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Research Article

Operating experience and ways to improve the performance of the service water supply system at the Novovoronezh NPP II (Units 1 and 2)*

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Abstract

The operating experience of Novovoronezh NPP II-1 shows that, in the summer period, the temperature of the cooling water exceeds the design value: this indicates the insufficient performance of the service water supply system. The main factor that has a negative impact on the performance of this system is the formation of carbonate deposits on the cooling tower filler. At Novovoronezh NPP II-1, the cooling tower water distribution system was cleaned from carbonate deposits by the method of combined vibration and aerohydraulic impact. The tested method of cleaning the filler cannot be considered optimal, since the main stage that determines the entire cleaning duration is the assembly/disassembly of the cooling tower filler. It is necessary to continue research on the choice of a strategy for controlling the carbonate deposition rate, taking into account the revealed influence of the design features of the main cooling water pipelines and pipelines of the cooling tower water distribution system on the mechanism of deposit formation in the peripheral spraying area.

As compensating measures to ensure the required temperature regime of the turbine plant equipment at Novovoronezh NPP II-1, it is practiced during the summer period to put the standby heat exchangers of the lubrication system and the standby pump of the nonessential services cooling water system into parallel operation. This solution is fraught with the risk of an unplanned decrease in the electrical load if this equipment is turned off in the event of a malfunction.

To increase the operating stability of Novovoronezh NPP II-1 and -2 in the summer period, it is proposed to carry out a number of measures aimed at mitigating the negative consequences caused by the elevated service water temperature.

Equipment upgrade options are evaluated, e.g., by installing an additional pump for the turbine building services cooling system and (or) laying an additional pipeline to supply part of the makeup water from the Don River directly to the suction pipelines of the pumps of the turbine building services cooling system.

Keywords

Novovoronezh NPP II, VVER-1200, engineering support, service water supply, operating experience, upgrading, cooling towers

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Introduction

Ensuring efficient and reliable operation of the service water supply system is one of the most important operating tasks – the NPP technical and economic indicators as a whole depend on its successful solution (Ponomarenko 1998, Nikoladze 1989).

At the VVER-1200 power units (Novovoronezh NPP 2006), the main cooling water supply system and the non-essential services cooling water system are designed as part of the general service water system for cooling the turbine condensers as well as heat removal from the unit auxiliary equipment.

The article presents the results of the analysis of the operating experience of these systems and evaluates the possibilities for increasing their performance by optimizing the conditions and operating modes in order to:

- increase the operating stability of the main power equipment; and
- ensure compliance with the conditions of the routine state of the equipment.

Service water supply system operating modes

The design basis conditions of the turbine condenser operation are provided at an inlet cooling water temperature in the range from 12 to 31 °C. Under these conditions, a long-term operation of the turbine is possible, without the need to reduce the power following the deterioration of the vacuum in the condenser (Bodrov and Savelyev 1994). In accordance with the requirements established by the turbine manufacturer (OJSC Power Machines), the allowable pressure in the condenser is 12 kPa. If this value is reached, the operating personnel is obliged to unload the turbine and, as a result, the power unit as a whole (Kostyuk and Frolov 2001, Basic rules of nuclear power plant operation). The issues of the performance of the service water supply system become most acute in the summer period: annually, from May to September inclusive, the cooling water temperature periodically exceeds the maximum design value of 31 °C, which entails a proportional decrease in the power generated by the turbine unit (Fig. 1).

At an elevated cooling water temperature, in order to ensure the required temperature regime of the turbine plant technological systems, it is necessary to put into parallel operation the standby heat exchangers of the lubrication system and the backup pump of the nonessential cooling water system (PCC01AP001 (002)), which increases the risk of an unplanned decrease in the electrical load when they are turned off in the event of a malfunction. Due to the lack of the backup equipment for the service water supply system of the turbine hall consumers (Asmolov et al. 2017), in the event of shutdown of one of the operating pumps, it becomes necessary to reduce the load of the power unit due to insufficient cooling capacity of the

