Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

THE GEOTHERMAL POWER PLANT AT NESJAVELLIR, ICELAND

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Key Words: Power plant, heat and electricity production, Nesjavellir, Iceland

ABSTRACT

The third stage of the Nesjavellir combined power plant was commissioned in late 1998 after a record construction period of only 22 months. Two 30 MW turbine generator units were installed and considerable modifications of the thermal power plant were made. The nominal capacity of the plant is now 60 MW_e electric and 200 MW_t thermal power.

Geothermal steam and water from 10 production wells are gathered in a central separator station, supplying up to 132 kg/s of steam and 240 kg/s of water. Electricity is generated in two condensing steam turbine units. The exhaust steam from the turbines is used to preheat fresh water in the condensers. The separated geothermal water is used in heat exchangers to heat the preheated water up to the required temperature. Finally, the water is treated in de-aerators to suit the requirements of the distribution system. Thus, the steam and the separated geothermal water are utilised, in the most economical way possible, for co-generation of electric and thermal power, which is also good for the environment as less heat is released to the atmosphere than in conventional geothermal plants.

The paper gives a general overview of the process, the design and the layout of the Nesjavellir plant. The main features of the equipment used are described, as well as the planned operation with load variations during summer and winter seasons to achieve an optimal use of the geothermal source.

1. INTRODUCTION

Production of thermal power started at the Nesjavellir power plant in September 1990. The initial rated output of the plant was 100 MW_t, corresponding to a flow rate of about 600 l/s of 80°C hot water for district heating. Gunnarsson *et al.* (1992) describes the development of the Nesjavellir geothermal field and the features of the first stage of the power plant.

The concept of the plant was to co-generate electricity for the national grid and hot water for district heating, but in the early nineties there was no demand for an increase in electricity production in Iceland. Since the commissioning of the first stage, the thermal capacity of the plant has been increased in harmony with the increasing demand of the district heating. Heat exchangers, for using the energy contained in the separated geothermal water, were tested to achieve a most effective use of the geothermal resource.

The production of geothermal steam and water is carefully monitored and the gained data have been used to recalibrate the first numerical reservoir model of 1986. The original model estimated a capacity of 300 MW_t (Steingrimsson *et al., 2000*). The updated report of Bodvarsson (1993) concluded that the generating capacity of the Nesjavellir geothermal field was about 30% more than originally estimated.

The capacity of the power intensive industry in the country, mainly aluminium smelters, increased considerably in the mid nineties requiring new electric power plants. On the other hand, the heat consumers had improved the efficiency of their equipment, leading to an unchanged load on the district heating system, regardless of new buildings connected to the distribution system (Ballzus *et al.*, 2000).

Accordingly the strategy of the energy utilisation was revised. More weight was put on electricity generation and the expansion of the heat production capacity was postponed due to the lower growth in the district heating market. In December 1996 Orkuveita Reykjavikur decided to start the third construction stage of the plant, adding two 30 MW condensing steam turbine units to the plant and modifying the existing thermal plant as needed due to the changes in the heating process.

2. PROCESS DESIGN

After commissioning of the third stage, the rated capacity of the Nesjavellir plant is 60 MW_e and 150 MW_t. The process diagram of the plant is shown in Figure 1. The diagram shows the two-phase flow from the geothermal wells being separated into steam and water at a 12 bar absolute pressure in a central separation station. The steam is piped to the power plant where it passes through moisture separators. By diverting the flow through the condensing turbines, electric energy is generated. The exhaust steam from the turbines is used to preheat fresh water while the water from the steam separators heats the preheated water from the condensers to the temperature required for the district heating system.

As the cold ground water is saturated with dissolved oxygen and becomes corrosive when heated, the heated water is de-aerated before leaving the plant. De-aeration is achieved by boiling under vacuum and by injecting small amounts of geothermal steam, which contains H_2S, as shown in Figure 1 and described in more details by Gunnarsson *et al.*(1992).

Demand for space heating varies over the year while generation of electricity is run as base load. To gain flexibility in the process, the condensing temperature of the steam can be adjusted between 60°C and 73°C. This means that the output of the thermal plant can by varied between 128 and 227 MW_t or by 77%; see data in parentheses in Figure 1. The output of the wells is regulated accordingly to the energy demand and thus, the steam and the geothermal water are utilised in the most efficient way possible for co-generation of electric and thermal power.

