ELECTRIC ACTUATOR MODIFICATION ONA TURBINE DRIVEN FEEDPUMP AT CALVERT CLIFFS NUCLEAR POWER PLANT

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ABSTRACT

Feedwater systems are a leading contributor to unit SCRAMs as indicated by the 2015 INPO data, where 9 of the 51 SCRAMs recorded were a result of feedwater issues. Digital feedwater control systems and enhanced feedpump control modifications can greatly improve performance and control of the plant feedwater systems and help drive down the potential for reactivity management events and unit SCRAMs. Westinghouse has a strong background in the implementation of digital feedwater control systems, and in planning for a recently completed feedwater control system upgrade at Calvert Cliffs, the Westinghouse team worked with Calvert Cliffs to design a solution to a number of common operational issues. Primarily, improving feedwater control over the entire operating range, eliminating single points of vulnerability (SPV) in the feedwater/feedpump systems and eliminating operational issues with the feedpump steam admission valve hydraulic control oil system. A robust first-of-a-kind design and implementation program was undertaken to split the existing hydraulic valve gear actuator with separate electric actuators. Westinghouse worked with Calvert Cliffs and Emerson Process Management (EPM) to install and commission General Electric (GE) feedpump turbines with separate electric actuators for the high-pressure (HP) and low-pressure (LP) steam admission valves. This successful mechanical and control modification was a first for both the nuclear and non-nuclear power generation industries. Westinghouse is working with a number of other utilities to implement similar modifications for PWR and BWR feedpump applications.

Key Words: Electric Actuator, Feedpump, DCS

1 INTRODUCTION

Calvert Cliffs Nuclear Power Plant is a nuclear power plant located in Maryland, southeast of Washington DC in Calvert County. The station consists of two Combustion Engineering Pressurized Water Reactor (PWR) units. Unit 1 and Unit 2 began commercial operation in 1975, and 1977, respectively. Unit 2 utilized a Westinghouse Balance of Plant (BOP) and Unit 1 utilized a General Electric (GE) Balance of Plant. The Unit 2 GE BOP consisted of one (1) GE main turbine and two (2) GE steam generator feedpump turbines. Each GE steam generator feedpump turbine consists of one (1) high pressure (HP) steam governor valve and five (5) low pressure (LP) poppet valves; GE Type DRV-631, Rated for 9140 HP @ 5350 RPM. These HP governor valves and LP poppet valves are connected through a common mechanical valve linkage, which was originally controlled by one hydraulic operating cylinder. The turbine speed governor controls were previously upgraded in 1994 from the original GE Prolop designed governor controls in a previous plant modification program.

1.1 Digital Upgrades of Steam Generator Feedpump Turbine Controls

Westinghouse was awarded a contract by Calvert Cliffs to upgrade the control system with a Distributed Control System (DCS) and other third party interfaces as required to address the issues of the feedpump control system obsolescence, reliability, maintainability, and monitoring capability. While upgrading the controls Westinghouse and Emerson Process Management (EPM) provided upgrades to the mechanical system. These mechanical upgrades were primarily driven by oil issues associated with control of the operating cylinder that was recognized as a single point of vulnerability. There are various mechanical upgrades that could be provided for the feedpump governor valve control but they still used a single valve actuator with potentially contaminated oil. The decision was made to use separate electric actuators for the high pressure and the low pressure governor valves since it is the only solution that eliminated the need of oil for valve control and eliminated the Single Point of Vulnerability (SPV) associated with the original single actuator.

1.2 Upgrade of the Steam Generator Feedpump Turbine at Calvert Cliffs Unit 1

The Exelon/Westinghouse team, which included Emerson Process Management, successfully executed the feedpump upgrade by splitting the HP and LP valve linkage, using new electric actuators and drives, and using a DCS for the feedpump governor control at Calvert Cliffs Unit 1. Key aspects of the project that facilitated this success are discussed including the project planning, project management/risks, software and hardware development, testing program, installation and commissioning. An integrated cyber security solution was provided with the DCS design, but will not be discussed in this paper.

