Laúca Hydropower Project / Angola
Impounding and Commissioning

Dr.-Ing. Jürgen Horn
Lahmeyer International GmbH
Hydropower and Water Resources Division
Friedberger Strasse 173
61118 Bad Vilbel, Germany

Eng.º Elias Daniel Estêvão
GAMEK
Gabinete de Aproveitamento do Médio Kwanza
Bairro Operário – Rua Massangano S/N°
Luanda, Angola

Introduction

The Laúca Hydropower Project, with an installed total capacity of 2,070 MW, is presently one of the largest hydropower projects in Africa and will be the future backbone for the electricity generation in Angola.

Angola is located in the sub-Saharan zone of Africa and has exceptional hydro resources, characterized by many rivers with high flow rates and significant hydraulic head. Particularly, the hydraulic head between the central plateau and the sea is significant. An estimated potential of 72,000 GWh/year, corresponding to an installed capacity of about 18,000 MW, has been identified. Special attention has been given to the Kwanza River due to its high hydropower potential.

Approximately 50 km upstream from the Laúca site is the Capanda HPP, with an installed capacity of 520 MW. It has been in operation since 2004. The Cambambe HPP is located downstream of Laúca. At the end of 2016 the second implementation phase was finalized and now the entire capacity of the Cambambe HPP has been increased to 960 MW. Lauca is the third hydropower plant constructed on the Kwanza River. Excavation works for the river diversion at the fourth hydropower plant, Caculo Cabaça, located 20 km downstream of the Laúca site, started in August 2017. The hydropower plants of Zenzo, Túmulo de Caçador and Luíme are still in the project phase. All seven plants are located on the Kwanza river form a cascade with a length of only about 120 km.

Thus, the flow to Laúca is mainly restricted by the regulation of the Capanda HPP. On the other hand, a sufficient flow during all the stages of impounding and commissioning of Laúca HPP had to be provided in order to guarantee the ongoing energy production for the other existing plants on the Kwanza river.
The enormous time pressure of this huge project created enormous challenges. For example, the main works started prior to the conclusion of the river diversion works. After closure of the river diversion tunnels and start of impounding the works at the upper elevation of the dam had to be finalized. The commissioning of the first unit started while the works of the other units continued and permanent access to the site, especially to the penstocks and the cavern had to be guaranteed. With the start of operation of the first unit only three units had finished ceilings in the Power House.

1. About this project

The site work started in 2012 with the preparation works for the river diversion. The main construction work started July 2013. The first parts of the electromechanical equipment were delivered in January 2015 and already in October 2016 the first diversion tunnel was closed. The closure of the second tunnel and the start of impounding of the reservoir has been realized on 10th March 2017.

The operation of the first power generating unit started July 2017. The planned operation of all six units in the Main Power House, the unit of the Ecological Power House and the finalization of the project is scheduled for the first half of 2019.

Fig. 2. RCC-dam and Power Intake area at the right abutment

The six power intakes tower, with a height of about 74 m, designed for a total flow capacity of 1,104 m³/s, has been constructed on the right abutment. The shafts (70 m high and 8 m diameter) have been executed by using the raise-boring method and were lined with reinforced concrete. Six, approximately 2 km long, headrace tunnels will lead the water to the underground power house, equipped with six Francis turbines, each with a rated capacity of 340 MW.

Less than 300 m of the head race tunnels required reinforced concrete lining to strengthen the rock surfaces. The strong gneiss rock permitted mainly a rock support consisting of fibre reinforced shotcrete, rock bolts and anchors. The tunnels were executed by using the conventional drill-and-blast method. The inverts of the tunnels were executed roller compacted concrete. 60 m before the entrance to the powerhouse (starting in the rock trap zone) the tunnels were fully lined with reinforced concrete. Additionally, the last 40 m of the headrace tunnels were steel lined.
The underground powerhouse (295 m length, 22.50 m width, and 53.30 m height) will house six Francis turbines, each with a rated capacity of 340 MW, and was excavated using the conventional drill-and-blast method. The erection bay has been lengthened in order to allow the parallel assembly of spiral cases, head cover with ring gate, generator stators and rotors. The two bridge cranes can be combined and thereby provide a total lifting capacity of 2 x 3,500 kN (= 700 tons) and will be used to place heavy hydomechanical components into their final position.

