ONLINE CONTROL LOOP TUNING IN PICKERING NUCLEAR GENERATING STATIONS

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Abstract

Most analog controllers in the Pickering B Nuclear Generating Stations adopted PID control scheme. In replacing the analog controllers with digital controllers, the PID control strategies, including the original tuning parameters were retained. The replacement strategy resulted in minimum effort on control loop tuning. In a few cases, however, it was found during commissioning that control loop tuning was required as a result of poor control loop performance, typically due to slow response and controlled process oscillation. Several factors accounted for the necessities of control loop re-tuning. Our experience in commissioning the digital controllers showed that online control tuning posted some challenges in nuclear power plant.

1. Introduction

Pickering Nuclear Generating Stations were built and commissioned about three decades ago. Many electronic devices based on analog technology have become obsolete and are no longer supported by vendors. The obsolescence of analog controllers is an issue that is being experienced across the nuclear and several other industries. Failure of the controllers could cause a process transient, requiring safety systems and/or operators to act. The obsolescence issue makes the acquisition of spare parts difficult. Without sufficient spares, any controller failure could lead to loss of redundancy and even forced outages while existing controllers are repaired. To address these issues before they posed excessive risk on safe and reliable operation, Pickering B Nuclear Generating Stations undertook a program to replace critical analog controllers with digital controllers a few years ago. The control strategies adopted for these controllers are mainly PID control scheme. For the digital replacement, the original control strategies, including the original PID tuning parameters were retained since they had been proven over a number of years; secondly, operators have become familiar with the system responses under these parameters; and thirdly control loop re-tuning could be minimized in commissioning.

After installation of the digital controllers, there were a few cases where the performance of the new digital controllers was inferior to the analog controllers. Typical performance issues included process oscillations, slow response of controlled process, and inconsistent loop performance at various operating conditions. These performance issues were rectified by re-tuning the controller. At the end of the project, all controllers were performing satisfactorily.

Reasons for tuning the controllers were explored during the process of finding new tuning parameters and these are presented in Section 2.0. Although controller tuning is a mature technique for conventional industry, applications of these techniques are limited to the operating processes in

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the nuclear power plant, which will be discussed in Section 3.0. Our experience in commissioning the digital controllers showed that control tuning posed some challenge and different strategies are required.

2. Reasons for Tuning Control Loops

There are various reasons for tuning the replacement digital controllers. Some of the relevant reasons are summarized in this section.

In the early stage of the Controllers Replacement Project, a "Simple Replacement Strategy" was adopted. The strategy requires the digital replacement controllers to have the same control strategy and the same tuning parameters as the analog controllers. It was deemed that the overall control performance of the analog controllers was acceptable and no significant changes in control algorithms were necessary except a in few cases such as deaerator level control systems and boiler level control systems. Pickering B Nuclear Generating Stations have four units, and for many controllers, tuning parameters were different from unit to unit. It was thought that it might be a good starting point to use the average of the tuning parameters for the four units for the digital controllers.

Since the analog controllers have aged, the readings of tuning parameters obtained from the analog controllers exhibited higher than usual uncertainty. Some of the controllers were tuned when the control loop components, such as control valves and signal processors, were replaced. Due to this uncertainty, it was expected that once the new digital controllers were installed with our best estimate of the existing tuning parameters, some re-tuning would be necessary.

Nonlinearity of actuate elements in the control loop posed big challenges in control loop tuning. A typical example would be control valves. To achieve tight closure of the control valve when required, equal percentage type of control valves are used. The control valve gain when the valve is slightly opened is smaller than the gain when the valve is wide open. If the controller has been tuned at the high open end of the control valve, then when the valve opens at the low end, the control system will likely suffer from sluggish response or even oscillation. On the contrary, if the controller has been tuned at the low open end of the control valve, then when the valve opens at the high end, the control system will likely be oversensitive or even unstable. For quick open type of control valves, a similar dilemma has to be faced. Even for linear control valves, the valve characteristics at low end are typically of nonlinear.

Nonlinearity can also be generated by other sources. For example, pressure control is sometimes achieved via flow control. From flow control perspective, the control system is linear, but due to the square root relationship between flow and pressure, the control system, is nonlinear from pressure control perspective. Any nonlinearity in the system can make the system highly sensitive to changes in tuning parameters. Nonlinear systems compounded the issue of uncertainty in the original tuning parameters.

Wide operating range accounted for another reason to tune control loops. For example, in pressure control of the heat transport systems, the compressibility of heavy water at high temperature is very different from that at low temperature which means the process gains are temperature dependent. At different operating environments, nonlinearity becomes a major factor as well. For example, in temperature control of recirculating cooling water, the control loop tuned in winter time might be becoming oscillatory in summer time. This is because the cooling water control valves open more in summer time due to higher cooling water from the lake, and the operating point for the control valve moved to higher gain area. In some cases it may be desirable to re-tune a controller for different operating regions or choose a set of tuning parameters that perform reasonably well in all circumstances but not optimally in any.

