Powering on with hydro designs

With over 60 years of experience, Studio Pietrangeli prides itself on merging technical qualifications with culture and creativity to find solutions to challenging engineering problems. Here the company discusses the importance of powerhouse design in hydropower project development.


ታላቁ የኢትዮጵያ ህዳሴ ግድብ ቦንድ
Grand Ethiopian Renaissance Dam Bond
Interest Rate
P.A
№ 0034784 HE
FIVE HUNDRED BIRR COUPON
Issue Center
Issue Date
Maturity Date
(Bondbuyer's Full Name)
Signature
500
Minister, MoFED
500

Above: Figure 1 – Sierra Leone's banknote with Bumbuna dam on the reverse side. Top right: Figure 2 – Grand Ethiopian Renaissance Dam Bond, issued in 2012. Right: Figure 3 – Recent outdoor power house with high head (Gibe II, 420MW)

Based in Rome, Italian consulting engineers Studio Pietrangeli was founded in the 1960s by Giorgio Pietrangeli. Since then the company's engineers have developed their skills and experience working mostly in Africa, Europe and South America. Powerhouse design has played an integral part of many of the company's projects. Several of these schemes, given their innovative solutions and importance, have been written about and/or cited in prestigious magazines, such as National Geographic, and used to illustrate banknotes and bond issues. The company has also recently completed the design of its 150th large dam and 50th hydropower project.

Powerhouse location: underground or outdoors?

The most important choice to be made during the design of a powerhouse is its location: cavern or outdoors? A number of factors influence this choice. Most importantly is the hydraulic scheme, ground morphology, geological factors and last, but not least, environmental aspects.

For medium to high head plants, the possibility of an open-air penstock with the powerhouse on flat ground on the river banks is an important, decisive factor for the outdoor alternative. On the other hand, a homogeneous and impervious rock mass, capable of withstanding high water pressures, favors an underground powerhouse.

For plants with a low to medium head and a high flow, it may well be convenient to build the powerhouse just downstream from the dam or even to incorporate it in the dam itself. In the case of pumped storage plants, the cavern solution is often obligatory given the high submergence required by the pump also at the minimum level of the lower reservoir. All these considerations are taken into account in choosing the most suitable solution, together with an economic comparison of different, technically feasible alternatives.

Recent trends

Although the cavern solution requires more attention to be paid to rock characteristics, drainage problems, ventilation requirements, fire-fighting systems etc, its adoption has recently been encouraged by the use of:

- Modern excavation techniques (in particular the wide use of TBMs for tunnel excavation).
- XLPE HV cables (instead of oil-filled cables) to connect the step-up transformers to the switchyard.
- Modern telecommunication systems (optical fibres).

Figure 6 shows a typical layout of a modern underground powerhouse. As far as the equipment layout is concerned, the underground solution often has the step-up transformers in a separate cavern from the powerhouse. In our recent projects, transformers are located in individual cells equipped with anti-blast and fireproof doors. The air insulated switchgear (AIS) or gas insulated switchgear (GIS) switchyard is then connected via XLPE HV cables running along the access tunnel or along a dedicated vertical pit. Alternatively, if the run of the bus ducts is not too long, the step-up transformers may be located outside near the switchyard.

In some cases, as an alternative to the AIS switchgear, where there is a shortage of space and/or environmental constraints, a GIS solution has been adopted.

Hydraulic transient analysis

Numerical modelling for transient analysis has allowed for design optimisation in some of the company's recent large projects. The relatively low water head (DH=210m), smallish head losses and high flow in the power tunnels (Q = 2x475m³/sec) require a large surge shaft cross section to ensure, on the one hand, acceptable water level surges in case of load rejection and, on the other, quick dampening of water level and power and frequency oscillations in the shaft during transients.

A straightforward application of Thoma's theoretical stability criteria (shown below) would lead to extremely high values for the surge shaft diameter.

$$A_s > \frac{L_t q^2}{2gJA_tH}$$

: Where A_s= area of surge shaft; L_t = tunnel length; A_t = area of power tunnel; J = head losses; H = waterhead; q = flow rate

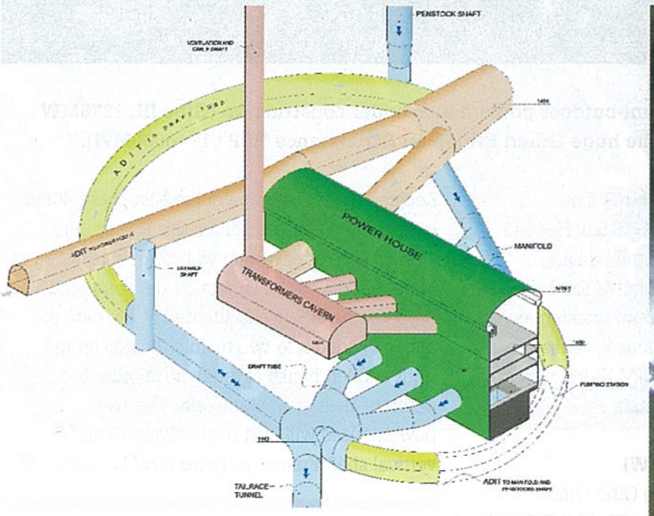
Therefore, knowing that the control system parameters and grid regulating energy also have a strong influence on system stability, a comprehensive model, including the hydraulic system, control system and electric grid, was set up which allowed a substantial reduction of the surge shaft diameter. The size of the shafts are, in any event, remarkable: 18m diameter, 120m high.

