PEREZ-GUERRERO TRUST FUND FOR ECONOMIC AND TECHNICAL COOPERATION AMONG DEVELOPING COUNTRIES

Final Report on

Case Studies on Technical Guidelines for Development of International Small Hydropower (SHP)

International Center on Small Hydro Power
November 2023, Hangzhou, China

Content

Ⅰ. Project Overview

1. **Project Title:** Case Studies on Technical Guidelines for Development of International Small Hydropower (SHP)

2. **Abstract:** There is still a vast potential of SHP in the world. They are untapped due to limitations in funds, hydrological data and technical and institutional capacity. in order to encourage more developing countries to develop the clean and renewable energies, technical guidelines and standards for SHP development are necessary. In past years, ICSHP made efforts to develop and publish the technical guidelines for development of SHP which include 5 sections and total 26 documents. Within such a substantial standard system, case studies of some key topics will be more vivid for beneficiaries to understand the SHP development and standards application. This project just aims to develop case studies of SHP technical guidelines which will serve as basis for knowledge dissemination and standards application of clean energies. ICSHP cooperated with counterparts from three targeted countries in the execution of this project. Experts were invited to provide input for this project. Two case studies were developed on key topics and adopted as the training materials for developing countries.

3. **Background Analysis:** Small hydropower (SHP) has long played a key part in providing access to sustainable and reliable electricity around the world. SHP is a simple, adaptable and low-cost technology, which makes it particularly suitable for remote and marginalized communities. When planned with environmental and socio-economic aspects in mind, it provides access to sustainable renewable energy, the basis for any development which also empowers communities, improves livelihoods and is the basis for more development opportunities. With increasing global focus on renewable energy and decarbonization, SHPs are expected to play a key role in meeting future energy demands, particularly in remote and underserved areas.

   To foster the growth of SHP, numerous countries have developed successful SHP technologies and established comprehensive guidelines and standards. These frameworks effectively support SHP planning, design, manufacturing, construction, operation, and management locally and regionally. Nevertheless, numerous developing nations, despite possessing ample natural resources for renewable energy development, lack the technical and managerial expertise to execute large-scale renewable energy programmes. Furthermore, they lack technical guidelines and standards for SHP construction and operation. This poses significant obstacles to electricity generation, poverty alleviation, environmental protection, and rural economic and social development. To promote consistent SHP development, it is imperative to establish integrated SHP technical guidelines and systematic standards. These guidelines and standards must consider costs, ensuring SHP is affordable for developing nations. The selection of useful and applicable technologies must adhere to product quality, safety, and reasonable economic principles. Additionally, the choice of standards significantly impacts project costs, benefits, and construction durations, sometimes determining a project's feasibility.

   The selected developing countries for this project are typical of lacking SHP policies and technical standards in the SHP development. While there is substantial capacity for constructing and operating such plants, the lack of well-defined legislative framework and standards, as well as the multiple financial obstacles prevented effective development in the SHP sector. The main barriers faced by the SHP sector in Nigeria include inappropriate policy, institutional and regulatory frameworks to stimulate demand and attract investors, the comparatively high initial investment costs of SHP development, inadequate private sector participation, limited access to relevant data, lack of public awareness of the potential and benefits of SHP as a viable source for electricity generation, as well as insufficient skilled labour and technical standards for SHP development. Zambian SHP industry is lack of a comprehensive energy policy to deal with requirements of private plants interfacing with the national grid. The tariff structure in Zambia is still not reflecting the real cost of investment on SHP sector and access to the capital markets for the general local private sector investors remains a challenge to new entrants in the hydropower industry. Like most African countries, lack of technical standards also creates obstruct for SHP development. Most of the sites in Tanzania are not yet developed due to lack of financial sustainability for project developers, lack of local skills and know-how and lack of self-initiatives for SHP development, lack and low level of local technology for SHP development, lack of infrastructure in the design, manufacture, installation and operation of turbines, etc. Insufficient information about potential sites and inadequate SHP awareness, incentives and motivation are also the obstacles to the SHP development.

International Center on Small Hydro Power (ICSHP) has been dedicated to the SHP development globally, accumulating rich experience over the years. Based on researches and support from previous projects, a comprehensive SHP standard system has been established and the technical guidelines for SHP development have been developed aligned with this system. Through communication and collaboration with target countries and other relevant developing countries, suitable cases have been selected and compiled into case studies, which serve as training materials. The aim is to promote the application of the small hydropower technical guidelines and advance the development of international standards for small hydropower.

Ⅱ. Implementation

To meet the objective of this project, it was implemented as the following steps:

- **The first stage** is to identify the demands of developing countries especially the targeted countries. At this stage, ICSHP organized virtual workshop with SHP experts from developing countries including Nigeria, Zambia and Tanzania. Based on the comprehensive analysis of the demand in the development of small hydropower in these countries, the preparation of feasibility study reports and the equipment selection in the technical guidelines were selected as the two topics for case studies.
- In **the second stage**, ICSHP collected relevant domestic and international cases on the SHP development for further development of case studies. A total of five cases were received. After comparison and analysis, the Otukpo SHP Project in Nigeria and Chipota Hydropower Plant in Zambia were selected for further preparation of case study reports. We have meticulously crafted the Otukpo SHP project into a comprehensive feasibility study report case. This report not only delves into the technical aspects of the project but also takes into account economic, environmental, and social considerations to assess its viability. Furthermore, we

have presented the Chipota Hydropower Plant as a case for equipment selection. This report focuses specifically on the selection of main electronical equipment, highlighting the criteria used. By approaching both projects in this manner, we aim to provide a clear and concise understanding of the feasibility and equipment selection processes, enabling informed decision-making and effective implementation.

- **The third stage** is to adopt the case studies as the training materials on some training sessions. At this stage, ICSHP used the two case studies as training materials in training workshop. The response was overwhelmingly positive, with participants providing unanimous praise for their relevance, practicality, and the clarity of the presented information. The case studies, focusing on the feasibility study project in Nigeria and the equipment project in Zambia, were designed to provide participants with real-world examples of small hydropower development challenges and solutions. Through interactive sessions and group discussions, the Center aimed to equip workshop participants with the knowledge and skills necessary to carry out similar projects in their respective countries.
- **The final stage** is to collect the feedbacks on case studies, further improving and finalizing the case studies as the formal training materials for dissemination of technical guidelines and standards application.

Beneficiaries:
The primary beneficiaries will be developing countries which legislations do not include any technical guideline or standard to build and operate SHP. The secondary beneficiaries will be the manufacturers, investors of the industry who will gain certainty when SHP plant owners decide to follow the set international SHP standards, which will reduce piecemeal application of technical requirements and discrepancies among countries. The project is expected to reap indirect economic, social and environmental benefits as a result.

Ⅲ. Completed Activities

Activity-1
Time: March 2023
Location: Online
Implementation: On 22nd March 2023, ICSHP organized a virtual workshop to consult and discuss with experts from developing countries, including Nigeria, Zambia, Indonesia, Tanzania, Kenya, and China, on selecting relevant topics and case recommendations. During the seminar, ICSHP introduced the technical guidelines for SHP development and purpose of the project. The experts were invited to provide their feedback and suggestions.
After conducting a thorough analysis of the demand for small hydropower development in these countries, we have chosen the preparation of feasibility study report and the equipment selection within the technical guidelines as the two focal topics for our case studies. These topics were chosen to provide insights into the practical application and implementation of the technical guidelines in small hydropower projects, with a focus on the feasibility assessment and equipment selection processes. The aim is to identify successful practices and challenges encountered during these critical stages, thereby contributing to the overall improvement and advancement of small hydropower development worldwide.

