

# Hydropower project in arctic area - Greenland

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## Introduction

Tuesday 30<sup>th</sup> October 2012 was an important day for the Ilulissat community on the West coast of Greenland, in the Disco Bay (69°28'N). On that day, a major milestone was achieved towards reducing the community energy dependence and using renewable energy with the commissioning of the first turbine of three in the framework of the Ilulissat Hydroelectric Project. Less than a year later, on September 6<sup>th</sup> 2013, the project was duly completed.

The Ilulissat power project now provides the town of Ilulissat and its 4,500 inhabitants with electricity produced from 2 run-off of natural glacial lakes. The power plant installed capacity is 22.5 MW. Main challenges to the project are linked to the fact that the Ilulissat Hydroelectric Project was to be implemented in a natural pearl and in the remote and arctic conditions of Greenland. This caused various design and implementation challenges related to construction and operation of a hydropower plant in remote and permafrost conditions. Furthermore, the implementation schedule was tightly set over a 48 month period from initiation of the project until the plant was to be completed and running, an interesting challenge for the Contractor, knowing that the construction site would only be accessible by sea 3 months a year as the fjord is otherwise blocked by ice.

The project management part was in many ways a unique task on an international level, and the contractor did manage to deliver all parts of the project according to original contract time schedule. Succeeding in delivering a hydropower plant in the challenging conditions of Greenland requires experience, well planned and organized logistics and intensive work coordination. The present paper recalls the story of this project in relation to its planning, design and implementation for remote arctic conditions.

## 1. The Ilulissat Hydroelectric Project

Ilulissat, see Figure 1 below, is a town with about 4,500 inhabitants located in the Disco Bay in western Greenland, approximately 200 km north of the Arctic Circle. It is the third largest settlement in Greenland, after Nuuk and Sisimiut. The town is Greenland's most popular tourist destination, mainly because of the nearby Ilulissat Icefjord declared a UNESCO World Heritage Site in 2004. The fjord is the sea mouth of Sermeq Kujalleq, one of the few glaciers through which the Greenland ice cap reaches the sea. It is one of the fastest and most active glaciers in the world. It calves over 35 km<sup>3</sup> of ice annually, i.e. 10% of the production of all Greenland calving ice and more than any other glacier outside Antarctica. The Ilulissat Hydroelectric Project was to provide the town with green energy and replace diesel generators producing electricity.



*Fig. 1. Ilulissat*

The project had already been identified in the 1980's as part of a national search for hydropower potentials in populated areas in Greenland. It is not until 2008 that the decision is taken to realize the project and Nukissiorfiit, the Greenland's national power company, tendered the project as a turn-key. The Icelandic EPC contractor Ístak, daughter firm of Pihl og Søn in Denmark, with Verkís, Icelandic consulting engineers, as the main consultant, came up with the most attractive proposal and was selected for implementation of the project. The Ilulissat Hydroelectric Project (22.5 MW) is the third one of this type in Greenland realized by Ístak as the main contractor, following the realization of the Qorlortosuaq 7.5 MW hydropower plant in operation since 2006 and the Sisimiut 15 MW hydropower plant in operation since 2009. Among the features that made the proposal attractive was the early commissioning of the first of its three turbines, enabling Nukissiorfiit to step down production from its diesel generators earlier than initially planned.

### **1.1 Project characteristics**

The Hydropower Project is located in a fjord some 45 km northeast of the town of Ilulissat as shown in Figure 2.



Fig. 2. The Ilulissat Hydroelectric Project – location.

The project harnesses the discharge from two natural glacial lakes in the area “Paakitsup Akuliarusersua” with storage obtained by drawdown of the water levels by respectively 30 and 50 m from the present. Water is diverted from the upper lake through a diversion tunnel controlled by valves. The lower lake serves as the intake reservoir and from there water is diverted through an intake structure equipped with bulkhead gates. From these the water is conveyed through an inclined unlined headrace tunnel, partly in permafrost, down to three 7.5 MW Francis turbines on a vertical axis in an underground powerhouse. The powerhouse is at sea level some 400 m inside the mountain. Adjacent to the powerhouse is a transformer and a switchgear cavern. Water from the turbines empties into a tailrace tunnel which again opens into the sea. Figures 3 and 4 below propose section showing the hydropower plant concept and an overview of the main power plant elements.

