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Unique Steam Turbine for Kizildere Geothermal Power Plant in Turkey

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ABSTRACT

A new 60MW steam turbine unit (Kizildere II) installed at Kizildere Geothermal Power Plant in Turkey owned by Zorlu Energy Group was put into commercial operation in September 2013. Fuji Electric Co., Ltd manufactured and supplied this steam turbine and generator. This paper introduces the unique features of the steam turbine.

This power plant adopts a triple-flash system. The steam turbine and generator are rotated with the steam with three different pressures (high, intermediate and low) to generate electricity. The exhaust of the high pressure (HP) turbine which uses HP steam flows to the heat recovery system with the higher pressure than the atmospheric pressure. The exhaust of the intermediate and low pressure (ILP) turbine which uses intermediate and low pressure steam flows to the condenser. This turbine system is tandem by coupling these two turbines to a single shaft.

In addition to the uniqueness of steam turbine configuration, the high-pressure steam is also unique because it includes 16.7 weight % of non-condensable gas, which is extremely high concentration compared with other geothermal power plants, and is the primary reason for not using a condenser.

1. INTRODUCTION

The power plant is placed at Kizildere Geothermal Field, located in southeast of Aegean Region of Western Anatolia, in the province of Denizli, Turkey (Figure 1). It is located at the southeast of Izmir where the steam turbine and generator were unloaded. It takes approximately three hours by car from Izmir to the power plant.

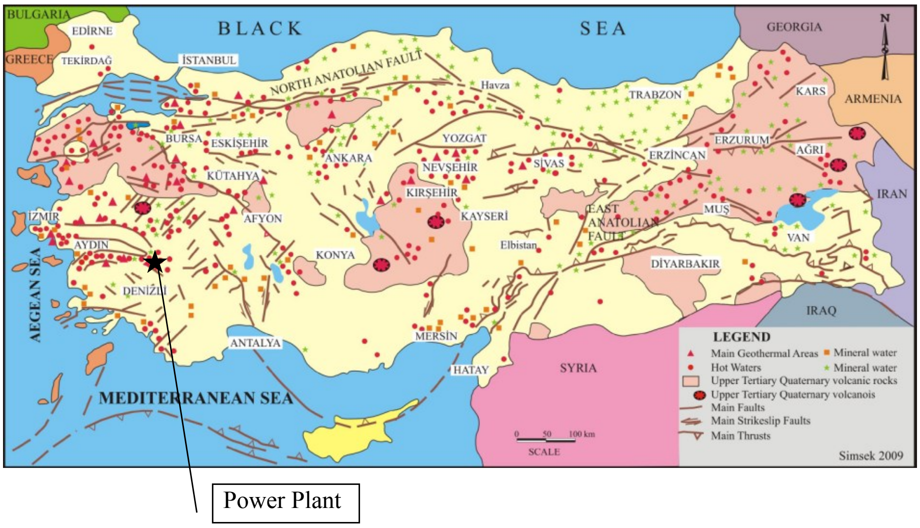

Figure 1: General Tectonic and Volcanic Feature of Turkey (Simsek at el, 2010).

Kızıldere is the first explored geothermal field in Turkey. In 1974, a 0.5 MWe pilot turbine was installed. After the pilot test study, in 1984, a 15MW steam turbine and generator unit (Kizildere I) was constructed (Kindap et al, 2010). The steam turbine is the condensing type and the single casing unit. This 15MW unit is still in operation at the time of year 2014.

Kizildere geothermal reservoir includes a high noncondensable gas (NCG) content, of which 99% is carbon dioxide (CO_2). CO_2 concentrations dissolved in the geothermal reservoir brine vary from 0.02-0.03 kg/kg of brine in the deep >225^{o}C reservoir and 0.01-0.02 kg/kg of brine in the intermediate <200^{o}C reservoir. (Haizlip et al, 2011) The intermediate reservoir wells are producing to the Kizildere I and the deep reservoir wells are producing to the Kizildere II plant.