2 SYSTEM REQUIREMENTS AND MODIFICATION SCOPE

2.1 Modification Scope

The feedpump governor controls were upgraded with a DCS. This DCS platform utilizes a duplex control architecture used in modern control applications in power plants worldwide. The DCS allows for the addition of future systems in one hardware and software platform. This control system upgrade gave plant operations an integrated feedwater and feedpump governor control solution.

The modifications included installation of two human-machine interface (HMI) monitors in the control room, installation of an integrated feedwater and feedpump governor controller cabinet, installation of two feedpump remote input/output (RIO) cabinets (one per pump), installation of two servo drive cabinets (one per pump) and the replacement of the original oil operating cylinder equipment with separate electric actuator assemblies. Each electric actuator assembly consisted of a servo drive and drive enclosure. The servo drive was sent demand signals from the DCS for valve position (speed) control.

The turbine mechanical modifications included splitting the HP and LP valve actuator linkage. Afterward, the HP and LP electric actuators were installed to eliminate the original single operating cylinder, which was an SPV.

3 PROJECT PLANNING AND MANGEMENT OF RISKS

For the project to be successful, it was essential to have effective project management and control using accepted project management principles. The project management was complex because one integrated project manager needed to be responsible for many phases of the project. To start, a detailed project plan was created and adhered to by the project team. The resource plan included selecting a mix of experienced resources for lead roles and less experienced resources for supporting roles. An open and cooperative relationship between all parties was established early in the project. From the project kickoff meeting forward, team meetings involved key leads from each phase of project design and implementation and included sub-suppliers and end users. The plant operators and engineers were involved in early design meetings to ensure familiarity with the project and understanding the decision process that lead to the design. The team had a common goal - Project Success - and held each other accountable. Weekly schedule and action item meetings were conducted to measure progress and communicate team decisions in addition to identifying project risks. A series of design reviews were planned and implemented for each phase of the project. The team design reviews were effective and produced high-quality end results. As the project team identified risks, proactive plans and contingent plans were scheduled and implemented to mitigate the risk. Lessons learned meetings were periodically conducted to track and review lessons learned from the following sources:

- Industry
- Calvert Cliffs past projects
- Project /walkdown lessons learned
- Westinghouse iKnow lessons learned
- Westinghouse past and ongoing turbine control projects

To mitigate the risk of a digital upgrade to a nuclear power plant, the project team reviewed and applied appropriate lessons learned from past digital upgrades.

4 SYSTEM DESIGN, TESTING AND COMMISSIONING

For digital system upgrades at operating plants, reliability and economics are important design considerations. SPVs in the system must be eliminated as much as possible, and performance must be better than, or at least equal to, the postulated failure modes analyzed in a plant's Final Safety Analysis Report (FSAR). Extensive verification and validation (V&V) activities must be performed in the design and testing phases. Labor-intensive activities, such as installation of new power or signal cables, must be minimized. Modification of the existing system and installation of new equipment must be completed within the plant outage schedule. Therefore, activities that can be completed with the plant online should be maximized.

The essential activities for the feedpump governor control and electric actuators were system design, factory testing, installation, system modification testing, and commissioning of the system. These activities are discussed in this section.

4.1 Feedpump System Design and Architecture

The digital feedpump system replaced the existing feedpump governor controls. The new system utilizes a DCS platform that provides the infrastructure to add and incorporate other plant control functions in the future, such as Main Turbine Controls, Reactor Regulation, Pressurizer Pressure and Level Control. The DCS equipment that was used in this design is summarized below:

- One set of redundant controllers for feedwater and feedpump governor controls
- Two new RIO cabinets (one for each steam generator feedpump)
- One combined engineering/database/developer tools/ historian workstation
- Two MCR operator workstations
- One set of DCS infrastructure equipment

The DCS utilizes duplex control architecture, with decoupled redundant I/Os between the controllers and I/O modules for critical control functions. A maintenance and test system (M&TS) was provided for maintenance training and testing of system equipment. The purpose of the M&TS is to serve as a platform for software development, software debugging, hardware maintenance and testing, and engineers' training and testing. It is an offline system not connected to the plant network or I/O equipment.