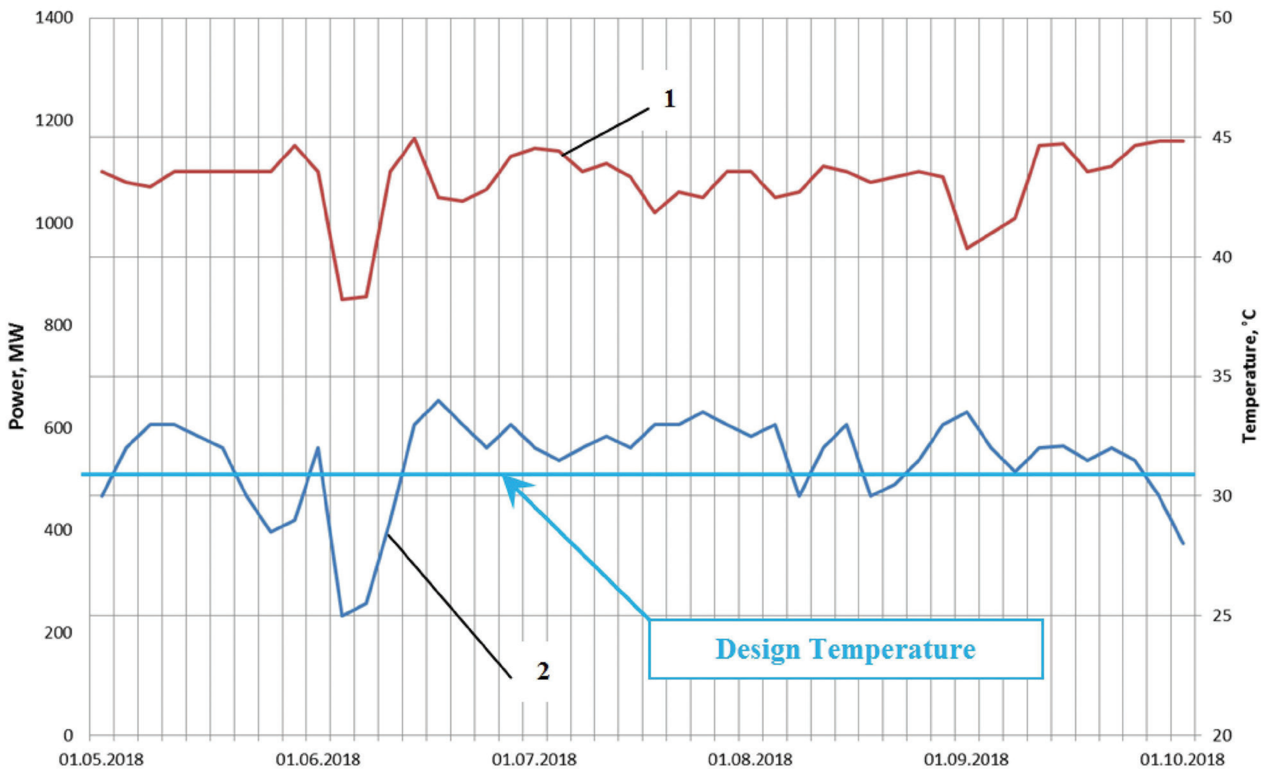

Figure 1. Dependence of the electric power of the unit onthe temperature of the cooling water: 1 – power of the unit, MW; 2 – cooling water temperature.

heat exchange equipment, including the oil coolers of the lubrication system.

In the period from May 1, 2018, to September 30, 2018, the total duration of parallel operation of the 10PCC01AP001 (002) pumps was more than 100 days.

On August 19, 2018, an emergency shutdown of the 10PCC01AP001 pump occurred due to a jammed bearing unit. Fig. 2 shows changes in the operating parameters of Novovoronezh NPP II-1 for the described case and operating mode.

It can be seen that, for the entire repair period, the unit electric power was reduced by about 50 MW.

Moreover, it is necessary to take into account the fact that, when the only operating pump is turned off, for example, for a common reason, the initial conditions for a design basis loss-of-vacuum accident are created in the turbine condenser, with the operation of the corresponding safety systems (Basic rules of nuclear power plant operation, Ostreykovsky and Shvyryaev 2008).

Therefore, the implementation of measures to improve the performance of the service water supply system is currently one of the key tasks of engineering support for operation (Kucherenko and Gladkov 1980, Kopylov et al. 2006).

The most significant factors leading to an increase in the cooling water temperature above the design values include:

- the formation of carbonate deposits on the water distribution system of the cooling tower due to deviations in the indicators of the water chemistry conditions;
- the formation of defects in the water distribution system;
- the design features of the process pipelines and the water distribution channels of the cooling tower.

During the operation of the circulating cooling water systems, due to the concentration of salts, including hardness salts, and the removal of carbon dioxide, water supersaturation with calcium carbonate is achieved, which leads to the formation of deposits on the surface of the heat exchange equipment (Vitkovsky et al. 2017).