Activity-2

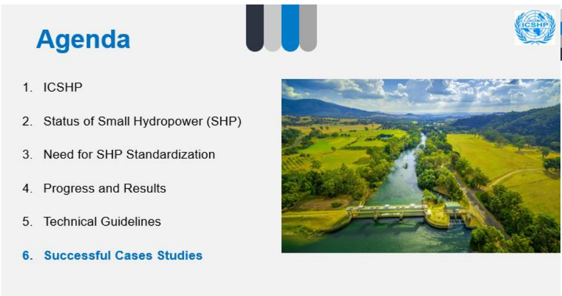
Time: June 2023

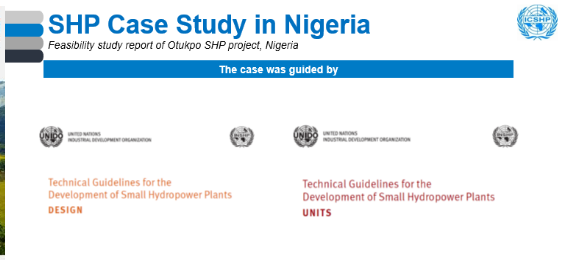
Location: Hangzhou, China

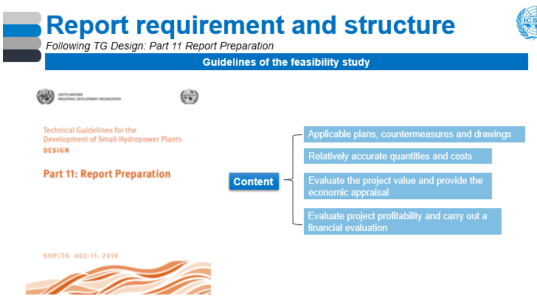
Implementation: From 31 May to 13 June 2023, ICSHP organized a training program titled "Small Hydropower Development and Sustainable Rural Community Development for Developing Countries." This program gathered a total of 30 participants, including experts, scholars, managers, and practitioners from the fields of small hydropower and community development from Kenya, Tanzania, Rwanda, Mozambique, Zambia, etc.

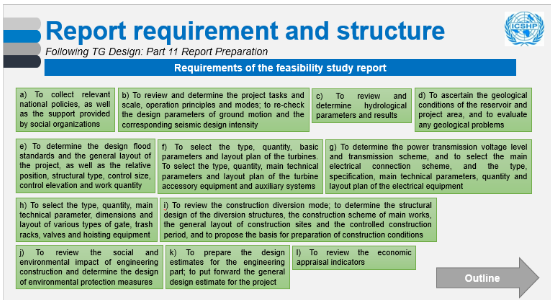
The training focused on key areas such as small hydropower technologies, green development, and the application of rural renewable energy technologies. Additionally, ICSHP integrated two case studies into the training content, using real-world examples to illustrate the challenges and solutions encountered during the design and development of small hydropower projects.

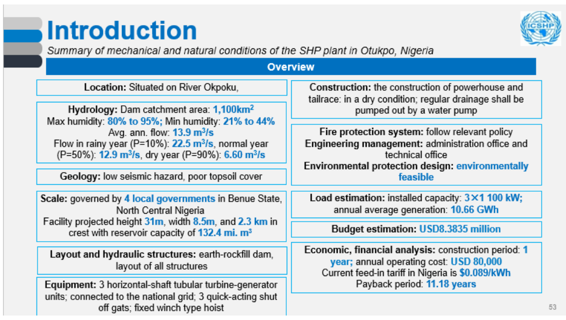
The feedback from the participants was overwhelmingly positive, with high praise for the case study presentations. They unanimously agreed that the combination of technical guidelines and practical case examples was an effective way to understand and apply the principles of small hydropower development. They also suggested to develop cases on management and construction for a small hydropower plant. The feedback is essential in ensuring that our case studies are not only accurate and comprehensive but also responsive to the needs and expectations of the intended audience. By gathering feedback, we aim to gain insights into how effectively our case studies communicate the technical guidelines and standards application, as well as identify any areas that may require further clarification or improvement.

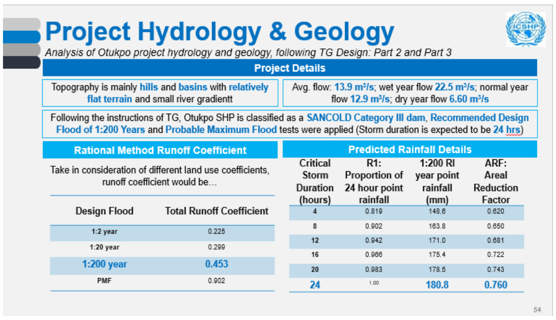


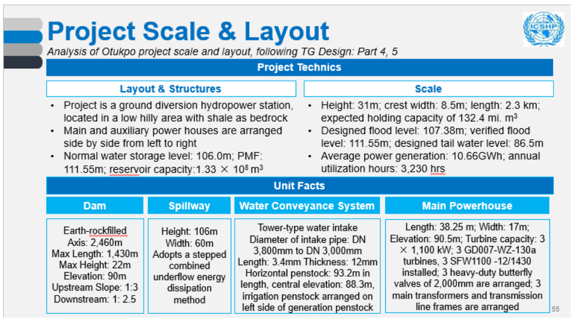


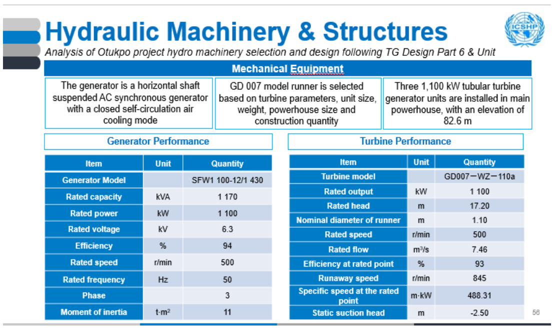


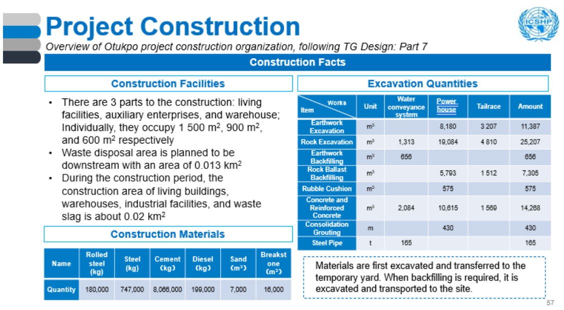


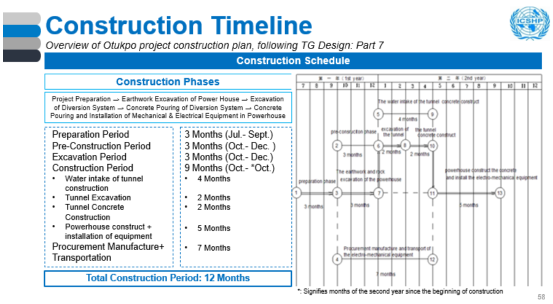












Activity-3:

Time: October 2023

Location: Hangzhou, China

Implementation: On October 19, 2023, Dima AI-Khatib, Director of the United Nations Office for South-South Cooperation visited ICSHP.

