Westinghouse Technology Systems Manual

Section 5.7

Generic Auxiliary Feedwater System

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5.7 AUXILIARY FEEDWATER SYSTEM

Learning Objectives:

1. State the purposes of the Auxiliary Feedwater (AFW) System.

2. List all suction sources for the AFW pumps and under what conditions each is used.

3. List the five plant conditions that will result in an automatic start of the AFW system.

4. Explain how decay heat is removed following a plant trip and loss of offsite power.

5. Explain how a minimum volume of water in the condensate storage tank is reserved for the AFW system.

6. Explain how the availability of other decay heat removal methods limits the AFW system's contribution to core damage frequency.

5.7.1 Introduction

The purposes of the AFW system are as follows:

1. To provide feedwater to the steam generators to maintain a heat sink for the following conditions.

   a. Loss of main feedwater (MFW),
   b. Unit trip and loss of offsite power, and
   c. Small-break loss-of-coolant accident (LOCA).

2. To provide a source of feedwater to the steam generators during plant startup and shutdown.

The AFW system supplies, in the event of a loss of the main feedwater, sufficient feedwater to the steam generators to remove primary system stored heat and residual core energy (decay heat). AFW must also be available under accident conditions, such as a small-break loss-of-coolant accident, so the plant can be brought to a safe shutdown condition.

The AFW system is designed to automatically start and supply sufficient feedwater to prevent the relief of primary coolant through the pressurizer safety valves. The AFW system has an adequate suction source and flow capacity to maintain the reactor at hot standby for a period of time and then cool the reactor coolant to a temperature at which the residual heat Removal (RHR) system may be placed in operation.

5.7.2 System Description

The AFW system, as shown in Figure 5.7-1, has two electric-motor-driven pumps and one turbine-driven pump. Each of the electric-driven pumps supplies two different steam generators; the turbine-driven pump supplies all four steam generators. All three pumps automatically deliver rated flow within one minute upon receipt of an automatic start signal.

The preferred source of water for all auxiliary feedwater pumps is the condensate storage tank (CST), which is required by the plant's Technical Specifications to contain a minimum amount of water available to the AFW system. An additional unlimited backup water supply, essential service water (ESW), is supplied to the AFW system. A separate train of ESW feeds each electric-driven pump (e.g., Train A of ESW feeds the A AFW pump), while the turbine-driven pump can receive backup water from either train of ESW.

To protect the AFW pumps from a loss of suction, the ESW supply valves are automatically (or remote-manually) opened if the suction pressure is low on two-out-of-three pressure detectors, and the AFW pump is running.

Since the ESW system supplies poor quality water, it is not used except in emergencies when the normal condensate supply is unavailable.

The AFW system is designed to deliver 40 to 120°F water for pressures ranging from the RHR system operating pressure (equivalent to approximately 110 psig in the steam generators) to the highest setpoint of the steam generator safety valves (1234 psig).

The AFW system piping is designed for pressures up to approximately 1650 psig where necessary. Separate engineered safety features (ESF) quality electrical power subsystems and control air subsystems serve the AFW pumps and their associated valves.

In addition to using high quality components and materials, the AFW system provides complete redundancy in pump capacity and water supply for all cases for which the system is required. Under all credible accident conditions each steam generator, not affected by the accident, will be supplied with its required feedwater. Only two steam generators are required to be operable for any credible accident condition.

Redundant electrical power and air supplies assure reliable system initiation and operation. The electric-motor-driven pumps are powered from vital ac distribution sources, while the turbine-driven pump takes steam from either of two main steam lines, up stream of the main steam isolation valves (MSIVs).

