10.2A Turbine-Generator

Depending on site specific data, equipment availability and utility requirements, alternative designs for the steam and power conversion system may be considered by the applicant for a combined license (COL). An optional design description for the turbine generator (TG) is provided in Section 10.2A. The alternative section outlines the changes to support the use of an optional TG design. Those areas of the U.S. EPR design not affected by selection of the optional TG design are so identified within the alternative section. Only one of the design descriptions is used by the applicant within the site-specific FSAR[1].

This section is the same as for the U.S. EPR (see Section 10.2).

10.2A.1 Design Bases

Same as for the U.S. EPR (see Section 10.2.1).

10.2A.2 General Description

The TG package is shown in Figure 10.2A-1—Turbine-Generator System. Performance characteristics are provided in Table 10.2A-1—Performance Characteristics.

The design and valves wide open (VWO) heat balances are presented in Section 10.1A (refer to Figures 10.1A-1 and 10.1A-2).

The turbine consists of an 1800 rpm, double-flow, high pressure (HP) element and three double-flow, low pressure (LP) elements in tandem. The generator has a hydrogen-cooled rotor and a water-cooled stator. The generator is directly coupled to the turbine shaft. It is equipped with a collector for the static excitation system directly coupled to the generator shaft. Moisture separation and reheating of the steam is provided between the HP turbine and LP turbines by two combined MSR assemblies. The MSRs have two stages of reheating.

10.2A.2.1 Component Description

Same as for the U.S. EPR (see Section 10.2.2.1).

10.2A.2.1.1 TG Package Equipment

The TG package equipment includes the HP turbine stop and control valves, reheat stop and intercept valves, MSRs, MSR drain tanks, steam lead piping, cold reheat piping, hot reheat piping, TG control system static excitation system and accessory

1. This paragraph denotes instructions for reviewers and other readers. It is not an integral part of the text.

equipment listed in 10.2A.2.1.2. A COL applicant that references the U.S. EPR design certification, and selects the alternate turbine, will provide a list of material specifications for the alternate turbine-generator components.

HP Turbine

The HP turbine design features a double flow HP turbine. The HP steam admissions are located at the center of the turbine and the exhausts at its two extremities. The HP turbine receives steam through four steam leads, one from each main steam control valve outlet. The steam is expanded axially across the stationary and rotating blades. Extraction steam from the turbine at two locations supplies the sixth and seventh stages of feedwater heating and the heating steam to the first stage reheaters. HP turbine exhaust steam is collected in four cold reheat pipes (two per MSR). Most of the exhaust steam is routed to the MSR inlet, but part of it is diverted and supplies the fifth stage of feedwater heating. After removal of the water content and reheating in the MSRs, the steam is directed through six (three per MSR) hot reheat steam pipes to the three LP turbines.

LP Turbines

Each of the three LP turbines receives steam from the MSR outlets. The LP turbines are identical double-flow turbines. The LP turbines are constructed of an inner casing and outer casing. The inner casing structure supports the LP blade carriers and the LP bearings. The outer casing collects the steam exhausted from the last LP stages. The outer casing is installed independently of the inner casing and is welded to the condenser, which is directly anchored to the foundation slab. The outer casing moves freely with condenser thermal movements. All connections between the outer casing and inner casing have flexible expansion joints that maintain vacuum tightness. The casing is provided with a piping header that allows water to be injected into the exhaust structures and prevents an excessive temperature rise during no-load or low-load operation. Each LP turbine has four extraction stages that are routed to the LP feedwater heaters.

HP Main Stop and Control Valves

Same as for the U.S. EPR (see Section 10.2.2.1.1).

Reheat Stop and Intercept Valves

The reheat stop and intercept valves are arranged between the MSRs and LP turbine inlets. The LP steam admission is controlled by six sets of two series-mounted individual valves. One valve fulfills a protection function (stop valve), and the other, a control and protection function (intercept valve). The valves are butterfly type valves. The disc of each valve can rotate 90 degrees, from closed to open position, by means of a servomotor. The stop and intercept valves close in approximately 0.30 seconds.