She highly praised the work of ICSHP, especially its outstanding contributions in promoting rural sustainability in global southern countries through green energy. She also acknowledged the significance of the "World Small Hydropower Development Report" and case studies on technical guidelines for the development of small hydropower in developing countries. She emphasizes the importance of expanding the promotion and application of our insights and methodologies. She expected us to summarize our experiences and cases, transforming them into valuable materials that can be effectively promoted and disseminated at various international events and training sessions. She emphasized the importance of enhancing capacity building in developing countries, believing that our efforts can contribute significantly to their ability to effectively implement and manage small hydropower projects. Through this approach, she hopes to contribute to the sustainable energy development and economic growth of these nations.

Activity-4:
Time: July to October 2023
Location: Hangzhou, China
Implementation: ICSHP organized experts to improve the case study report based on feedback from the training seminar. We made adjustments to the content, structure and presentation to ensure that they are more engaging, informative, and user-friendly. Two case studies have been thoroughly revised, and will used as formal training materials. These materials will then be disseminated to the relevant stakeholders and target audience, serving as a valuable resource for guiding them in the application of technical guidelines and standards. Through this process, we aim to contribute to the widespread adoption and effective implementation of these guidelines and standards, ultimately promoting the sustainable development of small hydropower in these countries.

Ⅳ. Activities Costs

Activities costs of this project were strictly based on the financial budget. ICSHP referred specialized accountants to manage the economic evaluation and review for this project. Project leaders were also responsible for monitoring of cost for each activity regarding to the project and required for submission of periodical report to the Director General of ICSHP for processing and stage of the project. The cost mainly included the international and national consultant fees, venue and equipment rental for the workshop, domestic trips and reporting cost, details shown below:

No.	Items	PGTF Fund	ICSHP Fund	Total
1	International consultants	10,000 USD	20,000 USD	30,000 USD
2	National experts	8,000 USD	10,000 USD	18,000 USD
3	Workshop organization	6,000USD	30,000 USD	36,000 USD
4	Domestic travels	0 USD	10,000 USD	10,000 USD
5	Reporting Cost	0 USD	6,000 USD	6,000 USD
	Total	**24,000USD**	**76,000 USD**	**100,000USD**

Ⅴ. Project Management Arrangements

The project is implemented by the International Center on Small Hydropower (ICSHP). ICSHP has appointed a project coordinator. All project staff is appointed by ICSHP. ICSHP is responsible for producing and submitting a report to the UNDP China Office following allocation of 90% of the budget resources. The ICSHP Director General (DG) bears the ultimate responsibility for overall management of the project.

IC-SHP has executed the project under UNDP National Execution modality (NEX). As executing agent for the project, ICSHP is responsible for the reporting and financial requirement foreseen under the UNDP's national execution procedures and guidelines.

Progress monitoring is mastered by the China International Center for Economic and Technical Exchange, Ministry of Commerce. However, any staff from the UNDP or Perez-Guerrero Trust Fund undertakes monitoring activities in line with managerial roles above. All lessons learned will be written into a report after the project has been implemented.

Ⅵ. Appendixes

Appendix-I Case study 01: Feasibility Study of Otukpo SHP Project

CS01: Feasibility Study of Otukpo SHP Project

Introduction

This chapter covers the main contents and main conclusions of this feasibility study report, including hydrology, geology, project scale, project layout and structures, hydraulic machinery, electrical system, hydro mechanical structures, construction organization, fire protection system, engineering management, environmental protection design, load estimation, budget estimation, financial and economic and policy analysis, conclusions and recommendation.

1. General description

The proposed Otukpo Multi-Purposed Dam project is located within four (4) local governments areas of Otukpo, Ohimini, Ado and Okpoku all in Benue State, North Central Nigeria. The proposed facility which has an approximate height of 31 m with 8.5 m crest width and a length of about 2.3 km with expected reservoir water holding capacity 132.4 million cubic meters is designed to be a multi-purpose as it will serve as source of public water supply majorly to Otukpo and its neigbouring communities, irrigation (to ensure year-round agricultural activities) and hydro-power generation (as a means of ensuring reliable electricity supply to the area). The project is however planned to be executed in two (2) phases with the dam construction and irrigation components and water supply and electricity generation as the second phase.

The Otukpo SHP Project may be executed with the construction of the remaining items of the dam. The power house is located at the downstream side of the dam, with the coordinates of 7o 6′ 50″ N, 8o 4′ 41″ E.

2. Hydrology

2.1 Overview of the basin

The proposed project is located on the River Okpoku. The selected location is accessible by the main highway, which is currently in a good condition, from Otukpo leading to Enugu in Enugu State. The Otukpo Dam catchment area was calculated to 1 100 km^2.

2.2 Climate and precipitation

This region has two seasons: rainy season (April to October) and dry season (November to March). Rainfall mainly occurs in the rainy season and the average annual rainfall is about 1 345 mm. The precipitation during the dry season only accounts for 3.36% of the annual in total, but the rainfall in the rainy season accounts for 96.64% of the annual in total. July, August and September receive the most rain, accounting for 17.93%, 19.68% and 16.3% of the annual rainfall respectively. Serious floods also happen in these three months. The maximum temperatures (27°C to 38°C) were recorded in the months of March to May, while the minimum temperatures (23°C to 32°C) were recorded in the rainy season months of July to September. The annual maximum humidity values of 80% to 95% occur around August to September while the minimum (21% to 44%) are recorded between November and March. The wind in the area varies between light, gentle and moderate breeze and speed varies from 3.1 m/s to 9.8 m/s for both the dry and rainy seasons.

2.3 Hydrological data

There is no hydrological station or precipitation station in the river basin. There is a hydrological station named Railway Bridge in the downstream of the project 1.2 km away. The Railway Bridge hydrological station has daily runoff data from 1972 to 1978 and 1987 to 1994 and daily precipitation data from 1973 to 1979 and 2001 to 2010. However, data for several months are not available.

2.4 Annual runoff

The runoff of the Otukpo SHP Project can be directly calculated based on the runoff series data from the Railway Bridge hydrological station. The data series is not long enough to calculate the runoff frequency. Therefore, according to the precipitation and runoff data, the runoff coefficient of this basin is assessed at 0.21. The average annual flow data of 20 years can be obtained from the extended runoff series with precipitation and runoff correlation interpolation, and the runoff frequency can be analyzed and calculated.

According to frequency analysis, the average annual flow of the Otukpo SHP Project is 13.9 m^3/s. The flow in rainy year (P=10%) is 22.5 m^3/s, the flow in normal year (P=50%) 12.9 m^3/s, and the flow in dry year (P=90%) 6.60 m^3/s.

The annual distribution of the designed annual runoff is calculated with the annual water volume control by the same ratio scaling method. For that purpose, 1974-1975, 1972-1973, and 1973-1974 were selected as typical years of the rainy, normal and dry years, calculating of the annual distribution of the designed annual runoff by the method of the same ratio scaling for the control of the designed annual runoff.

2.5 Flood

As no information with regard to the Design Flood Standards for Nigeria was available, the internationally accepted Design Flood Standards implemented in South Africa (SANCOLD, 1991), otherwise referred to as the "SANCOLD Guidelines" was applied. These guidelines specify design floods for existing or new dams based on the height of the dam and the dam's hazard potential rating (potential impact on life and property in the event of a failure). Based on the available information, the Otukpo Dam can be classified as equivalent to a SANCOLD

Category III dam, which implies a Recommended Design Flood (RDF) of 1:200 RI years and a Safety Evaluation Flood (SEF) equal to the Probable Maximum Flood (PMF).

There is no measured flood data series at or near the upstream and downstream of the Otukpo SHP Project, so the flow series cannot be used to calculate the design flood. The designed storm may be used to calculate the design flood. Due to the large catchment area of the project, the designed rainstorm duration shall be suitable for 24 hours (1 day).