The 132 m high dam of roller compacted concrete (RCC) type will create a 188 km² large reservoir with a storage capacity of about 5.5 x 10⁹ m³. The total volume of concrete of about 2,910,000 m³, emphasizes the enormous dimensions of this project. A conveyor belt between the batching plant, located at the right abutment, and the dam was installed to achieve an effective and efficient operation providing a peak concrete production rate of 180 000 m³ per month.

The bottom outlet (design discharge capacity from 800 to 1 200 m³/s) and the three spillway radial gates (designed for a total discharge of 10,020 m³/s) are located and integrated in the middle of the dam and were executed with conventional reinforced concrete.

Additionally, a separate open air power house will be located at the toe of the dam and will be equipped with a 67 MW Francis Turbine using the minimum required ecological flow rate of 60 m³/s of the Kwanza River for electricity generation.

2. Closure of River Diversion / Start of Impounding

During the construction of the dam the river Kwanza was diverted by two shotcrete-lined horse-shoe shaped tunnels located at the right abutment with a total length of about 1,020 m, a width of 14.0 m and a diversion capacity of 4,337 m³/s. In October 2016 the first diversion tunnel was closed by three sliding gates, followed by the construction of a concrete plug located in the axis of the dam.

In order to use the expected peak flow in the months of March and April of 2017, the start of impounding was rigidly determined by these dates. The start of impounding could not have been started later. Therefore, the various site works had to respect and adapt to this governing time constraint. The safety components, such as the bottom outlet and the intake gates of the power intake, had to be closed and operable in spite of the fact that the dam’s final crest level had not yet been reached. The site works at the upper levels, which were not impacted by the first impounding level, continued.
The bottom outlet radial gate in the dam was installed and commissioned before the impounding started. The radial gate controls the water flow via two hydraulic servomotors. At the entrance of the bottom outlet tunnel one intake gate was installed in the open position.

The structure of the second diversion tunnel features three bays which are equipped with stop logs for the final closure and, additionally, three bays in front. Before the installation of the final stop log a roller gate was inserted in front of the stop log to close the water way. For this procedure, a large capacity mobile crane was used. When the roller gate was in the closed position and the water flow was stopped, the installation of the stop logs began. With the stop logs in the closed position, the roller gate was removed. This sequence of installation for the stop logs was repeated twice. After all three stop logs were installed in the closed position, the roller gate was not removed and stayed in the center position.

The impounding of the reservoir started on 11th March 2017 with the closing of the second diversion tunnel. At that time the water level was 735 m asl and the working base for the mobile crane was at 760 m asl.

Only three hours after completing the closure of the river diversion tunnels the reservoir level increased by 14 m (749.0 masl) reaching the upper level of the bottom outlet of the dam and thereby guaranteeing the required minimum ecological flow of about 60 m³/s and, also, no less important, providing the required flow rate for the downstream Cambambe HPP operation.

At the Power Intake area the complete civil works had to be finished and cleaned up before the water level reached the bottom of the intake gates. All six trash rake installations had to be completed and the trash rake machine tested and operable. The area in front of the Power Intake was cleaned of loose rocks and sand to avoid any debris going through to the turbine. Each of the power intakes are equipped with one sliding gate with a dimension of 8,240 mm/6,650 mm. The gantry crane was finished and commissioned for the installation of the intake gate segments and stop logs.

Two weeks after the start of impounding the water level reached the closed gates of the Power Intake Towers. This reservoir level (elevation 785 m asl.) marked the first important benchmark during the impounding procedure since this constitutes the first proof of tightness of the closing devices of the Power Intake. All closing devices worked very well and no infiltration could be detected in the waterways.

The intake of the “ecological” power house (consisting of the trash rack and an intake gate (sill level 785.3 m asl.), incorporated in the RCC-dam at the left side) was reached two days later. Due to the fact that the penstock for the Ecological Power station had not been finished, the intake gate is locked in closed position for safety reasons and the required minimum ecological flow is guaranteed by the flow through the bottom outlet. Infiltration in the RCC-dam during impounding is measured periodically in the drainage galleries of the dam. To date the amount measured (0.04 m³/s) is not significant.
The water management during impounding until elevation +800 m (pre-condition elevation to start wet commissioning), reached on 25th April 2017, is reflected in the following figure:

Fig. 5. Water Management during Impounding of Laúca
Furthermore, with the start of impounding and the associated rising reservoir the important river crossing at the upstream cofferdam was no longer available and a direct access to the construction site was eliminated. Alternative access for the transport of material, equipment and personnel had to be managed in order to ensure the effective and efficient continuation of the works on the left embankment. Access was only possible from top of the dam, which at this time was not fully completed. Therefore, prior to the impounding all necessary equipment was located at the left embankment and connected by a conveyor belt with the concrete plant, ensuring continuous provision of concrete.