The deposits on the cooling tower filler negatively affect its aerodynamic resistance, impairing its air permeability. In addition, with significant deposits, the area of contact between air and water becomes smaller, the filler film-droplet operating mode is disrupted and the efficiency of heat transfer decreases (Laptev and Vedgaeva 2004).

The elevated cooling water temperature, in turn, also leads to accelerated contamination of the heat exchange surfaces of all types (plate and tubular) of coolers and cooling water outlet pipelines of small diameter (DN32 and less) with carbonate deposits.

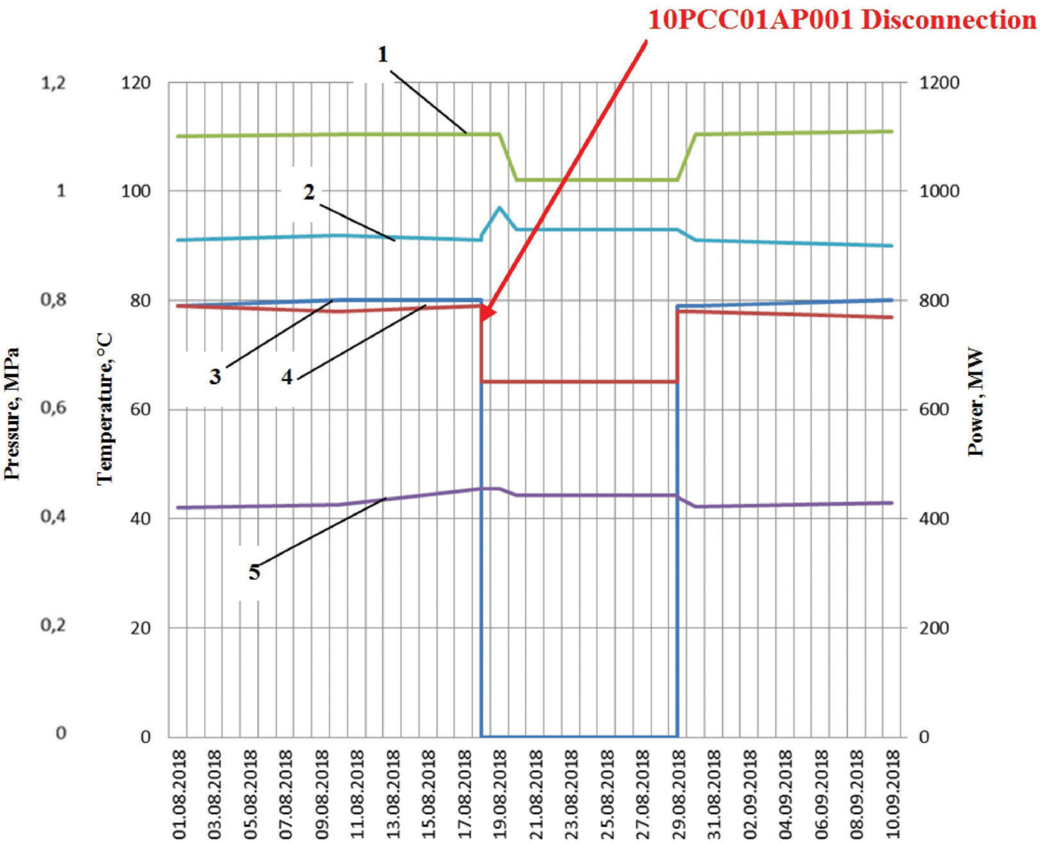

Figure 2. Changes in the unit parameters when 10PCC01AP001:is disconnected: 1 – pressure at the 10PCC01AP001 pump head, MPa; 2 – pressure at the 10PCC01AP002 pump head, MPa; 3 – electric power of the unit, MW; 4 – oil temperature of the lubrication system, °C; 5 – temperature of the babbitt of the turbine bearings, °C; 6 – oil temperature at the discharge from the turbine bearings, °C.

