OPERATION & MAINTENANCE STRATEGIES FOR HYDROPOWER

Six Case Studies
Operation and Maintenance Strategies for Hydropower

Six case studies illustrating preparation and implementation of O&M strategies
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### ABBREVIATIONS AND ACRONYMS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAPEX</td>
<td>Capital expenditures</td>
</tr>
<tr>
<td>CMMS</td>
<td>Computerized maintenance management system</td>
</tr>
<tr>
<td>EPC</td>
<td>Engineering, procurement, and construction</td>
</tr>
<tr>
<td>FOR</td>
<td>Forced outage rate</td>
</tr>
<tr>
<td>GW</td>
<td>Gigawatt (1 million kilowatts)</td>
</tr>
<tr>
<td>hm</td>
<td>Hecto cubic meter</td>
</tr>
<tr>
<td>HPP</td>
<td>Hydropower plant</td>
</tr>
<tr>
<td>ICOLD</td>
<td>International Commission on Large Dams</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and communications technology</td>
</tr>
<tr>
<td>IHA</td>
<td>International Hydropower Association</td>
</tr>
<tr>
<td>IPP</td>
<td>Independent power producer</td>
</tr>
<tr>
<td>ISO</td>
<td>International Organization for Standardization</td>
</tr>
<tr>
<td>KPI</td>
<td>Key performance indicator</td>
</tr>
<tr>
<td>MESL</td>
<td>Mainstream Energy Solutions Limited</td>
</tr>
<tr>
<td>MW</td>
<td>Megawatt (1 thousand kilowatts)</td>
</tr>
<tr>
<td>NBE</td>
<td>New Bong Escape</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Operation and maintenance</td>
</tr>
<tr>
<td>OEM</td>
<td>Original equipment manufacturer</td>
</tr>
<tr>
<td>OMT</td>
<td>Operation, maintenance, and training</td>
</tr>
<tr>
<td>OPEX</td>
<td>Operating expenditures</td>
</tr>
<tr>
<td>PPA</td>
<td>Power purchase agreement</td>
</tr>
<tr>
<td>RCM</td>
<td>Reliability-centered maintenance</td>
</tr>
<tr>
<td>SECO</td>
<td>State Secretariat for Economic Affairs, Switzerland</td>
</tr>
<tr>
<td>SKER</td>
<td>Statkraft Energias Renováveis</td>
</tr>
<tr>
<td>TSW</td>
<td>The Statkraft Way</td>
</tr>
<tr>
<td>WHC</td>
<td>World Hydropower Congress</td>
</tr>
</tbody>
</table>
Introduction to case studies

Hydropower is the world’s largest source of renewable energy generation. Hydropower-installed capacity continues to grow, reaching 1,290 GW in 2018 (IHA, 2019), and accounting for more than 60 percent of global renewable energy generation. Its importance is also increasing as its dispatchability facilitates integration of intermittent renewables into power systems, enabling decarbonization of electricity generation.

However, operation and maintenance (O&M) of hydropower facilities are not always undertaken effectively, especially in developing countries, meaning that the full benefits of hydropower are not realized. During the Hydropower O&M Workshop in Martigny, Switzerland (October 2016), and the World Hydropower Congress (WHC) in Ethiopia (May 2017), key stakeholders agreed on the need for a tool for supporting preparation of ad-hoc hydropower O&M Strategies for countries with low O&M capabilities and challenging business environments.

On this basis, the World Bank teamed up with different representatives from the hydropower community to prepare the companion report titled *Operation and Maintenance Strategies for Hydropower—Handbook for Practitioners and Decision Makers*. The handbook proposes recommendations and good practices to prepare ad-hoc O&M strategies for the hydropower fleet and aims at supporting stakeholders engaged in O&M of existing and new hydropower facilities to:

1. improve efficiency and reliability of hydropower by taking into account the full life cycle of a hydropower plant (from project design, construction, commissioning, operation, and refurbishment, to end-of-life decommissioning);
2. protect the natural environment, employees, and surrounding communities; and
3. maximize stakeholder benefits, including the provision of low-cost, reliable, renewable energy.

The present report gathers six case studies that were mobilized to feed the preparation of the handbook with examples and lessons learned from the ground. These case studies have indeed been prepared with

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public utilities and private companies from Brazil, Liberia, Nigeria, Pakistan, Uganda, and Uruguay/Argentina and are structured around the steps described in the handbook:

- **Step 1:** carry out a diagnosis to determine the current state of the O&M program and assess the performance of the plant;
- **Step 2:** establish the objectives to be achieved through the implementation of the O&M strategy;
- **Step 3:** determine activities and measures to reach the strategic objectives established in Step 2 based on the diagnosis completed in Step 1;
- **Step 4:** explore O&M contractual models based on the findings from Steps 1 to 3, including:
  - **Model 1:** The owner retains sole responsibility for O&M.
  - **Model 2:** The owner outsources some O&M responsibilities to consultants, contractors, or suppliers.
  - **Model 3:** The owner outsources all O&M responsibility to an independent operator.
- **Step 5:** investigate organization and staffing options;
- **Step 6:** evaluate financial resources needed for a sustainable O&M program;
- **Step 7:** validate the strategy through cost-benefit analysis;
- **Step 8:** implement the O&M strategy, including by developing operating plans.