3. Commissioning of the plant

The testing and commissioning of the first unit had started while the final construction works of the other headrace tunnels and also the works on the other units in the Power House were ongoing. Thus, the consecutive commissioning of each individual unit with the parallel finalizing construction works was a further complex challenge.

Due to the high hydraulic head (220 m) and large dimension of the penstock (more than 6 m diameter adjacent to the spiral case inlet), instead of using a valve, a ring gate was selected. The ring gate with a diameter of 5987 mm is located between the 24 wicket gates and the stay vanes to protect the turbine. In case of a wicket gate failure, the ring gate will close automatically and cut off the water flow and the unit can be stopped. Six hydraulic servomotors control the position of the ring gate. Each servomotor has its own control block and are synchronized to guarantee a precise level position. Ring gate commissioning tests were conducted successfully without any significant vibration.

![Fig. 6 Installation of runner and ring gate](image)

Preparation works before filling of the headrace tunnel

Prior to the filling of the headrace of Unit 1 the complete civil works in the penstock (including plugs to the neighboring tunnel) had to be finished and inspected including the rock trap and rock trap access. The draft tube of Unit 1 was inspected and all man doors (spiral case / draft tube) safely closed. The drainage valves and dewatering valves on Unit 1 had to be closed and logged.

At the water outlet area all six tail race tunnel were closed with stop logs prior to filling the water of the outlet area via pumps. The controlled filling with the pumps using the water of the Kwanza River was started on 26th May 2017 and finished 4 days later with a water level elevation of 627.8 masl. During and after filling of the outlet bay with water, the leakage rate of each stop log was measured.
Dry Commissioning Tests on the Turbine and Generator

After completing the installation works on the turbine and generator with the complete auxiliaries systems (cooling water, compressed air, bearing oil supply etc.) the completion of this installation was certified and the dry commissioning phase started. The ring gate was operated several times for the opening and closing time adjustments. For the wicket gates opening and closing time adjustment was also necessary. During these tests, no water was detected in the penstock or draft tube. All installed sensors on the turbine and generator (pressure, level, flow and temperature) was checked and adjusted in accordance to the commissioning procedure. The SCADA system (automation) was in operation to test all incoming and outgoing signals. The communication connection from the Power House to the substation, water intake and control room (outside of Power House) is made with optical fiber cable.

Filling of waterways

The start of the wet commissioning was scheduled at a reservoir level of +800.00 masl. The filling of the Unit 1 tailrace tunnel started on 07th June 2017 with the opening of two bypass valves from the stop logs. During the filling of the tailrace tunnel, the water pressure was continuously monitored with manometers. When the water level reached the level of the outlet bay (627.8 masl.) the stop logs of Unit 1 were removed.

Inspection of the water leakage on the turbine (spiral case, head cover and cooling water pipes) and civil parts (penstock with 2 plugs) were conducted. On 24th June 2017 the filling of the rest of the penstock started. Before filling the penstock, the ring gate and wicket gates were closed and hydraulically/mechanically locked. The intake gate was moved to the open position via one hydraulic servomotor. With the opening of the two bypass valves installed at the stop log, the controlled filling of the penstock started. Due to safety reasons the filling speed for the penstock was limited to 2 m/hr. The filling procedure required a 2 hour pause in filling after 5 hours. This was respected. The stop logs were removed. Continuous water leakage measurements on the penstock plugs were implemented.

Wet Commissioning Tests

Wet commissioning tests started on 04th July 2017. All the Unit auxiliaries had to be tested before the main generating unit could be wet tested. The complete alarm and trip matrix was tested according to the commissioning procedure. A simulation of the start and stop sequences was performed with the Unit 1. Then the wicket gates were manually opened to 5% and the Unit 1 started to spin.

Fig. 7. Underground Power House
The bearing heat run was performed with 25%, 50%, 75% and 100% turbine speed (100% = 200 rpm). When the nominal speed was reached the balancing and the vibration was verified. Subsequent to the wet commissioning, the trial operation started and had a duration of 72 hours.