5.7.3 Component Descriptions

5.7.3.1 Motor-Driven Auxiliary Feedwater Pumps

The motor-driven pumps are multistage, horizontal, centrifugal pumps, each of which supplies 440 gpm at a discharge pressure of about 1300 psig. The motor-driven pump design data are shown in Table 5.7-1. Power to the motor-driven AFW pumps is supplied from the 4.16-kVac Class IE vital distribution boards. Local switches permit local operation of the pumps. The switches in the control room have three positions: “Run,” “Stop,” and “Pull to Lock.” The pull-to-lock feature prevents the pumps from starting, even if an automatic start signal were present.

The following five conditions will automatically start both motor-driven AFW pumps:

1. Low-low water level in any single steam generator,
2. Loss of one main feed pump (MFP) if power is greater than 80 percent,
3. Loss of both MFPs at any power level,
4. Safety injection actuation signal, and
5. Loss of power to the Class IE power distribution system.

5.7.3.2 Turbine-Driven Auxiliary Feedwater Pump

The turbine driven pump is a multistage, horizontal, centrifugal pump. It is capable of delivering 880 gpm at a discharge pressure of approximately 1200 psig. This pump’s design data is shown in Table 5.7-1.

The steam-driven pump is driven by a horizontal, noncondensing turbine. The turbine is rated at 1100 hp and is designed to operate with a supply steam pressure varying from 1275 psig down to 100 psig. The steam to drive the turbine is supplied from the main steam system, with the piping penetrations located upstream of the MSIVs. The steam supply comes from steam generators number 2 and 3. Each supply line has an air-operated main valve and an associated bypass valve. The bypass valves are used for warming the turbine and are operated from the main control board.

During the AFW pump turbine operation, steam is supplied to the unit through normally shut flow control valve FC-HV-312. The control of the turbine speed is accomplished by adjusting the governor valve (HV-313) from the main control board.

To remove moisture in the main steam supply steam traps have been provided where necessary. Drains have also been provided on the turbine casing, steam chest and exhaust piping. The exhaust from the AFW pump turbine is directed to the atmosphere.

The five automatic start signals for the turbine driven auxiliary feed pump are as follows:

1. Low-low steam generator level in 2 of 4 generators,
2. Loss of one MFP if power is greater than 80 percent,
3. Loss of both MFPs at any power level,

4. Safety injection actuation signal, and
5. Loss of power to either Class IE vital distribution system.

5.7.3.3 Level Control Valves

The AFW system contains eight (8) level control valves. Four (4) valves are located on the auxiliary feed lines feeding the steam generators from the motor-driven AFW pumps. The remaining four (4) level control valves are on the auxiliary feed lines coming from the turbine-driven auxiliary feed pump. Each valve has a toggle switch which allows the operator to manually open or close the valve. Normally, the valves are fully closed and will automatically control steam generator level to a preselected setpoint upon an automatic actuation signal.

At some plants, these level control valves are provided with loop-break protection circuitry. This is accomplished by monitoring the pressure between the level control valve and its associated steam generator. If the pressure in this section of piping drops to a pre-selected setpoint (normally 100 psig), a signal is sent to close the level control valve. This protective feature is supplied so that, in the event of a steam or feedwater break, the auxiliary feedwater system will not continue to feed the faulted steam generator.

5.7.3.4 Water Supplies

The AFW system has redundant water supplies. The normal suction source is provided by gravity feed from the condensate storage tank, which is sized to meet the normal operating and accident needs. Each AFW pump takes its suction on a common header through a check valve and a normally open isolation valve. The suction pressure for the AFW pumps is normally indicated in the control room.

Availability of water from the CST for the AFW system is guaranteed by a standpipe in the supply line to the main condenser. Other means may be used at other facilities to ensure a minimum level in the CST. Other methods include a level control valve which closes when the quantity of water in the condensate storage tank drops to a preset value, or the supply line to the main condenser is tapped into the side of the condensate storage tank at a height that ensures a minimum level for the AFW system.

In the event that the CST is not seismically qualified, an emergency water supply must be provided as a backup. This backup supply must be seismically rated and must have some method for automatic initiation if needed.