As listed in Table I.1, the proposed case studies cover a range of types and sizes of facilities and show the practical application of the models described in Step 4 but also illustrate the options available under these models.

### TABLE I.1 | List of case studies and models adopted

<table>
<thead>
<tr>
<th>CASE STUDY</th>
<th>COUNTRY</th>
<th>NAME</th>
<th>INSTALLED CAPACITY—MW</th>
<th>MODEL</th>
<th>KEY FEATURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Brazil</td>
<td>Statkraft’s Assets</td>
<td>180 MW (six facilities)</td>
<td>1</td>
<td>O&amp;M taken in-house and Statkraft’s systems adopted</td>
</tr>
<tr>
<td>2</td>
<td>Liberia</td>
<td>Mount Coffee</td>
<td>88 MW</td>
<td>3</td>
<td>Interim measure while staff are trained to implement Model 1</td>
</tr>
<tr>
<td>3</td>
<td>Nigeria</td>
<td>Kainji and Jebba</td>
<td>1,338 MW (two facilities)</td>
<td>2</td>
<td>Most O&amp;M activities by the owner, but some specialist activities outsourced</td>
</tr>
<tr>
<td>4</td>
<td>Pakistan</td>
<td>New Bong Escape hydropower project</td>
<td>84 MW</td>
<td>3</td>
<td>Notionally Model 3, but outsourced O&amp;M is now undertaken by a subsidiary of the owner, so similarities to Model 1B</td>
</tr>
<tr>
<td>5</td>
<td>Uganda</td>
<td>Nalubaale and Kiira</td>
<td>380 MW (two facilities)</td>
<td>3</td>
<td>Fully outsourced concession</td>
</tr>
<tr>
<td>6</td>
<td>Uruguay/Argentina</td>
<td>Salto Grande</td>
<td>1,890 MW (two facilities)</td>
<td>1</td>
<td>O&amp;M by the in-house team</td>
</tr>
</tbody>
</table>

The six case studies also bring lessons learned from the implementation of selected O&M strategies, while sharing views on remaining challenges and future directions.

Readers of this report are invited to simultaneously read the companion handbook for full benefits. These publications together illustrate the key ingredients to an effective O&M strategy for hydropower. The focus of these resources is good management and mobilization of adequate capacity and skills. Measures to enhance management capability are indeed seen as crucial to the development and implementation of an effective O&M strategy. Examples of substantial improvements in performance and cost reduction through managerial reforms are particularly illustrated in Case Study 1 (Statkraft’s Assets) and Case Study 2 (Mount Coffee in Liberia).²

² Note: In both reports, O&M refers to all activities needed to operate and maintain hydropower facilities, including repair and refurbishment. Even though hydropower operation and maintenance should comply with a comprehensive dam safety program, the dam safety aspects are not addressed in detail in this series of reports since guidelines are already largely available on dam safety (some of them being listed in the handbook).
1. Statkraft Energias Renovaveis, Brazil

In July 2015, Statkraft took over control of the Statkraft Energias Renovaveis (SKER) Brazilian company, increasing their shares up to 81.31 percent, in partnership with FUNCEF, a Brazilian pension fund (18.69%). SKER is an existing company with almost 316 MW installed capacity, of which 128 MW is onshore wind generation and 188 MW is hydropower generation. A list of Statkraft-owned and operated facilities (180 MW) in southern Brazil is found in Table 1.1.

<table>
<thead>
<tr>
<th>NAME OF SITE</th>
<th>TYPE OF PROJECT</th>
<th>LOCATION</th>
<th>AGE (YRS)</th>
<th>INSTALLED CAPACITY (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monjolinho</td>
<td>Existing run-of-river</td>
<td>Passo Fundo R on the Rio Grande</td>
<td>9.3</td>
<td>2 units @ 37 MW, total 74 MW</td>
</tr>
<tr>
<td>Passos Maia</td>
<td>Existing run-of-river</td>
<td>Chapecó River, west in State Santa Catarina</td>
<td>6.8</td>
<td>2 units @ 12.5 MW, total 25 MW</td>
</tr>
<tr>
<td>Moinho</td>
<td>Existing run-of-river</td>
<td>Bernardo José River</td>
<td>7.3</td>
<td>2 units @ 7 MW, total 14 MW</td>
</tr>
<tr>
<td>Esmeralda</td>
<td>Existing run-of-river</td>
<td>Batá River northwest of Santa Maria</td>
<td>11</td>
<td>2 units @ 11 MW, total 22 MW</td>
</tr>
<tr>
<td>Santa Laura</td>
<td>Existing run-of-river</td>
<td>Chapecozinho River west in State Santa Catarina</td>
<td>11.2</td>
<td>2 units @ 75 MW, total 15 MW</td>
</tr>
<tr>
<td>Santa Rosa II</td>
<td>Existing run-of-river</td>
<td>On the Rio Grande</td>
<td>10.5</td>
<td>3 units @ 10 MW, total 30 MW</td>
</tr>
</tbody>
</table>

Average annual generation (GWh/yr) 936 GWh/yr

Source: Statkraft Energias Renovaveis (SKER 2019).

