Krafla Power Plant in Iceland - 27 Years of Operation

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Keywords: Krafla Power Plant, electrical generation

ABSTRACT

Krafla Geothermal Power Station has been operated for 27 years for power production by geothermal steam from Krafla high temperature geothermal field in Northeast Iceland. In this paper, the operational case history is described with main focus on experienced plant availability and reliability and necessary improvements on the original design, for example chemistry of the cooling water, gas extraction and blow-out systems and finally the steam blow out facilities and their noise reduction efficiency.

1. INTRODUCTION

For the last half a century, the electricity market in Iceland has grown faster than in any other western country and the electricity consumption per capita in Iceland is now higher than in any other country in the world. The Icelandic electricity market is split into 65% of power intensive industries with relatively constant electricity load variation, and the public market of about 35% with relatively little seasonal load due to the fact that over 90% of households in Iceland use geothermal district heating systems.

The present production capacity of electricity in Iceland is 1400 MW, approximately 1130 MW is from hydro power and 200 MW is geothermal power. Four projects, currently under construction, aim at increasing the production capacity by 65% in the next 2-4 years. A part from the 690 MW Kárahnjúkar hydropower plant East Iceland, 210 MW will be delivered by the fourth unit of the Nesjavellir geothermal power plant (Reykjavik Energy) and with the new geothermal plants at Hellisheidi (Reykjavik Energy) and in Reykjanes (Hitaveita Sudurnesja).

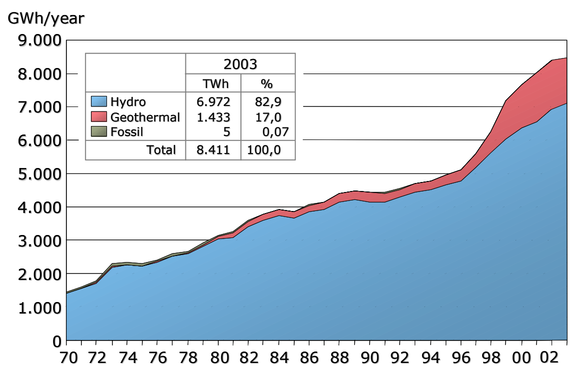

Figure 1: Sources of electricity production in Iceland.

These three geothermal power projects are the first in Iceland that are constructed with the main aim of providing electricity to aluminium smelters that demand high reliability and availability. As options for new economical hydropower plants are becoming limited, geothermal power plants will have to provide increased share of the electricity.

The fact that major international aluminium corporations are now accepting geothermal power production as sufficiently reliable for large smelters to depend on says everything about the current knowhow on how to build and operate geothermal power stations, gained the hard way from the "geothermal pioneer" in Iceland, the Krafla Power Station. This paper gives a brief overview of the numerous improvements that have been made to the production system in Krafla throughout the years to insure reliable operation.

2. THE KRAFLA GEOTHERMAL POWERSTATION

The Krafla geothermal field is located in the Krafla central volcano in Northeast Iceland, basically where the North Atlantic rift crosses the island.

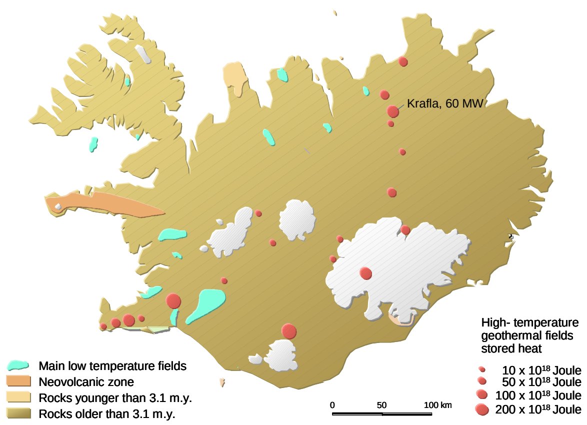

Figure 2: Location of Krafla Power Station in relation to other high temperature geothermal fields in Iceland.