Generator

The generator is directly driven by the turbine and supplies the step-up transformer with high voltage. It is a four-pole machine and is cooled by internal hydrogen circulation and stator cooling water. The field winding is directly cooled by hydrogen gas. The stator winding is directly cooled by an internal circulation of deionized water (stator cooling water). The auxiliaries include cooling system, gas supply and shaft sealing circuits. The generator static excitation system is controlled by an automatic voltage regulator. The frame, which constitutes the outer envelope, is made of fabricated steel. The outer casing is gas-tight after field assembly. Hydrogen detectors are located around the generator hydrogen system to provide warning of a hydrogen leak. The generator hydrogen system is designed in accordance with NFPA 55 (Reference 2). The generator rotor is forged from solid alloy steel stock.

Moisture Separator Reheaters

Two cylindrical-shell, combined MSRs are installed in the steam path between the HP and LP turbines. The MSRs dry and reheat the HP turbine steam exhaust. Cold reheat steam is piped into the MSR. Moisture is removed in chevron type moisture separators, drained to the moisture separator drain tanks and then drained or pumped to the feedwater deaerator storage tank. The dry steam then passes across two stages of reheaters, which are supplied with turbine extraction steam (first reheating stage) and main steam (second reheating stage). The steam is then routed to the hot reheat stop valves/intercept valves, which are located just upstream of the LP turbine inlet nozzles. The reheaters drain via drain tanks to the HP heaters. Safety valves are provided on the MSR for overpressure protection.

10.2A.2.1.2 TG Accessories

Same as for the U.S. EPR (see Section 10.2.2.1.2).

10.2A.2.2 TG Foundation

The TG foundation structure consists of a top reinforced concrete mat resting on spring elements. The mat on springs provides vibration isolation from the other Turbine Building structures. The top mat consists of longitudinal beams and transverse beams and carries the weight of the HP turbine, LP turbines and generator. The total machine weights, operational static and dynamic forces, as well the emergency forces, are transmitted from the top mat through spring elements into the substructure. The foundation is designed to withstand normal loads and abnormal loads under all TG operational conditions. Anchoring systems are designed to withstand these maximum loads.

The TG foundation is referred to as a low tuned foundation. This means that the fundamental vertical frequency is much lower than the rotational speed of the shaft.

The turbines and generator are mounted on steel base plates, which are grouted and bolted to the top mat. Transverse and axial guides are provided to prevent misalignment of the shaft due to thermal expansion, external pipe forces or an earthquake.

Intermediate steel platforms, which are also vibration isolated, are located below the turbines and the generator to provide access for the operational inspection of valves and other auxiliary equipment.

Transverse walls are located below the condenser bottom plate to transmit the weight and forces to the base mat of the Turbine Building. Each condenser shell is rigidly attached to its LP turbine exhaust and is supported on the basemat of the Turbine Building.

10.2A.2.3 Cycle Description

The main steam flows from the MSSS through the four combined main steam stop and control valves into the HP turbine. After expanding across the HP blading, the steam passes through the steam exhaust branches into the cold reheat piping system. There is a preseparator in each cold reheat line. Steam passes to each of the two MSRs in two cold reheat lines.

The first stage reheat steam is supplied from the HP turbine through an extraction line. The second stage reheat steam is supplied from the MSSS or from connections downstream of the stop valve. Condensed steam from the second stage reheater is drained to a drain tank and then flows to the shell side of a drain cooler, which is the last stage of feedwater heating. Condensed steam from the first stage reheater is drained to a drain tank and then flows to the shell side of the No. 6 feedwater heaters. The moisture removed from the MSRs is drained to a drain tank, and then drained or pumped to the deaerator.

Two extraction lines are connected to the HP turbine. The steam goes to the HP feedwater heaters No. 6 and No. 7. The steam passes from the two MSRs into the hot reheat piping system and then through six LP stop-intercept butterfly valve assemblies to the three LP turbines.

