Tricon: A field-proven triple modular redundant digital system for feedwater control and safety application in nuclear power plants

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Abstract

The Triconex® Tricon™ system is a triple modular redundant (TMR) digital system for feedwater control and safety applications in nuclear power plants (NPPs). Feedwater is a critical element in the continuous operation of NPPs. When a feedwater system goes offline, the entire plant goes down. Poor reliability of an existing obsolete control system is one of the major causes of feedwater system trips. A single component failure can result in a feedwater shutdown, causing unscheduled plant outages that cost hundreds of thousands of dollars per day in maintenance costs and lost revenue. The Tricon is a high-reliability, high-availability (99.99%) feedwater control system with no single point of failure. It provides an economical solution to the obsolescence, reliability, and availability problems while improving the operational efficiency of NPPs.

Introduction

Feedwater control systems are critical for the safe, efficient, and continuous operation of an NPP. Existing control systems are old, obsolete, unreliable, and hard to maintain due to the unavailability of spare parts. The staff at NPPs should not spend time trying to keep antiquated control systems running. The design and architecture of a critical control system should incorporate high reliability and high availability as inherent attributes. This type of control system allows the plant operator to focus on plant behavior, monitoring field parameters critical to maintaining the plant and quickly performing corrective actions when necessary.

Aging feedwater control systems must be replaced with high-reliability, high-availability modern digital control systems, so unnecessary feedwater system trips and plant outages can be prevented. New feedwater control systems must be easy to operate, maintain, upgrade, and expand in the future.

Most monitoring, control, and safety requirements are common to feedwater systems for various boilers/steam generators within NPPs. A feedwater control system must have the capabilities and flexibility to handle common requirements and vendor-specific requirements for all feedwater systems.
Major requirements

Reliability, availability, and maintainability
- High reliability and availability with no single point of failure for continuous plant operation
- Online diagnostics with over 99.9% coverage
- Online repair
- Easy to maintain, modify, and add future enhancements
- Easy to upgrade and expand in the future without affecting existing field elements and wiring

Field interface
- Interface to the existing and new field elements (such as vessel water level, vessel pressure, steam flow, feedwater flow, first stage pressure), if required, for the feedwater system
- Interface with other control systems throughout the plant

Control, safety, and test
- Maintain water level in the vessel within a predefined range (setpoint ± a specified value) by maintaining steam flow out/water flow in mass balance under dynamic load conditions
- Implement existing automatic or manual operational procedures and control strategies
- Implement a combination of single-element/three-element auto and manual control strategies with bumpless switching between the strategies (single-element control uses only water level as an input; three-element control uses water level, steam flow, and feedwater flow)
- Detect and safely shut down the system when unsafe plant conditions arise

Operator interface
- Easy-to-use operator interface for monitoring and control
- Enhanced visibility of critical feedwater parameters in real time
- Allow the operator to set the following control parameters (such as setpoint for the vessel water level, bypass for individual input signals, reset for individual alarms, auto/manual control mode, and ramp rate hi/med/slow)
- Easy navigation between the control, monitoring, and maintenance screens
Communications

- Ability to interface with existing plant computer and/or DCS system
- Redundant, high-speed, industry standard communication interfaces and protocols to transfer real-time data (such as feedwater system parameters, field status, alarms, trips, system status, field inputs and outputs) for control, monitoring, logging, and trending for field diagnostics purposes

The Tricon satisfies the above requirements for feedwater control in NPPs. The Tricon-based feedwater control system architecture is presented in Figure 1. This basic architecture can be adapted to satisfy existing plant-specific field elements and wiring requirements, additional field elements requirements, existing auto-manual feedwater control procedures and strategies, and communications requirements.

A typical feedwater control system consists of the following:

- Tricon TMR system
- TriStation 1131 application development station
- Feedwater control application software
- Foxboro™ Evo system and/or Wonderware™ human-machine interface
- Maintenance workstation
- TriLogger software

A brief summary of feedwater control system components is provided below.

Tricon system

The Tricon is a TMR architecture-based digital safety and control system. The system is certified by TÜV (a world-recognized, independent safety agency) at International Electrotechnical Commission (IEC) Safety Integrity Level 3 to be used for safety and critical control applications in process control and other industries. The Tricon is also certified by the Nuclear Regulatory Commission to be used for safety (1E) and critical control applications in NPPs.

The Tricon has three independent channels from the input terminal to the output terminal. Each input is scanned and voted by the three main processors (MPs), and the resultant voted input is provided to the same application running in the three MPs. The outputs from the application running in each MP go to the output modules where they are voted. The resultant voted output for each point goes to the output terminal field device.