The Krafla geothermal field development is mainly known for the volcanic eruptions during the construction time and the first years of production. A decision to develop the field was made in 1974 by two state owned organizations, Kröflunefnd (power station) and the National Energy Authority (steam supply system), on the basis of exploration wells. Construction on the 60 MW power station started in summer of 1975 but only a few months later, a volcanic eruption series started in the north part of the central volcano. When the eruptions series ended in 1984, magma had been released from the magma chamber 21 times, 9 times resulting in eruptions. Luckily, lava did not flow into the Hlidardalur valley, where the power station was located in the construction continued. Apart from surfaced elevation changes, the eruptions caused significant changes in fluid chemistry, mostly an increase in corrosive volcanic gasses in the wells located in the Viti area. As a result, wells had to be drilled in less favorable sites, further away from the eruption zone. The developers soon realised that the steam was insufficient for the planned power plant and only one of the turbines was fully installed.

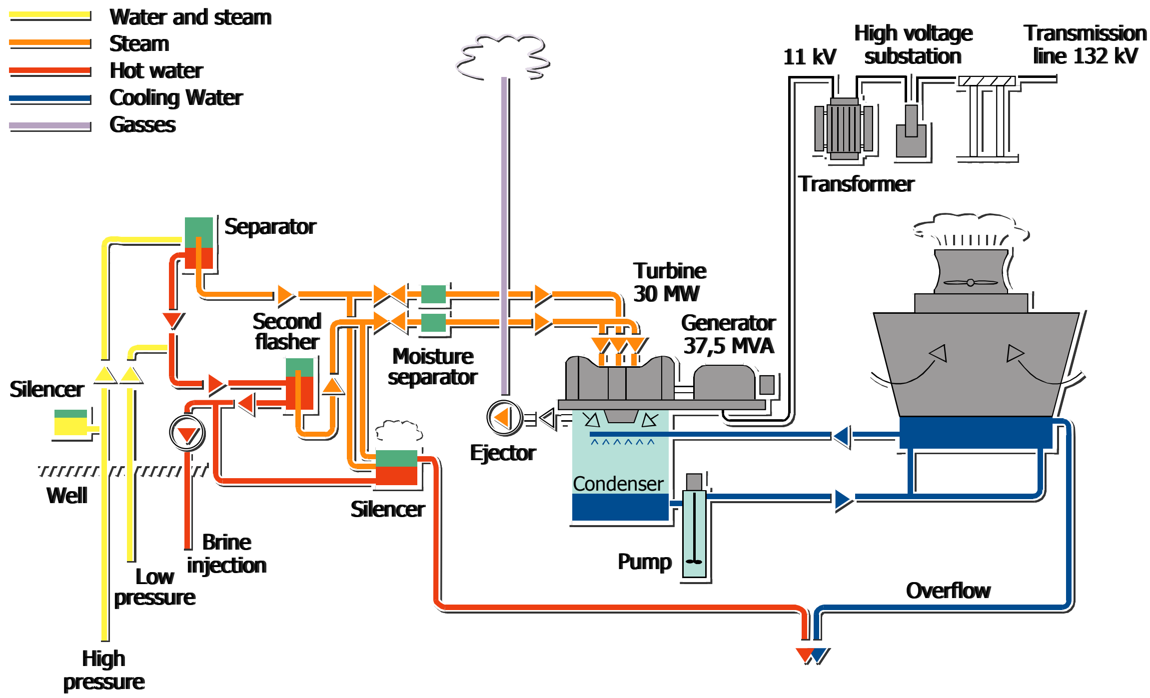

Figure 3: An overview of the Krafla Power Station.

The Krafla Power Station was commissioned in 1978, with only unit 1 installed, producing 7 MWe from 11 production wells. Gradually production was increased and the full capacity of 30 MW was reached around the time when the volcanic eruptions stopped (1984) and when Landsvirkjun (the National Power Company) took over the operation of both power station and steam supply system (1985). The following years the reservoir recovered and the gas content declined. In 1996, a decision was made to install the second turbine, that had been waiting on the shelf for 20 years, and the power station was finally on full 60 MW capacity in 1999. Currently, the power station is operating at full capacity of 60 MW and the reserve capacity of the steam supply system is equivalent to some 15-20 MW. In total 34 production wells have been drilled, 21 contributing to the steam supply system.

All permits and design are in place for a 40 MW extension, waiting for a customer to arrive.

3. IMPROVEMENTS FROM INITIAL DESIGN

The design of the Krafla Power Station is quite conventional for a high temperature hydrothermal field development. The Plant comprises two 30 MW dual flow, dual pressure Mitsubishi turbines, positioned on a condenser taking cooling water from a Marley cooling tower, as briefly described in figure 3.

Since the start-up of the power station in 1978, several modifications have been made to the initial design to improve the production system. Some of those are discussed here.

