MODIFICATIONS TO IMPROVE RELIABILITY IN DEAERATOR LEVEL CONTROL BY USING DIGITAL TECHNOLOGY

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Abstract

As electronic components of nuclear power plants age, their reliability decreases. With this decreased mean time between failures, there is increased cost. The increased costs are associated with replacing or repairing components and with the increased risk of production loss. To compound these problems there are issues of obsolescence.

The impact of these effects on the area of instrumentation and control electronics is especially severe. By utilizing digital technology that is relatively cheap and readily available, one can achieve improved reliability in complex control loops.

The deaerator level control loop in a nuclear power plant is a complex control loop. The control of the loop is achieved using a feed-forward control scheme. A station-specific implementation of this control scheme is achieved using several analog electronic components. A modification was performed to achieve increased reliability while implementing the same control algorithm by using digital components, an improved component arrangement and increased redundancy.

This paper will describe how the improved reliability was achieved.

1. Introduction

The nuclear power plants in Ontario have been in service for decades. As a result, the components that make up the systems of the plants are susceptible to age related deficiencies. This is a phenomenon that is occurring across many industries.

As components of nuclear power plants age, their reliability decreases. With this decreased mean time between failures, there is increased cost. The increased costs are associated with replacing or repairing components and with the increased risk of production loss. The cost of maintenance is a function of the probability of failure. As a device ages, that probability increases. It is often assumed that the probability of failure follows the exponential distribution. This gives rise to a constant failure rate. The exponential distribution is widely used and lends itself to easy calculation. Alternatively, the Wiebull distribution can be used. The figure 1 shows the probability density function and cumulative density function of the Wiebull distribution. This model takes into account the increased probability of failure as a reliable device ages, it somewhat resembles a skewed normal distribution. [1][3]

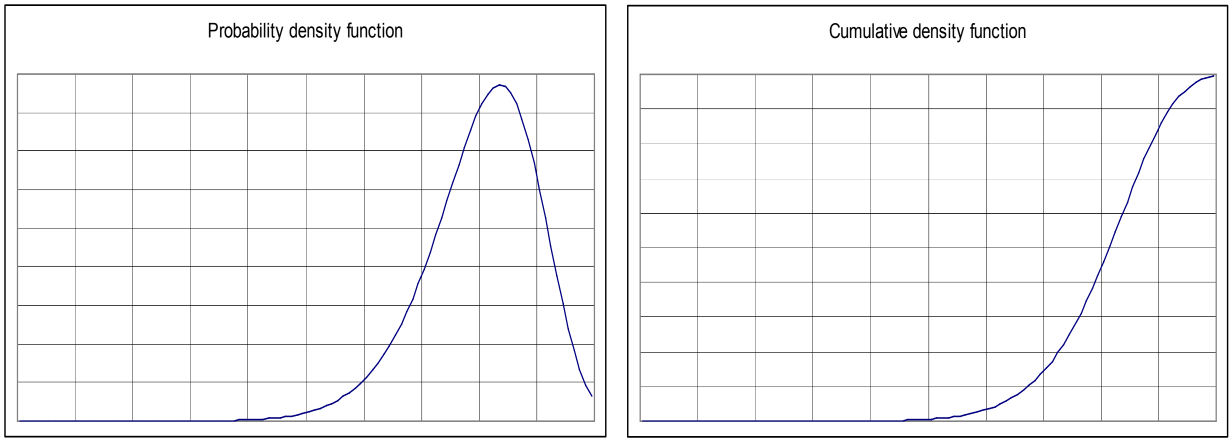

Figure 1 The Weibull distribution

In a system that has been designed to be highly reliable, preventative maintenance is often performed. This involves replacing or refurbishing a component before it fails. However, due to the age of many components in the plant, replacement parts are becoming more difficult to find because many are obsolete. This condition is making preventative maintenance and corrective maintenance difficult. The issue of obsolescence is particularly prevalent in electronic components.

To maintain the high reliability demanded by the operation of a nuclear facility, innovative solutions have been considered. Due to the emergence of highly reliable and relatively inexpensive digital components, the issue of aging electronic components can be addressed.

This paper will discuss an application of engineering techniques and the replacement of analog components with digital equipment to maintain and improve upon the reliability of the main condensate deaerator level control system at Pickering B Nuclear Generating Station.

2. Description of the system

The main condensate deaerator is a large vessel in the condensate / feed water system of the plant. The deaerator is one stage in a train of heat exchangers that raise the temperature of the condensate along the path to the steam generators. This pre-heating is used to increase the thermodynamic efficiency of the plant. The other major purpose of the deaerator is to remove non-condensable gasses from the condensate which improves the chemistry of the water and improves thermodynamic efficiency.