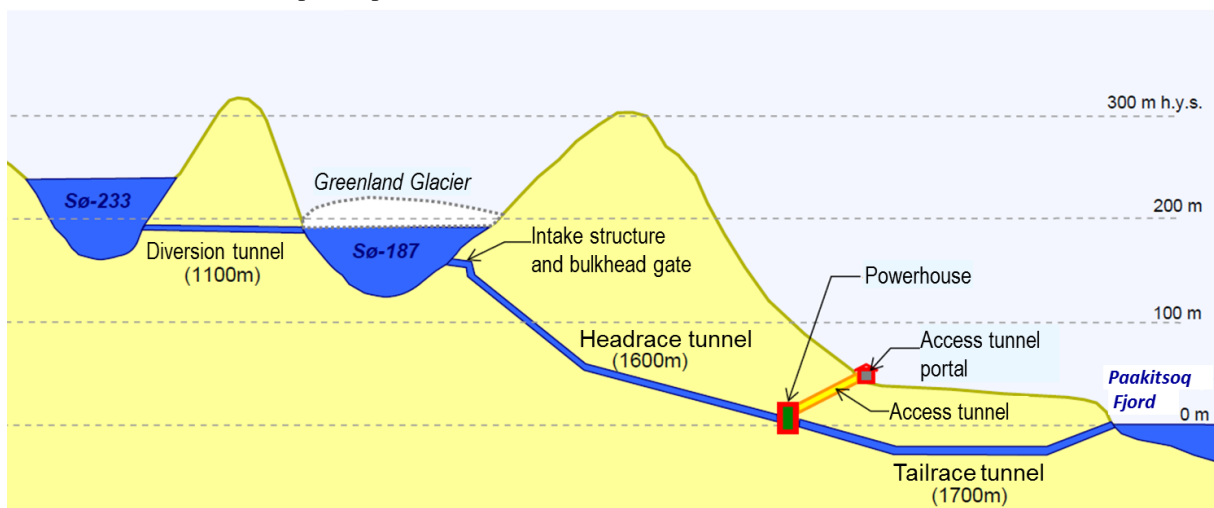


Fig. 3. Section showing the hydropower plant concept.