Centralised Separation Station

Initially, small wellhead separators were installed for each well or well pad. However, they were not effective and caused several streams of hot water to flow down the hills of Krafla. Therefore, a two phase steam gathering system and a centralised separation station were installed. The Separation Station was located approximately 400 m from the power station, based on lessons learned in New Zealand, and also at a convenient location where the main gathering lines from the Krafla hills and Leirbotnar met.

The two phase flow gathering system was a great success. No pitting problems have been experienced, pressure drop has been limited and controllable. The steam pipes are insulated with specially cut stonewool beams, strapped around the pipes and covered with bulged plastic cover. An aluminium cover protects the insulation cover on the outside.

The wells are still equipped with separators, functioning both as tests separators and silencers for well tests. Flow tests of dry wells have caused difficulties during tourist seasons due to noise exceeding 90 dB, measured 10 m away from the silencers. Now, a new type of mobile, rock-filled silencers has been designed. It is both smaller and significantly more effective for sound reduction.

Steam blow-out facilities centralised

The type and location of the main stream supply control valves and the associated steam blow-out system has been of great concern. In the initial design the control valves were located next to the cooling tower and the silencer was made of a high steal tower. The steal silencer was prone to corrosion and was as a result replaced by a rock muffler silencer. Then, another problem was discovered as corroding gas-rich air covered the powerhouse area and moisture caused icing problems during the winter months.

When the centralised separation station was built, the main steam supply control valves were moved next to it and the extra steam was blown through a pipe into a cooling pond. This solution was unacceptable as the pipe was prone to corrosion and when the power station tripped and 130 kg/s of 180°C hot water was flowing to the pond, it would boil and become dangerous for both employees and the increasing number of tourists.

Then, again, a 2 m wide, 15 m high blow-out towers were erected to distribute the steam and gas high into the air above the elevation of the powerhouse. The towers were covered by stainless steel on the inside to avoid corrosion. However, the thermal expansion of the stainless steel cover was not in phase with the outside pipe, resulting in buckling of the cover and pitting in the steel pipe on the outside. Finally, the towers were not particularly effective as silencers (95 dB).

Finally, in 2002 a centralised rock muffler was built next to the cooling pond. So far it has been a great success as practically removing all sound from the blow-out facilities (<60 dB). The new rock muffler was designed so that it could equally blow out steam from separators as well as two phase flow from the steam supply system during workovers of separators.

Cooling water chemistry

The chemistry of the cooling water has long been of concern. The initial design of the Krafla Power Station assumed that all "internal" cooling water was taken from the condense water in the cooling tower. However, significant amount of sodium had to be added to the cooling water to adjust the acid level and deposition problems were present in the heat exchanges. Therefore, a new 5 km long freshwater line was build in 1996, to allow fresh water to be used for air condition, generator, lubrication and gas cooling systems, eliminating problems with deposition, and by injecting fresh water into the condenser, reducing the acid level, was also an effective measure to reduce use of sodium. The impact of using 5°C freshwater instead of 20°C condense water has been greatest in the gas cooling system as the more effective cooling reduces the volume of gas to be extracted from the condenser making the gas ejector system more effective.

Use of sodium was finally made unnecessary last year by using relatively small amount of separation water (produced water), taken from the re-injection system, to improve the Ph value of the condense water in the cooling tower.

Gas extraction system

The gas extraction system has proven to be one of the hardest challenges for the operators of the Krafla Power Station.

The turbine unit was initially designed with a two-stage steam ejector system. That system has proven reliable but it requires about 10 kg/s of steam, equivalent of some 4.5 MW of electrical power. In 1998 it was decided to installing electrical gas pumps as an alternative. It was expected that the pumps would be equally effective in remove gasses but would only use 2.5 MW of electricity, therefore saving steam equivalent to 2 MW. However, the pumps were not successful in performance compared to the steam ejector system. They generated less vacuum and the steam savings were insufficient to justify the reduced turbine efficiency. This might partly be caused by new wells being drilled in more gas rich areas, resulting in gas concentration to rise from less than 1% at the time of gas pump design to being at present around 1.4%.

Cleaning of the gas coolers has also been of concerns. The holes in the top section of the cooling water spray system are prone to plugging and caused frequent and time consuming cleaning treatments. To mitigate this problem, a high pressured water cleaning system was developed that could be applied during operation, causing minimum impact. A spray nossle was prepared at the end of a pipe that could be fed into the gas cooler through a shaft seal and operated from the outside. The spraying nossle is now regularly moved across the punctured plate cleaning the holes sufficiently without stopping the station.