3. PLANT LAYOUT

Figure 2 shows an overview of the plant site, Figure 3 a close-up of the layout of the power station buildings and Figure 4 the equipment arrangement of the electrical generating units. The plant can be divided in following main components:

3.1. Steam Supply System

The geothermal fluid from 10 wells is gathered into one central separator station, which is located about 450 m from the powerhouse. During normal operation geothermal steam and water from eight production wells are required, the other two wells are stand-by. The steam/water mixture is transported in relatively long pipelines; the longest one, from well 14, is about 2.2 km. The topography and the relatively high steam fraction are favourable for this arrangement of the geothermal fluid gathering system. Throttling valves located on each wellhead control the flow from each well.

Some of the water coming from the wells is separated from the two-phase flow in a preseparator before entering the six steam separators. This arrangement was chosen instead of adding additional separators as the water flow has increased above the design flow of the separators due to the declining enthalpy of the well flow. Both steam pressure and water flow is controlled in the separator station. Excess steam and water is exhausted to 25 m high stacks, which combine a flasher, separator and silencer in one unit. Control valves regulating these exhaust flows are of the heavy-duty type and have been carefully selected and tested for reliability. From the separator station, steam and water is piped to the power station. Moisture separators are installed in the steam line as the last step in removing any carry-over from the steam separators and as safety devices, if a water injection should occur in the main steam line from the separator station. A more comprehensive description of the steam supply systems and the design criteria can be found in Ballzus *et al.* (1992).

3.2. Fresh Water Supply System

The fresh water pumping station is located near the Lake Thingvellir, approximately 6 km from the power plant. Fresh groundwater is taken from five wells. The wells are some 30 m deep and each yields more than 300 l/s. The water is pumped to two water tanks near the power plant, each having a capacity of 1000 m^3. Plant pumps connected to these tanks pump the fresh water through the condensers and heat exchangers to the de-aerators.

3.3. Electric Power Production

Steam flow from the moisture separators enters the steam turbines through two main stop valves and two governing valves installed in series on each unit. The condensing turbines are high efficiency machines of the top exhaust type made by Mitsubishi and have a rated output of 30 MW_e each. The design is single cylinder, single flow with eight stages running at 3000 rpm. The rated steam consumption is 57.2 kg/s at a design inlet pressure of 12 bar absolute and a 0.2 bar absolute condensing pressure. The inlet pressure range of the turbines is 10 to 15 bar absolute and the condensing pressure range is 0.2 to 0.35 bar absolute, depending on the required output of the thermal plant.

As shown in Figure 4, an overhead duct leads the exhaust steam from the turbines to the condensers. The condensers are of the shell and tube type, six passes with titanium tubing. The condensing surface of each condenser is 3500 m^2. As condensing of the steam is indirect, small condensate pumps are required and they have an electric power requirement of 11 kW at maximum load of each turbine unit.

Electrically driven vacuum pumps extract the non-condensable gases from the condensers. Less steam consumption and space requirements made this design more economical and environmentally friendlier than steam ejectors. Two pump units of the water ring type are installed for each turbine unit with a total electric power requirement of 300 kW at maximum load. The design load is 1% per weight of non-condensable gases in the steam. At the moment the gas content of the steam is about 0.5% and one pump unit per turbine unit is sufficient.

The turbo-generators, rated 40 MVA, 11 kV, are directly shaft coupled to the turbines. The generators are air cooled in a totally enclosed system with air/water coolers and purge fans to keep overpressure inside the generators. Excitation systems of the generators are of the brushless type. Cables connect the generator terminals to the terminal equipment cubicles, where the neutral end is connected to earth through resistor and the line end is connected to the generator circuit breaker. The generator circuit breaker is connected to the unit power transformer by cable.

The unit power transformers are of the oil forced, water forced type, three windings, YNd11yn0 and are rated 40/40/16 MVA, 132/11/11 kV. Each power transformer is equipped with two cooling systems, each capable of cooling the transformer at full load. The 16 MVA windings are for station power, equipped with an on load tap changer, designed for the total station load.

The indoors 132 kV switchgear is of the gas-insulated type, configured with a main and a transfer busbar. The switchgear consists of four bays, one for each unit, one for the transmission line and one for the bus coupler. A 2.5 km long cable connects the switchgear to the end of the Nesjavellir overhead transmission line.

