9. STEAM AND POWER CONVERSION SYSTEM

This Section provides design and operating parameters for the turbine, the generator, the steam supply system and associated equipment.

9.1 MAIN STEAM SUPPLY SYSTEM

Steam is supplied to each turbine by means of 8 steam pipelines (630x25) mm from each of the 4 steam drums (see Section 5.4). The pipelines include isolation valves, instrumentation and control sensors, valves used to heat up the drainage pipes, plus SDV-D and SDV-C valves. Each pipeline is supplied with one flowmeter and two Main Steam Isolation Valves (MSIV-I) and MSIV-II with bypasses. The MSIV-I bypasses are intended to decrease the pressure difference across the valve during its opening. Four of the MSIV-II have two bypasses, each with an isolation valve and a regulating valve, making it possible to vary the heat up rate of the turbine and regulating valves. Two SDV-D valves are connected upstream of the MSIV-I by means of branch pipes. Downstream branch pipes connect to the SDV-C valves. Drainage is provided to empty and to heat up the pipelines.

The SDV-C valves are described in the Subsection 5.4.1.1. SDV-D are fast acting isolating and regulating valves, and can be controlled either manually from the MCR or automatically by a regulating device. There are two SDV-D valves, each rated at 201.4 kg/s. They are used to decrease main steam pressure down to the pressure in the steam header for in plant needs, and for the heating of deaerator feed water. The technical specifications of the SDV-D valve is presented in the Table 9.1.

Equipment and piping of the system are located in a limited access zone in the main section of the main building in rooms periodically accessed by personnel. All these rooms and corridors are vented to the environment (i.e., a discharge from the steam line break

Table 9.1 Fast-acting steam discharge valve to deaerators (SDV-D) [62] (type 1034-300/300-E, manufacturer - Tchechovskoy Plant of Energy Engineering, Russia)

Number per reactor	2
Capacity, kg/s	201.4
Equivalent diameter, inlet/outlet, mm	300/300
Working pressure, MPa	7.1/4.2
Working temperature, ^{o}C	285
Time to full opening, s	10
Maximum cross-section of valve gate, cm^2	286
Average lifetime, years	30
Weight, kg	1353

is not confined). Some of the rooms are equipped with pressure gauges which are tied into the emergency protection system. A break in these rooms (i.e., in the compartment of the reactor building) will trip the reactor, and it will initiate ECCS flow within about two seconds.
Both the short-term as well as the long-term ECCS functions are activated. The remaining compartments and corridors (i.e., the volumes within turbine building) do not have any pressure gauges to provide an excess pressure signals to the emergency protection system. If a steam piping break should occur in any of these rooms, reduction of reactor power and long-term ECCS are initiated by out-of-range readings of steam flow parameters.

9.2 TURBINE AND CONDENSER

The steam turbine is a condensing turbine of type K-750-65/3000. It is designed to work together with reactor RBMK-1500, has single stage intermediate steam superheating and no regulated steam bleeds. It is intended to drive an AC generator of type TVV-800-2 at 800 MWt power, to carry the base part of the load, to provide normal and emergency regulation of power to an external grid and to cover the variable part of the load. The turbine is assembled on a single shaft and has five cylinders, which includes one high pressure cylinder and four low pressure cylinders with eight discharges and four condensers. The technical specifications of the turbine are presented in the Table 9.2.

The high pressure cylinder uses a two-stream design. There are 6 pressure cascades in each stream. Cascades 1, 2, 3 of each stream are placed within the inner case. Cascades 4, 5, 6 are placed in two casings - cascades 4 and 5 are placed in the first casing along the stream flow, cascade 6 is placed in the second one. The inner case, casing and outer case form the circular chamber, from which steam is bled-off to the condenser. The circular chamber, formed by the casings, is used for steam bleed-off to the Low Pressure Reheater - 5 (LPR-5). The low pressure reheaters are described in the Section 5.5.