The amount of NCG at the turbine inlet is 12-14 weight % (wt%) in steam at Kizildere I and 16-20 wt% in HP steam at Kizildere II.

2. THE STEAM TURBINE CONFIGURATION

Kizildere II plant uses a triple-flash system. The steam turbine and generator are rotated by steam from three different pressures (high, intermediate and low) to generate electricity. The HP turbine which uses HP steam is a back-pressure type, i.e, the exhaust pressure is 1.1 bara (16psia) and is slightly higher than the atmospheric pressure of 0.99 bara (14 psia) at Kizildere II site of which elevation is 155m above sea level.. The exhaust flows to the heat recovery system to reuse the exhaust energy. The ILP turbine which uses intermediate pressure (IP) and low pressure (LP) steam is a condensing system, i.e. the exhaust is condensed at the condenser. . This is tandem turbine system by coupling these two turbines to a single shaft (Figure 2 &3). The HP turbine is a single flow type. ILP turbine is a double flow type but IP part is only single flow because IP steam flowrate is relatively low compared to the LP. Six steam inlet ports (HPx2, IPx2, LPx2) are compactly arranged (Figure 4).

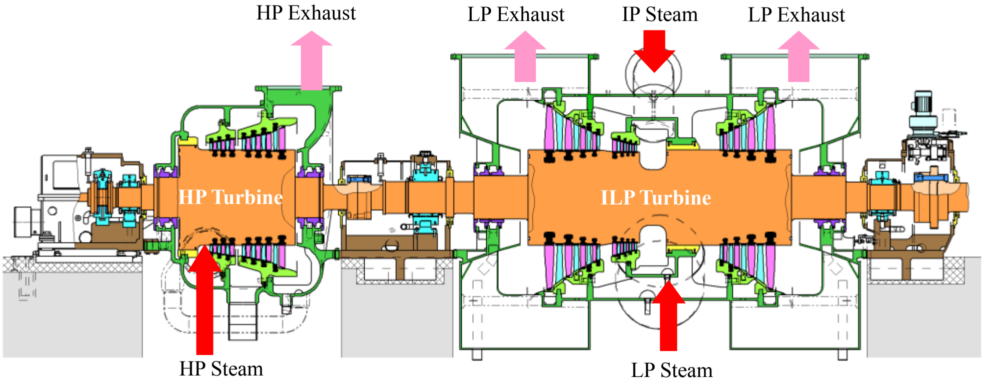

Figure 2: Sectional Drawing of Steam Turbine

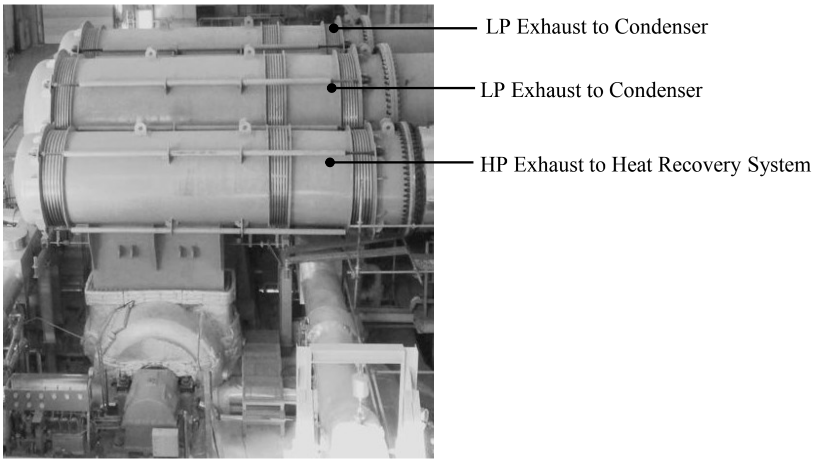

Figure 3: Photograph of Steam Turbine

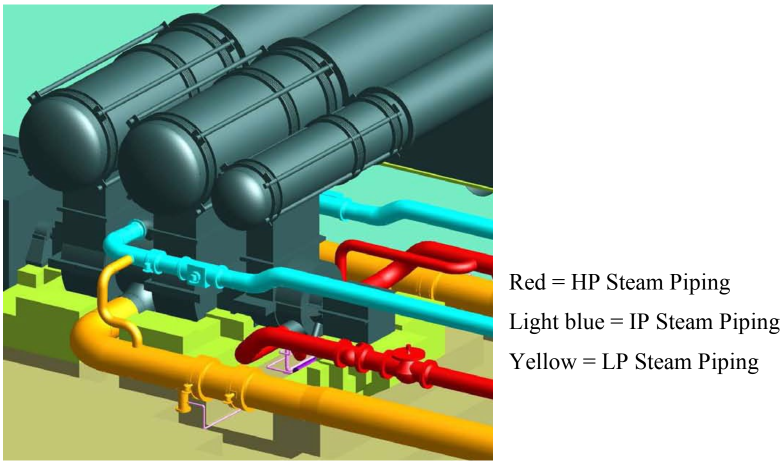

Figure 4: 3D Model of Steam Turbine

The major design parameter (rated condition) of the steam turbine is tabled as Table 1.

Output	60 MW Gross		
Rotation speed	3,000 rpm		
	HP	IP	LP
Inlet steam pressure	8.45 bara (122 psia)	3.5 bara (51 psia)	1.1 bara (16 psia)
Inlet steam temperature	169 °C (saturated) (337 °F)	139 °C (saturated) (282 °F)	102 °C (saturated) (216 °F)
NCG in steam	16.7 wt%	0.4 wt%	0.06 wt%
Exhaust pressure	1.1 bara (16 psia)	-	0.105 bara (1.52 psia)
Steam flowrate (including NCG)	372 t/h (819 klb/h)	129 t/h (284 klb/h)	210 t/h (463 klb/h)

Table 1: Design Parameter of Steam Turbine

3. CONSIDERATION FOR TANDEM TURBINE