3.4. Hot Water Production

The heating of fresh water takes place in shell and tube heat exchangers. There are two heat exchanger groups, one for heating fresh water from 5°C to about 60°C and the other for heating the preheated water from the condensers to 88°C, as shown in Figure 1. There are two heat exchangers in each group. Separated geothermal water is the heating source for both heating groups.

There are two shell and tube heat exchangers in series in group 1. Geothermal water is on the tube side and fresh water on the shell side. The heat exchangers have a single pass configuration with counter flow of fluids. They are made of stainless steel and are designed for heating 300 kg/s of fresh water. Separated geothermal water can be cooled from 188°C to some 40°C, if this group is used stand-alone and not in series with group 2. Each heat exchanger consists of 1430 tubes, which are 25.4 mm in diameter and 6 m in length. The heat exchanger surface is 643 m^2.

There are two heat exchangers in parallel in group 2. They are designed to heat the preheated water from the turbine condensers to 88°. As in group 1, the geothermal water is on the tube side and fresh water on the shell side. The tube side has a four-pass configuration while the shell side has two-pass configuration. Because of the multiple passes the geothermal water can only be cooled down to about 95°C. Each heat exchanger consists of 1030 tubes, which are 25.4 mm in diameter and 4 m in length. The heat exchanger surface is 310 m^2. Design flow for each heat exchanger is about 500 kg/s of preheated water.

3.5. Auxiliary Systems

The main distribution grid within the power plant is made on the 11 kV level. There are three 11 kV switchgears, one for the electric part of the power plant, one for the thermal part and the third for the fresh water pumping station. These switchgears are connected together in mask, but usually used in "unit-operation".

Distribution transformers are used for the 400 V a.c. main distribution systems in the plant. They are connected to each busbar in the 11 kV switchgears. The two main distribution systems are connected together by the third 400 V a.c. busbar, where the power plant's emergency diesel generation set is also connected.

Two separate 110 V d.c. and 24 V d.c. systems are used for the control and protection equipment of the plant and the emergency lighting. The capacity of the batteries in the systems are designed for 10 hours operation of the control and protection systems, and 3 hours operation of the emergency oil pumps for turning of the turbine generator units during black-out.

3.6. Control System

PLCs control every sub-system in the power plant. The control system for the electric power production includes a redundant PLC for each unit. Printers and engineering station are connected to the systems.

The PLC's network is connected to the station SCADA system through gateways. The station SCADA system is a part of the Orkuveita Reykjavikur SCADA system. The dispatch centre is in Reykjavik where the daily operation of the plant is monitored and controlled. Normally the control room at Nesjavellir is unmanned and the operators at the plant take care of the daily maintenance on a day shift basis.

3.7. Civil Construction

All main equipment is indoors due to weather conditions at Nesjavellir. The size of the buildings in 3rd construction stage is 2.523 m^2 and 20.136 m^3. The total facilities of the power plant are now 5.500 m^2 and 39.200 m^3. The ground floor level of the plant is 180 m above sea level.

The power plant is situated in a lava field. The loose lava was removed and the buildings founded on a compact filling. The turbine hall is a conventional steel structure, but connecting buildings that house electrical and control equipment are made of concrete to achieve a higher tightness of these buildings. The new buildings, as well as all new equipment, are designed to withstand an earthquake of the magnitude of 0.6 g without damage or stop in operation and withstand an earthquake of 1.1 g without extensive damages. Such severe requirements were adopted after an assessment by the University of Iceland, taking into consideration the earthquake history of the Nesjavellir area.

The gases from the geothermal field escaping both from natural fumaroles and the plant are highly corrosive. Therefore, all new buildings are clad with aluminium plates. Special care has been taken during design of the heating and ventilation systems of the plant. All airflow to rooms with electrical and control cubicles passes active coal filters to absorb H_2S. Clean compressed air is piped to sensitive equipment placed outside these areas.

3.8. Transmission to Customers

Electric energy is transmitted to the Reykjavik area with one transmission line from the power plant. The line voltage is 132 kV with a transmission capability of approximately 110 MW_e. The line is 31 km long, consisting of 2.5 km of cable from the Nesjavellir plant to the 15.5 km overhead line and ends with a 13 km cable connection to the substation in Korpa in Reykjavik. The relatively long cable at the Reykjavik end of the line is due to environmental aspects through populated area.

