The Geothermal Power Plant at Hellisheiði, Iceland

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ABSTRACT

The concept of Hellisheiði power plant was to co-generate electricity for power intensive industry and hot water for district heating. The power plant consists of six 45 MW_e high pressure and one 33 MW_e low pressure turbine generator units and 133 MW_t thermal production. The thermal plant is planned to be 400 MW_{th}.

Geothermal fluid from production wells is gathered in central separation stations. The geothermal steam is used in six high pressure units. The separated water is flashed again and the low pressure steam is used in the low pressure turbine but the separated water is piped to the thermal plant. The condensers of four high pressure turbines are used to preheat fresh water. The preheated water is fully heated in heat exchangers with separated water and then treated in de-aerators to suit the requirements of the district heating distribution system. Before entering the re-injection wells the separated water is diluted with condensate.

Co-generation of electric and thermal power therefore utilized the resource economically.

In this paper we give an overview of the process, the design and the layout of the Hellisheiði power plant. The main process design is described, as well as the intended operation for utilizing the geothermal resource optimally.

1. Introduction

The Hellisheiði power plant design is based on a long term experience for geothermal utilization for cogeneration of district heating an electrical generation starting with Svartsengi power plant in 1978 and Nesjavellir power plant in 1980 (Ballzus et.al (2000)).

The Hellisheiði power plant covers over 8 km^2 area and has 30 production wells connected to three separation stations and two power stations (Figures 1 and A1). The power plant was commissioned in five stages over a five year period with the first stage completed in November 2006 (Figure A2, Table 1). The total capacity of the power plant is currently 303 MW_e and 133 MW_t. Two stages for district heating generation are planned in the future.

Table 1. Commissioning overview.

Stage	Capacity	Date
1st stage	45 MW_e 45 MW_e	October '06 November '06
2nd stage	33 MW_e	September '07
3rd stage	45 MW_e 45 MW_e	September '08 November '08
4th stage	133 MW_t	December '10
5th stage	45 MW_e 45 MW_e	May '11 June '11
Further stages	133 MWt 133 MWt	Est. in 2020 Est. In 2030

In the next section we describe the process design, followed by an overview of the plant layout. The following sections briefly

Figure 1. The Hellisheiði power plant.

describe the environmental impact, investment and economy. The conclusion and future plans are described in the last section.

2. Process Design

The process flow diagram (Figure A3) shows that the two-phase flow from the geothermal wells is separated into steam and water at 10 bar_a pressure in central separation stations. The steam is piped through moisture separators and then passes through condensing steam turbines, with indirect condensers, where electric energy is generated.

The condensers for the first four high pressure units (units 1-4) have separate bundle so the cooling for the turbine generator units can be run either entirely on cooling towers or partly i.e. part of condenser is connected to the thermal plant and preheats the fresh water (Figure A3). This gives flexibility in the operation and minimizes the down time of the thermal plant but three condensers are sufficient for the planned full capacity of the thermal plant.

After the steam separators the separated water is flashed again at 2 bar_a in low pressure steam separators giving approximately 12% steam. The steam is then piped to moisture separators and then passes through a low pressure condensing steam turbine, producing power for generation of electrical energy.

As mentioned above the exhaust steam from four high pressure turbines is used to preheat fresh water in their condensers, while the separated water from the low pressure steam separators heats the preheated water in heat exchangers to the temperature required for the district heating system normally around 90°C.

Fresh water, which is saturated with dissolved oxygen, becomes corrosive when heated. The heated water is therefore de-aerated before leaving the thermal plant. De-aeration is achieved by boiling it under vacuum and injecting a small amount of geothermal steam, containing H_2S (Figure A3). For more detail see Gunnarsson et al. (1992)).

The demand for district heating varies over the year, while electricity generation is relatively constant. To gain flexibility in the operation the condensing temperature of the steam can be adjusted between 46°C and 57°C and also the separated water temperature can be adjusted between 120°C and 180°C. If insufficient separated water is available to reach full capacity of the low pressure turbine (unit 11) additional high pressure steam can be flashed to the low pressure turbine.

Figure 2. Separation station II.

3. The Plant Layout

The power plant is divided into the following components: steam supply system, fresh water supply system, electric power production, thermal production, auxiliary systems, control system, civil construction and transmission to customers (Figure A1 - A4). The following sections describe each component in detail.

3.1 The Steam Supply System

Geothermal fluid from 30 production wells is gathered in central separation stations supplying up to 503 kg/s of steam and 645 kg/s of water.