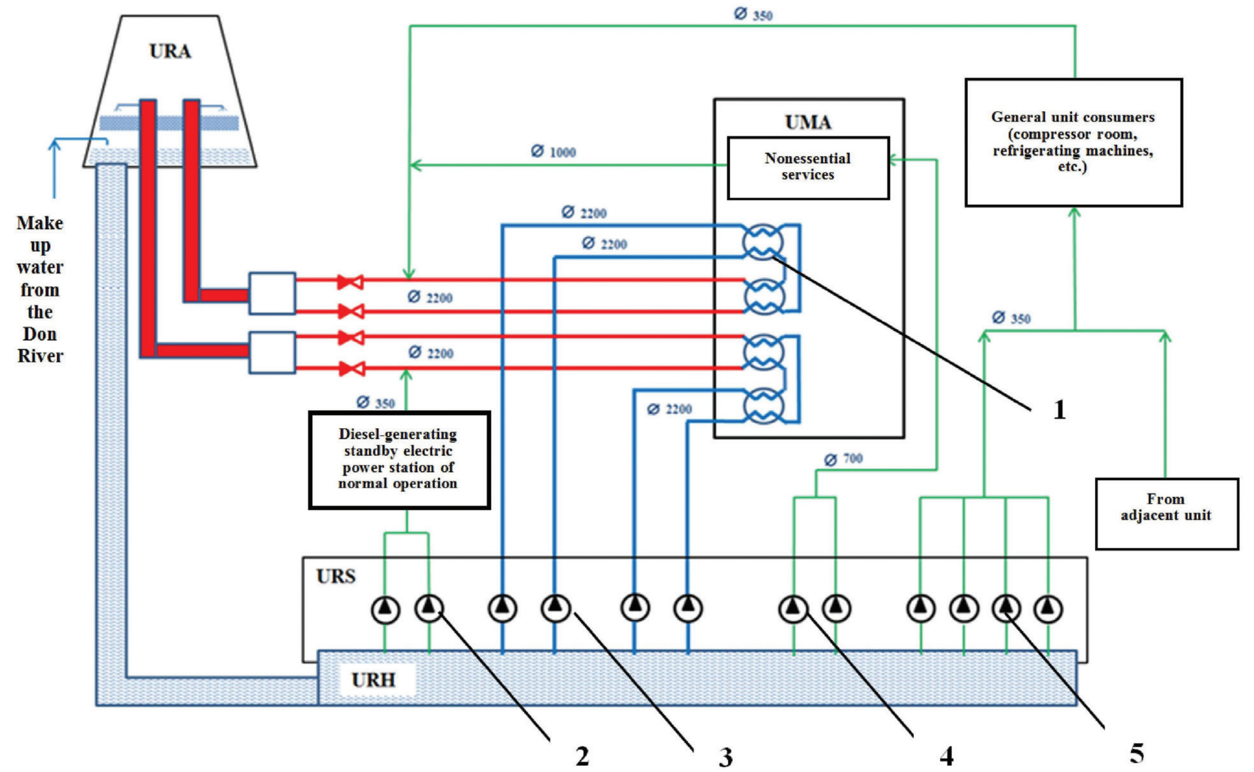

Figure 3. Service water supply system: 1 – turbine condenser; 2 – pumps PCC03 (2 pcs.); 3 – RAS circulating pumps (4 pcs.); 4 – PCC01 circulating pumps (2 pcs.); 5 – PCC04 pumps (2 pcs.); URA – cooling tower; URH – supply channel; URS – unit pumping station; UMA – turbine building (turbine hall).

The formation of carbonate deposits is reduced by maintaining the evaporation coefficient within acceptable limits as well as the calcium transport value at the level of 95–100%. Under these conditions, the rate of formation of deposits on the surface of the filler is within acceptable limits, which is confirmed by the monitoring of the state of the reference samples placed evenly around the periphery of the cooling tower spraying zone (Tiapkov and Krutskih 2018).

A sharp change in the water chemistry indicators is possible with a change in makeup-blowdown mode of the cooling tower bowl, for example, with periodic biocidal treatment of water or with violations due to a decrease in the consumption of makeup water (Lebedik et al. 2016).

Let us consider in more detail the process flow diagram and the design features of the main cooling water system and the nonessential services cooling water system.

The main cooling water system and the nonessential services cooling water system are made in a closed circuit with multiple circulations through the heat exchange equipment, cooling tower water distribution system (URA), cooling tower catchment tank (URH) and unit pumping station (URS). The cooler is a natural draft evaporative cooling tower with a counter-current flow of cooled water and air (Fig. 3).

The heated water passes through four drain pipelines and enters the cooling tower through vertical water-lifting channels to the distribution level.

The inner surface of the drain pipes of the main cooling water system has an anticorrosive polyurethane coating. During the operation of these pipelines, the possibility of local delamination of the anticorrosive coating was revealed, while the delaminated parts can be detached by a stream of water.

The horizontal distribution channels of the cooling tower water distribution system are connected to the top of the vertical water-lifting channels. The water then flows through the lateral distribution pipes to the spray nozzles.

The horizontal distribution channels are made of reinforced concrete and have two versions in terms of connecting the lateral distribution pipes.