The hot water is pumped from the plant to a tank at the highest point of the transmission pipe. The diameter of the pipe is 900 mm the first 3 km and 800 mm the remaining 24 km. The capacity of the tank is 2000 m^3, and the elevation is 407 m above sea level. From there, the water flows by gravity to the storage tanks of the district heating system from where it is distributed to the consumers.

4. ENVIRONMENTAL IMPACT

As discussed by Gislason (2000), about 6 million tons of geothermal fluid and gases are drawn annually from the geothermal field and released either to the groundwater or the atmosphere. Impact on the ground water is monitored carefully, especially in the nearby Lake Thingvellir, but so far environmental impact has been minor.

Comparison with alternative energy sources show that CO_2 and sulphur released to atmosphere, by using geothermal energy, is relatively small for the power production at Nesjavellir. E.g. the average amount of CO_2 released is within 1% of that of a conventional oil or coal fired power plant of similar capacity.

5. INVESTMENT AND ECONOMY

Investment in the third construction stage of the Nesjavellir power plant consists of all buildings and equipment for the electric power production as well as extensive modifications of the thermal plant and extensions to the existing auxiliary systems. During this construction stage five additional wells were connected to the steam supply system, separators and control valves added. One pump module was added to the fresh water pumping station and the capacity of the fresh water storage was doubled at the power plant. Two heat exchangers for geothermal water were added for the hot water production.

The total cost accumulated for the third construction stage at Nesjavellir is 52 million USD, including financial cost during the construction period. Investment for the transmission line to Reykjavik is 7 million USD.

Estimated pay-back time of this investment, based on a long-term contract to the Landsvirkjun, is 12 years, giving a acceptable profit and good margins for the unexpected.

6. DEVELOPMENT OF THE PLANT IN THE FUTURE

As the commissioning and initial operation of the plant has been successfully carried out, Orkuveita Reykjavikur has already decided to install a third 30 MW_e condensing unit. Commissioning is planned in June 2001. This unit will be operated at part load of 16 MW_e until drilling and testing has shown that the field can sustain a further long-term increase in production rate.

Based on today's knowledge of the field the plant is expected to be fully developed in the year 2010 with a capacity of 90 MW_e and 300 MW_t. If the enthalpy of the geothermal fluid decreases as predicted and the flow of geothermal water increases consequently, an option might open to utilise the excess separated geothermal water for an additional 16 MW_e in electric power production in a binary cycle system

7. CONCLUSIONS

- The combined electric and thermal power plant at Nesjavellir has operated successfully since October 1998 and has proved to be a highly efficient geothermal source utilisation.
- Extensive research opened up the possibility of using the separated geothermal water in conventional shell and tube heat exchanges.
- The possibility of varying condenser pressure gives flexibility for an optimal utilisation of the geothermal field for production of both thermal and electric power with varying load.

ACKNOWLEDGEMENTS

The authors acknowledge the assistance provided by our colleagues during preparation of this manuscript. We also thank Orkuveita Reykjavikur for allowing the publication of this paper.