The steam field is divided into three areas each with its own separation station (Figure A2). Geothermal fluid from 7 wells is gathered in separation station I which is located about 570 m from power station II. Geothermal fluid from 18 wells is gathered in separation station II which is located about 1540 m from power station I. Geothermal fluid from 5 wells is gathered in separation station III which is located about 1250 m from power station II.

In total 30 geothermal wells are connected to the three separation stations. After separation all water is joined together. In case of emergency the separated water can be released to the emergency exhaust.

Figure 3. Steam valve house for units 5 & 6, at steam blow out.

During normal operation, geothermal steam and water from 29 production wells is required with one well stand-by. The two-phase fluid is transported is a relatively long pipelines up to 3,2 km. The topography and the relatively high steam fraction are favourable for this arrangement of the geothermal gathering system. Throttling valves located on each wellhead control the flow from each well.

The power plant is of modular design. For each turbine one pre-separator and two steam separators are installed. About 80% of the water bypasses the steam separators and is diverted through the pre-separator. This arrangement was chosen to reduce the risk of a water injection into the steam.

The steam pressure is controlled in a steam valve house (Figure 3) where excess steam is exhausted to 25 m high stacks, one for each unit. The control valves are of heavy duty type and have been carefully selected and tested for reliability.

Water levels in the separators are controlled by control valves which relieve the water into a common separated water piping system. During normal operation the water is piped to the low pressure steam system where it is flashed at 2 bar_a@120°C. The steam/water mixture is separated in the low pressure separators. Steam is piped to the low pressure turbine generator unit but the water is pumped to the thermal plant. From the thermal plant, the separated water is piped to the re-injection piping system where it is mixed with condensate from four units, approximately 200 kg/s, Sigfússon (2011) in order to minimize silica scaling in the re-injection wells. The separated water / condensate mixture is finally piped to the re-injection wells.

3.2 The Fresh Water Supply System

Fresh water is taken from six ground water wells which are some 200 m deep with submerged pumps at 150 m. Each well yields more than 160 l/s of water which is pumped approximately 5 km to two water tanks near the power plant, each having a capacity of 1000 m^3. From there the water is free flowing through the four condensers, heat exchangers and de-aerators and on to the district heating system.

3.3 The Electric Power Production

The steam flows from the steam separators passes though moisture separators and enters two main stop valves and two governing valves, installed in parallel for each turbine generation unit, see Figure 4. All the units are condensing turbines of the axial exhaust type. The design is a single cylinder and single flow machine running at 3000 rpm. The first four high pressure units, units 1 to 4 are made by Mitsubishi and have a rated output of 40 MW each. The rated steam consumption is 75,2 kg/s at a design inlet pressure of 7,5 bar_a. The inlet pressure range of the turbine is 6,5 to 9,5 bar_a. For 9,5 bar_a inlet pressure the rated output is 45 MW_e. The condensing pressure range is 0,1 to 0,22 bar_a, depending on the required temperature of the district heating system.

The low pressure unit (unit 11) is made by Toshiba and has rated output of 33,6 MW_e. The rated steam consumption is 83,5 kg/s at a design inlet pressure of 2 bar_a and 0,068 bar_a condensing pressure.

The latest two units (units 5 and 6) are made by Mitsubishi and have a rated output of 45 MW_e each. The rated consumption is 82,4 kg/s at a design pressure of 7,5 bar_a and 0,1 bar_a condensing pressure. The inlet pressure range of the turbine is 6,5 to 9,5 bar_a.

Figure 4. Turbine generator unit no. 1.

All condensers are of the shell and tube type made by Balcke Dürr. The condensers are connected to the turbines with a transition piece (Figure A4). The condensers for units 1 to 4 have special heat exchanger bundles for district heating. The tubes are made of titanium and the surface of each condenser is in total 6673 m^2 where 2758 m^2 is the special bundle for district heating and 3916 m^2 is connected to the circulation water cooled in the cooling tower. For the low pressure unit, the tubes are made of stainless steel and the heat exchanger surface is 4655 m^2. For units 5 and 6 the tubes are made of titanium and the heat exchangers surface of each condenser is 4345 m^2. As the condensing of the steam is indirect rather small condensate pumps are required each with an electric power requirement of 75 kW at maximum load.

Liquid ring vacuum pumps extract the non-condensable gases from the condensers. The gas extraction system was selected with respect to steam consumption and space requirements.