For the peripheral zone, channels with an internal dimension of 1200 mm in height were used, the height of the axis of the horizontal distribution pipelines was 700 mm relative to the bottom; for the central zone, channels with a height of 2400 mm were used, the height of the axis of the horizontal distribution pipelines was 1700 mm (Fig. 4).

During the inspection of the cooling tower water distribution system as part of the scheduled preventive maintenance, significant carbonate deposits on the filler were identified and the following observations were made:

1. The formation of carbonate deposits is uneven: significant carbonate deposits were found mainly in the peripheral sectors of the cooling tower filler (Fig. 5).
2. Cases of overlapping the flow area of the nozzles with parts of the delaminated elements of the

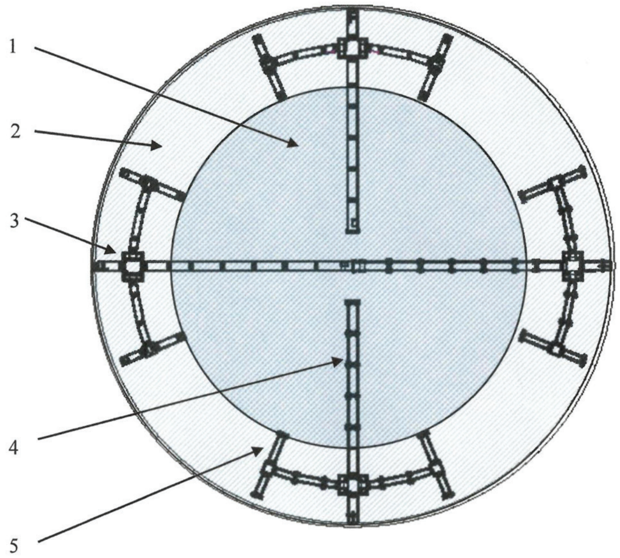

Figure 4. Location of the water distribution channels: 1 – central zone; 2 – peripheral zone; 3 – water-lifting channel; 4 – reinforced concrete channel of the central spraying sectors; 5 – reinforced concrete channel of peripheral spraying sectors.

anticorrosive coating were revealed (Fig. 6). At the same time, the maximum number of clogged nozzles falls on the cooling tower peripheral sectors and has a uniform distribution, similar to the distribution of carbonate deposits on the filler.

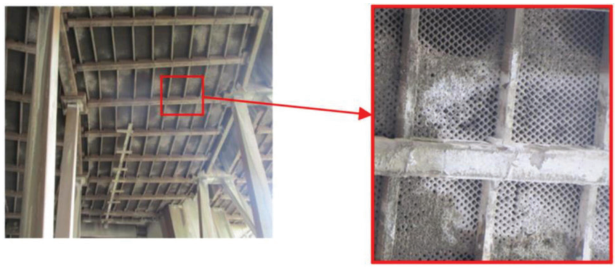

Figure 5. Condition of the filler of the cooling tower peripheral sectors.

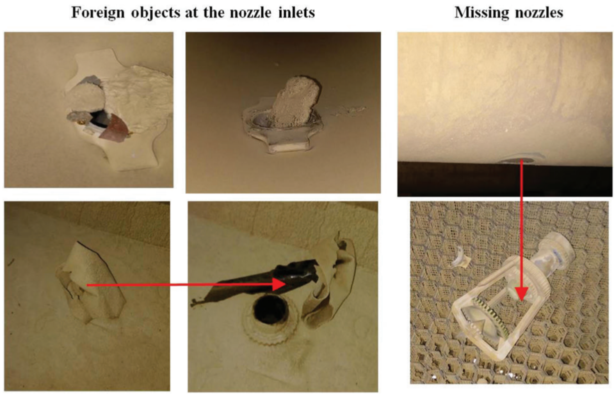

Figure 6. Typical defects of the cooling tower water distribution system.

These facts indicate that the formation of carbonate deposits is caused not only by deviations in the water chemistry conditions of the main cooling water but also by the design features of the pipelines of the cooling tower water distribution system. Foreign objects in the cooling water flow are separated and then deposit mainly on the surface of the water distribution elements of the cooling tower peripheral sectors.

The combination of nozzles that do not work in the design basis conditions, due to the overlap (full or partial) of their inlets, as well as the presence of a certain number of missing nozzles or mechanical damage to the elements of the spray pattern formation parts, up to complete destruction, leads to a deviation of the cooling tower filler operation from the design basis conditions, significantly changing the conditions of heat exchange between air and sprayed water.