Steam distribution in the turbine is of the throttle type. The steam intake chamber is cast together with the inner case, and steam is supplied into the lower half of the High Pressure Cylinder (HPC), where two flanges are placed to connect the steam supply branching pipes from the Turbine Isolating and Regulating Valves (TIRV). From the HPC steam passes through four lines to the four steam-separator reheaters. The steam-separator reheater SPP-750 is constructed from a single vessel. The heating steam (live steam, pressure

6.5 MPa) to the reheater is removed ahead of HPC. In the separator water drops are separated from the steam and the steam is reheated, (steam moisture after the last stage of the high pressure cylinder is 14.7 %, and after the reheater it is 1.0 %). Technical specifications of the steam-separator reheater are presented in the Table 9.3. From there the steam is fed to the Low Pressure Cylinders (LPC). Each of the four LPC is of two-stream design with five pressure cascades in each stream.

Table 9.2 Main technical characteristics of the turbine K-750-65/3000 [62]

Number per reactor	2
Power, MW	750
Type of steam distribution	throttle
Design structure of turbine	2LPC-HPC-2LPC
Number of cylinders, pcs	2
Number of LPC discharges, pcs	8
Number of cascades in HPC, pcs	6x2
Number of cascades in each LPC, pcs	5x2
Rotation speed of rotor driven by rotor device, rpm	3.8
Nominal rotation speed of turbine rotor, rpm	3000
Length of working blade of last cascade of HPC, mm	1030
Dimensions of turbine (without condenser):	
length, m	40.6
height from maintenance level, m	5.2
width (measured with HPC balcony), m	8.7
Absolute pressure of live steam:	
nominal, MPa (kgf/cm^2)	6.38 (65.0)
maximum (in case of trip of one turbine), MPa (kgf/cm^2)	7.55 (77.0)
Nominal temperature of live steam, °C	279.5
Dryness of live steam:	
nominal	0.995
minimal	0.99
Maximum mass flow rate of live steam to the turbine, including mass flow rate of heating steam to intermediate circuit, kg/s (ton/h)	1222 (4400)
Calculated steam dryness after separation	0.99
Calculated absolute pressure in condenser given calculated temperature of cooling water equal to 15°C and flow rate 122600 m^3/h (to 4 condensers), kPa (kgf/cm^2)	4.41 (0.045)
Maximum temperature of cooling water, when reliable turbine operation is ensured (with decrease of power), °C	33
Absolute pressure of steam in turbine seals, MPa (kgf/cm^2)	0.108 (1.1)
Absolute pressure of steam incoming into LPC, MPa (kgf/cm^2)	0.485 (4.94)
Temperature of steam after separator - steam reheater, °C	263

Intake of steam occurs symmetrically from two sides into the lower half. Discharge branch pipes of the LPC are connected to an intermediate pipe and to a condenser by welds. Steam bleeds are located in each LPC after cascades 1, 2 and 4. Steam comes from bleeds to LPR-3, LPR-2 and LPR-1 correspondingly.

The main turbine shaft consists of five rotors, connected to each other. It is connected to the rotor of

Table 9.3 Technical specification of steam-separator reheater SPP-750 [62]

Number for one turbine	4
Thermal power, MW	48.1
Hydraulic resistance, kPa (kgf/cm^2)	2.45 (0.025)
Parameters of reheated steam at the inlet:	
flow rate of wet steam, kg/s	212
pressure, MPa (kgf/cm^2)	0.47 (4.8)
temperature, °C	149
humidity, %	15.3
maximum pressure MPa (kgf/cm^2)	0.69 (7.0)
maximum temperature, °C	164
Parameters of reheated steam at the outlet:	
steam flow rate, kg/s	181
humidity, %	1.0
steam temperature, °C	263±3
Parameters of heating steam at the inlet:	
flow rate, kg/s	31.1
pressure, MPa (kgf/cm^2)	6.19 (63.1)
temperature, °C	278
humidity, %	0.6
maximum pressure, MPa (kgf/cm^2)	7.36 (75.0)
maximum temperature, °C	289
Height, mm	13240
Outer diameter of the case, mm	4000
Case wall thickness, mm	24
Weight:	
dry, kg	162000
filled with water, kg	264000
Filled volume:	
total, m^3	102
case, m^3	77
tubes with upper and lower chambers, m^3	25
Total surface of flow to the shutter, m^2	29.2
Number of tubes in the bunch of steam reheater, pcs	8420
Outer diameter of tube of the bunch, mm	16
Wall thickness of tube of the bunch, mm	2
Design length of heat exchanging part of tube bunch, mm	8200