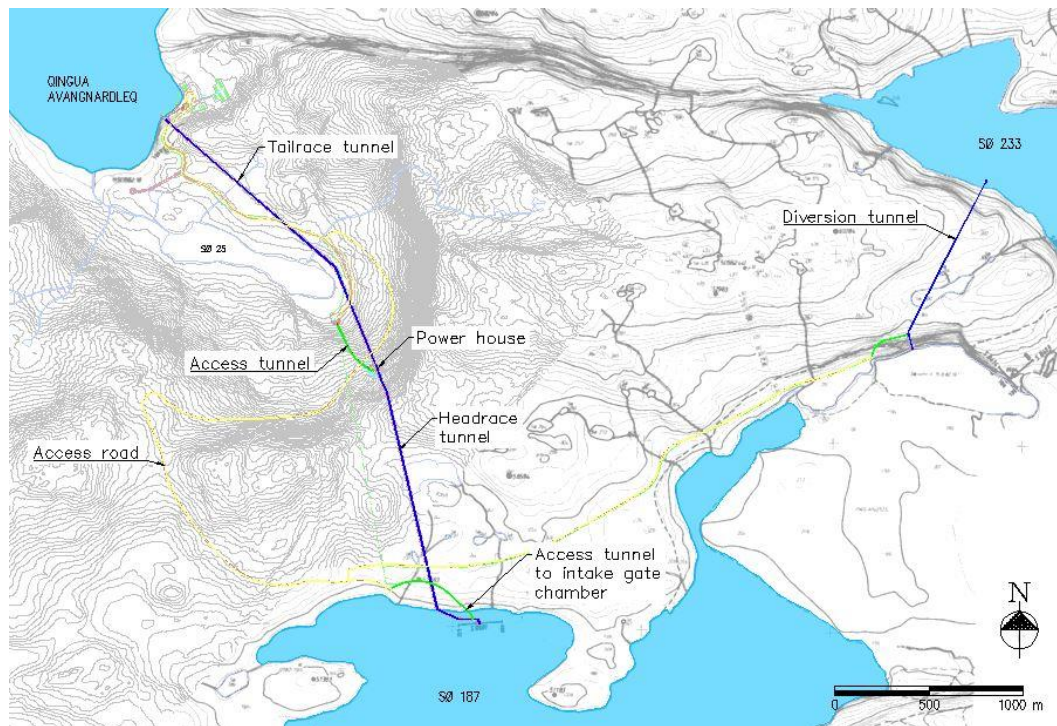


Fig. 4. Overview of the main power plant elements

A concrete service building is located at the access tunnel portal, housing service facilities and storages for the power station and its personnel. In addition, the building includes fully equipped accommodation for ten. The project also includes a helicopter platform with adjacent hut for transport vehicle, a harbor and associated facility housing the emergency diesel engine and transport vehicles.

#### General technical information

- Installed capacity and energy production: 22.5 MW; 65 GWh/a
- Turbines: Francis, 3×7.5 MW; Rated speed: 1,000 rpm
  - Gross head: 186 m
  - Rated discharge: 3×5.0 m<sup>3</sup>/s
- Generators: 3×10 MVA, 10.5 kV, brushless excitation
- Unit transformers: 3×10 MVA; 63/10.5 kV
- Substation in Power station: 4 bays 63 kV
- Substation in Ilulissat: 3 bays 63 kV, 2×21 MVA step-down transformers
- Reservoir I SØ 187 live storage: 54×10<sup>6</sup> m<sup>3</sup>
- Reservoir II SØ 233 live storage: 65×10<sup>6</sup> m<sup>3</sup>
- Headrace tunnel: 1.3 km; 4.0×4.5 m = 16.3 m<sup>2</sup>
- Tailrace tunnel: 1.8 km; 4.0×4.5 m = 16.3 m<sup>2</sup>
- Diversion tunnel: 1.0 km; 3.0×4.0 m = 11.0 m<sup>2</sup>
- Access tunnels:
  - To intake cavern: 374 m; 5.0×6.0 m = 27.3 m<sup>2</sup>
  - To diversion valve cavern: 374 m; 5.0×6.0 m = 27.3 m<sup>2</sup>
  - To powerhouse: 374 m; 5.0×6.0 m = 27.3 m<sup>2</sup>
- Powerhouse: 35×10.5×22 m; Transformer hall: 28.5×9×8 m; Service building: 35.6×10.4 m
- Transmission line: 63 kV, 50 km, 116 towers
- Location: 69°12' N, 51°05' W

## 1.2 Challenging conditions

As said before, the Ilulissat Hydroelectric Project was to be implemented in a natural pearl and in the remote and arctic conditions of Greenland posing therefore challenging conditions for its design and construction.

The Ilulissat icefjord, a UNESCO World Heritage Site, is considered a natural pearl. Implementing a project such as the Ilulissat Hydroelectric Project in an untouched environment is not only challenging for the design which was aimed at minimizing the visual impact of the new facilities but also during the construction phase. Logistics and work arrangements were to have minimal impact on the construction site environment.

One of the particularities of the project is also that it is located in a tundra area, characterized among other things by permafrost. This means that the ground and bedrock are frozen all year round down to several hundred meters and that thaw only occurs in the top layers of the ground over summer. Construction of hydropower plant and tunnel below ground in permafrost conditions is known in only one other place in the world, in the Kolyma region of Siberia where a 900 MW power plant was built in the years 1982-1995.

Operating a hydropower plant in arctic conditions and in remote conditions is in itself a challenge. In order to create acceptable operating conditions, Nukissiorfit required the plant to be designed as an automatic station, remote operated from Ilulissat. In addition, the plant was to be able to withstand a major stop for up to one week due to possible limited access in bad weather conditions.