Opportunities for solving operation problems

Restoring the required characteristics of the water distribution system – cleaning and removing deposits from the filler, replacing individual filler parts and defective nozzles – require a significant amount of time. The issues of choosing the optimal method and technology for cleaning the cooling tower filler should be considered taking into account its design features, the adopted water chemistry conditions of the circulating water supply system, require separate consideration, and are not the purpose of this article.

In addition to the issues of maintaining the required performance characteristics of the cooling tower water distribution system, it is proposed to consider possible options for measures aimed at compensating for the negative effects of the elevated cooling water temperature on the unit operation.

1. Mounting a crossover between the pressure pipelines of the nonessential services cooling water system of the turbine hall and the pressure pipelines of the cooling water system of the power unit auxiliary systems

To cool the heat exchange equipment of the power unit auxiliary systems (refrigerating machines, compressor plants), pumping units PCC04AP001 ÷ 4 with a capacity of 500 m^3/h, the head of which is 68 m, are used.

Due to the fact that there is a technological possibility of organizing temporary supply power to consumers of the heat exchange equipment of the auxiliary systems from the pumps of the unit pumping station (hereinafter ‘URS’) of any of the units; therefore, it is possible to direct the entire flow from the pumping units PCC04AR001 ÷ 4 through an additional crossover into the pressure pipelines of the turbine hall consumers (hereinafter ‘UMA’).

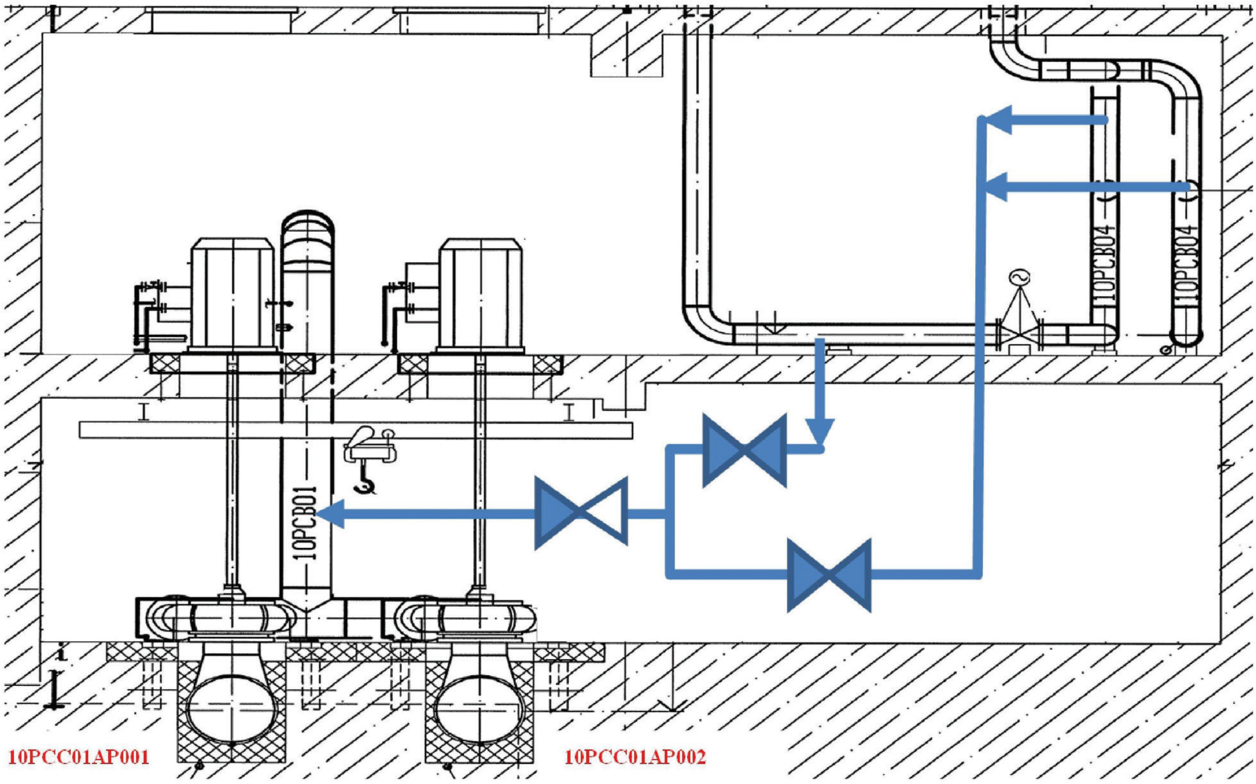

Figure 7. Crossover option.