The TMR architecture and design allows the Tricon system to perform its intended safety and control functions in the presence of a single hardware fault. In addition, the design allows the Tricon to run in TMR, DUAL, or SINGLE mode, thus providing high availability (99.99%).
The built-in online diagnostics provide more than 99.9% fault coverage, and isolate a fault to a specific module. The faulted module can be replaced with a new module online without affecting the feedwater system operation. The Tricon combines technology and architecture features to provide safety and control functions with the high reliability and high availability required for the safety and critical control applications in NPPs.

The Tricon can be expanded from a single chassis system to a 15 chassis system with a wide variety of I/O and communications (COM) modules. As shown in Figure 1, most feedwater control systems require a main chassis and two to three I/O expansion chassis, depending on the number of field elements and spare slot requirements for future expansion.
The COM modules provide the Tricon with the ability to interface with the existing plant computer, DCS systems, and operator stations. These COM modules provide the redundant, high-speed, industry standard communication interfaces and protocols for transferring real-time plant data for control, monitoring, logging, and trending for field diagnostics purposes.

The I/O modules allow the Tricon to interface with various types of existing and new field devices. The I/O modules include: analog input, analog output, thermocouple, pulse input, digital input, and digital output.

**TriStation 1131 Workstation**

TriStation 1131 is a PC-based safety and critical process control application development workstation that provides a comprehensive set of development, test, monitor, validation, and diagnostic tools for Triconex Programmable Safety Systems (Tricon and Trident). The TriStation 1131 is compliant with the IEC 1131-3 International Standard for Programmable Controllers, Part 3: Programming Languages.

TriStation 1131 includes the following major features for application development:

- IEC programming languages: Structured Text language (textual language), Function Block Diagram language (graphical language) and ladder diagram language (graphical language)

- IEC data types: Basic data types (BOOL, INT, DINT, REAL, LREAL, DWORD, STRING, TIME, TOD, DATE, and DT) and user-derived data types (ARRAY, STRUCT, CONSTANT, and ENUMERATION)

- Ready-made, thoroughly tested libraries for application development:
  - IEC standard library
  - Triconex library: System status and diagnostics functions, scheduler functions, PID functions, sequence-of-events functions
  - Feedwater control libraries: Special feedwater control functions developed by the domain experts at Triconex, based on the last 20 years of experience in control systems design and development

- User-defined libraries: Users can develop, test, and archive their own libraries to be used in various applications

- Easy-to-use Windows®-based graphical user interface

- A browser-based help system with extensive help for TriStation 1131 operations, library functions, and error messages

- Security features and audit trail

- Built-in application change control and version control
• Emulator for application testing prior to downloading to the Tricon system
• Project execution monitoring and control
• Comment boxes and variable annotation for in-line documentation

These features allow users to develop and test application software in a systematic and modular fashion.

Critical feedwater control application software
Critical control application software is developed using the TriStation 1131 workstation and associated standard, as well as feedwater control application-specific libraries. Please see the critical application software architecture section on page 9 for more information.

Foxboro Evo or Wonderware HMI
The Foxboro Evo or Wonderware InTouch™ HMI provides a graphical, easy-to-use operator interface for the control and monitoring of the feedwater operation. In addition, it provides real-time data, alarms, and events logging capabilities.

Standard feedwater control and monitoring screens are available for both workstations. The standard screens can be modified and/or additional screens can be easily developed to meet the NPPs operational requirements. Please see the operator screen section on page 13.

Maintenance/engineering workstation
This is a commercial off-the-shelf (COTS) ruggedized PC with the Tricon Diagnostic Monitor utility installed. This utility displays Tricon system and module status by simulating the actual Tricon chassis and slots so users can find the exact location (chassis number and slot number) of a module. This workstation may also include the TriStation 1131 application software and TriLogger software.

TriLogger
The TriLogger software provides the ability to record, display, play back, and analyze the field data from the Tricon system. Data can be viewed in real time (locally or remotely). Data trending and analysis capabilities assist in diagnosing field problems.
Critical application software architecture

Critical application software architecture consists of standard COTS software modules (programs, functions, and function blocks) developed using TriStation 1131 and associated libraries. The flexibility of the feedwater control application architecture, combined with the TriStation 1131 programming facilities and the expertise and experience of the personnel, makes it easy to adapt the architecture to satisfy any plant-specific feedwater control strategy and procedures.

The software implements the feedwater operational states (modes) and the specific control and monitoring functions in each state. This is based on the feedwater system status received from the field and inputs from the operator station (HMI). Figure 2 displays the feedwater system states and state transition diagram.

Figure 3 displays the major software modules and their interrelationships. These modules implement the field inputs processing, operator inputs processing, feedwater system states, and control strategy.

The vessel water level, steam flow, and feedwater flow modules process field and operator inputs. Each module scales the inputs, validates the inputs, and selects median, average, single, or zero value based on the number of valid inputs for each input type.

The feedwater system states and control strategy module implements the system states and associated control functions in each state. A brief summary of feedwater system states and associated monitoring and control functions is provided below.