The deaerator is a two part vessel made up of a tray section and a storage tank section. The condensate flows into the vessel at the top of the tray section through redundant control valves. The water then falls over the trays allowing steam to rise through it. It is this steam that warms the water and scrubs the non-condensable gasses from it; the gasses are vented to atmosphere.

After passing over the trays, the water falls to the storage tank. From the storage tank the water is taken to the steam generators. At power, this outflow is fairly constant. Level in the vessel is controlled by varying the flow of incoming water.

The control of deaerator level is very difficult. Throughout the industry, there have been several events where control of the level was lost or significantly challenged. There are a number of reasons for this difficulty which have been largely discussed in other papers but are briefly repeated here for completeness and clarity. A simplified version of the general arrangement of the system is shown in the figure 2.

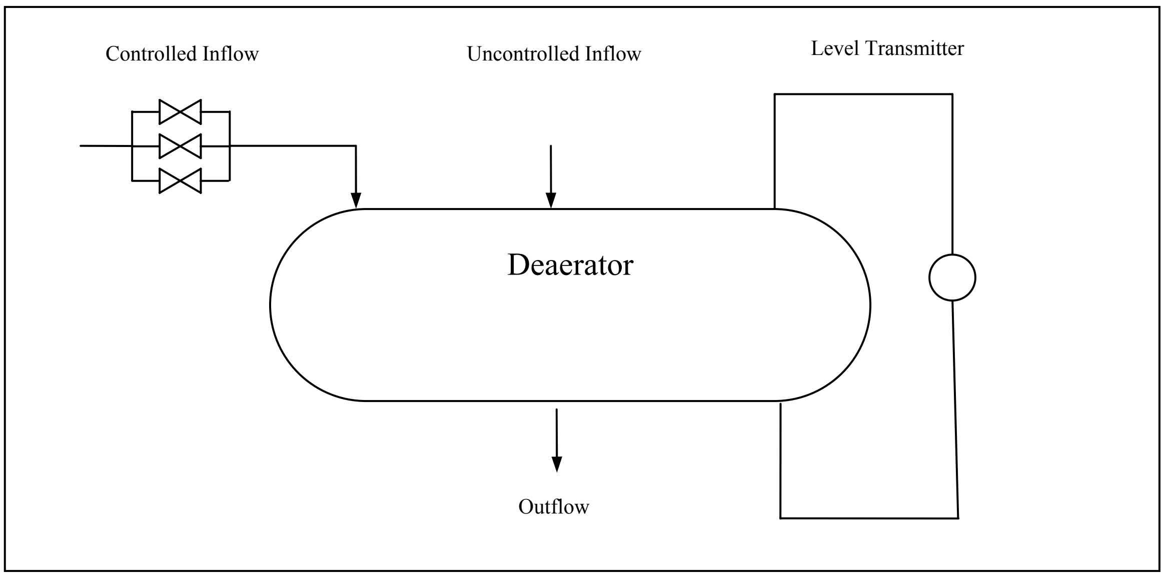

Figure 2 General arrangement of the system

The tank is very large and during level transients large amounts of water are allowed to enter it. This can cause a wave to form in the tank. Depending on the location of the level transmitters, this can make the apparent level much higher or lower than the actual level. This wave effect tends to act as positive feedback until the operator manually brings the level back into control.

To further complicate matters, there are significant temperature effects. The deaerator vessel is under pressure and the water inside the vessel is at a temperature very close to saturation. During pressure transients in the vessel, some boiling can occur. When boiling occurs in the stand pipe of the transmitter, the apparent level in the tank can oscillate wildly while the actual level is fairly stable. When the control system acts to compensate, it is correcting for an error that is not really there. More subtle temperature effects occur when increasing the amount of water flowing into the vessel. This water is relatively cold and can cause the overall volume in the tank to contract somewhat.

Finally, there are a number of uncontrolled inflows to the tank such as heater drains. During unit startup and shutdown, these inflows can vary by a large amount. During normal operation these flows are easily compensated however in certain conditions they become more significant.

2.1 Description of the control system

The control scheme for the deaerator level control is a cascade feed-forward design. The control system can operate in single element or three element mode. In single element mode, only level is considered in the calculation of controller output. In three element mode, level, condensate and feed water flows are used to calculate the output. Three element mode provides more accurate control at high power operations.

The implementation of this control system was originally achieved using analog devices. To achieve such a complex control scheme, many physical devices were needed. In addition to controllers, there are several relays, switches, summers and square root extractors in the system. At the time of construction, each one of these devices was a stand-alone unit.