Finally, the implementation schedule was tightly set over a 48 month period from initiation of the project until the plant was to be up and running. Not much unusual there, except that the construction site was only accessible by sea 3 months a year as the fjord is otherwise blocked by ice. Transporting people, machines and equipment on site was also to take into account the strong streams through the narrow opening of the fjord resulting from the melting of the glacier and high tide in the area. Not to forget the arctic weather conditions with temperatures going as low as  $-30^{\circ}\text{C}$  in winter and icebergs floating in the Disco Bay all year round.

## 2. Design

It was quite clear from the beginning that the permafrost conditions combined to the fact that the water temperature is close to  $0^{\circ}\text{C}$  would pose challenges for the design. There is a risk, especially in the first year of operation, of having ice forming on the walls of waterways, in particular in the tailrace tunnel lying in permafrost.

For better understanding the behavior of the permafrost and to predict the influence on the operation and structures in permafrost, a three dimensional finite element permafrost model was developed. The model and its findings are discussed in a paper on Hydro 2011 [2].

During excavation of the tunnels, thermometers were placed in boreholes in the tunnel walls at different depths to monitor temperature changes in the surrounding rock. The results of these measurements have been used to calibrate the temperature model and will without doubt continue to benefit future research on the influence of permafrost on underground hydropower plants. The 3D heat transfer model was calibrated to fit known temperature measurements and used to estimate the minimum required water flow that prevents water from freezing in the head- and tailrace tunnels of the power plant in case of a stop in the power production. Using a combination of calibrated boundary conditions vs. known data, conservative assumptions and a number of worst case scenarios, it was concluded that the minimum water flow required through the tunnel was no more than 315 l/s whereas the plant is designed for a rated discharge about 45 times the minimum flow required to prevent freezing conditions to occur. This value was presented without a safety factor, as a combination of several unlikely worst case scenarios. The required by-pass flow of  $0.315\text{ m}^3/\text{s}$  was easily obtained with three by-pass connections, one per turbine.

Because the plant was to be unmanned and operated from Ilulissat, it was designed to be able to withstand up to one week without being serviced in the worst weather conditions. A specific risk analysis was conducted during the design phase, aimed at identifying major failures due to permafrost and weather conditions as well as the risk of flood in the plant and assessing their impact on the operation of the plant. Results from the analysis were then taken into account in the design.

One of the results from the risk analysis was that in case of the transmission line failure, the station could be out of operation for several weeks at worst. It is not possible to run a one turbine only for the station load as the minimum load for Francis turbine is about 30 % load but the station power is only maximum 7 % load. On the other hand, it is rather costly to run a diesel generator for a long time and would require to have sufficient amount of oil stored for this event. The discussion on how to mitigate this risk led to the decision of installing an electro boiler of 2.5 MW that would enable running one of the turbines in case of line failure in the transmission system or in case of maintenance.

Erection of a transmission line in an untouched site such as the Ilulissat icefjord posed another challenge, although more common and with more well-known solutions. The transmission line designed by Efla in Iceland is with steel lattice towers, fastened down with steel ropes. The transmission line crosses Quingua Kujatdleg with approx. 600 m span. Most of the towers are anchored by rock anchors embedded in drilled holes with special adhesive mortar, suitable for sub-arctic conditions. The line is a Peterson coil grounded overhead line with continuous earth conductor with fiber wire for remote communication. The last 3 km of the transmission line to the substation in Illulissat is in underground cable to fulfil environmental requirements. The line was also hidden from the fjord behind the mountains.

The power plant was required to be unmanned and remotely operated from the dispatch centre in Illulissat. The SCADA system for control, acquisition and reporting of all controlled devices in this project includes two redundant servers placed in the power station, three operator clients, one in dispatch centre in Illulissat, one in the powerhouse and one in the portal building. The communication between the servers and clients is a ring connection with fibre connection from the power plant to dispatch centre and back from there to the power plant through a radio link.

### **3. Implementation**

The geographical location of the project and difficult access to the construction site meant that the project was highly exposed to any delay in execution of work that could occur due to unforeseen circumstances. The EPC contractor planned the project implementation accordingly and decided i.a. to manage the project risk by:

- Conducting a comprehensive design review;
- Using certified suppliers (for example, ABB, Kössler and Montavar);
- Having a sufficient stock of essential spare parts and goods at site;
- Emphasizing management of storage and workshop facilities;
- Using experienced key personnel; and
- Using conventional and traditional working methods.