The crossover can be mounted within the URS building between the pressure section of the cooling water system pipelines of the UMA building consumers (from the PC-C01AP001 (002) pumps) and the pressure section of the water supply pipelines for cooling the consumers of the refrigerating machine building and the compressor building (from the PCC04AP001, 002, 003 pumps, 004) (Fig. 7).

Analysis of water consumption in the nonessential services cooling water system shows that for the consumers of the UMA building, the minimum required flow is at least 2600 m^3/h (for winter conditions), for summer conditions this value is almost doubled. The total possible flow through the considered crossover will be no more than 2000 m^3/h.

The crossover can only be used during periods of simultaneous operation of Novovoronezh NPP II-1 and -2, since it is necessary to ensure constant cooling of the heat exchange equipment of the power unit auxiliary systems (refrigerating machines, compressor plants). This condition is not met when one of the units is taken out for scheduled preventive maintenance and requires a significant amount of technological switchovers to restore the standard cooling system in the event of an unscheduled shutdown of one of the units.

Mounting a crossover between the pressure pipelines of the nonessential services cooling water system will provide the consumption of service water required only to ensure the operation of fast-acting condenser reducing unit (BRU-K), which, depending on the season, is estimated at 600 ÷ 1200 m^3/h, which is ensured by the operation of 2 ÷ 3 PCC04 pumps.

Thus, mounting a crossover between the pressure pipelines of the nonessential services cooling water system can only be considered as a backup shutdown cooling scheme in addition to the existing reactor shutdown cooling systems.

2. Installing an additional pump for the turbine building services cooling system

To reduce the temperature of the process media and the parameters of the main technological equipment of the turbine hall as well as to ensure the routine condition of the equipment, first of all, the backup heat exchangers of the lubrication system, it is necessary to increase the consumption for consumers. Based on the calculations obtained by means of the unit program model implemented in the intelligent operator support system (Gusev et al. 2019), the value of the required flow rate addition is estimated at the level of 1500 m^3/h.

In the URS buildings, it is possible to install an additional cooling water pump for nonessential services with a capacity of 1500–2000 m^3/h (Fig. 8).

The pressure pipe of the additional pump is connected to the common pressure pipe of the PC-C01AP001,002 pumps.

The additional pump will provide an additional supply of cooling water to the consumers in parallel operation with one of the PCC01AP001 (002) pumps, and will also ensure the operation of the standard cooling systems without activating the safety systems in the event of failure of both PCC01AP001,002 pumps.