2.2 Reliability and Modularization

From basic reliability theory, two devices in series are less reliable than one device on its own (for a given probability of device failure). As illustrated in the figure 3, the arrangement of devices for a given reliability greatly affects the system reliability. [2]

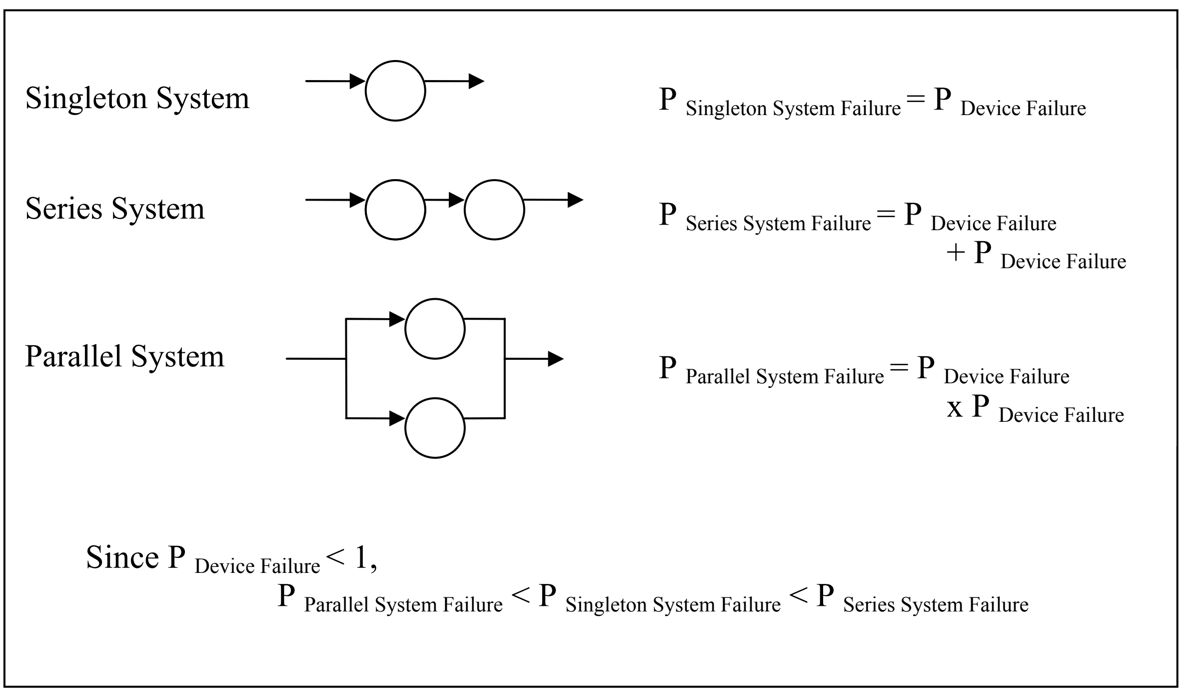

Figure 3 Probability basics

If the necessary care is not taken when designing the system, the gains in reliability that are made by increasing redundancy can be lost to common mode failures. A common mode failure is one in which a failure of a supporting device (for example a power supply) can cause a failure of many of the redundant components in the system. These types of failures increase the overall probability of a system failure. Greater independence of the components can reduce the common mode failure probability.

The deaerator level control system (both the original and newly designed system) has been designed in such a way to be sufficiently independent that the probability of a common mode failure is small enough (relative to the overall probability of failure) to be neglected. This independence is achieved through techniques such as increasing redundancy and channelization.

Due to the complexity of the design of the control loop, it was necessary to place several components in series. The system was still highly reliable and met all targets however, the devices in series had the effect of reducing overall reliability from the theoretical maximum achievable value.

The general arrangement of devices in the control system is shown in figure 4. Each circle in the diagram represents a device which implements a logic function. The interconnections of the devices are shown with arrows. The communication paths between the devices are assumed to be reliable enough that their probability of failure can be neglected. The probability of failure for each device is approximately equal. Using the reduction techniques illustrated in figure 3, it can be shown that the failure probability of the original analog system is much higher than that of the individual devices. This realization was one of the major drivers for the project.