The HP turbine and ILP turbine are physically connected. However, from the viewpoint of the process, there is no connection. There is no steam flow between HP turbine and ILP turbine. The reason is as follows. If the HP steam, which includes the high NCG, flows into the ILP turbine, then the gas extraction system (GES) capacity must be larger because the ILP turbine exhaust flows to the condenser. NCG accumulated in the condenser must be extracted by GES. This will have a large negative impact on the plant cost and efficiency.

The HP turbine and ILP turbine are physically connected. Therefore, even if there is no steam to ILP turbine, ILP turbine can be rotated by HP turbine with HP steam, and vice versa. However, such situation must be avoided because there is no process connection between HP and ILP turbines and ILP turbine will overheat due to windage loss without IP/LP steam or HP turbine will over heat without HP steam. This means that HP and IP steam must be always supplied to the HP and ILP turbines respectively. To supply the HP and IP steam all the time, the start-up and shutdown procedure and interlocks were carefully established. This includes the following.

1) Before start-up turbine, both HP and IP steam shall be available by monitoring the production well valves position and vent valve position.

2) During the start-up and shut down process as the turbine is under speed control mode or power control mode and the turbine HP control valves (HP-CVs) and IP control valves (IP-CVs) are opened or closed by the single governor position command. Also, to avoid the no or low flow to IP part at low load operation, LP steam is permitted to supply only at 35% MW load or higher (Figure 5).

3) After reaching 35% MW load, the HP-CVs are gradually opened by remote manual operation until the HP vent valves are fully closed, then the HP-CV control mode is changed to Inlet Pressure Control (IPC) mode. The same operation is applied to the IP system. After that, the LP-CVs are opened. The LP-CVs are gradually opened further by remote manual operation until the LP vent valves are fully closed and the LP-CV control mode is changed to IPC mode.