1.1 Status of existing fleet

Availability

The Brazilian hydroelectricity market tracks the performance of hydro fleets following two parameters: real generation compared with concessional physical guarantees and availability level.

3 Concessional physical guarantees represent the maximum amount of energy that the asset can supply to the system. The Brazilian Ministry of Energy and Mines calculates the guarantees as part of the concession process.
Figure 1.1 illustrates that SKER’s annual average capacity output for the past five years was 109.4 MW, compared to the total physical guarantee of 99.7 MW.

Although results vary widely across hydropower plants (HPPs), most plants are exceeding their physical guarantees, except for Moinho and Santa Rosa II HPPs. For the latter, lower-than-average performance results from ecological flow increases by the environmental authority (after the project began construction), led to a reduction in generation, compounded by several consecutive dry years in the basin.

Over the last three years (2015, 2016, and 2017), the availability of the six SKER hydro plants averaged 97.7 percent (Figure 1.2), which is an optimal level for SKER assets, based on a commercial basis with profitability, risk, long-term planning, and cost-benefit decisions as key goals.

**FIGURE 1.1** Physical guarantee vs real generation over five years

![Graph showing physical guarantee vs real generation over five years.](image)

Source: SKER operational information.

**FIGURE 1.2** Hydro assets average hydropower availability indices (%)

![Graph showing hydro assets average hydropower availability indices.](image)

Source: SKER six hydro plants yearly availability average.
In general, by industry standards, a world-class maintenance organization is one that consistently demonstrates industry best practices. Table 1.2 illustrates some of the world-class levels of achievement of SKER’s assets.

### 1.2 O&M strategy and contractual arrangements

**O&M strategic model**

In July 2015, began full implementation of Statkraft’s Requirements and Policies (The Statkraft Way: TSW). In 2015, the O&M model was structured with limited ownership representation, and outsourced management and execution (between Model 2 and 3). By 2017 it transitioned to Model 1 with full-ownership control, management, and execution carried out in-house, which aligned O&M processes with Statkraft’s business plan and its long-term goals.

**O&M strategic blocks of activities**

In general, TSW for O&M begins with the alignment of O&M processes with the company business plan and long-term goals. The forecast of energy prices and hydrologic conditions both define the energy

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### TABLE 1.2 | Criteria for world-class O&M

<table>
<thead>
<tr>
<th>WORLD-CLASS OPERATION AND MAINTENANCE CHARACTERISTICS (DEFINITION)</th>
<th>WORLD-CLASS LEVEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance schedule compliance (comparison between executed and planned schedule)</td>
<td>&gt; 90%</td>
</tr>
<tr>
<td>Maintenance overtime (percentage of overtime cost as part of the overall maintenance cost)</td>
<td>&lt; 5%</td>
</tr>
<tr>
<td>Maintenance direct work (percentage of in-house work)</td>
<td>&gt; 75%</td>
</tr>
<tr>
<td>Planned maintenance work (comparison executed—planned maintenance cost with the overall maintenance cost)</td>
<td>&gt;90%</td>
</tr>
<tr>
<td>Preventive maintenance schedule compliance (execution of preventive maintenance schedule)</td>
<td>100%</td>
</tr>
<tr>
<td>Ratio of work order (percentage of work order completed versus work order planned)</td>
<td>90 to 100%</td>
</tr>
<tr>
<td>Equipment availability (yearly plant availability)</td>
<td>At least 90%</td>
</tr>
<tr>
<td>Equipment productivity (for hydro industry: yearly real generation versus physical guarantee)</td>
<td>At least 95%</td>
</tr>
</tbody>
</table>

Source: SKER.
management plan, which forms the basis for planning asset production targets and maintenance works (schedule major overhaul during periods with low prices), taking into consideration asset conditions and a risk and vulnerability assessment 14 (RAV).

The current SKER O&M model implements the following strategies:

1. Operate on a commercial basis with profitability as the key objective, aligning the O&M processes with Statkraft’s requirements and policies that are grounded on four principles: (i) safety and preparedness, (ii) optimization of generation and profits, (iii) empowered teams, and (iv) continuous learning.

2. Ensure that health, safety, and human rights of employees are valued, protected, and aligned with the guidelines in OHSAS 18001 and ISO 14001, or equivalent national standards.

3. Undertake a risk assessment vulnerability (RAV) process annually for each power plant.

4. Ensure efficient use and development of the hydropower resources by:
   - maximizing revenue within a given framework
   - striving for the most cost-effective operation and maintenance program
   - targeting an optimal reinvestment level
   - implementing a long-term asset management plan.