2.6 Sediment

The Otukpo SHP Project basin has a relatively good vegetation cover, which belongs to mild soil erosion area. The soil erosion modulus is not large, and the suspended sediment and bed sediment content in the basin are both small.

2.7 Stage/flow relation

The stage-flow relation at the tailwater section of the project is analyzed and determined by applying the hydraulic calculation formula based on both the measured river section data and the river section characteristics.

3. Geology

3.1 Regional geology

The land is generally low (averaging 100 m to 250 m) in the Benue valley. The basement rocks are dominated by porphyritic granites, migmatites, diorites, pegmatites and gneisses. These rocks are rich in solid minerals, such as limestone, baryte, coal, gypsum, salt, shale, silica, sand and kaolin which are currently being mined.

The dam site is located in an area underlain by sedimentary strata of the Asata Nkporo Group which mainly comprises shale and mudstone. Intrusive dolerite dykes are present in the general area.

3.2 Seismic hazard

In terms of seismic hazard, Nigeria is characterized by low seismic hazard. An internet source (http://earthquake.usgs.gov/regional/world/africa/gshap.php) indicates peak ground acceleration with a 10% probability of being exceeded in a 50-year period (equivalent to a recurrence interval of 1:475 years) for neighbouring Cameroon to be in the order of about 0.02 g to 0.04 g. A peak ground acceleration of 0.05 g was adopted as the Maximum Credible Earthquake (MCE) for the site due to its proximity to Cameroon.

3.3 Engineering geological conditions

The geological profile in the engineering area may be summarized as follows:

- Poorly developed topsoil cover (average thickness of 0.2 m);

- Lateritic clay which comprises soft to stiff clay containing laterite nodules (thickness generally between 0.9 m and 1.7 m;
- Residual clay derived from the weathering of the underlying shale with average thicknesses varying between 1.5 m and 3.7 m.

The geological parameters of the plant site are as follows: the unit weight of the red soil is 1912 kg/m^3, c = 6 kPa, φ=32 °; and the unit weight of the residual slope deposit soil is 1 526 kg/m^3, c = 0 kPa, φ= 28 °.

3.4 Quarry

The relatively high percentage of secondary minerals (19% to 22%) identified in the limited number of rock samples is an indication that the process of decomposition of the rocks is well advanced.

The durability tests on the hard rock dolerite indicated that the rock can generally be considered acceptable for use as coarse aggregate/rip-rap.

Since the spillway of the Otukpo Multi-purpose Dam has been completed, the burrows for the spillway will be made with concrete composed of coarse aggregate and sand. The amount of concrete necessary for the construction of the power house is not large, and, therefore, the same kind of concrete made of coarse aggregate and sand can be used for building the power house.

4. Project Scale

4.1 Brief introduction

The proposed Otukpo SHP Project is located within four (4) local governments areas of Otukpo, Ohimini, Ado and Okpoku all in Benue State, North Central Nigeria. The proposed facility which has an approximate height of 31 m with an 8.5 m wide and a 2.3 km long crest with expected reservoir capacity of 132.4 million cubic meters. It is designed to be a multi-purpose project as it will serve as a source of public water supply majorly to Otukpo and its neighbouring communities, irrigation to ensure year-round agricultural activities and hydropower generation to provide reliable electricity supply to the area. The project is planned to be executed in two (2) phases with the dam construction and irrigation components and water supply and electricity generation as the second phase.

4.2 Storage capacity curve

The storage capacity curve of the Otukpo reservoir is quoted that in the dam design data.

4.3 Runoff regulation analysis

The Otukpo SHP Project is of an annual regulation hydropower station, and the regulation and operation principle of the hydropower station is that the power generation dispatching operation is carried out on the premise of meeting the water supply and the irrigation. The hydrological year of this basin is from April till following March. At the beginning of April, the reservoir starts to fill in with water from the lowest level of power generation. When the flow is larger than the regulating flow during the flood season, the water is not only used to generate electricity but also stored the excess water in the reservoir. When the reservoir water level is high, the flow for power generation will be increased to full load operation, and the reservoir will be back to normal level and then discharge the excessive water through the spillways. When the river flow is weaker than the regulated flow during the dry season, the regulated flow supplemented by the reservoir is used to generate electricity. By following March, when the water level in the reservoir is decreased from the normal level to the lowest level, an annual regulating cycle is completed.

4.4 Flood regulation analysis

According to the Otukpo dam design data, the spillway is 60 m long with the weir crest elevation of 106 m. The normal water level of the reservoir is 106 m. According to the flood calculation, the peak inflow of the reservoir in the 1:200 RI year is 885 m^3/s, the peak outflow of the reservoir is 215 m^3/s, and the design flood level of the reservoir is 107.38 m. The flood peak inflow of Probable Maximum Flood (PMF) is 4 370 m^3/s with the peak outflow of PMF of 1 760 m^3/s, and the verified flood level of 111.55 m.

4.5 Characteristic stage selection

According to the Otukpo dam design data, the normal water level (full supply water level) of the reservoir is 106.00 m. Through the flood regulation calculation, the design flood level of the reservoir is 107.38 m and the verified flood level is 111.55 m. The design tailwater level of the power station is determined to 86.5 m considering the riverbed elevation at the tailrace and the stage-discharge relation curve.

4.6 Project scale

There are three installed capacity options, 3×700 kW, 3×1 100 kW and 3×1 500 kW, which are proposed for technical and economic comparison. The Otukpo dam has already been under construction, and the water conveyance system of the power station has almost been completed. According to the diameter of the penstock and water flow of the power station, the installed capacity of the power station is determined to be 3×1 100 kW in line with the comparison of the schemes.

According to the reservoir inflow of three hydrological representative years, that are the rainy, normal and dry years, and the operation mode of the power station, the station should operate at the high water level as far as possible. It is calculated that the average multi-year power generation of the station is 10.66 GWh annually, equipment utilization reaches to 3 230 hours yearly with the full capacity.

5. Project layout and hydraulic structures

5.1 General project layout

a) Dam

The constructed dam is an earth-rockfill dam with axis of 2 460 m long. The dam axis is a mansard line. The left section of the dam is 1 430 m long and the right section of the dam is 1 030 m long. The elevation at dam foundation surface is 90.00 m, the elevation at dam crest is 112.00 m, and the maximum dam height is 22.0 m. The dam crest is 8.0 m wide, the upstream slope is 1:3 and the downstream slope is 1:2.5, and the maximum dam foundation width is 93.0 m.

b) Spillway

The constructed open channel spillway is located at the right section of the dam, and the central line of the spillway is located at dam Chainage No. 1+600 m. The crest elevation of the spillway is 106.00 m and the width of the spill way is 60.0 m. It adopts a stepped combined underflow energy dissipation method. The spillway outlet is located in the downstream of the power house connected with the original river.

c) Water conveyance system

The water conveyance system is composed of an intake, penstock and branch pipes. The tower-type intake, which is converted from the diversion culvert, is arranged in the left section of the dam. The irrigation water supply pipes and the power generation penstocks are placed in parallel. The diversion culvert has been almost completed.

The constructed intake of the diversion culvert has two openings. The bottom elevation is 85.8 m, the dividing pier thickness is 1.2 m, the side pier is 4.3 m, the top plate is 1.0 m, and the top elevation is 93.0 m and top platform width is 16.8 m. The diversion culvert is in the shape of square arched, with a bottom elevation of 85.8 m to 85.3 m.