4.1.1 Feedpump electric actuator design

The new digital feedpump governor control system incorporated into one set of redundant controllers. The overspeed protection portion of the system includes diverse hardware and software to protect against a common cause mode failure. The electric drives receive a 4-20mA demand signal generated from the DCS. Westinghouse used the DCS's Redundant Loop Interface (RLI) modules and Westinghouse designed Arbitrated Redundancy Modules (ARM) to create an arbitrated demand signal. This design removes the DCS's hardware from being a Single Point of Vulnerability. Westinghouse used a Small Loop Interface Module (SLIM) manual/auto (M/A) station with each electric drive and associated actuator to provide the plant operators with a dedicated M/A station. The SLIM M/A stations operate in parallel with the operator graphic display soft M/A stations and provide the same control functionality. Each SLIM M/A is connected to the DCS's Loop Interface module that is configured and connected to an associated controller. The RLI module outputs are configured to fail "as-is" if the module watch-dog timers reach time out. This provides an additional level of protection in the unlikely event there is a failure of both the primary and backup controllers. For example, if the demand signal was 65% prior to the failure, the loop interface module will maintain the demand signal at 65% and the operator can maintain valve position control using the SLIM M/A stations in local manual control mode.

Westinghouse supplied each feedpump with a dedicated drive enclosure to house the LP and HP electric drives and associated hardware. The design of the drive enclosure cabinets included front panel switches to enable/disable the electric drives and to "home" the electric actuators. The drives used for the project were Emerson Control Techniques Unidrive SP Servo Drives. Westinghouse configured these drives with design inputs from the Emerson Process Management mechanical designers and input from Exelon. These drives allowed Westinghouse to write custom code to protect against the electric actuators from applying excessive force against the seat of the valves during normal operation and while shut down. These electric actuators are equipped with a serial connection that was wired into the DCS to monitor essential parameters, such as drive temperature, actuator position, actuator demand and drive amperage.

Westinghouse worked with Emerson Process Management as the mechanical designer for the electric actuator design and to split the original feedpump turbine valve rack (or valve gear). The separation of the valve rack significantly increased the fault tolerance of the system by eliminating the single point of vulnerability associated with the original single hydraulic operating cylinder that was used for control of the HP and LP governor valves. A failure of the operating cylinder, its servo valve or its associated hydraulic oil supply could cause a loss of the feedwater pump which could have resulted in a reactor trip, or at a minimum would have required the unit to operate at reduced power until fixed. A significant benefit from installing electric actuators is the elimination of hydraulic control oil contamination that can cause unstable feedpump control potentially leading to a feedpump trip.

The separated valve gear design incorporated two electric actuators, one for the HP valve and one for the LP poppet valves. Exlar GSX series electric actuators were used in the design since they include an integrated motor and roller screw mechanism. This roller screw mechanism converts electric motor power into linear motion. Planetary rollers are assembled around the actuator extending rod to follow the threads that are precisely machined on the inside of the actuator's hollow rotor. These actuator assemblies were designed to shut the HP valve and LP poppet valves on loss of power to the drive or actuator. This was accomplished with springs used on the electric actuator assemblies.

4.1.2 Software, HMI, and dynamic model integration

A dynamic model was created to simulate plant conditions. The operator interface displays and control functions were integrated with this model to simulate system performance in a secure virtual development system and for development and testing of the control system software. Important control functions such as the feedpump governor control algorithm was individually tested and its dynamic response was reviewed. The feedpump governor control system performance and the integrated dynamic model was subsequently validated using plant startup test data from Calvert Cliff's steady-state and transient performance tests. The software running in this secure development system was implemented and operated in the actual system control equipment.

4.1.3 HMI design

A set of HMI displays was developed for the feedpump governor control, based upon extensive Westinghouse experience in digital upgrades of feedpump governor control systems. In addition, displays for the electric actuators and drives were created. These displays provide plant operators with indication and alarms of essential parameters for the actuator drive electronics. Maintenance control functions were also added to these displays. Prior to formal testing of the system software, Exelon's personnel performed reviews of the displays, and made recommendations for improvement. The display improvements and enhanced functionality were incorporated prior to the performance of the formal factory acceptance tests.

4.1.4 System verification and factory testing

The major control functions are below and were extensively tested.