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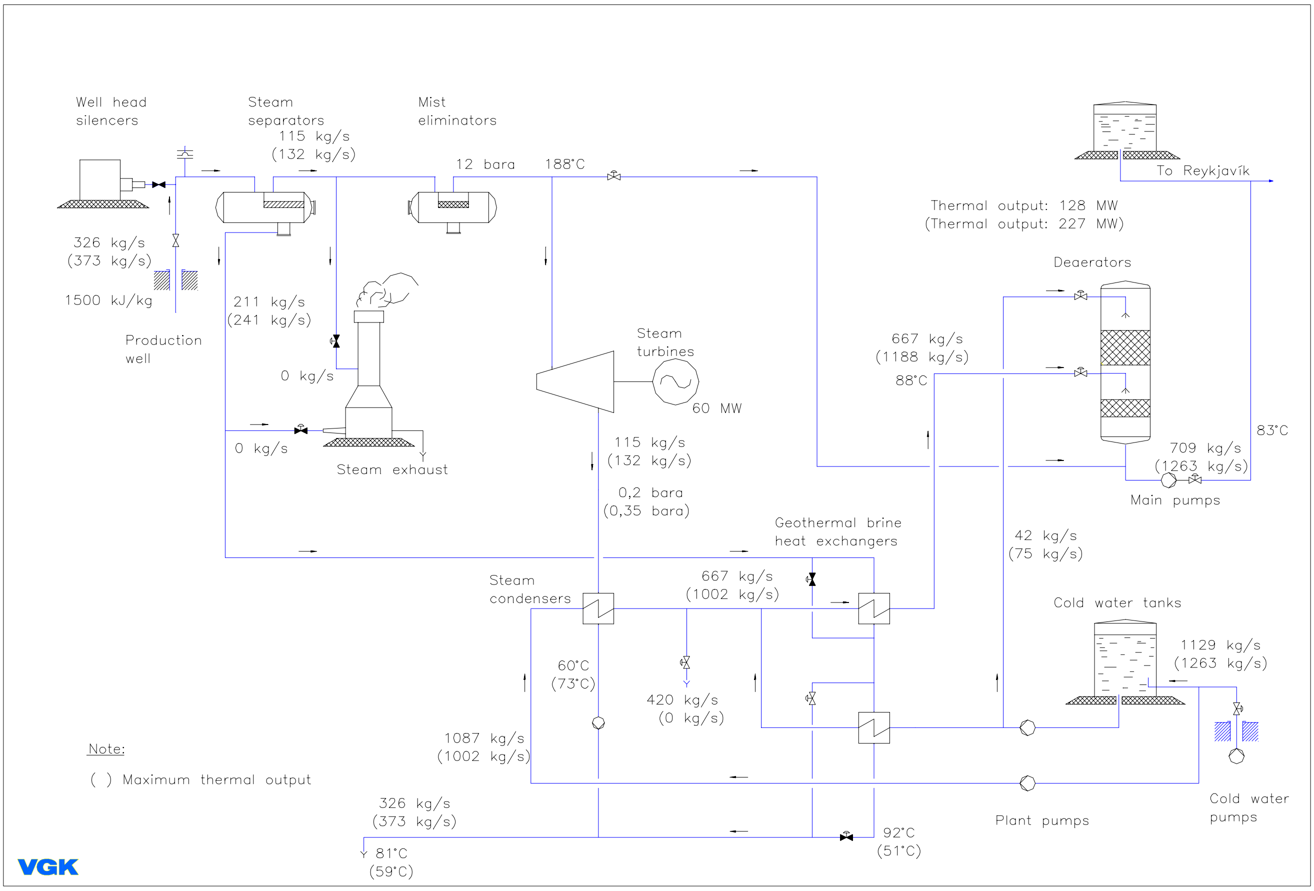