![Fig. 8. Transformer Bay (left) / Outlet area and substation-platform](image)

The step-up transformers (18kV / 400 kV) are located outside of the Power House adjacent to the tail race. The energy transport from the generator to the transformer uses a bus duct with about 150 m length. The substation (located approximately 300 m above the Power house) is connected with the transformer via a power cable. This cable has to span 400 m across the river to another tower on the hill and then re-cross the river above the first power cable to connect with the substation (see figure 8 above). The 400 kV substation is designed with two bars (bar A and bar B) and three circuit breakers for each unit. Presently there are three power lines installed. Line 5 is connected with Capanda, Line 4 is connected with Catete (under construction) and Line 3 is connected with Cambutas (see figure 9 below). The power lines 1 and 2 will be used at a later date.

![Fig. 9. Transport System associated with Laúca – Construction of transmission lines and Substations](image)

**Integration in the electrical grid**

After the open and closed circuit tests with the generator, several tests and adjustments for the Unit Protection were conducted. The digital speed governor was tested for start-up and speed no load conditions. The excitation system was tested with speed no load and the parameters were set. During several start-up and stopping the unit, the Automation sequence were tested and optimized. Before real Synchronization with the grid, two dummy
synchronization were made to verify the correct parameters and settings for the synchronization equipment. On 12th July 2017 the first synchronization and load tests with the transmission line to Capanda was performed.

Extensive studies of the grid behaviour in Angola were made in advance of the load rejection tests. The influence of one unit in Lauca is relatively high when load rejection tests occur. The estimated total power available in the Angolan grid is 1500MW-2000MW during the load rejection. The maximum power generated by the Unit 1 in Lauca was 300 MW. This translates to about 20% of the Angolan grid. The load rejection tests started with 25% (80MW) of power. Before the load rejection tests started, several safety measures were installed on the grid protection system (e.g. the grid frequency was increased to 50.1 Hz and the under frequency trip relay was adjusted to 47 Hz). After each step of the load rejection tests (25%, 50%, 75% and 100%) the frequency behaviour was analysed before the next load rejection was tested. Before the maximum load rejection was tested, the grid frequency was increased to 50.48 Hz to avoid that an under frequency relay trip the complete grid. It was also planned, that during the maximum load rejection, a small partial grid section near to Luanda was disconnected to avoid the under frequency of 47 Hz of the grid. The load rejection tests were finished without any black-out. The measured over speed on the unit and the maximum pressure in the penstock were within the calculated values.

4. Forthcoming challenges

Finally, the handing-over for commercial operation of the first unit in Lauca started on 26th July 2017. Despite the successful commissioning of Unit 1, the challenges are ongoing. For example, the remaining works in the tunnels are hampered logistically because all equipment and material have to pass via the bridge at the transformer bay. Also, access to the downstream toe of the dam is now only accessible by using the penstock tunnels which still are to be completed.

After finalization of the dam works access to the left abutment will be dramatically improved. Also, finalizing the access tunnel to the Ecological Power Plant, would dramatically facilitate all transports from and to the plant and accelerate the outstanding works, scheduled for the first half of 2019.

In the next years Laúca HPP will be the backbone of the electricity grid in Angola and substantially increase the available electricity in Angola. Nevertheless, the site works for Caculo Cabaça HPP, located downstream close to Lauca, already started already in August 2017, emphasizing the importance of hydropower electricity generation in Angola.

References

The Authors

Dr.-Ing. Jürgen Horn graduated in the field of civil engineering and obtained a PhD with a thesis on the formulation and numerical treatment of discontinuous systems in rock mechanics. After his employment as Scientific Assistant at the University of Hannover he worked for more than 16 years for construction companies as Site and Project Manager for several infrastructure and turn-key projects. In 2011, he joined Lahmeyer International where he focuses on project management of Hydropower Projects, particularly in Sudan and Angola. Since 2014 he is the Head of the Department Hydropower and Hydraulic Structures Design at Lahmeyer International.

Eng.” Elias Daniel Estêvão graduated in Civil engineering from the University of Saint Petersburg, Russia. At GAMEK Mr. Estêvão worked in the Department for the Development of the River Kwanza Scheme which is located in Angola. He served as Technical Manager and was involved in various feasibility studies. Mr. Estêvão worked for several years at the HPP Capanda as Head of Department for the Civil Works and Quality and Cost Control. During his assignment at the National Energy Directorate of MINEA he was in charge of the tender evaluation of hydropower plants. He returned to GAMEK in 2012 and is presently the Resident Project Director for the Laúca HPP.