There are three pressure switches located on the suction line for each AFW pump which are used to switch the suction from the CST to the safety-related ESW system (which is seismically qualified). To prevent an inadvertent injection of ESW into the steam generators, automatic opening of the ESW supply valves is initiated by a 2-out-of-3 logic on low AFW pump suction pressure coincident with an AFW pump running.

On the discharge of each motor-driven pump, there is a blind flange connection for the installation of a spool piece to tie the high pressure fire protection system into the AFW system. The pressure in the steam generator must be below 120 psig for use of the high pressure fire protection system.

5.7.4 System Features and Interrelationships

The safety-related portions of the AFW system are designed for seismic events and meet the single failure criteria requirements, including the consideration that the rupture of a feedwater line could be the initiating event. This system will provide the required feed flow to two or more steam generators regardless of any single active or passive failure.

The valves associated with the turbine-driven pump are served by both electric and control air subsystems, with appropriate measures precluding any interaction between the two subsystems. The turbine-driven pump receives control power from a third dc electric channel that is distinct from the channels serving the electric pumps.

In the event of a loss of site power, 440 gpm of AFW delivered to two steam generators prevents relief of reactor coolant via the pressurizer safety valves, and ensures that the water levels in the steam generators remain above the required minimum for tube coverage. If the AFW system were not to respond for ten minutes, then 880 gpm would be required to meet the above requirements. The AFW system meets the single-failure assumptions of the Final Safety Analysis Report (FSAR).

Following a LOCA, primary-to-secondary heat transfer in the steam generators, with the AFW system providing the heat sink, may be necessary for decay heat removal. For a spectrum of small-break LOCAs, the cooling flow through the reactor (emergency core cooling injection and flow out of the break) is not sufficient by itself to avoid core damage.

Generally, AFW components are constructed of carbon steel. The condensate storage tanks are lined to prevent corrosion; while other components are protected by chemical additions to the water.

5.7.5 PRA Insights

The AFW system provides feedwater to the steam generators to allow continued heat removal from the primary system when the main feedwater system is not available. In this capacity, the AFW system serves as one means of early core heat removal following a transient or small-break LOCA.

Loss of the AFW system is a small contributor to core damage frequency as part of major accident sequences (1.4% at Zion and 2.6% at Sequoyah). One of the reasons for the relatively small contribution is the ability of the plant to initiate bleed-and-feed cooling using high pressure injection and the pressurizer power-operated relief valves (PORVs). At a unit such as Surry, where two PORVs are required to open to provide sufficient bleed and feed capability, the AFW system can be a larger contributor (14.8%).

When performing the PRA for the AFW system certain items are plant specific, such as human error. If the AFW system is normally configured so that one pump is locked out, failure to start that pump becomes critical. Failure to correctly realign the system after testing or maintenance is another. Common-mode failures are also plant specific. One such failure is an undetected flow diversion through a cross-connect line to the second unit on multiple unit sites (Surry risk achievement factor - 400). A second example of a common-mode failure is steam binding of the AFW pumps due to main feedwater leakage through system check valves (Surry risk achievement factor - 400).

PRAs for 13 PWRs were analyzed to identify risk-important accident sequences involving the loss of AFW and to identify and risk-prioritize the component failure modes involved. Below is a list of four accident categories explaining how AFW failure is a contributor to the analysis. Included at the end of the list are the risk-important component failure modes.

1. Loss of Power System - A loss of offsite power is followed by the failure of the AFW system. Due to the loss of actuating power, the (PORVs) cannot be opened, preventing adequate bleed-and-feed cooling, resulting in core damage.

   A station blackout fails all ac power except the vital Class IE ac busses from the dc invertors. All decay heat removal systems, except the turbine-driven AFW pump, also fail. AFW subsequently fails due to battery depletion or hardware failures, resulting in core damage.

   A dc bus fails, causing a trip and failure of the power conversion system. One AFW motor-driven pump is failed by the bus loss, and the turbine-driven pump fails due to loss of the turbine or valve control power. AFW is subsequently lost completely due to other failures. Bleed-and-feed cooling fails because PORV control is lost, resulting in core damage.