Each LP turbine has a total of four extraction stages. No check valves are necessary in the two latter extraction lines since the pressure level in the associated feedwater heaters is low. One free-swinging and one actuator-assisted swing check valve are provided in each of the other extraction lines.

The turbine casings, turbine valves and turbine piping are provided with drain valves or traps for removing condensate during startup and transient operation.

The turbine shaft seals are fitted with connections to the gland steam system. The leakage from the main steam valve glands flows to the gland steam system. The glands of the intercept valves are connected to the gland steam system.

10.2A.2.4 Excitation System

A static excitation system incorporates automatic voltage regulating, excitation cubicles and three single phase excitation potential transformers connected to a three phase transformer bank. Also included is an isolated phase bus duct connecting the excitation transformer and the excitation cubicles, which also connect the excitation cubicles with the slip rings. The excitation transformers are dry type and are enclosed in indoor enclosures. Cooling of excitation equipment is by forced air cooling or forced air-to-water cooling.

10.2A.2.5 TG Control System

Same as for the U.S. EPR (see Section 10.2.2.5).

10.2A.2.6 Speed Control

Same as for the U.S. EPR (see Section 10.2.2.6).

10.2A.2.7 Load Control

Same as for the U.S. EPR (see Section 10.2.2.7).

10.2A.2.8 Valve Control

The flow of main steam entering the HP turbine is controlled by four stop valves and four governing control valves. Each stop valve is controlled by an electro-hydraulic actuator, so that the valve is either fully open or fully closed. The function of the stop valves is to shut off the steam flow to the turbine when required. Actuation of the emergency trip system devices closes the stop valves.

The turbine control valves are positioned by electro-hydraulic servo actuators in response to signals from their respective flow control unit. The flow control unit signal positions the control valves for wide-range speed control through the normal turbine operating range and for load control after the TG unit is synchronized.

The reheat stop and intercept valves, located in the hot reheat lines at the inlet of the LP turbines, control steam flow to the LP turbines. During normal operation of the turbine, the reheat stop and intercept valves are fully open. The intercept valve flow control unit positions the valve during startup and normal operation and closes the valve rapidly on loss of turbine load. The reheat stop valves close completely on turbine overspeed and turbine trip.

10.2A.2.9 Overspeed Protection

A protective trip system is provided to quickly close the main stop, control, reheat stop and intercept valves in the event of an unsafe condition or to provide overspeed protection. The system is designed to minimize false and spurious trips during normal operation and testing of the trip system. A power load imbalance function is provided, which compares turbine and generator load and initiates an appropriate momentary intercept valve closure when the turbine load exceeds the generator load by a specified amount.

Two independent overspeed trip devices are provided, one of which may be a conventional mechanical type device located on the turbine control shaft or an electrical overspeed protection system.

The first overspeed trip device fully closes the valves at about 110 percent of rated speed. An independent and redundant backup electrical overspeed trip circuit is provided to fully close these valves at about 111 percent of rated speed. The TG rotor is designed for a maximum speed of 120 percent of rated speed.

The actuation of the turbine protection system does not rely on components in the electro-hydraulic control system. Conversely, turbine trip initiation devices are not used for normal control of the unit.

Provisions for on-line testing of the emergency trip system, including individual trip devices, are provided.

After receipt of a trip signal, the hydraulic controllers for the main stop, control, reheat stop and intercept valves sufficiently close off these valves quickly to preclude an unsafe turbine overspeed. The response of the controllers considers the residual steam in the piping between the valves and the turbine.

10.2A.2.10 Turbine Supervisory Instrumentation

Same as for the U.S. EPR (see Section 10.2.2.10).

10.2A.2.11 Other Protective Systems

Same as for the U.S. EPR (see Section 10.2.2.11).

10.2A.2.12 Turbine Inservice Inspection and Testing

Major TG system components are readily accessible for inspection and are available for testing during normal plant operation.