#### **3.1 Planning and logistics**

Since the construction site was not easily accessible and in order to minimize impact of the Project in the Ilulissat icefjord, various storages were organized for the implementation of the Project in Sarfac (fjord passage) and Ilulissat. Part of the project included construction of harbor for transport of the machines and equipment and for transport of people. A heliport was also constructed near the harbor to transport people. Everything was to be transported to site to support the construction activities and provide accommodation and subsistence for the whole construction work force. Figure 5 illustrates the most common means of transportation in the project.



*Fig. 5. Ilulissat Hydroelectric Project – the way to travel...*

Equipment for the Project was mainly procured from European manufacturers. As a general rule, the equipment was transported to Ålborg in Denmark and shipped or transported by air from there to Sarfac and Ilulissat. Ship and barges were then used from these intermediary storages. The heaviest pieces of equipment included the turbines, the generators with stator and rotor – about 35 tons, the transformers – about 25 tons, the steel liners for the penstock – about 9 m, valves and gates. Transport by sea to the construction site was only possible from June to November and logistics and construction activities had to be planned accordingly. Transportation of these elements to the construction site was most critical because of the strong currents and high tide – about 5 m - setting limits on the type of ships that could be used, see Figure 6. The Project could not afford to lose or damage these long lead items during transportation to the site. It can be mentioned here that during transport of one of the heavy pieces of equipment, it turned out that an iceberg was on the ship planned trajectory. The deviation required to avoid the iceberg almost put the ship at risk when it entered the strong current of the fjord but this went well in the end thanks to the experienced contractor mandated for these activities.



*Fig. 6. Shipping of equipment to the site*

About 170 persons were on site when construction was in full swing with locals and people from various nationalities with citizen from among others Iceland, Greenland, Slovakia, Croatia, Poland, Slovenia, Austria and Germany. A camp was erected close to the harbor site some km from the main construction site. Drinking water had to be obtained by osmosis from sea water because potable water was not readily available on site. An environment, health and safety plan was prepared and implemented for the construction phase. Since the project was in a remote location, sometimes difficult to access due to weather conditions, team members specially trained for first help were to be always available on site. Other safety measures included among others a firefighting system, a fire truck and trained firemen on site.

The construction site included a harbor, a concrete plant, a workshop, offices, a storage, a carpenter shop, a diesel generator and fuel tanks in addition to shelters for the workers. Communication to site included microwave links, VHF system, telephone, internet, satellite telephones and direct satellite links.

### **3.2 Construction**

Due to permafrost, the traditional methods of reinforcement in tunnels, rock bolts and concrete had to be revised. The temperature of the rock was down to  $-4^{\circ}\text{C}$  and in some places, cracks in the rock were filled with ice that melted as the tunnel was constructed. As a result, the rock stress situation changed from day to day.

One example illustrating the difficulties to implement such a project with the unforeseen that usually follow at the design stage is the realization of the intake. One of the key structures of the power plant is the intake at the intake lake SO-187. The intake is located some 30 m below the surface of the reservoir. The intake structure consists of a cave specially designed to be able to receive without obstructing the intake the rocks and sediments falling in the intake as a result of the final blasting of the cave cap. A bulkhead gate is located right after the intake structure.

Initial measurements and assessment study of geology and thickness of sediments indicated that the sediment layer was about 4 m thick at the bottom of the reservoir. Due to the difficult site conditions, it was not possible to verify these results, except that the water depth was investigated which revealed good accordance with previous observations. Exploration holes were drilled regularly during excavation of the tunnel, indicative of the quality of the rock ahead each time, and the need for grouting. When the work came close to the intake, the exploration wells revealed that previous studies underestimated the thickness of sediments at the bottom considerably. Their thickness was found to be 8-10 m and the rock under the surface sediments was found quite irregular. Clearing away the sediments by dredging was considered as this practice is rather common but such action would have delayed the project considerably and would have been expensive and technically difficult due to the site conditions. Instead, it was decided to redesign the intake according to the new data.