2. Transient-Caused Reactor or Turbine Trip - A transient-caused trip is followed by a loss of the power conversion system and the AFW system. Bleed-and-feed cooling fails either due to a failure of the operator to initiate it, or due to hardware failures, resulting in core damage.

3. Loss of Main Feedwater - A feedwater line break affects the common water source to the steam generators from both main feedwater and AFW. If the operators fail to provide feedwater from alternate sources and fail to initiate bleed-and-feed cooling core damage will result.

   A loss of main feedwater trips the plant, and the AFW system fails due to operator error and hardware failures. If he operators fail to initiate bleed-and-feed cooling, core damage will result.

4. Steam Generator Tube Rupture (SGTR) - A SGTR is followed by a failure of the AFW sytem. Coolant is lost from the primary until the refueling water storage

tank is depleted. High pressure injection fails since recirculation cannot be established from the empty containment recirculation sump, and core damage results.

Risk-Important Component Failure Modes

The generic component failure modes identified from the PRA analyses as important to AFW system failure are listed below in decreasing order of risk importance:

1. Turbine-driven pump failure to start or run,
2. Motor-driven pump failure to start or run,
3. Turbine- or motor-driven pump unavailable due to testing or maintenance, and
4. AFW system valve failures, such as failures of steam admission valves, trip and throttle valves, flow control valves, pump discharge valves, or pump suction valves, and valves in testing or maintenance.

Reductions in core damage frequency through improvements to the AFW system are negligible for the plants studied in NUREG-1150.

5.7.6 Summary

The AFW system supplies high pressure feedwater to the steam generators to maintain a water inventory for removal of heat energy from the RCS by secondary side steam release in the event of the inoperability of the main feedwater system or during startup and shutdown evolutions. The discharge pressure generated by the AFW pumps is sufficient to deliver feedwater into the steam generators at any pressure up to the safety valve setpoint pressure. The capacity of the AFW system is designed so that the four steam generators will not boil dry, nor will the primary side relieve fluid through the pressurizer relief valves following a loss of main feedwater flow in conjunction with a unit trip.

The AFW system consists of two subsystems. One subsystem utilizes a steam-turbine-driven pump, with the steam capable of being supplied from the No. 2 or No. 3 steamlines upstream of the MSIVs. This system supplies a total of 880 gpm to all four steam generators. The second subsystem utilizes two motor-driven pumps, each with a capacity of 440 gpm. The discharge piping is arranged so that each motor-driven pump supplies two steam generators.

The automatic start signals for the auxiliary feed pumps are as follows:

1. Motor- and turbine-driven pumps:

   a. Loss of both main feed pumps,
   b. Loss of one main feed pump if power is > 80%,
   c. Low-low level in two or more steam generators,
   d. Safety injection actuation signal, and
   e. Loss of power to the Class IE vital distribution system.

2. Motor-driven pumps only:

   a. Low-low level in any single steam generator.

The preferred source of water for all AFW pumps is the CST. A Technical Specification minimum of 280,000 gallons is required for the AFW system. As an unlimited backup water supply, a separate ESW system suction is provided for each pump.

In addition, at some plants, the fire protection system may be connected with a spool piece to the auxiliary feed system downstream of each electric-driven pump. This feature allows raw water to be supplied directly to the steam generators. It would only be used if there were no other water source, or in the unlikely event that no auxiliary feedwater pumps were available.