The turbine inservice inspection and test program is used for the governor and overspeed protection system to provide reasonable assurance that flaws or component failures are detected in the overspeed sensing and tripping subsystems, main steam control and stop valves, reheat steam intercept and stop valves or extraction steam non-return valves; or any other condition that could lead to an overspeed condition above that specified by the design overspeed. The inservice inspection program for operability of the governor and overspeed protection system includes, at a minimum, the following provisions:

- For turbine governor and overspeed protection systems, at intervals of approximately three and one-third years, during refueling or maintenance shutdowns coinciding with the inservice inspection schedule required by the ASME BPV Code, Section XI, (Reference 3) for reactor components, at least one main steam stop valve, one main steam control valve, one reheat stop valve, one reheat intercept valve and one of each type of steam extraction valve are dismantled for examination. Visual and surface examinations of valve seats, disks and stems are conducted. Valve bushings are inspected and cleaned and bore diameters are checked for proper clearance. If any valve is shown to have flaws or excessive corrosion or improper clearances, the valve are repaired or replaced. Other valves of that type are also dismantled and inspected.

- The main steam stop and control valves, reheat stop and intercept valves, and steam extraction no return valves are exercised on a frequency consistent with turbine manufacturer recommendations.

- The components of the overspeed trip, are tested on a frequency consistent with turbine manufacturer recommendations.

10.2A.3 Turbine Rotor Integrity

Same as for the U.S. EPR (see Section 10.2.3).

10.2A.3.1 Materials Selection

The turbine rotor is made from a material and by a process that tends to minimize flaw occurrence and maximize fracture toughness properties, such as a NiCrMoV alloy or equivalent alloy processed by vacuum melting or vacuum degassing. The material is examined and tested to meet the following criteria:

- Chemical analysis is performed for each forging. Elements that have a deleterious effect on toughness, such as sulfur and phosphorus, are controlled to low levels.

- The 50 percent fracture appearance transition temperature (FATT) as obtained from Charpy tests performed in accordance with specification ASTM A370 (Reference 9) or equivalent standard is no higher than 0°F for low-pressure turbine rotors. The nil-ductility transition (NDT) temperature obtained in accordance with specification ASTM E208-95a (Reference 10) or equivalent standard may be used in lieu of FATT. NDT temperatures are no higher than -30°F.

- The Charpy V-notch (C_v) energy at the minimum operating temperature of each low-pressure rotor in the tangential direction is at least 60 ft-lb. A minimum of three C_v specimens are tested in accordance with specification ASTM A370, Reference 9, or equivalent standard.

A COL applicant that references the U.S. EPR design certification will provide applicable material properties of the turbine rotor after the site-specific turbine has been procured.

10.2A.3.2 Fracture Toughness

As noted in Section 10.2A.3.1, a suitable material toughness is obtained through the use of selected materials to produce a balance of adequate material strength and toughness and maintain a reasonable level of safety, while simultaneously providing high reliability, availability and efficiency during operation.

The low-pressure turbine disk rotor fracture toughness properties meet the following criteria.

The ratio of the fracture toughness (K_{Ic}) of the rotor material to the maximum tangential stress at speeds from normal to design overspeed are at least 2 in, at minimum operating temperature. Bore stress calculations include components due to centrifugal loads, interference fit and thermal gradients. Sufficient warm up time is specified in the turbine operating instructions to provide reasonable assurance that toughness is adequate to prevent brittle fracture during startup. Fracture toughness properties are obtained by any of the following methods:

- Testing of the actual material of the turbine rotor to establish the K_{Ic} value at normal operating temperature.

- Testing of the actual material of the turbine rotor with an instrumented Charpy machine and a fatigue precracked specimen to establish the K_{Ic} (dynamic) value at normal operating temperature. If this method is used, K_{Ic} (dynamic) is used in lieu of K_{Ic} (static) in meeting the toughness criteria.

- Estimating of K_{Ic} values at various temperatures from conventional Charpy and tensile data on the rotor material using methods are presented in J. A. Begley and W. A. Logsdon, Scientific Paper 71-1E7-MSLRF-P1 (Reference 5). This method of obtaining K_{Ic} is used only on materials which exhibit a well-defined Charpy energy and fracture appearance transition curve and are strain-rate insensitive.