Lastly, it might be helpful to mention that calibration and the change of calibration practice of the components in control systems would have some impact (although minor) on the control loop performance. As a device, for example a valve or transmitter, experiences calibration drift the performance of the control loop can become sub-optimal. Tuning the controller can counteract this effect.

The newly installed digital controllers have better precision in displaying process and control signals compared with the analog controllers. Some small amplitude or high frequency oscillation might not be observed in the analog controllers but could be easily seen from the digital controllers. In this situation, it may be reasonable to tune the controller to achieve better steady state control. Process offset (a difference between process value and set-point) is another example. For analog controller, slight process offset could have been thought within allowable uncertainty, but from digital controllers, the same offset would be deemed unacceptable and require controller re-tuning.

3. Challenges in Controller Tuning

Most of the controllers used in Pickering B Nuclear Generating Stations use PID control scheme. PID is one of the simplest control logics and adopting the control strategy agrees with the simplicity principle in designing nuclear power plant. PID control scheme is robust and can accommodate some nonlinearity and some process uncertainties. Compared with other complex control schemes, PID algorithms are easy to implement and easy to tune, only three parameters to be determined in commissioning. Finally a number of tuning methods and automatic tuning software applications are commercially available.

In commissioning the digital controllers, it was found some challenges remain in tuning the controllers and they are discussed in the following:

One of the approaches commonly used in deciding controller tuning parameters is based on system responses to step changes in process set-point. Figure 1 shows a typical response of a second order system to a step change in input. Using the values of overshoot, rising time and settling time, one can obtain a set of tuning parameters that will likely work well.

For nuclear power plant, the operations of certain process parameters are limited to a narrow range centring at the control set-point as a result of safety and/or regulatory requirements. The technique discussed above requires creation of a process upset to check out loop performance. Such process upset is sometimes limited to very small perturbation and is not enough to serve the purpose.

Controllers are typically tuned at operating point. The controller parameters obtained at one operating point do not always provide ideal control loop performance at all other operating points. Nuclear generating units typically run at full power, but the unit could run at different power levels and could be maintained at these levels for long time. For example, when a unit starts up, it needs to run at low power to allow performance of various start-up tests. The unit also needs to stay at a certain power level for a reactor physics purpose. It may be necessary to tune the controllers at low power level. The controller tuning parameters have to balance between various operating points. However, it is impractical to adjust reactor power level just for the purpose of controller tuning.

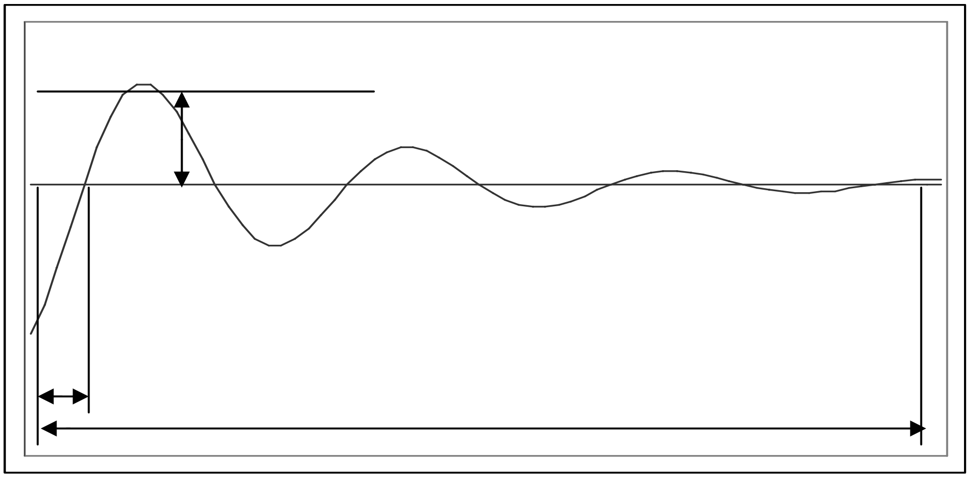

Figure 1. Second order system response to step changes

As mentioned above, commercial software applications are available for controller tuning and in some cases it is even provided with the controllers at the time of delivery. However, these applications require introduction of process perturbations and the magnitude of these disturbances is often not well defined. These perturbations could challenge the operational safety limits of the systems. In addition, there are issues around software qualifications and a general “uneasiness” for solely relying on the automatic software to tune the process. For those reasons, this tuning method has never been considered in our commissioning.