The gas extraction system for the high pressure turbines is designed for 1% per weight of non-condensable gases in the steam but at the moment the gas content is about 0,5% per weight in the geothermal steam. For each unit four pumps each with 300 kW power requirements are installed, two running and two stand-by. For the low pressure turbines, the design is 0,1 % per weight of non-condensable gases in the steam. Two pumps each with 132 kW power requirements are installed. Currently, high pressure steam containing more geothermal gases is used to reach full capacity and therefore an additional 300 kW pump was installed.

The turbo-generators rated 50 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 are of the brushless type. The generator terminals are connected to the terminal equipment cubicles, where the neutral end is connected to earth through resistors and the line end is connected to the generator circuit breaker. The generator circuit breaker is connected to the unit power transformer by insulated busbars.

All unit power transformers are of the oil forced, water cooled type and are rated 50 MVA for all units. Each power transformer is equipped with two cooling systems, each capable of cooling the transformer at full load.

3.4 Thermal Production

The final heating of district heating water takes place in shell and tube heat exchangers. There are two heat exchangers groups in parallel each containing two serial heat exchangers. Separated water is the heating source.

Separated water is on the tube side and preheated water from the condensers on the shell side. The heat exchangers are counter flow. They are made of stainless steel with SMO254 tubes and are designed for heating 325 kg/s of fresh water. Separated water can be cooled from 180 - 120°C to some 60°C. Total heat exchanger surface is 3384 m^2.

3.5 Auxiliary Systems

The main distribution grid within the power plant is 11 kV. There are nine 11 kV switchgears, one for each turbine generator module, one for the thermal part and the one for the fresh water pumping station. The ninth switchgear is for the auxiliary load. These switchgears are connected together but are usually used in "unit-operation".

Distribution transformers are used for the 400 V AC. 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 with the third 400 V AC busbar, to which the power plant's emergency diesel generation set is also connected.

Two separate 110 V DC and 24 V DC systems are used for the control and protection equipment of the plant for each module. The capacity of the batteries in the systems corresponds up to 10 hours operation of the control and protection systems and 3 hours operation of the emergency oil pumps for protection of the bearings while the turbine is stopping.

3.6 Control System

PLCs control every sub-system in the power plant. The control system includes a redundant PLC, data storage server, printers and engineering station. The data storage server stores historical data which is useful for operational data analysis as well as disturbance analysis.

The PLC´s network is connected to the SCADA system through gateway. The SCADA system is connected to a dispatch centre in Reykjavik, where daily operation of the plant is monitored and controlled. Normally the control room at Hellisheiði is unmanned and the operators at the plant take care of the daily maintenance during day shift basis.

3.7 Civil Construction

Due to local weather conditions all main equipment is located indoors at Hellisheiði. The size of the buildings for each unit is 3.432 m^2 including the steam valve house, separation valve house and separation station. The total facility of the power plant is 35.152 m^2 including all common facilities. The ground floor level of the plant is 260 m above sea level.

The turbine hall is a conventional steel frame structure but connecting buildings that house electrical and control equipment are made of concrete to achieve a higher tightness of these buildings and avoid H_2S contamination of the electrical rooms.

The power plant is designed to withstand an earthquake of a magnitude of 0,6 g without sustaining damage or a stop in operations and to withstand an earthquake of 1,3 g without extensive damages. These strict requirements were adopted after an assessment by the University of Iceland, taking into consideration the earthquake history of the Hellisheiði area.

In 2008 an earthquake of a magnitude 6,2 on the Richter scale hit in the vicinity of the plant. The turbine protection tripped the turbine units but other incidents or damages did not occur.

3.8 HAVAC System

The gases form the geothermal field escaping from natural fumaroles and the plant are highly corrosive. Therefore all buildings are clad with aluminium plates. Special care has been taken during the design of the heating and ventilation system of the plant. All airflow to the 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.

3.9 Transmission to Customers

Electric energy is transmitted to a closed substation which is directly connected to the national grid. The line voltage from each unit is 220 kV.

The hot water is pumped from the plant to a storage tank at the highest point of the transmission pipe. The capacity of the tank is 950 m^3 and the elevation is 266 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. The diameter of the underground pipeline is 1000 mm the first 5 km and then 900 the remaining 14 km.

4. Environmental Impact

Two environmental impact assessments have been made for the Hellisheiði power plant (Verkfræðistofa Guðmundar og Kristjáns 2003 and Verkfræðistofa Guðmundar og Kristjáns 2005). It is the conclusion of these assessments that the environmental impact is not significant.