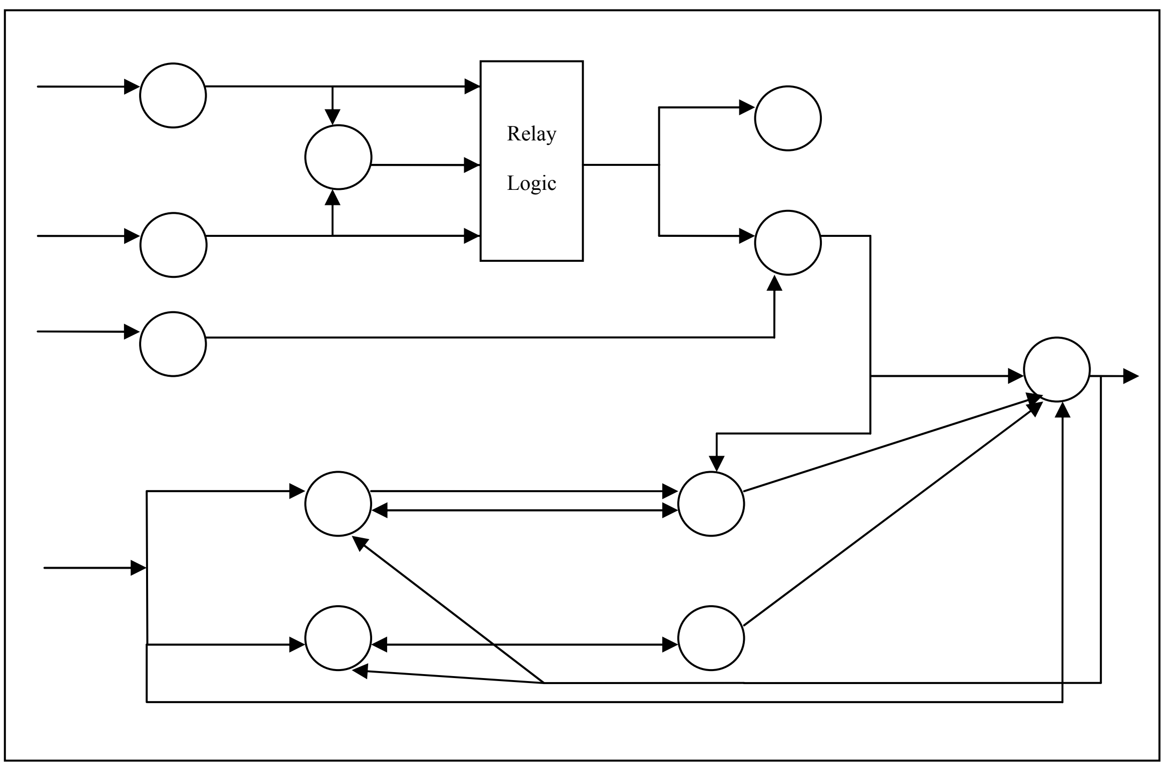

Figure 4 Original analog system

The disadvantage of the original design in terms of reliability was offset by an advantage in maintainability. Since each step in the algorithm was implemented by a different device, a failure of the system was more easily diagnosed. This modularity also allowed the failed device to be swapped more quickly and easily than if the devices were integrated into one unit.

As time progressed, the advantages gained by the modular design were diminished. The number of equipment failure increased and the availability of replacement parts decreased. Replacement parts were increasingly obtained by refurbishing old components. This work increased the cost and time taken to perform the repair.

Due to this increased cost and the increasing risk of lost production due to failure, the decision was taken to undertake a project to replace the control system for deaerator level control.

3. Description of the project

The mandate given to the project team was to improve the reliability of the control loop and ensure that parts would be easily available. Improvements in controller performance were beyond the scope of the project since the existing control loop performance was considered acceptable.

A project team was formed to address this issue. The team included design engineers, performance engineers, components engineers, and representatives from reactor safety, operations, maintenance, and supply chain. Project management functions were provided by Ontario Power Generation (OPG) engineers and potential vendors were consulted for solutions.

Several design alternatives were developed and proposals were put forward by the potential suppliers. Each design was analyzed to determine the optimal balance between reliability, maintainability and cost.

After the design structure was set, design requirements were formed based on the old analog controller. Several defensive design features were added to take advantages of the digital technology with little increase on the cost.

A design agency was hired and detailed engineering were carried out by the agency and vendor. OPG design engineers coordinated the activities and provided oversight. The major deliverable from this process was a technical specification of the solution to be provided.

The vendor manufactured the controllers and developed software applications. The final detailed design information was reviewed by OPG and a third party. The final product was tested in the vendor facility and witnessed by OPG. Once the controllers arrived to OPG's facility, it was bench tested, installed and commissioned.