Figure 1. Process diagram of the Nesjavellir plant

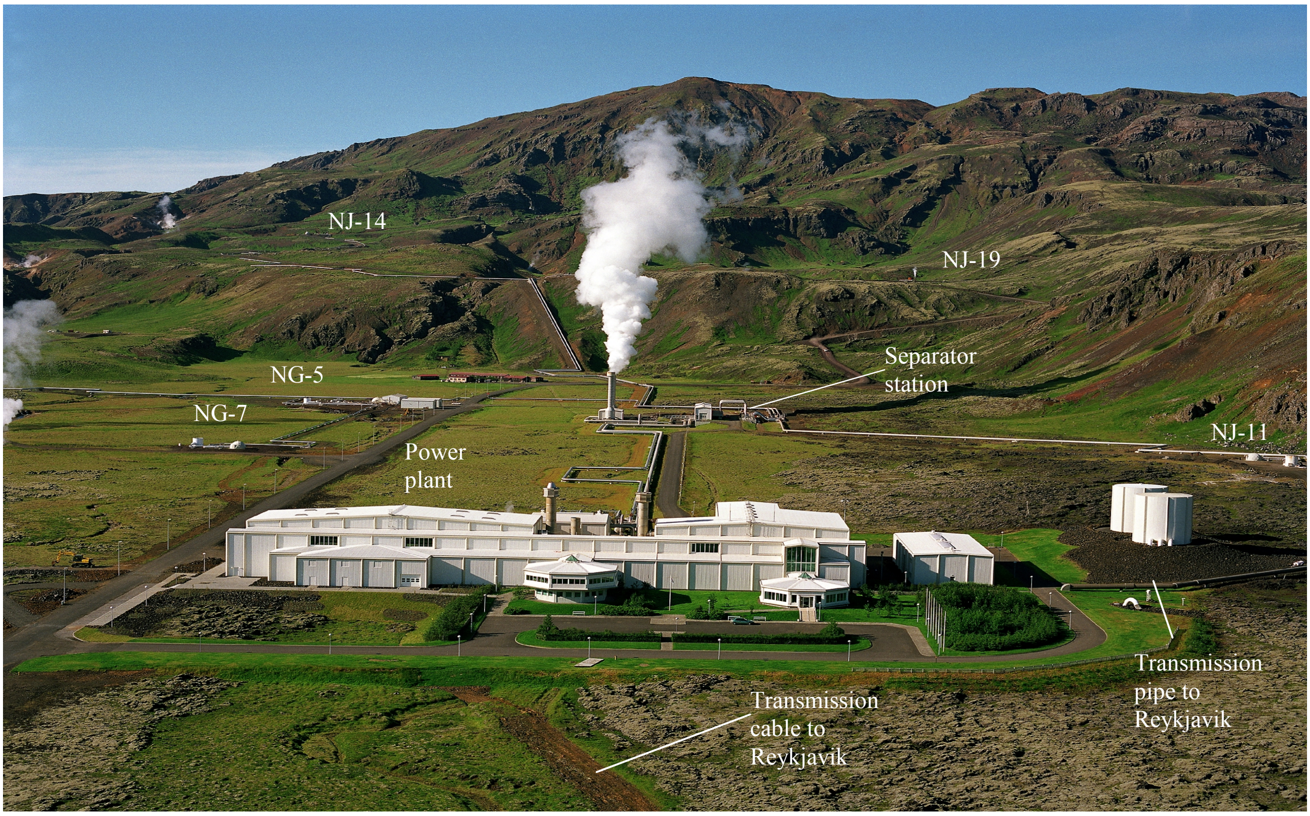

Figure 2. Overview of the Nesjavellir plant site