5. Secure future utilization of licenses and concessions.

6. Assign a market-adjusted availability for each asset.

7. Comply with internal and external requirements.

8. Uniformly apply corporate principles, methods, and tools, adjusted to local conditions.

9. Efficiently use and develop expertise through continuous improvement processes.

1.3 O&M human resources

The planning of O&M human resources involved communication with workers and unions. During transition toward in-house implementation, all 67 workers were evaluated from a technical point of view to assess their potential career progression in Statkraft. From this exercise, 35 plant workers were selected, along with 10 existing technical staff, for a total of 45 full-time employees (FTE) to manage the six hydropower plants and four windfarm assets.

Figure 1.4 illustrates the organizational structure of 35 FTE O&M hydro staff within SKER.

The optimization of the staffing plan led to a 32 percent reduction in staff, from 67 FTE positions to 45 positions. The maintenance optimization was based on implementation of the TSW O&M model and resulted in a significant reduction in the maintenance workload and an opportunity to reduce the staffing requirement significantly. During the optimization process, it was necessary to add two FTE positions, in order to comply with local Brazilian regulations, and TSW requirements. Before and after the implementation of the in-house O&M model, a communication and training process was carried out. Figure 1.5 illustrates the main activities during the first six months of the integration process.
**FIGURE 1.4** O&M organizational structure across the six hydropower plants

![O&M organizational structure diagram](image)

Source: SKER O&M in-house implementation project.
Note: L1 & L2 staff are centralized support based in Florianopolis and L3 and L4 staff are field based.

**FIGURE 1.5** Implementation plan for human resources for in-house O&M (Model 1)

<table>
<thead>
<tr>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>Talent maps</td>
</tr>
<tr>
<td>Integration program—headquarters Enex transition</td>
</tr>
<tr>
<td>Integration program—plants Enex transition</td>
</tr>
<tr>
<td>Workshop change management</td>
</tr>
</tbody>
</table>

Source: SKER.
1.4 O&M financial resources

The financial resources allocated annually to the company’s O&M program are primarily based on the corporate energy management plan, which in turn is defined largely by basin hydrology and market conditions. Once the financial resources are allocated, an annual energy production forecast is prepared. Thereafter, the O&M work plan is prepared, based on the condition of assets and a risk and vulnerability assessment that includes a 360-degree risk process.

The long- and short-term plans take into account asset condition and maintenance requirements, including predictive and preventive maintenance, major upgrades, and modernization works, to determine the OPEX and CAPEX resources necessary to fulfill the company business plan. The O&M budget is allocated at the plant level, including all O&M expenses, administrative and financial supporting requirements, overhead, and commercial and tax expenses (in Brazil each plant is an operating company).

The O&M director submits the OPEX and CAPEX budget to the asset manager for review and approval in August, and in November the board approves the next year’s O&M budget. The OPEX and CAPEX disbursing process follows the company’s power of attorney mandates and limits.

Statkraft implemented their operating model in Brazil, supported by Peruvian Statkraft’s O&M vice president, with the aim of achieving the status of a world-class company, as shown in Figure 1.6, with a focus on:

- 5S implementation program; 5S is a Japanese system designed to organize a workplace for efficiency and effectiveness, “Sort,” “Set in order,” “Shine,” “Standardize,” and “Sustain.”
- Integrated management system (IMS), aligns with: ISO 9001 (quality), ISO 14001 (environmental), and OHSAS 18001 (Occupational Health and Safety Assessment Series).
- Extended condition assessment (ECA).
- Risk and vulnerability assessment (RAV).
- Reliability-centered maintenance (RCM) implementation.
- Root cause analysis (RCA) and learned lesson.
- Computerized maintenance management system (CMMS).

It was determined that maintenance workload requirements could be optimized by implementing the world-class maintenance approach (Figure 1.7), with a focus on reliability-centered maintenance (RCM) strategies. As a result, maintenance workload decreased 28 percent, lowering average annual maintenance man-hours from 32,959 to 23,680, and asset-availability increased.
**FIGURE 1.6** SKER path to a world-class company

![SKER path to a world-class company diagram](image)

Source: SINTEF Energy Research: Literature study concerning world-class maintenance.

**FIGURE 1.7** RCM implementation: Comparative maintenance workload

![RCM implementation chart](image)

Source: Statkraft Brazil in-house model implementation.

### 1.5 Lessons learned from implementation of the O&M strategy

The implementation of O&M strategies in asset management that began in 2015 has been demonstrated to be successful by the O&M audit process, which rates the O&M processes against best practices on a scale of 5 to 10 (Figure 1.8). The implementation of the new strategy was completed in 2017.

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4 Statkraft is one of 42 partners of the Norwegian Research Centre for Hydropower Technology (HydroCen), contributing approximately USD 1.5 million, the largest contribution from an industry partner for developing O&M tools for the hydropower technology.