Outer heat exchanging surface of tube bunch, m^2	3468
Width of tube bunch desk, mm	400

a generator by stiff clutches. The rotor of the LPC is welded and stiff, the rotor of the HPC is forged from a single piece and is flexible. Turbine design makes it possible to remove moisture from the steam flowing through the turbine and thus keep steam humidity at a minimal level. The turbine case, blades and rotor seals are designed to resist erosion and corrosion caused by wet steam. The surface of the horizontal joint, contacting surfaces of diaphragms of the inner case and the casing of the LPC are clad with stainless steel. In case of steam flow through the horizontal joint of the HPC provisions are made for the removal of drainage water. The turbine includes a special sprinkler device to the discharge branch pipe of the LPC to prevent its overheating during startup and when the turbine load is below 150 MWt.

The turbine is equipped with a regulating and protecting system, which provides control of turbine operation and automatic maintenance of required parameters during power operation of the turbine, during loading, unloading, start-up and shut-down. It protects the turbine from over speeding and initiates an emergency trip in accident conditions. The automatic regulation and protection system is an electric hydraulic system which can be controlled in two ways - employing the hydraulic or the electric hydraulic control mechanisms.

Standard control is based on an Electric Hydraulic Control System (EHCS). It is provided by the electronic part of the regulation system ASUT-750. EHCS, as the principal means to regulate the turbine.

A Hydraulic Control System (HCS) serves as an auxiliary means of control. This system is provided with hydraulic sensors monitoring the rotation speed of the turbine rotor (impeller and sliding valve of the speed regulator), hydraulic components for regulating feedback and mechanism of turbine control. The HCS is in a standby mode if EHCS is in operation.

An automatic regulation and protection system actuates TIRV drives, which are used to supply and to regulate the steam flow through the turbine within the operating margins for the EHCS and HCS modes. The system features the ability of HCS to affect EHCS operation by a ball relief valve. This valve performs a protective function and serves to mitigate consequences in case of loss of electric load and failure of EHCS.

An automatic ring type safety device is provided to protect turbine from exceeding rotor rotation speed limits. The device is actuated, if the rotor rotation speed increases by 10-12% above nominal values. Actuation of any ring in the device leads to closure of all TIRVs. Test of the rings and sliding valves, which are controlled by the rings, can be performed by an increase of rotation speed or by modulation of the oil supply to the rings at nominal rotation speed. After actuation of the safety device, reopening of the TIRV is possible only after the rotor rotation speed is decreased down to 3050 rpm.

The turbine is provided with two redundant electromagnetic protecting devices. These are actuated by the following conditions:

- local manual actuation,
- remote manual actuation by the turbine trip key,
- actuation of protective measures which generate a turbine trip.

Actuation of any of protecting devices leads to closure of the TIRVs.

Measures designed to prevent a turbine run-away during a turbine emergency trip due to backflow of steam from the LPR and the header of the in-house steam supply, and to prevent ingress of a steam-water mixture from the reheaters into the turbine include: check valves of KOS type installed in steam supply pipes from bleed-off to LPR-2, 3, 5, in pipes to the header of the in-house supply and in pipes to boilers of the intermediate circuit of district heating. Each check valve includes a hydraulic drive, which is actuated by condensate through two automatic valves. The valves are controlled by electric magnets. The magnets are controlled by a signal coming from either the end breakers, which are installed on the drives of the TIRV, or from generator circuit breakers.