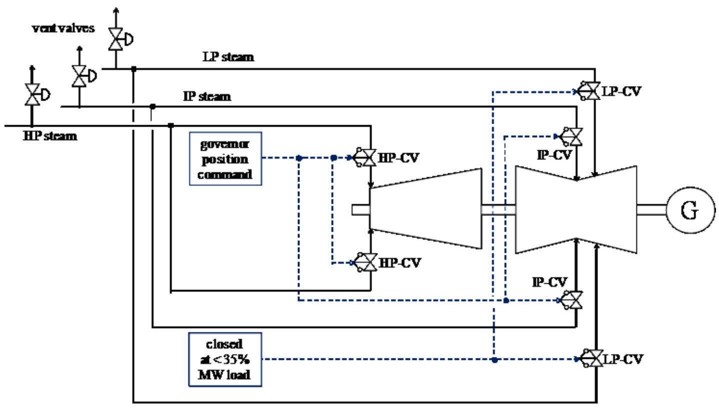

Figure 5: Turbine Control Valve Operation Concept during Start-up and Shut-down

When the turbine is operated under IPC mode, if the HP vent valve opens due to a malfunction or if the HP rupture disk bursts, then the HP-CV will be throttled to try to maintain the pressure and it may fully close in the end and the HP turbine will rotate with no steam. To avoid this, if the HP-CV closes more than a pre-set value, then the HP, IP & LP IPC mode will be turned off by interlock and the all of HP-CVs, IP-CVs and LP-CVs will be closed down to full close and then turbine will trip by reverse power. The same logic is provided for IP vent valve open or IP rupture disk burst case.

4. CONSIDERATION FOR HIGH NON CONDESABLE GAS

The HP steam includes 16.7 wt% NCG and 99% of NCG is CO_2. This has an impact on HP turbine sizing, output (turbine shaft power) and corrosion issue.

4.1 Consideration for HP Turbine Sizing and Output

Compared with the pure steam, the steam with high CO_2 concentration has

1) smaller enthalpy drop -> negative impact on the output

2) smaller specific volume -> smaller turbine steam path and

3) smaller wetness at exhaust -> smaller moisture loss and positive impact on the output

The turbine was designed and its output power was calculated considering these process properties. The performance of the turbine was confirmed during the commissioning.

4.2 Countermeasure for Corrosion

When CO_2 contacts water or wet steam, the water or water droplet is acidified and can corrode the steel. The HP steam includes 16.7 wt% NCG and 99% of NCG is CO_2 . Therefore the impact is severe compared with other geothermal power plants and Kizildere II IP &LP steam. The special countermeasure for or corrosion is required for Kizildere II HP turbine.

4.2.1 Material Selection

As the countermeasure for corrosion, 12%Cr stainless steel was overlaid on the turbine rotor which is forged from l%CrMoNiV steel. The 12% Cr stainless steel provides properties that resists corrosion, stress corrosion cracking and corrosion fatigue. Also, 13%Cr cast steel is selected for the stationary blade holder and 13%Cr stainless steel is selected for both stationary and rotating blades (Figure 6&7).

