Development of District Heating System for APR1000

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1. Introduction

KHNP has been in the bidding process for Dukovany unit 5 Nuclear Power Plant (NPP) in Czech Republic [1]. One of technical requirements is district heating system that consistently supply 300 MWt from 100% to 50% power plant load. Subsequently, several specific requirements are changed in comparison with those for Request For Information (RFI) issued by Czech government in 2016 [2].

The District Heating (DH) system in an NPP is unfamiliar with people in Korea because all the district heat from the Combined Heat and Power (CHP) plants is produced by conventional fossil fuels such as coal, natural gas and oil though there are many CHP plants in Korea.

In this paper, overall design of DH system for APR1000 is described.

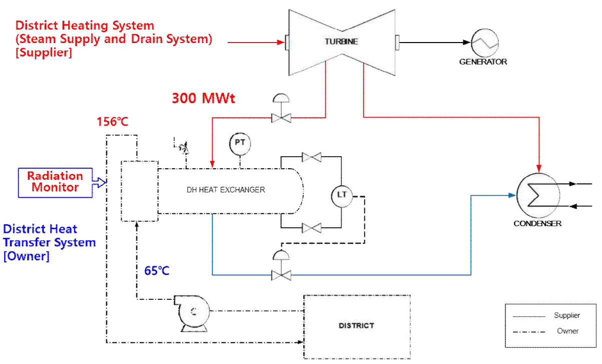

Fig.1. Schematic Diagram
of District Heating System in APR1000

2. Design Features of the District Heating system in APR1000

2.1 Design Bases

The district heating (DH) system is designed to provide heat to the DH water supplied from DH heat transfer system from 65℃ to 156℃ based on 100% DH and 50% DH flow conditions in the heat balance diagram.

The design pressure from each extraction steam line to the DH heat exchangers drain line is greater than the turbine stage pressure on the 100% DH flow heat balance with 15% margin.

The design temperature for each extraction steam line is not less than the saturated steam temperature at the design pressure. The design temperature of each DH heat exchanger drain piping is the same as that of the upstream DH heat exchanger shell side.

The emergency drain line is sized for the maximum drain flow in the event drains cannot be sent to the downstream DH heat exchanger.

The extraction piping is designed such that the pressure drop from the turbine connection to the DH heat exchangers does not exceed 3% of the extraction pressure at the turbine outlet based on the 100% DH heat balance diagram.

The DH heat exchanger is shell and tube type heat exchanger. It is designed to allow continuous operation at rated capacity including margin, and a standby DH heat exchanger string is installed in case of a failure of the DH heat exchangers during operation.

The DH drain pumps are designed to handle the maximum DH system operation, and the capacity should be designed by adding 10% margin considering the surge or wear in the system. Minimum flow recirculation line is installed at the discharge line of the DH drain pump to protect the DH drain pumps.

Continuous vent is provided for the DH heat exchangers' shells to prevent air and non-condensable gases from accumulating in the shell and to increase the thermal efficiency of DH heat exchangers. The design vent flow rates are based on 100% or 50% DH heat balance conditions and a minimum of 0.5% of the steam entering the DH heat exchangers during normal string operation.

In order to maintain a constant state in the temperature condition for the DH water supplied to the DH heat transfer system, the flow rate of the DH water supplied to the DH heat exchanger is controlled through a DH heat exchanger bypass line flow control valve. The flow rate and temperature of DH water supplied from DH heat transfer system is constant.

Table I shows the difference of several technical requirements for DH system between RFI in 2016 and Bid Invitation Specification (BIS) in 2022.

Table I: Comparison Table for Technical Requirements for District Heating system

Items	RFI (in 2016)	BIS (in 2022)
Heat to supply (MWt)	200	300
Inlet Temperature (℃)	140	156
Outlet Temperature (℃)	65	65
Flow rate (ton/hr)	2273.8	3410.8

2.2 System Description

The District Heating (DH) system transports steam from the main turbine to the DH heat exchanger for the purpose of heating district heating water. The DH system also transports the condensed steam from the

DH heat exchangers to the next lower heat exchangers or the deaerator.

The DH system is composed of three 50% capacity DH drain pumps, one 100% capacity DH drain tank, and three stages of horizontal DH heat exchanger consisting of two 100% capacity parallel strings of three DH heat exchangers each (six heat exchangers in total).

The main turbine consists of one High Pressure (HP) turbine and three Low Pressure (LP) turbines. The extraction steam line connections are located between the main turbine and DH heat exchangers. There are three extraction points such as the second stage from LP turbine, the last (sixth) stage and fourth stage from HP turbine in an order of pressure from lower to higher.

Motor-operated shutoff valves are provided in the extraction steam lines to all DH heat exchangers to permit manual or automatic isolation of the heat exchangers from the steam supply. Power-assisted check valves are also provided in the extraction steam lines to all DH heat exchangers to prevent backflow of steam into the main turbine.

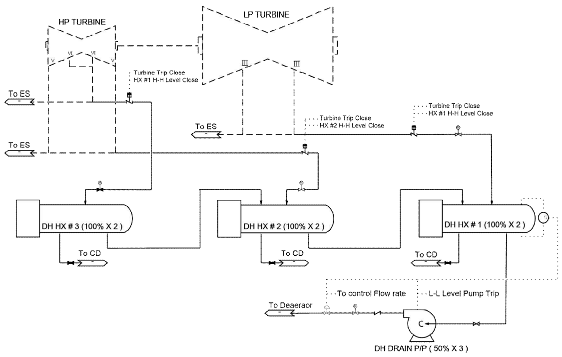

Fig.2. Schematic Diagram of District Heating Steam Supply and Drain System in APR1000

The level control valve in the drain line of each DH heat exchanger automatically maintains normal water level within its respective heat exchangers. Each heat exchanger is equipped with the provision for emergency drainage to the condenser.