5 The world-class rating is shown in Figure 1.6: 1 to 3: Mainly preventive maintenance, 4 to 5: Began process to WC organization, 6 to 8: Almost WC organization, 9 to 10: WC organization; refer to Statkraft/SINTEF base document.
The weighted-maintenance object (WMO) hydropower benchmarking model was developed by Statkraft and PA consulting in 1989 and has been used successfully for almost three decades to support performance improvement within the Nordic hydropower industry. The WMO method is designed to provide an evaluation method that puts hydropower facilities of all sizes on a level playing field, utilizing a point system to score the entire hydropower plant, based on technical conditions and complexity. Statkraft has applied the model at facilities in South America and Asia over the last decade and has successfully achieved improved performance for those assets.

As shown in Figure 1.9, after Statkraft implemented its O&M optimization methodologies for the six plants in Brazil, the overall annual OPEX amount was reduced from 34 thousand USD/WMO (overall budget: 9.5 million USD) to 20.3 thousand USD/WMO (5.8 million USD), an annual saving of 3.7 million USD. This results in a projected increase in profits of 29 million USD after 2017 (net present value over 25 years at 12 percent discount rate).
1.6 Challenges and future direction

Recently, Statkraft’s operations in Brazil have expanded. On December 21, 2018, Statkraft signed an agreement with EDP Energias do Brasil, acquiring eight additional operational hydropower plants in the state of Espírito Santo in Brazil representing a total installed capacity of 131.9 MW. The Brazilian organization is executing an integration plan for these hydro plants, in order to bring them to TSW standard levels by 2020.

The development of new renewable energy technologies is creating new challenges for operating hydropower assets in the world and will result in some of the following key trends in O&M:

- Increased penetration of variable renewable technologies can result in increased operating costs and underscores the need for even greater overall efficiency as a key target.
- Since contract and business models are changing, a competency-based continuous improvement process will need to be implemented.
- Digitalization offers solutions for revenue optimization and cost reduction through automated, smarter O&M processes, enabled by enhanced digital monitoring systems and predictive analytics.
2. Mount Coffee Hydropower Plant, Liberia

After years of civil unrest in the nineties, culminating in the destruction of the Mount Coffee hydro-power site, the facility has been fully rebuilt (Figure 2.1). After the site was rendered inoperable, Liberia Electricity Corporation (LEC) lost its in-house experience and expertise in operating the hydropower plant. In 2016, LEC signed a five-year operations, maintenance, and training (OMT) contract with a Swiss firm, Hydro Operation International (HOI), to operate and maintain the Mount Coffee facility while carrying out theoretical and hands-on training to qualify O&M staff.

FIGURE 2.1 | Mount Coffee rebuilt powerhouse

Source: Hydro Operation International (HOI).
During the period of civil unrest, the dam was breached, and the plant was subsequently looted. Starting in 2013, the facility rehabilitation\(^6\) included:

- rebuilding dams and associated civil works structures
- rehabilitating the spillway and gates, including new drives and controls
- constructing an emergency spillway
- rehabilitating the intake structure and associated hydro-mechanical equipment
- rehabilitating the powerhouse civil structure
- replacing all powerhouse electromechanical equipment including turbines, generators, gantry crane, state of the art controls, etc.
- new 132 kV switchyard and two transmission lines, including 11/66 kV unit transformers.

### 2.1 Status of existing fleet

The first unit in the new powerhouse was commissioned in December 2016, and the remaining units were progressively commissioned through 2017 and 2018. By 2018, three out of the four units had been taken over by Liberia Electricity Corporation (LEC). The fourth one was taken over by LEC mid-2019.

Although steadily rising, development of the distribution network in Liberia remains slow, and as a consequence, the full 88 MW output of the Mount Coffee plant is not being fully utilized. For the time being, only two units are needed to meet network demand (Table 2.1).

For most of the year, Mount Coffee is the sole supplier of power to the Liberia Electricity Corporation (LEC) network in Monrovia and is operated on an isolated network providing frequency and voltage control. During the dry season, when natural inflows can be significantly reduced, LEC needs to supplement the electricity supply with diesel and heavy fuel oil generation. The hydropower units often have to cope with large network load swings and other instabilities, which can cause the units to trip out of service. Although a significant improvement has been achieved since the plant came back into operation, blackouts still occur (105 unit trips in 2017, reduced to 61 in 2018 and 56 in 2019). As the units have black-start capability, they are generally used to restore the network after a blackout. Thus, one of the Mount Coffee units is generally back on line within minutes and the system fully restored within 30–90 minutes.

It should be noted that the Mount Coffee switchyard is not within the scope of facilities entrusted to HOI for operation, maintenance, and training.

### TABLE 2.1 Mount Coffee Hydropower Plant as of 2018

<table>
<thead>
<tr>
<th>NAME OF SITE</th>
<th>TYPE OF FACILITY</th>
<th>LOCATION</th>
<th>AGE OF FACILITY (YRS)</th>
<th>INSTALLED CAPACITY (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mount Coffee</td>
<td>Existing run-of-river</td>
<td>St. Paul river system, Liberia</td>
<td>Original facility 52 yrs; rebuilt facility 3 yrs</td>
<td>4 units @ 22 MW for total 88 MW</td>
</tr>
</tbody>
</table>

2018 average annual generation (GWh/yr) 159 GWh/yr (*)

Source: HOI.