- Feedpump governor control
- Overspeed protections
- Electric drive and actuator control

The actual system equipment was staged in the factory for formal tests. Test procedures were developed for dynamic system performance tests, software and logic functional tests, and factory acceptance tests. These tests were performed using a dynamic model or as an integrated software and hardware test, and witnessed by Exelon personnel consisting of project management, design, instrumentation and control (I&C), maintenance, and plant operations. Test reports were reviewed and approved, and issues resolved prior to equipment shipment to the site.

4.1.5 Site acceptance testing

After completion of the factory acceptance testing activities, the equipment was shipped to the site. The following activities were performed:

- Software testing
- Electric drive software configuration
- Integrated system testing

Some of these tests overlapped those performed at the factory acceptance test but provided additional confidence that the equipment will perform as expected after installation. The site acceptance testing was also used to test and perform the modification acceptance tests.

4.1.6 Installation

Modification of the existing system and installation of new equipment had to be completed within the plant's aggressive outage schedule. The equipment installation is normally limited to 10 days. Electric actuator drive cabinets, DCS feedpump cabinets, conduit, and most of the new cables were installed while the plant was online.

During the outage, the existing feedpump governor control system was modified, the HP and LP valve gear rack was modified and the electric actuator assemblies were installed. Cable terminations were completed for input signals and output signals.

4.1.7 Modification acceptance testing

The purpose of the modification acceptance test (MAT) is to test specific functions of electric actuators and the DCS's governor control functions to demonstrate acceptable performance of the equipment installed to replace the existing system. The MAT included the following tests performed after equipment installation:

- DCS system testing
- Instrument loop calibration
- Electric Actuator and Drive calibration
- Electric Actuator and Drive tuning

Because these tests were performed with the plant off-line, sensor inputs (such as speed) were simulated using function generators, respectively. Discrete inputs were simulated by forcing logic states using an HMI test feature. In conjunction with the successful performance of software test, factory acceptance test, and site acceptance test, successful performance of these tests formed the basis for declaring the electric actuators and feedpump governor control ready for plant startup.

4.1.8 Power ascension testing

The final tests for the feedpump governor control and electric actuators were the performance tests p erformed in actual plant operation. These tests included control stability tests included the following:

- Operating on HP and LP steam
- Transferring between steam sources
- Feedpump speed step changes
- Normal operational startup transients

Data for these tests were captured by the DCS data capture and trending tool, as well as by the plant process computer data acquisition system. System performance was evaluated for each test against specified acceptance criteria. Successful tests validated that the system performed as expected, and enabled continued plant operation with confidence.

5 LESSONS LEARNED

There were a few key lessons learned from this project that should be considered on future I&C upgrade project. They are as follows:

- There should be cooperation between all stakeholders (Exelon, Westinghouse and EPM) to ensure all stakeholders were in good open communication and exchanging design ideas.
- There should be involvement of the customer's team with their different stakeholders including: I&C designers, plant maintenance and plant operators.
- There should be a system walkdown, which includes all stakeholders. For this project the walkdown consisted of using a FaroArm measure device to gather the required measurements.

- A pre-job brief should be done prior to the walkdown, to ensure all required parameters for measurement or inspection are clearly identified and identified to the customer to ensure you have access. A checklist or equivalent should be created to ensure critical data is not overlooked.
- In a pre-startup condition, the design of the HP valve was to have the HP electrical actuator under no mechanical load. The site designed an alignment tool to aid in setting the required gaps for the HP Actuator.

6 CONCLUSIONS

The Calvert Cliffs Feedpump upgrade was successful and achieved the project and utility requirements. Breaking the tie to the hydraulic oil for the Steam Generator Feedpump Turbine Control Valves will allow for the setup and testing of the control system much earlier in the outage. Historically, the Steam Generator Feedpump Turbine testing became a critical path item for the plant. This project demonstrated that a first of a kind I&C upgrade can be successfully implemented when the following attributes are incorporated into the process:

- Adequate planning
- Well-staffed organization, including utility and vendor representatives
- Committed utility management sponsorship
- Adequate communication protocols
- Completed design
- Adequate testing, both pre- and post-modification
- Risk identification and mitigation measures

Tremendous financial and operational paybacks are achieved by applying proven applications and the right technologies, and incorporating lessons learned from past I&C upgrade projects. When the strategies outlined in this paper are employed and the team approach between utility and vendor is utilized, great innovation and rewarding success is achieved in upgrading I&C systems in our nuclear plants. This upgrade is now currently being planned and offered to other nuclear power plants.