The penstock, irrigation and water supply pipes are all exposed pipes and arranged side by side on the top platform of the diversion culvert, and the penstock is arranged on the right side (near to the side of the power house). The horizontal projection center line length of the penstock from the gate to the bifurcating point is 110 m, and the central elevation of the bifurcate pipe is 87.3 m.

d) Power house

The power house is arranged downstream next to the right side of the diversion culvert. The current ground elevation is 92.0 m to 96.0 m, and the downstream riverbed bottom elevation is 84.0 m.

5.2 Water conveyance system

The water conveyance system is composed of an intake, penstock and branch pipes.

a) Intake

The intake for power generation is of a tower-shaft type, which is arranged in a hexagonal plane with a side length of 6.45 m, locating on the upper floor of the tower while the inlet of the diversion culvert is at the lower floor. The tower shaft is 13.4 m wide, its length in the direction of water flow is 12.1 m. The tower top elevation is 112.0 m. There is a working platform inside the tower shaft with the elevation of 99.5 m. The tower shaft wall is 1.7 m thick, and the tower top is covered with the reinforced concrete beam and plate structures. A 0.80 m wide reinforced concrete staircase is arranged inside the tower shaft as the passage. The tower shaft adopts the C20 reinforced concrete structures.

A gradually expanded intake is used for water conduit for power generation, with its center line elevation of 96.0 m and the steel adopted. The diameters of the intake are between DN3 800 mm to DN3 000 mm, with its length is 3.4 m, followed by a vent hole and an accident butterfly valve. The intake is covered with C20 reinforced concrete.

Two sliding trash racks are installed 1.5 m upstream of the intake. The elevation of the working platform of trash rack is 112.0 m, and its total width is14.0 m. The trash racks are made of C20 concrete.

The irrigation inlet is arranged on the left side of the generation intake and multi-level inlet structure is used. The diameter of the steel pipe is DN1 000 mm and its walls are 8 mm thick. The divergent steel pipe is used as the inlet. It is followed by the accident butterfly valve and the 0.8 m diameter vent hole.

One sliding trash rack is installed 2.2 m upstream of the irrigation inlet. The trash rack, which is made of C20 concrete, is 3.0 m high and 2.4 m wide.

The tower shaft is connected to the dam crest by an access bridge.

b) Penstock

The intake and the penstock are connected by 2 elbows which have 80° of angle, and R=4.5 m which is 1.5 times of the pipe diameter.

The penstock is arranged along the diversion culvert. The penstock, which is a horizontal exposed pipe, is 93.2 m long and the central elevation is 88.3 m to 87.9 m. The penstock adopts a steel pipe 3 000 mm in diameter, 12 mm thick walls. At the end of the penstock, a horizontal 90° elbow is placed in front of the power house and embedded in a reinforced concrete anchorage.

The exposed horizontal irrigation pipe is arranged on the left side of the generation penstock with a center distance of them is 2.8 m. The pipe adopts steel pipe 1 000 mm in diameter, 8 mm thick wall. A control gate valve is installed at end of the pipe.

c) Branch pipes

The penstock is arranged along the upstream of the power house building after elbowing, the diameter of the main pipe is 3.0 m, and the central elevation of the pipe is 87.9 m. The setting elevation of the turbine unit is 84.0 m. The penstock is divided into three 2.0 m diameter branch pipes to feed the three turbines. The main pipe and branch pipes are connected by bifurcated pipes with a 60° split angle.

5.3 Power house and substation

5.3.1 Layout of project area

The project is composed of the main power house, auxiliary power house, substation, tailrace and road to the station. The project is the type of ground surface diversion hydropower station.

According to the project layout and topographic conditions, the main and auxiliary power houses are arranged side by side from left to right. Both face to south by east. The longitudinal axis of the power house is orthogonal to the axis of the penstock.

The tailrace is located downstream of the main power house with a rectangular cross-section with a width of 21.00 m.

The substation is located on the right side of the auxiliary power house, and the elevation of the floor of the substation is 90.35 m.

The road to the station is conveniently located at the back of the power house and is connected to the road to the downstream of the dam.

5.3.2 Power house layout

a) Main power house

The main power house is 38.25 m long, 17.00 m wide. Three shaft-extension-type tubular turbines are arranged in the power house with the setting elevation of 84.0 m. There is an electric single-beam crane which has 13.2 m of span and 16/3 t of lifting capacity. The erection bay is located on the left side inside the main power house. It is mainly used for installation and maintenance, and the entrance gate is located upstream side of the erection bay.

The auxiliary equipment floor is located at the elevation of 86.25 m of the main power house, and mainly arranged with auxiliary equipment such as electric panel and cabinets. The ground elevation of the turbine generator floor is 83.19 m.

The butterfly valve pits are located upstream side of the power house with a bottom elevation of 82.6 m. Three heavy-duty butterfly valves are arranged there. Downstream side of the butterfly valve pit, there are stairs connecting the butterfly valve pit and the turbine-generator layer.

There are stairs on the left and right sides of the main power house to connect the upper and lower floors which is very convenient.

b) Auxiliary power house

The auxiliary power house is located on the left of the main power house. The central control room, 6 kV switch room, 33 kV switch room, bathroom and stairs are arranged in the auxiliary power house.

d) Substation

The outdoor substation is located on the left of the auxiliary power house. The outdoor substation is 10.74 m long, 19.83 m wide. Three main transformers and transmission line frames are arranged there.

6. Mechanical and electrical equipment & hydro mechanical structures

6.1 Mechanical and electrical equipment

The water head of the project varies from 10 m to 20 m. After comparison, three horizontal-shaft tubular turbine-generator units are adopted, and the installed capacity of each unit is 1 100 kW.

It is recommended that the model of the hydro-generator unit is GD007-WZ-110a, the rated speed is 500 r/min, corresponding rated point specific speed is 488 m·kW, and the rated output is 1 100 kW.

It is recommended that the model of the generator is SFW1 100-12/1 430, the rated capacity is 1 170 kVA, rated voltage is 6.3 kV, rated speed is 500 r/min, and moment of inertia is 11 t·m^2.

The crane is installed in the main power house.

6.2 Electrical system

The Otukpo SHP Project is near Otukpo city with 65 000 of population. Electricity generated by the project is delivered to Otukpo city and also connected to the national grid.

The main connection wiring scheme: the power station adopts one 33 kV transmission line to Otukpo city at the distance of about 12 km. As one outgoing wire is arranged for 3 sets of units, the power station uses the generator voltage side (6.3 kV) is adopted as the unit connection mode of generator-transformer assembly in the power station. The high voltage side adopts single busbar connection with the voltage of 33 kV. Two circles of line are provided for the power supply of the station: one 33 kV /0.4kV line for the160 kVA transformer, and another line for a 150 kW diesel generator.

The main power house is equipped with 3 turbine-generator units; the excitation device cabinets, the unit temperature measuring cabinets and the unit LCU cabinets are arranged next to the units. The auxiliary power house is equipped with a central control room, a 6.3 kV switch room, a 33 kV switch room, a station transformer room, a communication room, and a duty lounge, etc.

6.3 Hydro mechanical structures

Three quick-acting shut off gates, with the type of submerged planar fixed-wheel steel gate, shall be installed at the outlets of the draft tubes. The gates shall be able to be closed in dynamic water and opened in static pressure of the water.

The fixed winch type hoist is selected. The gates are normally suspended 1 m above the orifice in an emergency standby state.

7. Construction organization

7.1 Construction diversion

According to the hydrological situation in this region, the duration of diversion and flood can be divided into rainy season and dry season. The monsoon is rainy season from May to October and dry season is from November to April of the following year.