Note: (*) Limited by current network demand, expected to increase in the coming years.

---

\(^6\) The rehabilitation project was financed jointly by the European Investment Bank (EIB), the German government, within the scope of German Financial Cooperation with Liberia administered by Reconstruction Credit Institute of Germany (KfW), the Norwegian government through the Norwegian Ministry of Foreign Affairs, the Millennium Challenge Corporation (MCC) and the government of Liberia.
2.2 O&M strategy and contractual arrangements

O&M strategic model

Since 1990, LEC lost its experience and expertise in operating hydropower facilities. To secure sustainable generation, Liberia Electricity Corporation (LEC), with financial support from lenders, awarded a five-year O&M and training contract (Model 3) in 2016 to Hydro Operation International (HOI), a Swiss firm, which would:

- be responsible for the O&M of the plant according to international standards for a period of five years, during the anticipated development period of the transmission and distribution grid in Liberia.
- establish O&M procedures for sustainable operation of the plant and be responsible for its implementation over the five-year period.
- train local staff appointed by LEC and share skills, so that the local staff will have the necessary skills to operate the plant with little to no assistance after the five-year period (back to Model 1).

The award of the operation, maintenance, and training (OMT) contract to HOI followed an international tendering process led by LEC’s consultant, under the bidding rules of the Reconstruction Credit Institute of Germany (KfW). The process started in 2014 but was interrupted by the Ebola crisis and was finalized in 2016.

Overall O&M strategies

Operation of Mount Coffee HPP aims to maximize availability and minimize outages by ensuring that best practices and standards are incorporated into the daily operation and maintenance of all utility components and in the training of local staff by the O&M contractor.

Experience shows that even after careful project planning and implementation of good quality control measures from construction to commissioning, unforeseen problems still occur, resulting in unplanned outages, loss of generation, load shedding, and possible deterioration of equipment and machinery, etc.

The OMT (operations, maintenance, and training) contract at Mount Coffee aimed to mitigate this. After significant funds were invested in restoring the plant, it was essential that adequate on-the-job expertise and experience was made available on-site to ensure that the long-term goal of sustainable and reliable operations during the remaining life of the plant would be met.

Maintenance at Mount Coffee HPP is centered on preventive maintenance (following O&M manual requirements and best practice), event-based maintenance, and corrective maintenance. Planned maintenance outages follow an annual schedule that is revised as needed. Whenever possible, the outages are planned at a time when they have the least impact on electricity production. Maintenance activities are carried out in mixed teams of expatriate and local staff, allowing the local staff to acquire on-the-job experience.

Regular preventive maintenance activities are necessary to ensure quality control and reliable operation of equipment in a difficult service environment. Maximum availability of equipment and a minimum of unplanned shutdowns are achieved by using scheduled outages to inspect all equipment (serviceable and non-serviceable), identifying potential risks of failure and replacing or repairing components as required.
Performance incentives in the OMT program administered by HOI include:

a. **Plant performance**: evaluated using key performance indicators (KPIs—Table 2.2) in several areas including:
   - plant performance
   - maintenance budget
   - spare parts management
   - health and safety

b. **Training Performance**: an incentive is provided for the OMT contractor if a trainee can be promoted (i.e., tested and agreed for promotion by the ad-hoc training committee), and the corresponding expatriate counterpart can be withdrawn prior to the contract target date. Currently LEC does not offer any incentive to its local staff to perform or to take on responsibilities.

**TABLE 2.2 | Sample KPI table**

<table>
<thead>
<tr>
<th>KPI</th>
<th>TARGET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant availability factor</td>
<td>≥97%</td>
</tr>
<tr>
<td>Generation forced outage rate</td>
<td>≤1%</td>
</tr>
<tr>
<td>Budget performance variance</td>
<td>≤5%</td>
</tr>
<tr>
<td>Increase of store inventory value</td>
<td>≤5%</td>
</tr>
<tr>
<td>Accident frequency</td>
<td>1/year</td>
</tr>
<tr>
<td>Accident severity</td>
<td>10 lost day/year</td>
</tr>
</tbody>
</table>

Source: HOI.

### 2.3 O&M human resources

The operations and maintenance staff at Mount Coffee is structured as follow (as shown in Figure 2.2):

a. **Management staff** is under the responsibility of an experienced plant manager and includes an operations manager, maintenance manager, and a chief engineer heading up technical services, plus administration and general services staff. This management structure is currently staffed by HOI, with an LEC counterpart assigned to each position, with the exception of the plant manager. General services such as the management of the plant offices and on-site living facilities, including petrol station, car maintenance facility, sport and leisure facilities, etc., are not under HOI’s responsibility.

b. **Operation staff** is comprised of five HOI shift supervisors and five LEC counterparts, as needed to have a team of two operators 24/7 in the plant control room, including rest and leave time. In 2018, a second generation of LEC trainee staff has been added to prepare for the transition of 1st generation staff once they have been promoted, after which the HOI shift supervisors will leave. It is anticipated that after three years of training, the operation shifts will be solely staffed with LEC personnel.

c. **Maintenance staff** is under the responsibility of HOI senior staff: a mechanical technician, an electric technician, a process and controls technician, and a general maintenance technician. Each position is matched with an LEC counterpart trainee.