Spent steam from the LPC is directed to turbine condensers (type K-16560). The turbine condenser is intended to condense waste steam coming from the turbine. In addition to this, the condenser receives steam bypassing the turbine (from SDV-C valves) during startup and during transient operation modes. It is also used to collect leaks and blowdown water coming from equipment and valves. There are 4 condensers installed for one turbine. They are single-flow, two-path condensers with provisions for the removal of noncondensable gases located in the central section. The technical specification of the turbine condenser is presented in the Table 9.4.

Each condenser has atmospheric valves, which protect the condenser from excessive pressure loads. Atmospheric valves are designed for pressures of 103 kPa. Because of the vacuum in the condenser, air enters through any available openings. This air and noncondensable gases are removed from the central part of the condenser by the main steam ejectors. The noncondensable gases include hydrogen and oxygen which, if present at certain concentrations, can form an explosive mixture. The hydrogen is generated by radiolysis, when the two-phase water-steam coolant passes through the reactor core. An ejector propels this gas mixture into a combustion chamber where recombination of H_2 occurs. The resulting vapor-gas mixture is then directed to the de-contamination unit where the activity of gas-air mixture is reduced before it is released to the atmosphere. The technical specification of the main steam ejector is presented in the Table 9.5.

Table 9.4 Technical specification of turbine condenser K-16560 [62]

Number per turbine	4
Cooling surface, m^2	16560
Calculated mass flow rate of condensed steam, kg/s (ton/h)	176.4 (634.91)
Absolute steam pressure near condenser flange, kPa (kgf/cm^2)	4.41 (0.045)
Temperature of cooling water:	
in the inlet, °C	15
in the outlet, °C	26
Number of cooling tubes, pcs	16440
Dimensions of cooling tubes, mm	28x1, 28x2
Active length of tubes, mm	11460
Tube material	copper-nickel alloy
Number of water passes, pcs	2
Mass flow rate of cooling water, kg/s (ton/h)	8514 (30650)
Water speed in the tubes, m/s	1.95
Hydraulic resistance in water piping, kPa (kgf/cm^2)	51.0 (0.52)
Hydraulic resistance in steam piping, kPa (kgf/cm^2)	0.432 (0.0044)
Permissible absolute working pressure in the water volume, kPa (kgf/cm^2)	196.2 (2.0)
Condenser weight in working conditions, kg	572000

The condensate is retrieved from the turbine condensers by two groups of condensate pumps. Each group consists from three pumps (one is on stand-by) for each turbine (see Section 5.5).

9.3 GENERATOR

The turbine generators convert mechanical energy of the rotating turbine shaft into three-phase a.c. 50 Hz 24 kV electricity. Operating together with a 24/330 kV main transformer, the generator supplies power to the grid at 330 kV. Under normal operating conditions, the generator serves as the in-house power source (via service transformers 24/6 kV).

Each unit is equipped with two TVV-800-2UZ turbine generators. A rigid coupling connects the generator with the steam turbine. The generator is a synchronous three-phase electrical machine. The excitation system is powered from an auxiliary three-phase synchronous 50 Hz generator (exciter) which is connected with the shaft of the main generator by a rigid coupling. The technical specifications of the generator are presented in Table 9.6.

Table 9.5 Technical specification of the main turbine ejector of EPO-3-220 type [62]

Number per turbine	4
Steam pressure , MPa (kgf/cm^2)	0.785 (8)
Steam temperature, °C	172
Steam flow rate , kg/s	1.055
Capacity related to Steam-Gas-Air Mixture (SGAM), kg/s	0.06
220 Pressure of SGAM after I cascade, kPa, (kgf/cm^2)	0.402 (0.0041)
Temperature of SGAM after I cascade, °C	23
Pressure of steam in the discharge, MPa (kgf/cm^2)	0.11-0.13 (1.1-1.3)
Flow rate of cooling water, kg/s (ton/h)	152.8 (550)
Temperature of cooling water, °C	31
Length of hydraulic lock between second and third cascade, m	8
Length of hydraulic lock between first and second cascade, m	4

The generator cooling system is designed as follows: stator and rotor windings are cooled directly by distilled water and hydrogen, respectively, while the active steel parts of the stator are cooled indirectly by hydrogen. The generator has been designed as a closed sealed machine. The gas-tight body consists of three sections: a central section and two end sections. The central section which contains the stator core with the windings is integral. The stator winding is three-phase, two-layer.