Since the diversion culvert is transformed into the power generation diversion tunnel, a gate has been installed in front of the original diversion intake. The original gate can be directly used to block the water. Therefore, the construction site of the power house area will be in a dry condition when the gate in the front of the diversion intake is closed. So there is no additional construction diversion engineering measures needed for power house. For this reason, the plan of transforming the diversion culvert into the power generation intake shall be conducted in the dry season.

The tailrace of the power house shall be constructed in the dry season also, and the simple soil cofferdams shall mainly be used to block the water.

The regular drainage, including construction waste water and the seepage from the foundation pit as well as in the diversion tunnel, shall be pumped out by a water pump.

7.2 Construction of the main civil works

a) Construction of the water conduit system for power generation

The rock excavation is carried out by hand air drill, explosive blasting, excavated and loaded excavators and transported by dump trucks.

The concrete mixtures are mixed by mixer machines and transported by the manual dumper with double rubber wheels. The concrete is poured through the concrete pump.

The steel pipes are manufactured in the factory and transported by the truck to the construction site, and then to be installed.

b) Construction of the power house

The earth-rock excavation of the power house and substation shall be carried out in line with the sequence of the bank slope first and then the power house foundation. The earthwork is performed by the excavator, and transported them about 1 000 m away from the power house site by the dump truck. Rock is excavated with the method of hand-drill and blast, then, to be excavated by the excavators and transported by the dump trucks.

The concrete is poured in two phases. In the first stage, the lower part of the concrete construction shall be placed by the method of layered silo pouring, and the passage shall be temporarily paved. The concrete mixtures are mixed by the mixers, and transported less than 100 m by the 1 t tilting carts to the place. Since there is less quantity of concrete in the second phase, and it is mainly placed in conjunction with the process of the installation of electro-mechanical equipment.

c) Installation of electro-mechanical equipment

The installation of the turbines and generators is carried out after the power house is capped, and the turbines and generators are successively hoisted by the crane into the pit for assembly.

The hydro mechanical structure installations mainly include the emergency-maintenance gate and the trash rack at the intake of the water conveyance system. After the inspection and measurement are conducted, the gate and trash rack shall be placed in the slots correspondingly by the hoist or the mast. And the opening and closing test is carried out then.

7.3 General schedule for construction

Combined with the layout characteristics of the hydro structures and the owner's planning for the project, after conducting comprehensive analysis the total construction period is determined to be 12 months.

The maximum number of construction workers is 360 people per day while the average number of construction workers is about 300 people per day with a total of 200 000 working days.

The maximum earth-rock excavation is about 14 000 m^3 per month and the maximum pouring amount is about 300 m^3 per month.

8. Fire protection system

Fire protection system for a hydropower plant should follow the policy of "Prevention first and combining prevention and fire-fighting." Practical fire prevention measures should be taken for the parts and equipment that may cause fire in order to prevent fire from spreading. Underground structures should be set up with ventilation and a fire prevention system, smoke extraction measures and safety exits, evacuation passages and signs, etc. to provide conditions for personnel to evacuate in time if fire happens. Fire extinguishing measures shall be provided for major fire hazard sites and major equipment.

9. Engineering management

The power station should have the administration office and technical office. The administration office is responsible for labor and management, while the technical office is responsible for power station operation, equipment maintenance and building maintenance.

According to the scale of the project, the power station should at least have 15 operation and administrative staff, including 7 operation personnel, 2 inspection and commissioning personnel and 6 administrative staff.

10. Environmental protection design

10.1 General environmental impact assessment

The adverse impact of the project on the environment is mainly concerned with the construction aspect, but the impact is not significant and can be reduced by environmental protection measures. Therefore, there is no unfavorable factor restricting the construction of the project. From the environmental point of view, the construction of the project is feasible.

10.2 Environmental protection measures

During construction, management has to guarantee water and soil conservation is enhanced in order to ensure implementation of the water and soil conservation plan.

Environmental protection awareness of residents should be enhanced. Reasonable soil and water conservation farming measures should be adopted to reduce newly-added soil erosion.

During construction, temporary measures for water and soil conservation should be adopted, in order to minimize the water and soil loss during the construction.

During construction, disturbance and occupation of the land outside the construction area should be forbidden.

Steel slag must be stored in the designated slag yard.

11. Load estimation

According to the hydrological analysis, calculated results of the hydropower station and the comparison of the results of installed capacity, final installed capacity of the project is 3×1 100 kW, and annual average generation is 10.66 GWh. According to the geographical location, the main power supply load is the near-area power load and the power load of the dam area with the excess power is connected into the grid.

12. Budget estimation

Total investment for the project is estimated on the basis of the bill of quantities and the method of project cost estimate defined in relative criteria.

Main materials include sand, macadam, block stone, cement, reinforcement, diesel oil, explosives, etc. Prices of these materials and their transportation and collection fees are all defined in local criteria.

It is estimated that the total static investment of this project is USD 8.3835 million.

13. Economic, financial analysis

13.1 Economic analysis

According to the estimate of project investment, the total static investment of the project is USD 8.33 million. The shadow investment will be USD 8.08 million after deducted the internal transfer payment. According to the construction design of the project, the construction period is 1 year. The annual operating cost is USD 80 000 and the liquidity needed is USD 20 000.

After the commission of the project, the main income is from power generation, the average annual power generation is 10.66 GWh, effective coefficient of electricity is 0.97.

The current feed-in tariff in Nigeria is USD 0.089 /kWh. The fixed tariff is adopted for economic analysis for the whole operation period, and average annual power generation benefit is calculated to be USD 900 000.

Economic indicators are calculated according to the dynamic method, and the social discount rate is 7%. Economic analysis period of the project is 30 years, the construction period is 1 year, and the discount calculation reference point is from the beginning of the construction period.

It is calculated that the Economic Internal Rate of Return (EIRR) of the project is 9.38%, which is greater than the social discount rate of 7%. The Economic Net Present Value (ENPV) is USD 1.92 million, which is greater than zero; the Economic Benefit-cost Ratio (EBCR) is 1.22, which indicates that the project is economically feasible.

13.2 Financial analysis

The total static investment of the project is USD 8.38 million. The investment constitutes a capital fund of USD 1.67 million accounting for 20% and; the loan is USD 6.66 million accounting for 80%.The loan interest rate refers to the loan interest rate of the World Bank and the African Development Bank, which is estimated at 1.20% for the project.

The liquid capital is USD 20 000 and the cost of the interest of the project loan during construction period is USD 40 000.

The total cost of the project consists of the depreciation fee, annual operating cost and interest expense. The annual depreciation fee shall be 3.3% of the fixed assets value. The repair fee, project maintenance fee and other expenses shall be 0.5% of the fixed assets value at USD 40 000 per year. The total cost of the project is USD 11.18 million within the calculation period.

Over a 30-year operating period, the project could have USD 27 million totally in sales income.

The project′s financial profitability index uses dynamic calculation considering the time factor. It is calculated that the payback period of total investment in the project is 11.18 years (static investment before income tax), and the FIRR for total investment is 9.11% (before tax), 8.69% (aftertax), and FIRR for capital is 13.87%. FNPV for total investment is USD 1.72 million (before tax), USD 1.37 million (after tax), and FNPV for capital is USD 2.85 million.

14. Project parameters

Table 1-1 shows the main technical parameters of the project.