- Estimating "lower bound" values of K_{Ic} at various temperatures using the equivalent energy concept developed by F. J. Witt and T. R. Mager, ORNL-TM-3894 (Reference 6).

Low pressure shrunk-on disk rotors are designed to prevent stress corrosion cracking through design features, material, quality, stress limitation and control of steam purity.

A COL applicant that references the U.S. EPR design certification will provide applicable turbine disk rotor specimen test data, load-displacement data from the compact tension specimens and the fracture toughness properties after the site-specific turbine has been procured.

10.2A.3.3 High Temperature Properties

Same as for the U.S. EPR (see Section 10.2.3.3).

10.2A.3.4 Turbine Rotor Design

The rotor of the HP turbine consists of a forged, monobloc shaft with forged-on coupling flanges with the moving blades held in slots.

The rotors of the LP turbines are of the built-up type with the moving blades held in slots. The individual rotor segments and coupling flanges are shrink-fitted to the shaft core.

LP shrunk-on-disk rotors have a high resistance to stress corrosion cracking due to design features, material, quality stress limitation and control of steam purity. The first lateral critical speed of the LP turbine rotors is below the operating speed.

The turbine assembly is designed to withstand normal conditions, anticipated transients, and accidents resulting in a turbine trip without loss of structural integrity. The design of the turbine assembly meets the following criteria:

- The design overspeed of the turbine is 120 percent of rated speed, which is higher than the highest anticipated speed resulting from a loss of load. The mechanical overspeed trip device fully closes the valves at about 110 percent of rated speed. An independent and redundant backup electrical overspeed trip circuit is provided to fully close these valves at about 111 percent of rated speed.

- The combined stresses of low-pressure turbine rotor at design overspeed due to centrifugal forces, interference fit and thermal gradients do not exceed 75 percent of the minimum specified yield strength of the material, or 75 percent of the measured yield strength in the weak direction of the materials if tensile tests are performed on the actual rotor material.

- The turbine shaft bearings are able to withstand any combination of the normal operating loads, anticipated transients and accidents resulting in a turbine trip.

- The natural critical frequencies of the turbine shaft assemblies between zero speed and 20 percent overspeed are controlled by design and during operation to minimize adverse effects to the unit.

- The turbine rotor design facilitates inservice inspection of high stress regions, including bores and keyways, without the need for removing the disks from the shaft.

10.2A.3.5 Turbine Rotor Preservice Inspections and Testing

Except for the addition of the following bullet, this section is the same as for the U.S. EPR (see Section 10.2.3.5).

- Finish machined bores, keyways and drilled holes are subjected to magnetic particle or liquid penetrant examination. No flaw indications in keyway or hole regions are allowed.

10.2A.3.6 Turbine Rotor Inservice Inspection Program Plan

A turbine rotor inservice inspection program detects rotor or disk flaws that can lead to brittle failure at or below design speed in the steam turbine rotor assembly. In accordance with the turbine manufacturer's procedures, the turbine rotor inservice inspection program uses visual, surface and volumetric examinations to inspect turbine components such as couplings, coupling bolts, LP turbine shafts, blades and disks, and HP rotors. The inspections are performed during plant shutdown on an interval consistent with the inservice inspection schedules in Reference 3 and be consistent with inspection intervals from the turbine manufacturer's turbine missile analysis.

A COL applicant that references the U.S. EPR design certification will provide the site-specific turbine rotor inservice inspection program consistent with the recommendations of the manufacturer

10.2A.4 Safety Evaluation

Same as for the U.S. EPR (see Section 10.2.4).

Table 10.2A-1—Performance Characteristics

Turbine-Generator	**Details**
Nominal Rating	1710 gross MW_e
Turbine type	Tandem compound, six flow
Operating speed	1800 rpm
Turbine throttle steam pressure	1089 psia
Throttle steam nominal moisture	0.42%
Moisture Separator/Reheaters (MSR)	
Number of MSRs per unit	2
Stages of moisture separation	1 with preseparator
Stages of reheat	2