A final challenge associated with the gas extraction system was the location of the gas extraction outlet. The gas blow-out is corrosive and damages electrical appliances. Therefore, the gas extraction pipes were extended to the cooling tower fans to blow the gas further away from the power station. Still, this could cause problems in certain wind direction, as the wind would blow the gas from the tower to the ventilation intake for the power station. This caused excessive maintenance and the cost of coals for the air filters was great. Therefore, an alternative gas blowout tower was built on the other side of the power station and an automatic switch, linked to a weather vane, controlling if the gas was blowing through the cooling tower fans or the alternative blowout tower.

Improvements in cooling tower

Various methods have been tried to improve the efficiency of the cooling tower. One of the hardest tasks of operating the tower has been to keep the spraying nossles at the top of the tower clean, especially in bad winter weather. To solve this new, bigger nossles were designed by Marley and as a result, the nossles only have to be cleaned during scheduled maintenance stops.

Various smaller actions have been taken to improve the efficiency and reliability of the cooling system. To mention some, taking a part of the condense water from the line to the cooling tower and sending it through a few km of snow melting tubes and hence, bypassing the cooling tower as had measurable impact on the overall efficiency of the power station.

4. PLANT AVAILABILITY AND RELIABILITY

The plant capacity, load and availability are three factors that have been analysed to measure the improvements in the operation of the Krafla Power Station.

$$\text{Capacity Factor (\%)} = \frac{\text{Total [MWh] generated in the period * 100}}{\text{Installed Capacity [MW}_e\text{] * Period [hours]}}$$

$$\text{Load Factor (\%)} = \frac{\text{Total [MWh] generated in the period * 100}}{\text{Maximum Load [MW}_e\text{] * Period [hours]}}$$

$$\text{Availability Factor (\%)} = \frac{\text{Total hours of Plant in operation during the period * 100}}{\text{Period [hours]}}$$

Landsvirkjun´s operational goal is that during the winter months (October-Mars) the availability factor of the plant's turbines shall be > 99%. Tables 1 and 2 present a summary of these indicating factors for turbines 1 and 2 in Krafla respectively during the years 2000-2003.

The Capacity Factor is based on turbine rated capacity of 30 MWe but as can be seen, the turbines often exceed that.

The equivalent availability of Landsvirkjun´s hydro power plants was 98,8 % during the winter 2001/2002 and 99,3% during the winter 2002/2003.

Table 1: The reliability indices for turbine 1 in 2000-2003.

Turbine 1	**2003**	**2002**	**2001**	**2000**	**Average**
Capacity Factor [%]	100,92	101,24	98,32	97,87	99,59
Load Factor [%]	97,67	97,97	95,15	94,72	96,4
Availability Factor [%]	99,7	99,6	99,8	99,9	99,8

Table 2: The reliability indices for turbine 2 in 2000-2003.

Turbine 2	**2003**	**2002**	**2001**	**2000**	**Average**
Capacity Factor [%]	101,92	101,18	103,10	96,89	100,0
Load Factor [%]	98,64	98,88	99,77	93,73	97,8
Availability Factor [%]	99,6	99,8	100,0	99,9	99,8

5. CONCLUSIONS

After more than 27 years of operation of the Krafla Power Plant most of its key components are still in full operation.

However, various actions have been made to improve the efficiency of the Krafla Geothermal Power Station and a few of them have been reviewed in this paper.

The learnings made from the 27 years of operation in Krafla have been used for improved design of the more recent geothermal power plants in Iceland and given confidence for further geothermal developments. Currently, scheduled turbine maintenance stops in Krafla Plant are every 3rd year and soon 4th year.

Geothermal power has several benefits ahead of hydropower, most importantly that the power production is independent of the seasons and the weather. The power output can be maintained constant making geothermal power suitable for base load production with high capacity factor (between 8200-8500 h/yr on full load).

Operation of geothermal power stations in the active volcanic zone has an inherent risk but it is not of major concern since the intervals between volcanic eruptions are usually much longer than the economic lifetime of the plants. Next volcanic eruption period in Krafla is not expected within the next 200 years.

The availability factor of the Geothermal Power Plants is equivalent to the availability of Hydropower Plants, indicating that geothermal power production is competitive for delivering electricity to power intensive industries with high reliability requirements.

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