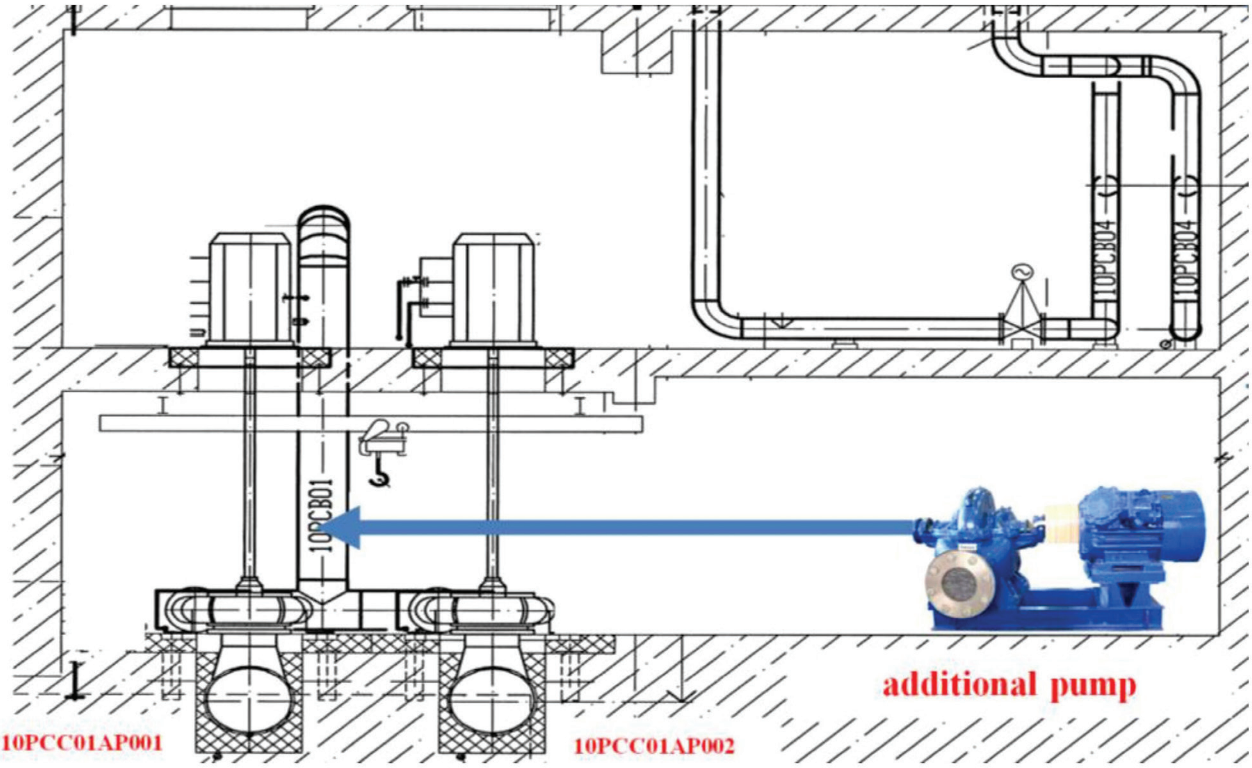

Figure 8. Installation of an additional pump.

3. Laying an additional pipeline to supply makeup water from the Don River to the water distribution channel of the unit pumping station

The temperature of the cooling tower makeup water in the hottest period of the year does not exceed 25 °C, which is significantly lower than the temperature of the cooling water (30 °C and more) circulating in the unit recycling water supply system.

It is proposed to lay an additional pipeline to supply makeup water with a flow rate of up to 1000 m^3/h directly to the suction of the PCC01AP001,002 pumps bypassing the main makeup line, which is brought into the cooling tower bowl. In this case, the total amount of makeup water supplied from the Don River to the service water supply system will remain unchanged, and the temperature of the water supplied to the UMA building consumers will decrease due to the addition of colder makeup water.

Conclusion

The need for measures to upgrade the nonessential services cooling water system is based on the operating experience and monitoring of the heat exchange equipment, and is aimed at:

- enhancing the power unit ability to carry a given load;
- increasing the power unit equipment operating stability of the main power equipment;
- mitigating possible consequences of system equipment failures;
- ensuring compliance with the conditions of the routine state of the equipment; and
- creating the necessary equipment reserve.

Of the considered modernization options, priority should be given to the measures related to installing an additional pump and laying a pipeline for supplying ‘cold’ water directly to the suction of industrial water supply pumps. The implementation of these measures will make it possible to have the necessary equipment reserve and ensure the design thermal characteristics of the equipment.

The implementation of measures related to ensuring the possibility of cooling the unit in case of failure of the PCC01AP001.002 pumps through the BRU-K due to a crossover mounted between the pressure pipelines will not provide a full-fledged reserve for the existing safety systems aimed at ensuring the transfer of the reactor plant to a ‘cold’ state, since the nonessential services cooling water system does not affect safety, and, in accordance with (NP-001-15 2016), has a classification designation ‘4H’. Thus, if implemented, it will require significant time and material costs in order to justify the possibility and feasibility of using this solution to prevent accidents.

To maintain the efficiency of the cooling tower water distribution system, in order to minimize carbonate deposits on the filler, first of all, it is necessary to provide the required water chemistry conditions of the cooling tower makeup water (RB-002-16 2016). It is also necessary to continue research on the choice of a strategy for controlling the rate of formation of carbonate deposits, taking into account the revealed influence of the design features of the main cooling water pipelines and pipelines of the cooling tower water distribution system on the mechanism of deposits formation in the peripheral spraying area. The method for cleaning the filler tested at the Novovoronezh NPP II by means of combined vibration and aerohydraulic impact on individual filler parts cannot be considered optimal, since it is associated with partial disassembly of the filler, and the main stage that determines the entire cleaning duration is the filler assembly/disassembly.

Given the significant impact of the service water system on the economy and reliability of the unit, as well as the commissioning of new power units with service water systems similar to those of the Novovoronezh NPP II in the composition and characteristics of the basic equipment, there is a need for a centralized service, the objective of which will be to ensure the effective operation of the NPP service water system.

The limitation of the power unit capacity associated with service water supply is a serious problem not only as a factor reducing the installed capacity but also as a possible reason for a decrease in reliability and deterioration in the performance of the unit as a whole.

Improving the performance of the service water supply system is a complex task: to successfully solve it, a number of measures should be implemented both to optimize the operating conditions of the unit heat exchange equipment and to select the optimal strategy for managing the state of the cooling tower water distribution system.

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