Field manual state
The field manual state is entered upon cold/warm start, and when a field auto-manual signals from the valves, servo controllers, or feedwater pump control system is activated.

The operator controls the feedwater flow manually from the servo controllers for the valves and the feedwater pump control system. In this mode, the application disables the demand signals to the field (a zero is sent to the servo controllers and feedwater pump control system).

This state is exited when the field auto-manual signals from the servo controllers and the feedwater pump control system become true.

Local automatic/manual
The local automatic/manual state is entered when the current state is field manual and the field auto-manual signals from the servo controllers and the feedwater pump control system are true. This state is also entered when one of the following occurs:

- The local auto mode flag is set by the operator
- A loss of feedwater flow is detected in single- or three-element control mode
- A loss of vessel water level is detected in single- or three-element control mode

The operator controls the feedwater flow from the HMI through the Tricon system. From the HMI, the operator can set the system in remote mode by setting the remote mode flag on.
Figure 2
Feedwater system states and state transition diagram

Figure 3
Feedwater control application software architecture
This state is exited when one of the field auto manual signals is activated or when the remote mode flag is set by the operator and the prerequisites (field conditions) for the single-element control mode are satisfied.

**Single-element (water level)**

The single-element (water level) state is entered when the current state is local automatic/manual, the remote mode flag is set by the operator, and the prerequisites (field conditions) for the single-element control mode are satisfied.

In this mode, the water level target (setpoint) is compared to the actual vessel water level to generate an error signal. This error signal is processed by the proportional-integral-derivative (PID) function to generate the demand signal (setpoint) for the feedwater flow controller's PID. The gain and integral settings for the PID are derived from the adaptive tuning parameters across the full spectrum of the power band for optimum level control. The single element control is used for low load condition (power level less than 16% of full power). The first stage pressure input is used to estimate the current power level. Please refer to Figure 4 for an example of single- and three-element control strategies.

The state is exited when any of the following occurs:

- One of the auto-manual signals is activated
- Loss of vessel water level or feedwater flow is detected
- Local auto mode flag is set by the operator
- The power level is greater than or equal to 16% and the prerequisites (field conditions) for the three-element auto mode are satisfied

**Three-element (water level, steam flow, and feedwater flow)**

The three-element state is entered when the current state is single-element and the prerequisites (field conditions) for the three-element control mode are satisfied.

In this mode, the water level target (setpoint) is compared to the actual vessel water level input to generate an error signal. This error signal is processed by the PID function to generate the demand signal. This demand signal is combined with the steam flow input to generate a setpoint for the feedwater controller's PID. This setpoint is compared to the feedwater flow input and the resultant error signal (feedwater flow error) is the demand signal for the field control elements. The gain and integral settings for PIDs are derived from the adaptive tuning parameters across the power band for optimum level control.
The system automatically switches between single- and three-element control mode depending upon the plant conditions. Once in three-element control mode, the system remains in that mode as long as there is at least one valid input for the water level, steam flow, and feedwater flow. Please refer to Figure 4 for an example of single- and three-element control strategies. Note that the Figure shows one of the various ways of implementing control strategy. Triconex has implemented various strategies for different NPPs based on plant-specific control requirements.

The state is exited when any of the following occurs:

- The auto-manual signals is activated
- A loss of vessel water level, a loss of steam flow, or a loss of feedwater flow is detected
- The local auto mode flag is set by the operator
- The power level is less than 14% of full power
The following standard feedwater control and monitoring screens with security levels are available for both the Foxboro Evo workstation and the Wonderware workstation. These standard screens can be modified and/or additional screens can be easily developed to meet NPP operational requirements.

- Feedwater overview screen
- Control screen
- Alarms screen
- Maintenance screen
- Field I/O screen
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About the author

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Schneider Electric is a customer-centric company that provides a complete solution to the nuclear industry for safety and critical control. Schneider Electric has installed more than 1,500 critical control systems in plants all over the world, including NPPs.

The Tricon is a high-reliability, high-availability (99.99%), digital feedwater control system with no single point of failure. The built-in features of the Tricon (high reliability, high availability, low maintenance, self-calibration, built-in online diagnostics, online repair, easy to expand and upgrade) help reduce life cycle operations and maintenance costs.

The built-in online diagnostics provide more than 99.9% diagnostic coverage, providing a basis to potentially reduce periodic surveillance testing between refueling cycles. Online repair increases availability even further, as turbines are not required to be shutdown to perform repairs.

Tricon solves the obsolescence, reliability, and availability problems of NPPs while improving the operational efficiency of the NPP.

With a Tricon installation, you not only receive proven TMR technology, but the experience and knowledge of the Triconex feedwater control domain experts who are ready to assist. Schneider Electric offers experience in design, development, installation, and support of the feedwater control system, efficient project execution and integration capabilities, around-the-clock customer support, and customized training for the I&C and plant operation personnel.

Summary