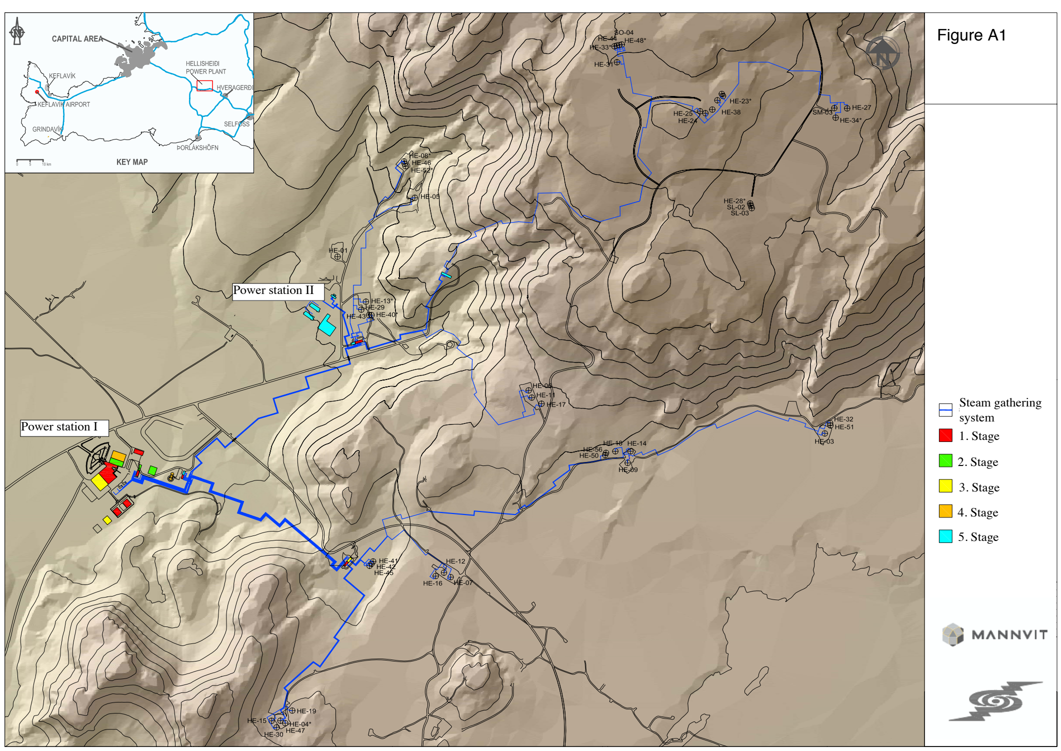

Figure A1.

At present H_2S is released to the atmosphere with the draft from two cooling towers but in the year 2014 new regulation for allowable H_2S content in resident areas will take effect. This regulation will affect how H_2S needs to be released from the Hellisheiði power plant. At present Orkuveita Reykjavíkur is carrying out experiments for injecting H_2S into the field (Gunnarsson et al. (2011)).