Maintenance covers not only the power plant, but also the maintenance of the hydromechanical equipment (e.g., spillway, intake gates), reservoir clearing, dam surveillance and vegetation cleaning, and
intake trash-rack management as well as road maintenance, etc. Other facilities, such as switchyard, camp and ancillary facilities, and site security are still under direct LEC management.

Staffing of the functions in Figure 2.2 is distributed as follows (expatriates/locals):

- Plant management: 3/3
- General services: 3/3
- Technical services: 1/5
- Operation: 6/6
- Maintenance: 5/5
- Training: 1/1

Once training and certification are complete (Figure 2.3), only the local staff will remain.

**O&M training**

Hydro Operation International is implementing an extensive O&M training program which covers six main topics:

1. **Plant management**: coordination with the utility, budget and cost control, performance monitoring, environmental reporting.
2. **Operations**: establishment of operating procedures and routines, coordination with the dispatch center, plant operation, flood management, operation of spillway gates, water intake and trash-rack operation, reservoir cleaning, emergency procedures and training.
3. **Maintenance of generation equipment**: establishment of a maintenance plan and procedures, preventive and corrective maintenance, preparation of heavy maintenance work, and management of spare parts and consumables.

4. **Maintenance of other equipment** including: spillway gates, intake structures, telecommunications, dam maintenance and surveillance.

5. **Other associated training**: recruitment and evaluation, basic mathematics, physics, energy courses, professional training: management, engineers, technicians.

6. **Other services**: security, access control, quality control and safety management, fire brigade, first-aid and paramedical services, etc.

**FIGURE 2.3** | Training session and runner inspection

![Image of training session and runner inspection](Source: HOI)

It was initially planned that this training would be completed with internships in hydro plants and workshops in Switzerland. However, this part of the plan could not be implemented because of the lack of adequate funds either from project funds or LEC’s own internal resources. Training is therefore limited to on-the-job training and learning-by-doing, until adequate budgets can be made available.

### 2.4 O&M financial resources

The overall O&M budget for Mount Coffee is in the range of USD 5 million per year, including OMT contract costs, some provision for periodic overhauls, and some replacement of spare parts and consumables. This corresponds to around 1.5 percent of the cost of reconstruction, or about 3¢/kWh under the current demand-constrained production. The cost per kWh is expected to reduce once Mount Coffee is producing at its design capacity.

During the first year of operation, the O&M budget was covered by the project rehabilitation funds (grants and loans). Thereafter, the costs of the OMT contract were to be covered by LEC’s own funds (revenues generated by the sale of electricity).
An escrow account funded from LEC’s balance sheet was planned in the OMT contract to provide security for the financing of the O&M, as well as reserves for future major maintenance and overhaul. This has not yet been achieved by LEC.

An advance payment corresponding to six months of services was put in place at the onset of the contract. The advance was funded by the project lenders and is maintained until the last year of the contract, to provide short-term financing to secure the contract, and funds to offset any unpaid invoices.

After the five-year period of the OMT contract, the plant O&M will come under the sole responsibility of LEC (transition to Model 1). Some additional costs were anticipated to be required during the first few years after commissioning including:

- training costs, and some external operation support to implement good practice and procedures
- additional investment costs that have yet to be included in the project financing: e.g., an operator’s village and associated services, to provide good living conditions for the staff and their families, designed for the anticipated lifetime of the plant
- additional maintenance equipment, some of which is not normally considered under an OPEX budget, e.g.: maintenance workshop, heavy maintenance vehicles, fire truck, mobile crane, tools, etc.
- a communications system.

LEC’s current financial situation does not allow allocation of funds for these items.

2.5 Lessons learned from the implementation of the O&M strategy

After receiving on-the-job training, there may be a tendency for outward migration of staff who choose to leave the plant for other utilities or the private sector, particularly if more competitive salaries are offered by external companies and if the living conditions at the plant site are not improved from the current state. This underscores the importance of enrollment and training of a second generation of operators to ensure that the O&M program is fully staffed and trained before HOI’s contract is complete.

The plant manager must have sufficient authority to spend the O&M budget to preserve the performance and condition of the asset and its sustainability. In some cases, the support of an external advisor may be helpful to provide an annual and biannual audit of the O&M program and an annual review of budget and long-term asset management plans.

2.6 Challenges and future direction

Challenge 1: Human resources and capacity building

The most challenging issue regarding capacity building for the O&M of Mount Coffee HPP (as in many developing countries) is building and retaining human resources. Long-term sustainable O&M is only achieved under Model 1 if the O&M is locally staffed, with managers and technicians duly trained and motivated.
The challenges with training staff at Mount Coffee included:

- affording the O&M contractor adequate and sufficient control and authority over the trainees through a formal agreement with the employer, the O&M contractor, and the seconded trainee.
- setting up an individual performance reward system to acknowledge progress, commitment, and dedication of the trainees. It is recognized this may conflict with the employment status and salary structures of local government agencies.
- retaining the newly trained staff who may be attracted by other opportunities in other sectors.