APPENDIX A

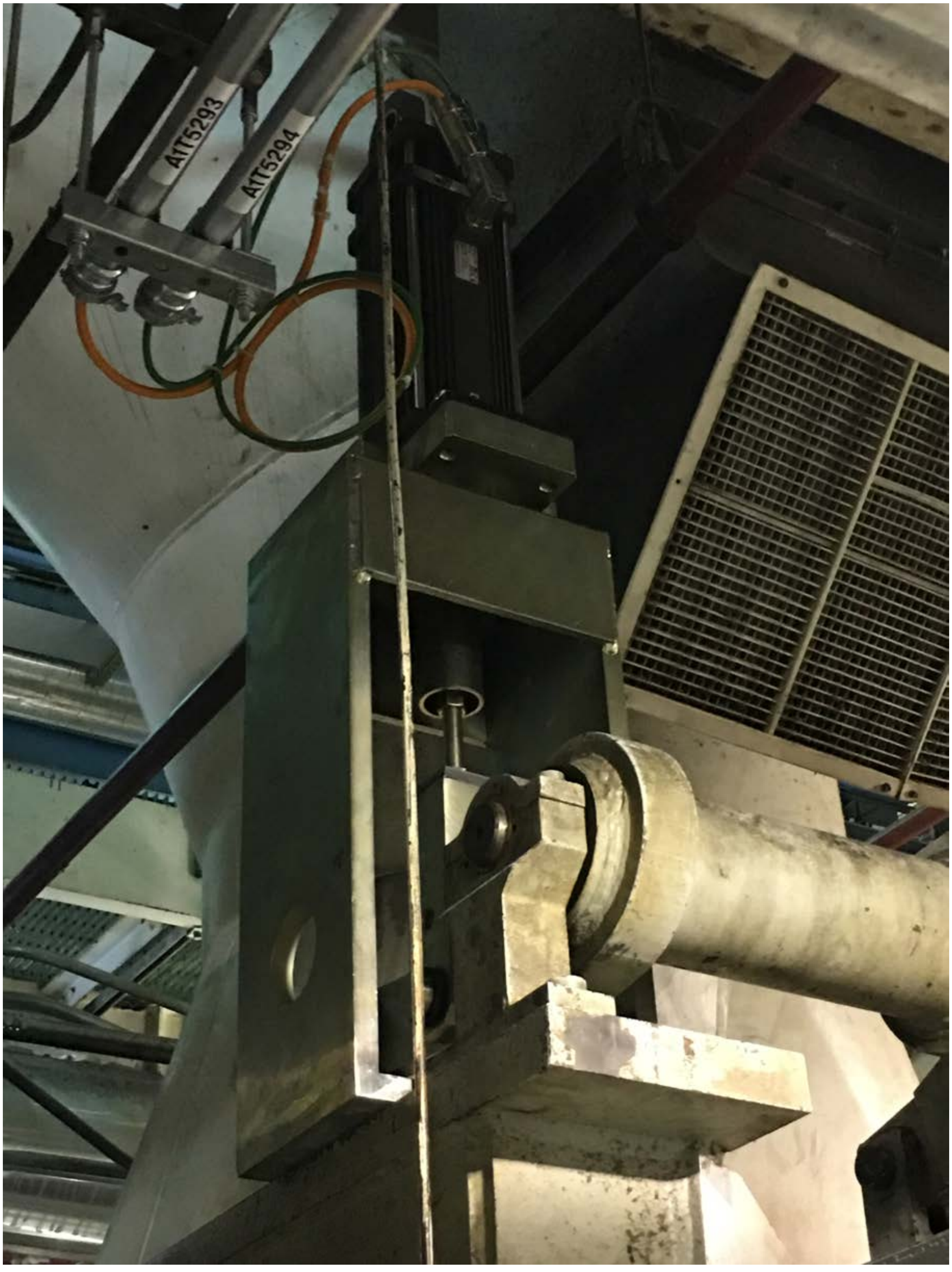

Figure 1. – Installed HP Electric Actuator Assembly

Figure 2. – Installed LP Electric Actuator Assembly