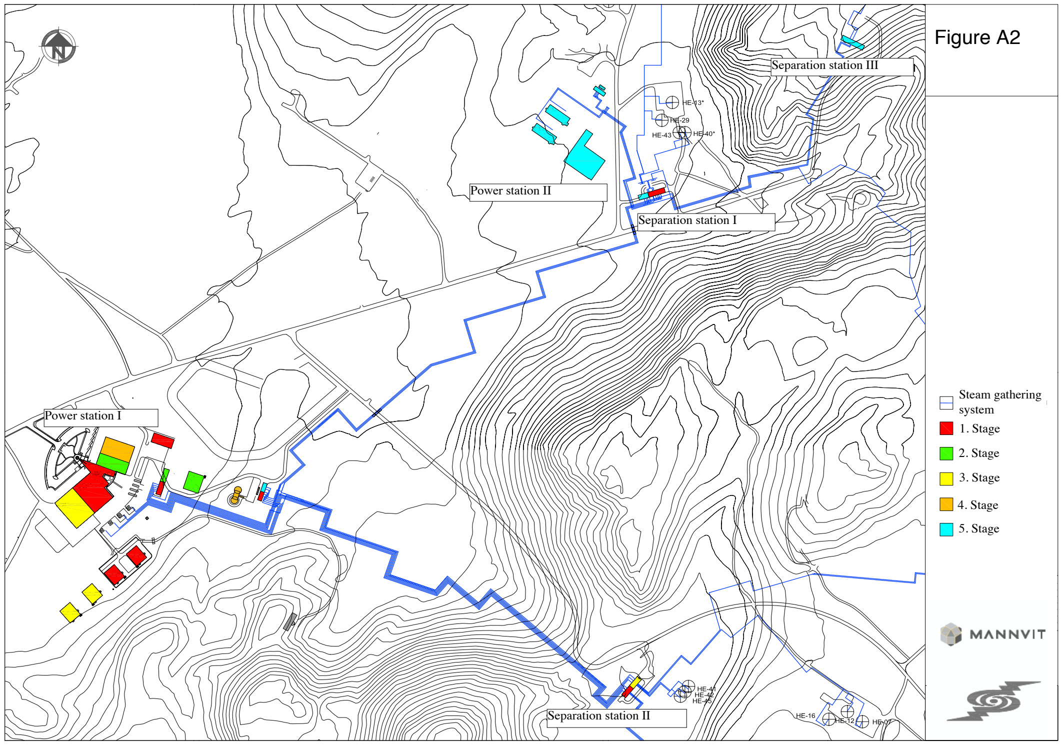

Figure A2.

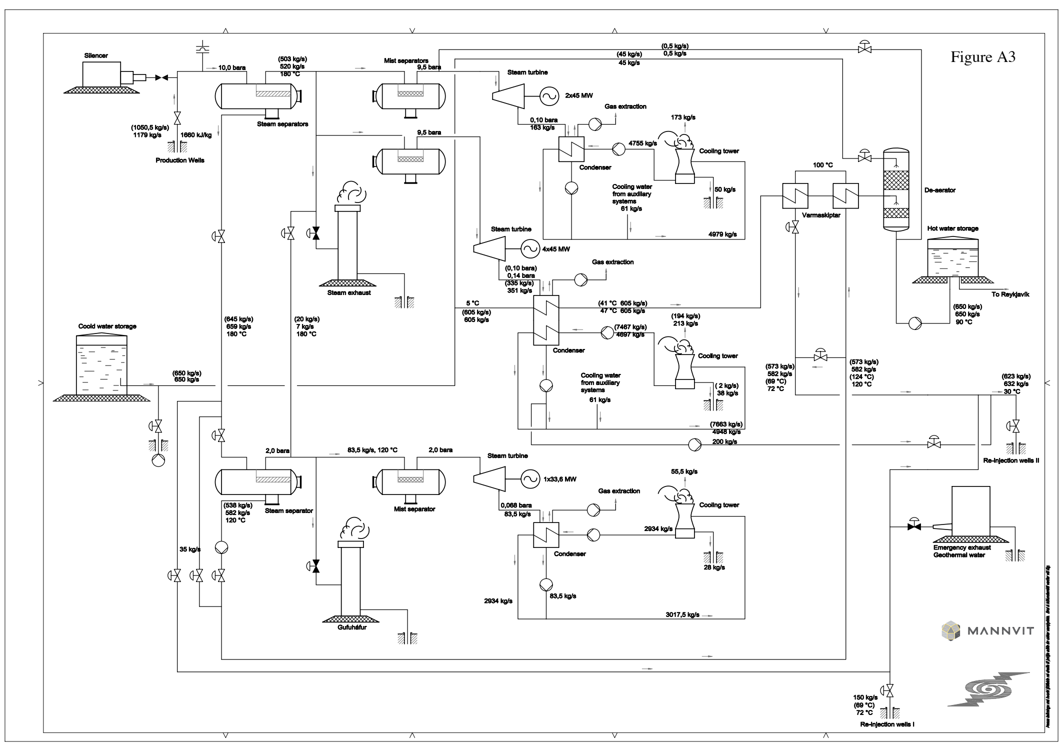

Figure A3.

5. Investment and Economy

Investment in the first five stages of the Hellisheiði power plant consists of buildings and equipment for the electric power production as well as the first stage of the thermal plant. During this construction 49 production wells, 17 re-injection wells and 6 ground water wells were drilled, 2 power stations as well as 7 cooling towers were built.

The total cost accumulated for these 5 stages at Hellisheiði is 800 MUSD, including the financial cost during the construction period. Investment for the hot water transmission pipe to Reykjavik is 24 MUSD.