Table 5.7-1
AFW System Design Data

Number of pumps per unit	3
Motor driven	2
Turbine driven	1
Design flow rate, gpm	
Motor-driven pumps, each	440
Turbine-driven pump	880
System design pressure, psig	1650
Design feedwater temperature, °F	40 - 120
Design discharge head, psig	
Motor-driven pumps	1300
Turbine-driven pump	1200

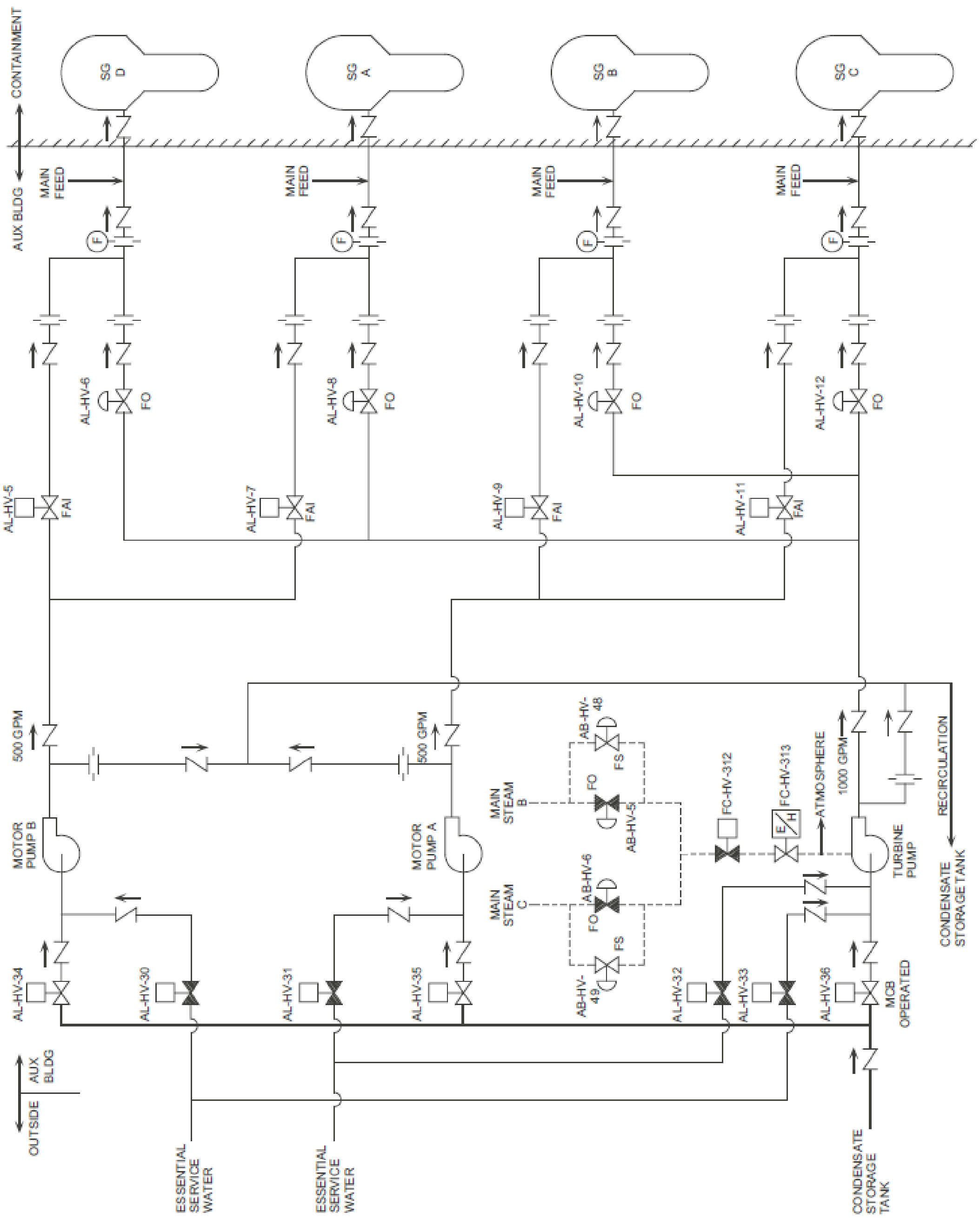

Figure 5.7-1 Auxiliary Feedwater System