Another famous tuning method is the Ziegler-Nichols method. This method involves adjusting the proportional band while removing reset and derivative actions from the controller. The proportional band (loop gain) is decreased (increased) until the system oscillates in a regular sustained pattern. The value for the gain at the time of oscillation is called the critical gain (see Figure 2); and it can be used along with the oscillation period to derive a set of tuning parameters. This method of tuning will typically provide good system response. However, in a nuclear plant, it is not acceptable to purposely create system oscillation. For those reasons the Ziegler-Nichols method should not be used in the tuning of control loops in a nuclear plant.

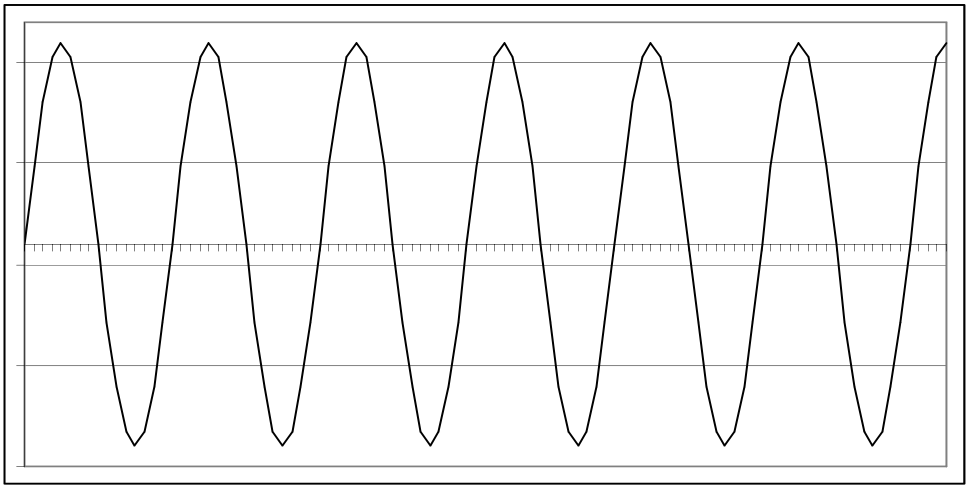

Figure 2. Controller response at critical gain

Most people think of controller tuning as a trial-and-error process. This philosophy does not work in nuclear power plant. The procedural and cultural expectations in the nuclear power plant are such that every piece of work to be performed must be authorized by the shift manager. This involves explaining the process to be followed and the expected results. The shift manager will exercise a questioning attitude and have given confidence in the work to be performed. If initial retuning of the loop is unsuccessful, one might get a second chance to tune the controller, but it would be very difficult to get authorization for a third chance. Our experience has shown that shift managers and the control room authorized nuclear operators are not comfortable with this trial-and-error approach. Therefore it is critical to do adequate analysis based on process characteristics and operating conditions before suggesting a set of control parameters.

4. Conclusions

Obsolescence of equipment and component has becoming a challenge in most nuclear power plants in North America. These plants were built decades ago, the equipment has aged and often vendors support is no long available. Replacement of analog devices by digital devices is inevitable thanks to the penetration of digital technology everywhere (even at transmitters).

Digital devices require new engineering considerations, controller tuning being one of them. Performance acceptable for analog control loop might not be acceptable to digital control loop since process oscillations are easily observable from digital devices due to its better precision in display parameters. Operators have higher expectation on digital devices than on analog devices. Beside controller tuning, a number of other challenges exist in digital controller design. Some of them are discussed below and could be considered for future work.

Adaptive control scheme [1] could be considered to tackle the nonlinearity in processes that were discussed earlier. In the analog world, it was difficult to implement complex control schemes; this becomes a non-issue for digital controllers. Adaptive control schemes can adjust control parameters and ever control strategies in response to changes in process and operating conditions. For example, it may be desirable to have one set of tuning parameters at low power and a different set at high power.

Defensive design techniques can be incorporated in the design of digital controllers, and they can be implemented by software. The exceptional event handlings include input signal error, controller health error, output error etc. When an exceptional event occurs, the controller can take some logical action to remove, mitigate or accommodate the error. Again, these techniques were difficult to implement in analog devices but with digital technology this is achievable.

For safety and mission critical controllers, it becomes increasing crucial to apply formal and rigorous design techniques to reduce and avoid design errors and deficiencies. Formal design techniques have been used in the design and verification of many nuclear systems including the Shutdown System Software in Darlington Nuclear Stations. Similar rigorous approachs could be applied in the designing of critical process controllers. Yu et al ([2], [3] and [4]) have explored a formal design approach for hybrid systems which consist of continuous and logical processes (digital controller is a typical case), and could be applied in the design and verification in more complex digital controllers in the future.

5. References

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