6. Conclusions and Future Plans

Based on today's knowledge of the geothermal field, no further electric generation is planned. For the thermal plant additional 266 MW_t will be installed in two stages, 133 MW_t in 2020 and the last 133 MW_t in 2030.

The combined electric and power plant at Hellisheiði has operated successfully since October 2006 and has proven to be a highly efficient geothermal supplier both for the national electrical grid and the Reykjavík area district heating system.

The possibility of varying the condenser pressure and separated water temperature gives flexibility for an optimal utilization of the geothermal field for production of both thermal and electric power with varying demand for electrical and heat.

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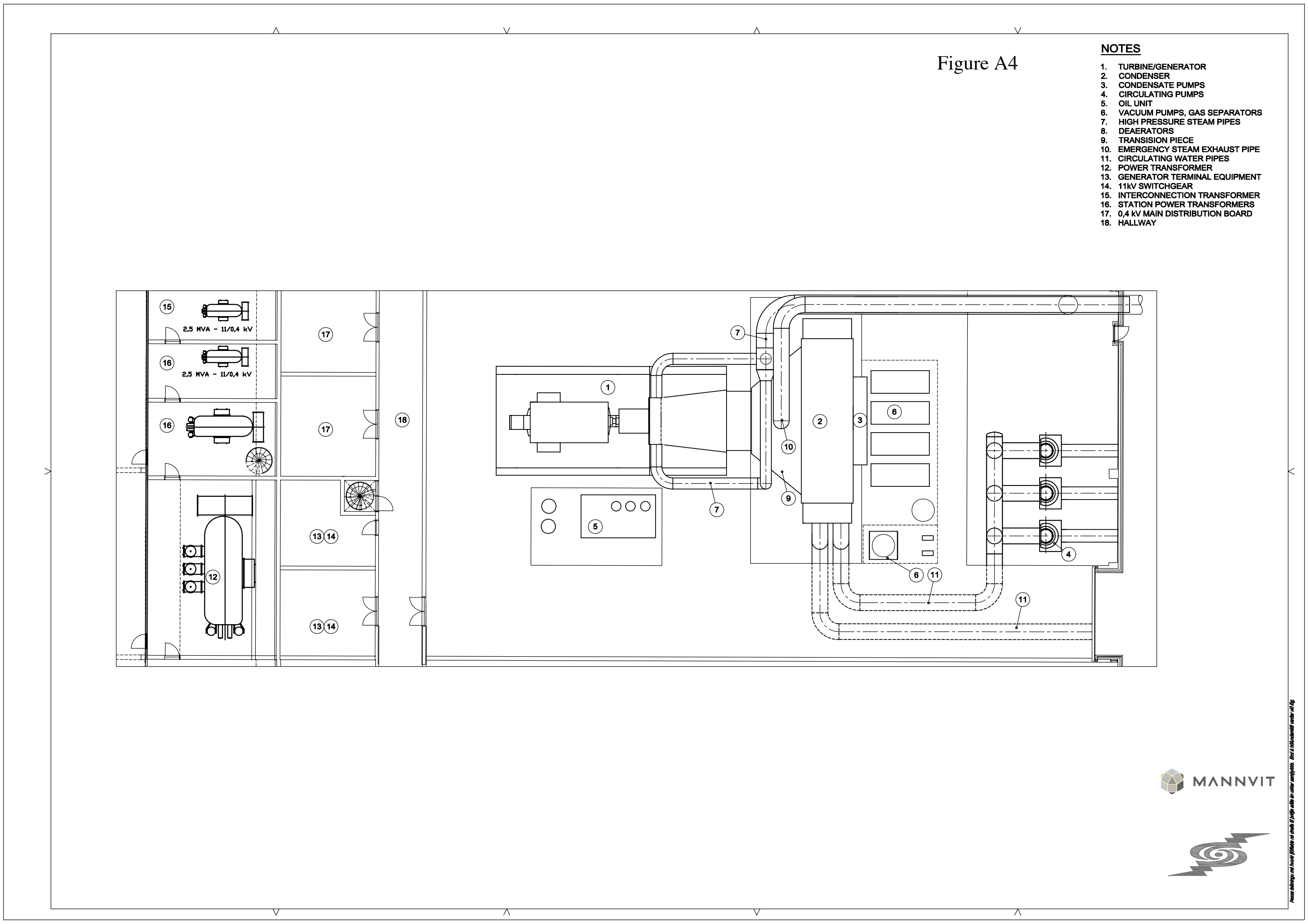

Figure A4.

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