Table 1-1 Project Parameters

No. and Item	Unit	Qty.	Remark
A. Hydrology			
1.Catchment area	km^2	1 100	
2.Typical discharge			
Multi-year average discharge at dam site	m^3/s	13.9	
3.Flood peak flow			
Probable Maximum Flood (PMF)peak inflow	m^3/s	4 370	
Probable Maximum Flood (PMF)peak outflow	m^3/s	1 760	
1:200year RI flood peak inflow	m^3/s	885	
1:200year RI flood peak outflow	m^3/s	215	
B. Reservoir			
1.Water level			
Verified flood level	m	111.55	PMF，masl
Design flood level	m	107.38	P=0.5%，masl
Full supply level (FSL)	m	106.0	masl
Storage capacity at FSL	Mm^3	133	
Minimum Operating Level	m	101.0	
2.Regulating characteristics		Yearly regulating	
C. Discharging flow and tailwater level			
1. Maximum flow at verified flood level	m^3/s	1 760	PMF
2. Maximum flow at design flood level	m^3/s	215	P=0.5%
3.Design tailwater level	m	86.50	Q~~8.0m^3/ s
4.Normal tailwater level	m	87.6	Q~~22.5m^3/s
D. Project performance indicators			
Installed capacity	MW	3.3	3×1.1MW
Average annual output	GWh	10.66	
Annual operation hours	h	3 230	Factory factor 0.37

E. Submerged loss and permanent occupied land			
1.Permanent occupied land			
Forest	m^2	0	
2.Migrant	people	0	
3.Submerged road	km	0	
F. Main buildings and equipment			
1.Embankment			
Type of embankment		Zoned earth-fill	
Seismic Characteristics		Residual slope strata in hilly areas	
Seismic basic intensity		Ⅵ	
Non-overspill crest elevation (excluding settlement allowance)	m	112.0	
Maximum height of embankment (above river bed level at d/s toe)	m	22	
Embankment crest length	m	2 460	
Base width of embankment at maximum cross section	m	93	
Crest width of embankment	m	8.0	
Upstream slope	m/m	1V:3H	
Downstream slope	m/m	1V:2.5H	
River bed level at downstream toe	m	90.0	masl
2.Spillway			
Type		Ogee overflow weir	
Overflow weir crest length	m	60	
Overflow weir crest level	m	106.0	masl
Total freeboard	m	6.0	
Maximum discharge with zero freeboard	m^3/s	2 000	
Energy dissipation		Stepped discharge chute and stilling basin	
3.Outlet Works			
3.1 Diversion culvert			

Bottom elevation	m	85.8	
Size of the opening	m ×m	2—3.5×6.2	2 bays
3.2 Intake of water conveyance system for power generation			
Intake	Type	Tower-shaft	
Intake pipe diameter / length		DN3 800 mm～DN3 000 mm/3.4 m	
Intake central elevation	m	96.0	
Vent hole diameter	m	0.8	
Accident butterfly valve platform elevation	m	99.5	
Movable trash rack	unit	2	
Orifice size of the trash rack	m ×m	6×2.4	Height×width
3.3 Intake of irrigation			
Pipe diameter	mm	DN3 000	
Moveable trash rack	set	1	
Orificesize of the trash rack	m ×m	3×2.4	Height×width
3.4 Traffic bridge on the tower-shaft platform			
Width	m	4.5	
length	m	36	
3.5 Penstock for power generation			
Type		Exposed	Along with the diversion culvert
Horizontal length	m	93.2	
Central elevation of main penstock	m	88.3～87.9	
Central elevation of bifurcation	m	87.3	
3.6 Irrigation pipe			
Type		Exposed	Along with the diversion culvert
Horizontal length	m	125	
Center elevation	m	87.3～86.8	
4.Power house			

Type		ground surface	
Main power house	m ×m	38.25×17.0	Height×width
Auxiliary power house	m ×m	19.89×17.0	Height×width
Floor elevation of tailrace	m	80.2	
Setting of turbines	m	84.0	
Butterfly valve floor elevation	m	82.6	
Elevation of turbine floor	m	82.6	
Elevation of erection bay	m	90.5	
Elevation of generator floor	m	90.5	
Top elevation of crane rail	m	96.5	
Ceiling elevation of power house	m	100.9	
5.Substation			
Type		Outdoor	
Size	m × m	10.74×19.83	
6.Main electro-mechanical equipment			
Turbine model		GD007-WZ-130a	Horizontal shaft tubular turbine
Number		3	
Rated output	MW	1.1	
Rated speed	r/min	500	
Maximum head	m	19.2	
Rated head	m	17.2	
Minimum head	m	11.8	
Diversion discharge	m^3	22.8	
Generator model		SFW1 100－12/1430	
Rated capacity	kVA	1 170	
Rated power	kW	1 100	
Rated voltage	kV	6.3	
Power factor		0.85	

Rated frequency	Hz	50	
Number		3	
Diameter of Heavy-duty hydraulic butterfly valve	mm	2 000	Operating oil pressure of 16 MPa
Number		3	
Governor model (high oil pressure digital microcomputer dual adjustment)		YWT-1000-16	Operating oil pressure of 16 MPa
Number		3	
Crane model		16/3t Electric single-beam crane	
Number		1	L_k=13.2 m（span）
Main transformer model		S13-1 600/36.3	
Number		1	
Capacity	kVA	1 600	
Ratio		36.3±2×2.5%/6.3 kV	
Outgoing transmission line voltage	kV	33	
Number of circuit		1	
Transmission destination		Otukpo City	
Population		65 000	
Distance	km	12.0	
Sectional area of the transmission line	mm^2	150	Steel-cored aluminium strand wire
7.Hydro mechanical structure			
No. of emergency gate at tailrace		3	
Model of Emergency gate at tailrace		Submersible steel gate with fixed wheels	
Opening size	m ×m	3.0×2.0	
Hoist model		QPK-2×160kN-14.0m	Fixed winch quick hoist
Number		3	
8.Construction organization			
Construction period	month	12	
Maximum workers	people/d	360	
Normal workers	people/d	300	

Total working days	10^3working day	200	
Rolled steel	kg	86 000	
Steel	kg	747 000	
Cement	kg	8 066 000	
Diesel	kg	199 000	
9. Construction budget			
9.1Civil Works	USD	3 521 296	
9.2Electro-mechanical equipment and installation works	USD	2 461 882	
9.3Hydro mechanical structure and installation works	USD	844 967	
9.4Temporary works	USD	112 354	
9.5Miscellaneous cost	USD	644 509	
9.6 Basic reserve funds	USD	758 501	（10% of 9.1~9.5）
9.7Financial interest in construction period	USD	40 000	
Total static investment	USD	8 383 509	
10. Financial analysis			
10.1 National economic evaluation			
(1) EIRR	%	9.38	Social discount rate = 7%
(2) ENPV	10^6 USD	1.92	
(3) EBCR		1.22	
10.2 Financial evaluation			
(1) Static investment	10^6 USD	8.33	
Capital fund	10^6 USD	1.67	
Loan	10^6 USD	6.66	Interest rate =1.20%
(2) Loan interest	10^3 USD	40	
(3) Liquid capital	10^3 USD	20	
(4) Feed-in tariff	USD/kWh	0.089	
(5) Total sales income	10^6 USD	27	Within the calculation period
(6) Total cost	10^6 USD	11.18	Ditto
(7) Total profit	10^6 USD	15.82	Ditto

(8) Income tax	10^6 USD	0.85	Ditto
(9) Profit after tax	10^6 USD	14.97	Ditto
(10) Profitability index			
(10-1) FIRR			
Total investment (before income tax)	%	9.11	
Total investment (after income tax)	%	8.69	
Capital fund	%	13.87	
(10-2) FNPV			
Total investment (before income tax)	10^6 USD	1.72	
Total investment (after income tax)	10^6 USD	1.37	
(10-3) Investment return			
Static investment (before income tax)	year	11.18	
Static investment (after income tax)	year	11.57	
(10-4) Return on total investment	%	6.46	
(10-5) Net profit margin on capital	%	29.95	

