was required to implement the program on 18 major systems at Bruce A.

- The preventive maintenance program changes resulted in no significant change in overall maintenance effort but in some cases up to 40% of the tasks were deleted and new ones added as a result of the analysis.

- In some cases new technology was adopted to eliminate the need for periodic overhauls and make use of condition based monitoring techniques by the maintenance staff. In addition, condition based maintenance surveillance tasks such as vibration monitoring, thermography, oil analysis, system parameters were also added.

The benefits arising from optimization of the maintenance program were measured using a number of plant indicators namely:

- System availability for safety systems
- Unit incapability
- Ratio of preventive maintenance to total maintenance
- Compliance with the preventive program
- Backlogs of corrective maintenance
- Results from audits and plant evaluations
- Maintenance Costs

Implementation of the maintenance optimization process on a number of pilot systems resulted in the following:

- The number of maintenance preventable forced outages dropped from 5 per year in 1992 to 2 in 1996 at Bruce A.
- The ratio of preventive maintenance to total maintenance increased from about 40% to over 55% from 1992-1996 at Bruce A.
- The backlog of corrective maintenance dropped from about 350 work orders per unit to about 150 from 1992 to 1996.
- The result of the review generated 55,673 work hours of new maintenance tasks but 54,067 were deleted resulting in negligible change in resource requirements
- The incapability due to fuel handling systems at Pickering dropped from 4.5% to less than 0.5%.
- While the process considered the need for plant modifications, the number of modifications identified through the maintenance optimization process were small.
- Implementation of a condition based maintenance program on Pickering instrument air compressors resulted in cancellation of 40K$ worth of unnecessary annual overhaul and identified a specific defect which was causing major compressor damage requiring complete rebuild.

With these early successes, a standard approach to maintenance optimization is being developed. This approach will be systematically applied on a priority basis to all plant systems.

3. USE OF PSA IN MAINTENANCE DECISIONS

The Probabilistic Safety Assessment was originally developed to assess the probability of major core damage incidents and to ensure that all potential contributing accident sequences were considered. These tools are now being used in support of plant operation and maintenance as risk management tools. The actual applications vary from plant to plant as a function of the type of PSA and the level of detail modeled. Some of the specific applications are discussed below:

3.1 Changes to Safety Related Component Testing Frequency

Under certain circumstances, safety system tests cannot be carried out as scheduled due to maintenance being underway on redundant equipment. These tests are part of an overall surveillance program to demonstrate safety system availability. The PSA model can be used to assess the public safety implication of delaying a safety system test for a given period of time. If the impact on risk is insignificant, then approval from the appropriate authority for the test deferral is obtained.

Under other circumstances, the testing frequency can be optimized using the PSA models. If a component can be tested at a lower frequency thereby reducing wear and tear without impact on safety, then this leads to improved component reliability and reduced maintenance. This approach was used successfully to change the test frequency of steam reject valves and standby generators for example.

3.2 Removal of redundant standby safety related equipment from service

The PSA models are used to assess the public safety impact of removing certain components from service for regular maintenance with the unit on line. This analysis is essential for the development of a set of requirements documented in the plant operating procedures with respect to system and unit configuration. The planning and scheduling of maintenance activities are then governed by these requirements. Under unusual unit configuration, the PSA is also used to analyze a specific unit configuration before other equipment is taken out of service for maintenance reasons.

3.3 Identifying Critical Structures, Systems and Components

The PSA can be used as a source of information for optimizing maintenance through reliability centred maintenance process. Components critical to plant and public safety can be easily identified including the performance requirements such as reliability and availability and the failure mechanisms considered in the analysis.

3.4 Outage Planning Support

The PSA models are used extensively during plant outages to ensure risk is maintained within prescribe limits during maintenance activities. This is particularly necessary in CANDU where the reactor core remains fueled during the outage. At any time during an outage, two different method of heat removal must remain available as well as ability to maintain the reactor shutdown and the containment boundary intact. With the large volume of work scheduled and the number of parallel activities being carried out, the potential exist for unknowingly reducing the defense in depth. Analysis of the outage sequence prior to the outage using the PSA tool and monitoring progress during the outage provides an added verification that omissions have not been overlooked.

While these applications are extremely beneficial, the PSA still has limitations in support of plant operation and maintenance. In particular, the models only address plant and public safety and therefore only include certain safety related systems. For example, systems intended for production such as the reactor control systems are not modeled in detail. For these systems, separate engineering analysis is required. The potential expansion of existing PSA's to probabilistic reliability analysis to include energy production is under consideration.

4. IMPLEMENTATION CONSIDERATION AND TECHNOLOGY DEVELOPMENT

Optimization of plant maintenance program depends on development of technology and use of innovative information systems to facilitate data collection, analysis and storage for easy retrieval. These developments are essential to maintaining a competitive edge. Atomic Energy of Canada Limited has been developing new technologies in a cooperation with the CANDU utilities. Some of the more important ones are summarized for information:

4.1 Condition Based Monitoring Systems

Advanced plant monitoring and display systems gather 1000's of data points continuously from plant systems. Historically, the data collected was strictly monitored and only parameters outside of a specified range were recorded and provided to the unit operator. With advancement in condition based maintenance, the data being collected by the plant monitoring systems can be trended, recorded and provided to the plant maintenance personnel as well as system engineers on a continuous basis through the plant information network. This allows monitoring of plant critical components as well as system performance including chemistry parameters. These systems can be easily backfitted to existing plants to transmit the parameters already monitored by the plant computer display systems. If additional parameters need to be trended, then modifications are required or alternatively, the data can be collected from field measurements by maintenance and operations staff and transmitted to the engineering staff via hand-held computers.

For new plants, a systematic analysis of the critical plant systems and components similar to the one outlined in section 2 above will determine the critical parameters which should be monitored and provisions can be made in the design.

4.2 Historical Data Storage System

To manage the large amounts of data collected during plant operation and maintenance, a historical data storage system is being developed which interfaces with computer display systems as well as the plant work management systems. This tool allows the systems and equipment engineers to easily retrieve records, display trends, and even compare results with other units in order to analyze and resolve problems.

4.3 System Health Monitoring

To facilitate engineering analysis of plant processes, system health monitors are being developed to easily display systems or multiple systems where their performance is interdependent. For example, steam generator chemistry condition depends on the performance of the condensers, feedwater and condensate systems. Another application would to monitor unit thermal efficiency. The analysis of adverse trends requires monitoring of many interrelated parameters. Presenting the information in schematic or flow diagram form facilitates this analysis.

4.4 On Line Instrument Monitoring

Routine calibration and testing of the numerous instruments and transmitters is a significant workload for the maintenance department and could lead to potential errors and unit disturbance. A transmitter accuracy monitoring system has been developed which can alert the operator of instrument drift before it becomes a potential impairment. For a given process parameter, trending the individual transmitter signals and comparing the results between themselves can alert operator of a developing trend. Maintenance can then be scheduled before a failure occurs or a potential impairment due to drift outside of tolerances. This technology can be used to replace the periodic calibration of instruments.

5. CONCLUSIONS AND NEXT STEPS

Based on a pilot projects at a number of CANDU plants, it has been demonstrated that optimization of the maintenance program is well worth the investment and essential for long term competitiveness. The benefits of implementing a systematic process for the analysis of critical systems structures and components and then developing a surveillance and maintenance program range from improved system performance, plant safety, reliability and cost minimization. This optimization must also be carried out in concert with the implementation of supporting new technology to improve plant surveillance. Furthermore, analytical tools such as probabilistic reliability analysis can assist in the development and planning of maintenance activities.

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