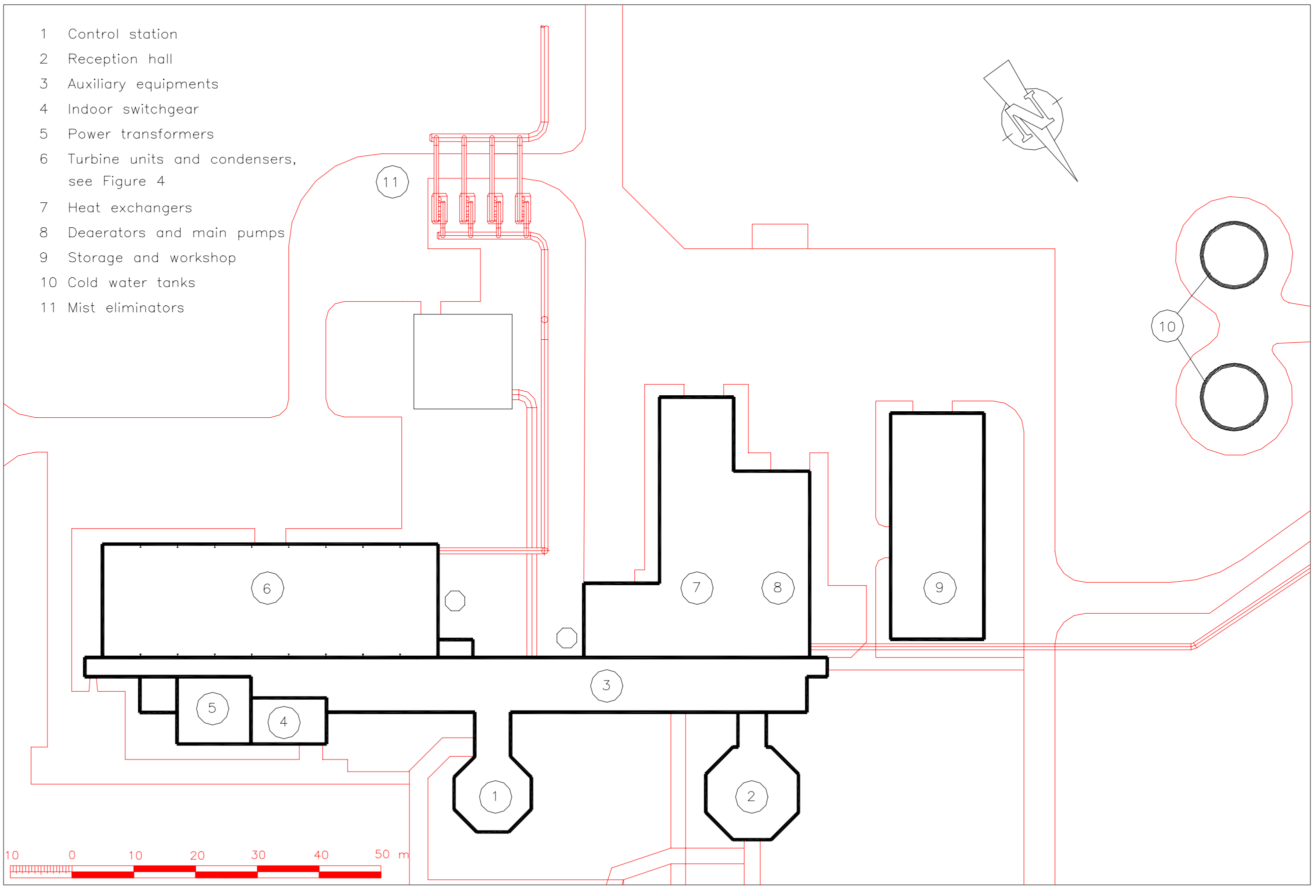

Figure 3. Layout of the power station

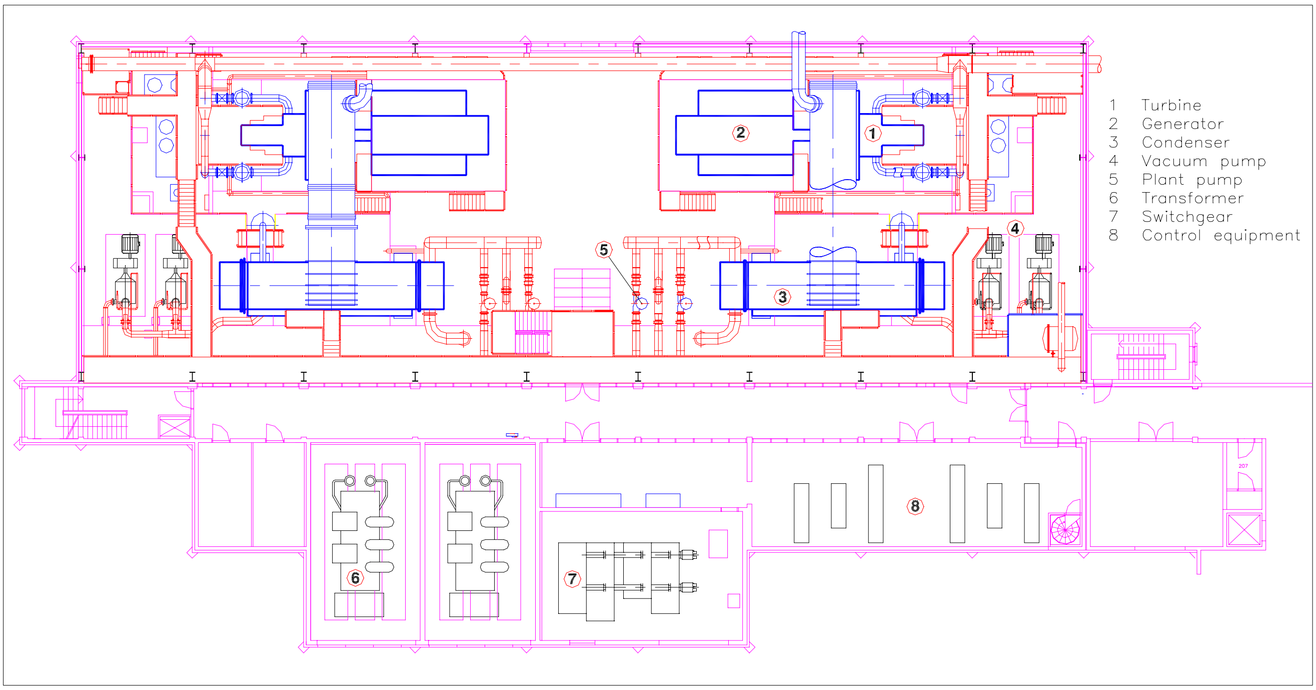

Figure 4. Layout of the turbine hall