CS 02: Selection of Main Electrical Connection in Feasibility Study of CHIPOTA Hydropower Plant

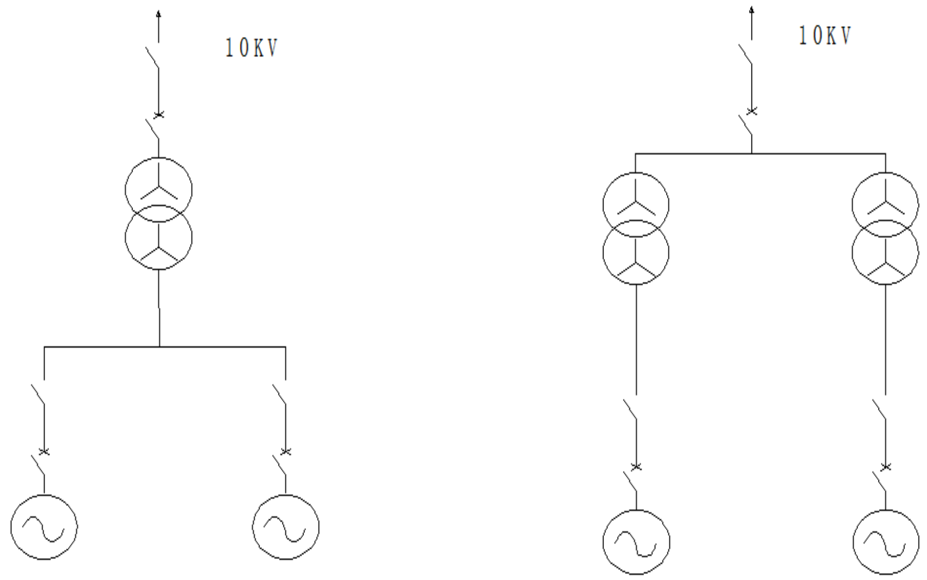
1 Introduction

CHIPOTA hydropower plant is located on the MULEMBO River, CHELA TAMBULE village, SERENJE region of the Central Province of Zambia, 400 km away from Lusaka, the capital. The catchment area above dam site is 140 km2 and the main object of the power plant is power generation.

The residents in the nearby areas of the power plant mostly have no access to illumination and other household electricity. It is known that very few residents have solved the problem of illumination through household solar devices. This power plant will power a population of 15 000 in the nearby areas. There is no power grid nearby, thus, the plant will operate off the grid. The total installed capacity of this power plant will be 2×100 kW and annual power generation will be 1.3553 million kWh. The distance from the power plant to the supply area is 10 km. A 11 kV line will be adopted to deliver electricity to the community. After the voltage is reduced to 400 V, the electricity will be supplied to the users.

2 Selection of Main Electrical Connection

There are 2 sets of units in this power plant. The rated voltage of the generator is 0.4 kV. There is one single circuit of outgoing line from the high voltage side, without nearby loads. According to the combination of generator and transformer, the two types of main electrical connection options are analyzed, see figure 2-1 for details.



a) Option 1 **b) Option 2**

Figure 2-1 Main electrical connection options

Option 1: Expanded unit connection is adopted at the generator voltage side and the two units share one main transformer; transformer-line unit connection is adopted at the boosted voltage side. Connection of this scheme is simple and clear and is convenient to maintain. It simplifies the connection at the high voltage side, occupies less land and needs smaller excavation and less investment. Its disadvantage is that when the main transformer is under failure or overhaul, the electricity from the two generators can't be transmitted. However, the failure rate of the main transformer is low, requiring longer overhaul cycle and shorter outage time.

Option 2: Unit connection is adopted at the generator voltage side, with one unit connecting to one transformer; single bus connection is adopted at the boosted voltage side. This scheme operates flexibly. With small failure influence range and simple relay protection, it features higher reliability. However, there will be more high voltage electrical equipment, leading to increases of space for equipment layout and investment on the whole electrical connection.

Based on the above analysis and considering the actual operation experience of small-sized hydropower plant, option 1 is recommended.

3 Selection of Main Electronical Equipment

3.1 Calculation of short circuit current

Because it operates as an independent system (take 0.8 as the power factor of the system and

25 kVA as the contralateral breaking capacity), the short circuit current of the recommended electrical connection scheme is calculated. See Figure 3.1-1 for the system connection and equipment parameters and table 3.1-1 for the calculation results of short circuit current.

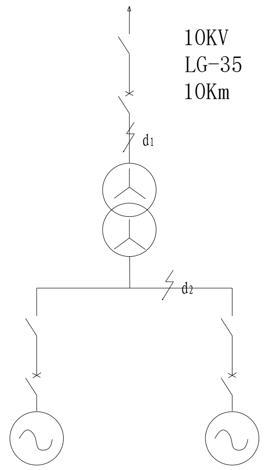


Figure 3.1-1 Diagram of short circuit current calculation

Table 3.1-1 Calculation results of short circuit current

Short circuit point	T = 0 s Short circuit current（KA）	T = 0.6 s Short circuit current（KA）	T = 1 s Short circuit current（KA）	Short circuit current peak value（KA）
d_1	1.52	1.48		3.82
d_2	6.94		3.87	18.01

3.2 Selection of the main electrical equipment

The selection of electrical equipment should be based on the principle of advanced in technology, rational in economy and simple and convenient in maintenance. It should also meet the requirements of latest regulations and specifications.

Technical parameters of the electrical equipment are selected under normal working conditions and the performances of the electrical equipment are checkd as per different short circuit circumstances. Both of the above two should be met at the same time.

3.2.1 Preliminary selection

a) The control and distribution devices at the generator voltage side will apply a triad NDK-2001 low voltage generator unit with intelligent control panels, inside of each installed with a ME-630A air circuit breaker, which is safe and reliable in operation and convenient in maintenance. The outgoing lines of the generator will adopt a ZR-VV22-120 mm^2 flame retardant PVC insulated cable, with one single line per phase.

b) The switching device at the 11 kV line side is of outdoor type, using a ZW8-12/630 vacuum circuit breaker as its circuit breaker and GW1-10/630 as its disconnector.

c) To match with the capacity of the generator, the main transformer will apply a three-phase oil-immersed two copper core winding transformer with natural cooling. According to the main connection design, its model is S11-250, 12.1±5%/0.4 kV, with a capacity of 250 kVA.

d) The excitation system in this power plant adopt static silicon controlled excitation system, which is powered directly by the generator. The excitation system shall be supplied by the manufacturer of the generators.

e) The rated voltage of the generator is 0.4 kV, so the plant service power supply will come directly from the 0.4/0.23 kV voltage busbar of the generator. Plant service power supply adopts a GGD distribution panel.

f) DC system of this power plant adopts non-maintaining lead-acid battery, with complete sets of DC equipment with a rated voltage of 220 V and a capacity of 50 AH. As the DC power source of the plant, it shall meet the requirement for DC loads in the operation of automatic devices for plant control, protection and safety, the operation of circuit breakers, emergency lighting, etc.

3.2.2 Check the equipment with short circuit current

To simplify the calculation, take the total current of the corresponding short points as the short circuit current to check the equipment. The full opening time of the circuit breaker is 0.1 s. Back-up protection action time at the 11 kV side is 0.5 s and the thermal stability calculation time is 0.6 s; protection action time at the 0.4 kV side is 1 s and the thermal stability calculation time is 1 s.

All the equipment selected has been checked to be acceptable.