All heat exchangers are provided with continuous shell side vents to the condenser to prevent the accumulation of non-condensable gases.

All miscellaneous drains and vents of the heat exchangers (shell and tube sides), except the drain cooler vent, are discharged to the non-radioactive equipment vents and drains system. The drain cooler vents are discharged to the condenser.

Safety relief valves are provided on the tube side/shell side of each heat exchanger to protect the heat exchangers from over-pressurization.

3. Operation of District Heating System in APR1000

3.1 Normal Power Operation

During normal operation, extraction steam from the HP and LP turbines is supplied to the shell side of the DH heat exchangers for DH water heating. Drains from the DH heat exchangers cascade to the next DH heat exchangers and DH drain tank. The drains in the DH drain tank is transferred to the deaerator by DH drain pumps.

During normal operation, the operating DH heat exchanger string shutoff valves and the power-assisted check valves in the extraction steam line are fully opened and the low point drain valves are placed in the auto-mode.

Flow in the normal drain lines from each heat exchanger is controlled by air-operated control valves. The normal drain valve is an air-to-open, fail-closed valve, and it is used to maintain the water level within the heat exchangers during normal operation.

All heat exchanger vents discharge steam and air through restriction orifices to the condenser.

The differential pressure between the DH heat exchangers is the driving force that effects venting during normal operation.

The DH drain pumps are operated with two pumps depending on the level of DH drain tank and one of them is on standby.

The temperature of the DH water supplied to the DH heat transfer system is maintained by the DH heat exchanger bypass line.

3.2 Startup and Shutdown Operation

During DH heat exchangers start-up, the vent orifice bypass valves are opened to rapidly evacuate any non-condensable gases accumulated in the shell. Channel vent and integral drain cooler starting vent valves are also opened. After the venting operation is completed, the vent orifice bypass valves and the start-up vent valves are closed.

During start-up and low load (less than 50% turbine load) operation, the low point drain valves are kept open to prevent moisture from accumulating in the extraction steam lines and back flowing into the turbine. In addition, when the pressure differential between heaters is not sufficient to induce full flow between heat exchangers, the emergency drain valves are modulated to drain part of the flow to the condenser.

The extraction steam supply of the last stage DH heat exchangers is controlled by the turbine control system, from more than 50% turbine load until the extraction steam has sufficient heat supply.

During start-up, the motor-operated shutoff valves in the extraction steam line are manually and sequentially opened from the lowest heat exchanger shutoff valve.

Two of the three DH drain pumps are manually started after ensuring that the DH drain tank level is reached on the normal operation range. After that, the operating pumps are placed in the auto-mode. One of them is placed in the standby-mode.

During shutdown, the low point drain valves are kept open and the motor-operated shutoff valves are automatically closed. And then, operating DH pumps are manually shutdown. The DH drain pump discharge isolation valves are interlocked to close when receiving the DH drain pump shutdown signal.

During an extended shutdown, the shell and tube side of all the heat exchangers, are subject to nitrogen blanketing to minimize corrosion. After shutdown, the heat exchangers are drained, then all isolation valves are closed and checked for proper closure. Nitrogen supply valves are manually and gradually opened to allow the nitrogen to displace the remaining condensate or steam of heat exchangers shell and tube side through the drain valve. This process is performed before the heat exchangers has cooled down. When heat exchangers shell side has been completely replaced by nitrogen gas, the heat exchangers shell and tube side are isolated.

All drains and vents for the shells and tube sides are transported to drain system and condenser.

4. Status on Development of DH System for APR1000

4.1 Development of Heat Balance Diagrams with District Heating

In general, Heat Balance Diagram (HBD) shows the result of calculation for the distribution of the heat energy supplied to a thermomechanical system such as turbine and main steam system among the various drains upon it including both useful output and losses. It is reference data for the detailed design of corresponding systems.

HBDs at 100, 75 and 50% reactor powers with district heating condition have been developed. Fig. 3 shows an example of HBD in district heating condition.

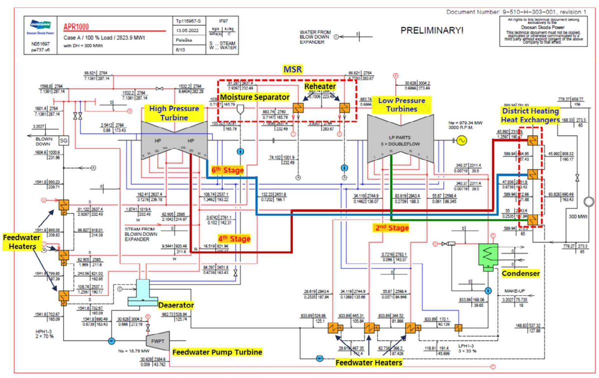

Fig.3. Heat Balance Diagram at 100 % Reactor Power with District Heating (300 MWt)

4.2 Further Study

First, the simulation model of CHP for APR1000 should be developed to test its safety in district heating condition.

Second, the model integrity is to be proven through steady state test at 100, 75 and 50% reactor powers with district heating condition.

Finally, the safety of APR1000 is to be validated through transient tests in district heating condition.

5. Conclusions

KHNP has been developing APR1000 to win the bid for Dukovany unit 5 that requires district heating function to consistently supply 300 MWt in conditions of 50% and more reactor power loads.

In this paper, overall design of DH system for APR1000 is described. In the future, the safety of the system should be validated with a simulation model through steady state and transient tests.

REFERENCES

[1] BIS, “Bid Invitation Specification”, EDU II, Jan. 2022.
[2] RFI, “Request for information for strategic decision-making on the next process of new nuclear power plant construction project,” Ministry of Industry and Trade in Czech Republic, 2016.