Fast track implementation

The "fast-track" implementation methods have been adopted by the company for turnkey construction of large hydro plants, especially in Africa.

Figure 4: Large semi-outdoor powerhouse located downstream of the dam (Gibe III, 1870MW)

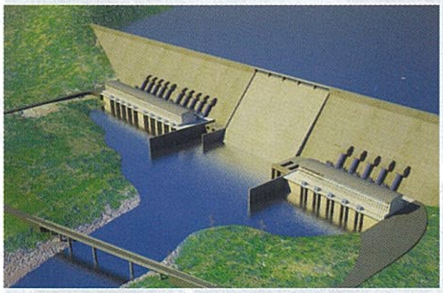
Above: Figure 5 – Semi-outdoor powerhouse located at the dam toe (Bumbuna, IP=50MW).
Below, left: Figure 6 – Typical layout of a modern underground powerhouse (Beles , IP=460MW);
Below: Figure 7 – Underground powerhouse during construction (Beles, IP=460 MW)



The basic concept of this method is to implement as many critical operating phases as possible simultaneously thereby drastically reducing, in some cases up to 30% of total construction time. Thus the fast-track plant starts producing benefits and income long before traditionally built plants, generating a much quicker economic return against a minimum (or no) increase in upfront costs.

Moreover the extensive use of the cutting-edge technologies for the investigations, such as satellite imagery, laser scanning, tomographical geophysics, etc. remarkably shortens the traditionally lengthy periods required saving several months of time during feasibility design.

Over the past few years Studio Pietrangeli has designed numerous large hydropower plants totaling over 20000MW. The most remarkable projects currently under construction or recently commissioned include Bumbuna (50MW), Beles (460MW), Gibe II (420MW), Gibe III (1870MW) and the Grand Ethiopian Renaissance dam (6000MW).



Above: Figure 8 – Large semi-outdoor powerhouse under construction (Gibe III, 1870MW.)
Left: Figure 9 – Design of the huge Grand Ethiopian Renaissance HPP (IP=6000MW).

All the engineering services for these plants were, or are being performed entirely by Studio Pietrangeli.

Bumbuna (Sierra Leone, 50MW First Phase)
Bumbuna is the first large hydropower project in Sierra Leone. It includes a 88m high rockfill dam, a semi-outdoor powerhouse and a 161kV transmission line, 200km long, from the power station to Freetown.

The powerhouse is at the downstream toe of the dam and houses two 25MW Francis turbines coupled with 33MVA synchronous generators. The machine hall is 41m high x 17m wide and 24m deep. To allow for future expansion, a second blind off-take from the power tunnel was provided to serve the future penstocks.

Beles (Ethiopia, 460MW)
Beles exploits the water resources of Lake Tana. The plant's 20km, 7.2m diameter, underground waterway was excavated entirely by TBM. The underground powerhouse includes a main machine hall equipped with four 115MW high-head Francis turbines and 130MVA, 15kV generating sets, together with a 400/15kV transformer cavern (figures 6 and 7). The powerhouse cavern (L=90m, W=18.5m, H=40m) hosts the erection bay and control building. A suspended floor design was adopted for the machine hall to provide maximum working area at turbine floor level. The powerhouse is linked to the outdoor switchyard via 400kV XLPE cables which run through a vertical shaft.

Gibe III (Ethiopia – 1870MW)
Gibe III is the third plant of the Gibe-Omo cascade comprising Gilgel Gibe (IP=200MW) and Gibe II (IP=420MW), both operating, and Gibe IV and V (planned). It includes a 246m high RCC dam which, when completed, will be the world's highest of its kind.

The powerhouse is on the left bank of the river, about 500m downstream of the dam axis. The building, 235 x 38m wide and 50m high, houses ten Francis turbines (H=214m, Q=95m^3/sec, IP=187MW each) at 18m intervals with the erection bay and control building at the downstream end. The outdoor transformer yard lies on a berm excavated at the powerhouse roof and will host five terns of single-phase step-up transformers (15/15/400/√3 kV, 147MVA) each connected to two generators by means of bus-bars passing through dedicated shafts.

Grand Ethiopian Renaissance dam (Ethiopia – 6000MW)
Once completed, with 6000MW of installed power, Grand Ethiopian Renaissance dam will be the largest hydroelectric power plant in Africa. Located on the Ethiopian Blue Nile, about 40km east of the Sudanese border, the 155m high, 11Mm^3 RCC gravity dam will create a reservoir of about 63Bm^3, one of largest on the continent. The outdoor powerhouse is situated at the dam toe and is divided into two main buildings on the right and left banks of the river, in order to optimise river diversion works. The two powerhouses will host respectively 10 and 6 vertical shaft Francis turbines (375MW each). ■

Author information

The authors are Antonio Pietrangeli, Partner at Studio Pietrangeli, antonio.pietrangeli@pietrangeli.it

Antonio Brasca, Dam & hydropower expert at Studio Pietrangeli, antonio.brasca@pietrangeli.it

Stefano Galantino, Electro-mechanical expert at Studio Pietrangeli, stefano.galantino@pietrangeli.it

Giuseppe Pittalis, Senior dam & hydropower engineer at Studio Pietrangeli, gibe3@pietrangeli.it

Reference

M. Cadeddu et al., Frequency stability of an islanded grid supplied by hydropower plants, Hydropower and Dams, issue No. 6, 2010.