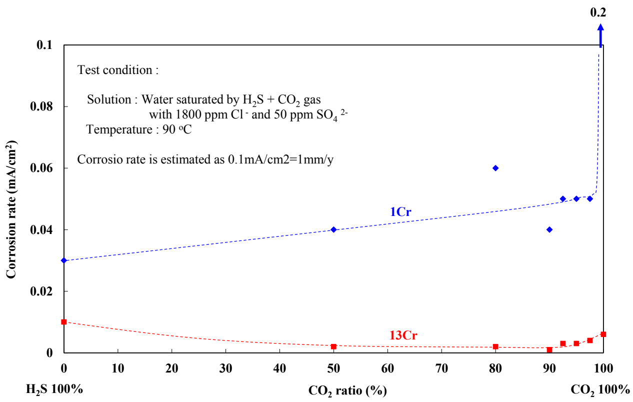

Figure 6: Influence of CO_2 Ratio on Corrosion Rate

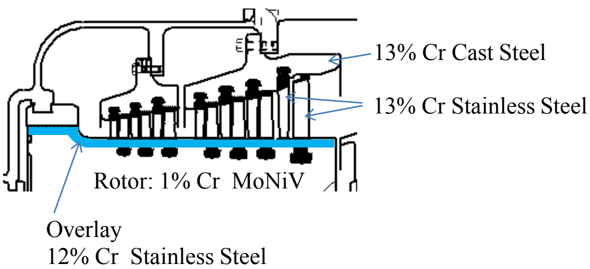

Figure 7: HP Turbine Material

4.2.2 IP Steam for HP Gland Sealing

The turbine gland must be sealed with steam but the HP steam is not suitable because of the high CO_2 content which may corrode the gland parts. Therefore IP steam is used for the gland sealing steam for both the HP and the ILP turbine. The HP turbine exhaust pressure is 1.1 bara (16 psia) (refer to Table 1) and the gland sealing steam pressure must be higher than this to avoid the CO_2 rich steam leaking out to the gland part, On the other hand, the ILP turbine exhaust is to vacuum, so that ILP gland sealing steam pressure must be slightly higher than atmospheric pressure, 0.99 bara (15.3 pisa) but it does not have to be higher than 1.1 bara (16 psia). To minimize the gland steam consumption, the HP gland steam supply system is separated from the ILP (Figure 8).

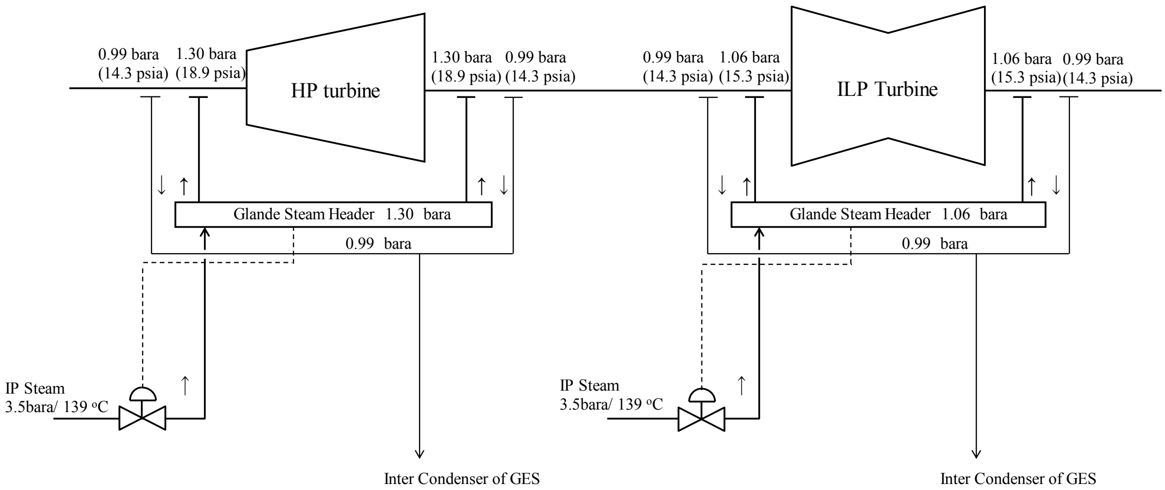

Figure 8: Gland Sealing System

4. CONCLUSION

The Kizildere Geothermal Field is unique with its high NCG concentration. As the solution, a unique turbine was required. The tandem turbine consists of a back-pressure type HP turbine and a condensing type ILP turbine. This unique turbine was put into the commercial operation in September 2013 and since then, it has been continuously and steadily operating. Each geothermal field has its own characteristics, regarding NCG concentration, pressure and temperature but the design and operation concept of Kizildere II steam turbine can be effectively applied to many other geothermal resources.

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