Various options were evaluated but in the end it was decided to increase the diameter of the inlet from 4.0m to 6.5m as well as to expand the volume of the cave significantly in order to be able to receive increased quantities of sediments without blocking the intake. The redesign assumed that the cave was to be able to receive 2,500-3,000m<sup>3</sup> of loose sediment instead of 600-700 m<sup>3</sup> in the original design. Once the cave was ready, it was about 16-19 m high and extensive scaffolds had to be arranged in order to install the explosive on the cap in safe conditions. The scaffolds were removed prior to blasting. It is to be mentioned that during these activities, the cave was only accessible through manholes and an 800 mm steel tube. The cave was then filled with water and arrangements were made to make sure enough air was available for the explosive to ignite properly. It was clear that the circumstances of the inlet cap was difficult to deal with. Norwegian consultants who assisted with the project, said that it had only been tried once before in the world to blast rock covered with sediment of a similar thickness, and then the operation had failed.

The blasting was triggered at 7:15 on the morning of Sunday September 30, 2012. Air was expected to rise to the surface of the reservoir soon after. Much was at stake and about 1 ½ minutes later when the air finally came to the surface, everyone was relieved as one of the key milestones of the project was finally reached, see Figure 7.





*Fig. 7. Air reaching the surface after blasting the cap of the cave*

### **3.3 Starting up the power system - commissioning**

One of the particularities of Greenland electrical system is that there is no high voltage grid. Each town or village is run as an “island”. This leads to the problem of energizing the power transformers in case of a total black out of the system. The manufacturer of the generators do not allow direct start the unit transformers as the inrush current when energizing can be higher than the allowed current of the generator. The same counts when energizing the substation transformers as they are twice the size of the unit transformers. The solution to this specific problem lies in the so-called “soft start” of the 63 kV system including all the power transformers.

This is done by taking one of the turbines up to speed with help of the diesel generator and without energizing the generator. The respective generator circuit breaker is then closed as well as all the 63 kV circuit breakers in the system, four in the power plant and three in the substation in Illulissat. Next is to energize the generator slowly until full voltage is reached. After that it is possible to synchronize to the station system run by the diesel generator in the power plant and to the diesel generators in Illulissat town.

One of the requirement to the power plant was that the plant should be tested under full load i.e. 22.5 MW but on the other hand the maximum load of the town was only 5 MW and no actual grid as named before. It was also required that the town load should not be used for testing purposes. The solution was to install a 15 MW electro boiler outside in vicinity of the service building using water from adjacent lake as “cooling” water. Additional load to this was the electrical boiler 2.5 MW named before as load in case of “no-load” running of one of the turbines as well as the station and construction load of 0.5 kW. The rest of the load up to 21 MW was taken from the town load as the owners agreed on lowering the requirement.

Landsvirkjun Power, daughter firm of Landsvirkjun the main power producer in Iceland, has contributed to training Nukissiorfiit staff and has been in charge of the operation of the plant over the first year of operation.

## **4. Conclusion**

The Ilulissat Hydroelectric Project has mainly been characterized by logistical challenges due to the remote location of the site, the Sarfac Canal Passage, the cold climate and short summers, the ice blocking of the West Coast of Greenland and in the Pakitsaq fjord as well as communication and transportation to the site. Implementing such a project in remote arctic conditions requires detailed planning, experienced professionals, good coordination of all stakeholders involved and discipline. The Ilulissat Hydroelectric Project being a Turn – Key project, the contractor had to carefully coordinated the work of the designers, the contracts of all subcontractors, the procurement of all electrical- and mechanical deliveries, the construction of concrete buildings, the blasting of the tunnels, the erection of the transmission line and the startup, testing and commissioning of the Power plant and delivery to the customer. The deliveries and subcontractors were on a high international level with subcontractors from many countries.

The project management part was in many ways a unique task on an international level, and the contractor did manage to keep all milestones and deliver all parts of the project according to original contract time schedule. The task to design and build this automatic power station with sophisticated high technological control system and complex electrical and mechanical components was a challenge with a duration of 4 years for the construction period.

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