4. Description of the solution

The design took advantage of the principles outlined above, i.e. using modular design and reduced number of components. This reduction in the number of components greatly improved the reliability of the system. A major technological development that made this project successful was the availability of reliable and relatively cheap micro-processor based digital devices. Digital devices allow for greater integration of functions into a device. The control strategies and signal processing functions are all integrated to a single main controller.

In addition to the main control unit, three redundant auto-manual (A/M) stations were added to the control scheme. In automatic mode, these stations simply repeat the signal given to them by the main controller. In manual mode, they override the signal. This feature allows the system to maintain flow to the deaerator in the event of a loss of signal from the main control unit either through a failure or planned maintenance. The new implementation of the control scheme is shown in figure 5.

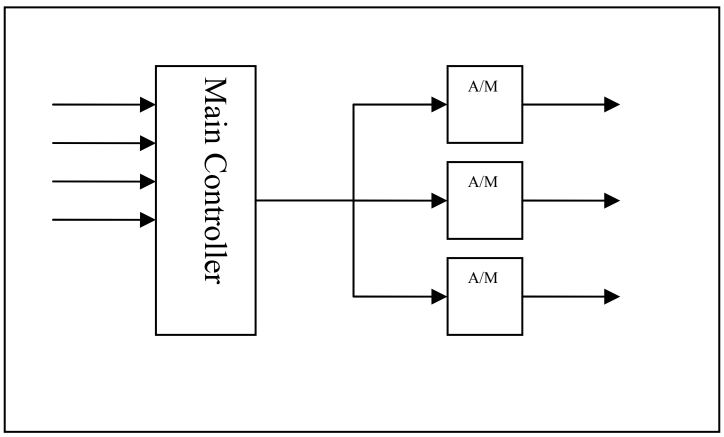

Figure 5 Newly designed system

Although the control algorithm remained essentially the same some additional features were added as enhancements to deal with situations with irrational inputs and other postulated failures with the controller itself. These defensive design features were made possible thanks to easy implementation by software and greatly improved the ability for the controller to handle exceptional conditions rather than potentially rely on operator's manual intervention.

Controller interface design was improved and additional information was made available to the operator through addition interface design. This provided the operator alarms if the input fails or the controller itself experienced problems. The controller hardware and interface were designed following human factors principles. Some considerations were also given in hardware design for easy maintenance. The main control unit was designed in such a way that a laptop computer with specialized software installed on it could be connected. The software allows the user to see the calculated values at various points in the algorithm to aid in troubleshooting. This feature negated the loss of modularity due to the reduction in number of components.

In the original design, only the main controller was located in the control room. The other components of the system were located elsewhere due to limited available space. In the new design, because of the reduced number of components, all of the devices were located in the main control room panel. Therefore the information of the deaerator level control system was able to be centralized.

The controller software was carefully categorized based on its safety role and other system impacts. It was decided to use stringent industry software standards to guide the software development and maintenance process. By using rigorous review, verification and approval process, the chance of design error and software coding error was reduced.

In the past, when all of the logic functions were implemented in analog hardware, failures could change the effective algorithm. When the algorithm is implemented in software, which has been produced to high quality standards, it does not change.

Since the units were newly installed, the effects of aging on the failure rate were minimized. This also allowed procurement of sufficient spares for repair and preventative maintenance. It can be shown that the new implementation of the control scheme is much more reliable than the original design. This is a notable achievement considering that the nominal reliability of devices in the old and new schemes were the same. The implemented solution was created by the vendor using off-the-shelf hardware and customizing their software. This approach helped control initial and ongoing costs.

5. Conclusion

The current generation of nuclear plants in Ontario has now been in service for some time. Many devices in the plants are now experiencing aging related issues. Some devices have shown increased failure rates. Other devices are difficult to repair and maintain due to obsolescence of the parts. These issues are increasingly driving plant operators to consider innovative solutions to address these issues.

As a result of technological limitations at the time of initial plant construction, the deaerator level control system was designed as a highly modular system. This design had major benefits in terms of troubleshooting and maintenance at the time. However, this design could be further optimized to improve reliability to better-than-target levels.

By utilizing digital technology and high quality software, the complex control algorithm was implemented in one unit. To further enhance reliability and maintainability, three auto-manual stations were added.

The new design increased reliability, eased maintenance, and allowed procurement of adequate spare parts.

6. References

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[2] Snell, V. “Probability Tools and Techniques”, *Lecture Notes for UN0801 – Nuclear Reactor Safety Design*, 2006, Whitby, Ontario. Chapter 4.

[3] Pandey, M. “Common Probability Distributions”, *Lecture Notes for UN0701 – Engineering Risk and Reliability*, 2007, Oshawa, Ontario. Module 1.