The winding rods are braided from solid and hollow conductors. To cool the winding, distilled water flows in hollow conductors. Outer stator shields are combined with inner shields to which the shields of the internal fans are connected. All sections of the fan shields are isolated from the inner shields and from each other. The generator rotor is a single-piece forging made from special steel which ensures its mechanical strength under all operating conditions. The rotor winding is made of copper bars with a silver additive. Wedges which hold winding in slots have intake and outlet holes to let the cooling gas in and out. The holes coincide with internal channels in the conductors of the winding coils. The rotor winding is cooled directly by hydrogen in a self-ventilation pattern, with gas taken from the air clearance in the machine. Hydrogen circulates in the generator body driven by fans installed on the rotor shaft. To cool hydrogen circulating in the body, four gas coolers are installed in the end sections of the generator.

Each generator has its own excitation system; there is also a backup excitation system shared by two generators. The change from one system to the other is

Table 9.6 Main characteristics of turbine generator TVV-800-2UZ [62]

Number per reactor	2
Full capacity, kVA	889000
Active power, kW	800000
Stator voltage, V	24000
Stator current, A	21400
Rotor current, A	3800
Rotor voltage, V	600
Capacity factor	0.9
Efficiency, %	98.75
Connection of stator winding phases	Star-to-star
Frequency, Hz	50
Rotational speed, rpm	3000
Flywheel torque, TM^2	56
Critical rotational speed, rpm	690/1960
Nominal hydrogen overpressure in the body, kPa	490
Nominal distillate overpressure at the stator winding inlet, kPa	442
Nominal temperature of incoming distillate, °C	40
Permissible temperatures:	
Temperature of generator stator winding, °C	75
Rotor winding temperature, °C	115
Temperature of active stator steel, °C	105
Distillate temperature at stator winding outlet, °C	85
Temperature of hot gas in the generator body, °C	75
Temperature of hot gas at the brush cross-arm outlet, °C	75
Oil temperature at bearing/sealing inlets, °C	45
Oil temperature at bearing/sealing outlets, °C	65
Maximum permissible excess of rotor winding temperature over temperature of incoming cold hydrogen (40°C), °C	75

performed by operators manually. The systems can be changed when the generator is operating within the grid. Slip-rings which supply excitation d.c. to rotor winding are installed on the rotor shaft downstream from the bearing on the exciter side. An excitation current is supplied to the slip-rings by a brush cross-arm. The cross-arm with the brushes is mounted on the foundation-plate near the bearing. The slip-rings and the brush set are cooled and ventilated by fans mounted on the rotor shaft between the slip-rings, with air taken from the turbine hall.

The joints connecting the stator body and outer shields are sealed by rubber seals. Inner shields (relative to the stator body) are sealed with a circular rubber cord. Mechanical strength of all parts of the body and outer shields is sufficient to withstand pressure resulting from hydrogen explosion inside the generator. The generator shaft sealing system prevents hydrogen leakage along the rotor shaft penetrations via end shields of the generator body.

Thrust bearings in the generator are of a stack type, they are movable, with a self-positioning ball insert. The bearing installed on the exciter side is isolated from the foundation-plate and oil pipelines to avoid bearing currents. Exciter bearings are isolated from the fourndation-plate as well.

To make the system explosion-proof, the generator and the auxiliary systems are equipped with instruments monitoring hydrogen leakage. Signals from the sensors are picked up by the MCR. In case hydrogen appears in the bearing casings, gas trap and other locations, the operator injects nitrogen there to prevent formation of an explosive mixture. Hydrogen composition in the generator body is monitored continuously.

All generator systems holding oil are equipped with foam fire extinguishers. Other fire extinguishing means are available near the generator and serve to confine potential ignition locations in small volumes. Nitrogen supply is provided to extinguish fire in the generator body, exciter, bearings, seals, 24 kV current buses.