The purpose of capacity building is to develop expertise and knowledge within the country, and not just within the confines of the utility. Based on the experience gained working in Mount Coffee, HOI proposed that the optimal solution could be to create a specific private local O&M company, staffed with mainly local staff and managed by the O&M contractor for the purpose of operating and maintaining the plant in a sustainable way.

Such a company could be a joint venture between the O&M contractor and the owner of the plant, or other local interests, remunerated through a lump sum contract, with an incentive based on KPIs and funded by the revenue generated by the Mount Coffee HPP. This company would be in charge of the selection, employment, and training of the local staff and would have the capacity to reward, motivate, or sanction the staff when necessary. It would also have a vested interest in putting in place a succession plan to replace retirees.

**Challenge 2: Financing the O&M**

Multiyear budgets should be prepared in advance and reserves allocated for major maintenance works and overhauls. The Mount Coffee plant is owned by LEC and will be managed by LEC after the end of the O&M contract. However, because the plant does not have its own budget, accounts, and control, the plant management does not have the freedom to operate the facility in an optimal way.

The financial plan should allocate capital in a reserve fund to finance overhauls when they become necessary. In the absence of reserve funds, overhauls are typically not completed or postponed, threatening the life of the equipment.

Some elements required for the O&M program for Mount Coffee considered to be critical to ensure safe and sustainable O&M by the contractor were not included in the project rehabilitation budget and remain the responsibility of LEC to finance, e.g.: a village, some of the major maintenance equipment (e.g., truck with jib crane, mobile crane, fire truck, etc.), site communications, and modern IT facilities.

A specific profit center for the plant, with its own management and its own financial and operational targets and sources of revenues may enable more optimal asset management, which could go further toward guaranteeing the performance, reliability, and sustainability of the plant.

**Challenge 3: Grid stability**

In developing countries, the operation of hydropower facilities can often be correlated with the stability of the grid and the distribution network. Voltage, frequency, and load instabilities add stress to the generating equipment and may affect its reliability. A properly funded maintenance program would...
allow additional protection and monitoring systems to ensure early detection and monitoring of damage caused by these grid instability issues. Once identified, these issues could be addressed in a timely manner to avoid premature failure.

**Challenge 4: Flow regulation**

The seasonal nature of the St. Paul River and the unpredictability of its hydrology make it difficult to manage the operation of Mount Coffee HEP to ensure reliable electricity supply throughout the year. The uncertainty of flows is likely to be exacerbated by climate change. The Via reservoir is planned upstream on the main tributary of the St. Paul River (pre-feasibility studies are currently underway). When completed, this storage reservoir will regulate the flow, allowing the Mount Coffee plant to generate more power during the dry seasons.

From the experience of Mount Coffee reconstruction, a key lesson is that all elements necessary for O&M should be funded in the project budget. Although the cost of these components may be small compared with the overall construction or rehabilitation cost, if overlooked, it can have significant impacts on O&M performance and sustainability. In the case of Mount Coffee, although it is only about 30 km away from Monrovia, it is a relatively remote site, and therefore needs to be provided with:

- suitable housing, health, recreation, and other facilities for O&M staff to allow permanent residence onsite.
- industrial grade, redundant, high-bandwidth communication systems (voice and Internet) to allow communication with the local control center.
- vehicle pool, equipment pool, workshops, and tools to allow all regular O&M to be carried out in-house, without recourse to third-party equipment or skills.
3. Kainji-Jebba Hydropower Complex, Nigeria

Since Mainstream Energy Solutions Ltd. (MESL) took over the Kainji-Jebba hydropower complex in 2013, the company has undertaken a capacity recovery program to restore the joint capacity of the two plants. The capacity has doubled from 460 MW at the time the asset was acquired to 922 MW today, out of an overall installed capacity of 1,340 MW (Figure 3.1 and Table 3.1). Through a 30-year concession agreement with the government of Nigeria, MESL is the private owner/concessionaire with responsibility for the O&M for the Kainji-Jebba complex.

MESL’s O&M program strives for continuous improvement by utilizing internationally proven processes, in order to ensure optimized plant availability and reliability. MESL has instituted a plan around staff recruitment and retention by encouraging promotion within the organization and putting in place an innovative training program and an on-boarding system.

**FIGURE 3.1** Aerial view of Kainji hydropower complex

Source: © Mainstream Energy Solutions Ltd.
### 3.1 Status of existing fleet

#### Joint operation of Kainji-Jebba hydropower complex

The Kainji-Jebba hydropower complex, owned by the Nigerian government, has been operated by Mainstream Energy Solutions Limited (MESL) since November 2013, under a 30-year concession agreement. MESL was incorporated and licensed as a power generating company in 2011, reporting to the Board of Directors who are the shareholders and the owners of the company. The management team runs the day-to-day affairs and formulate strategic policies for the company.

Kainji and Jebba hydropower plants were commissioned in 1968 and 1984 respectively, with a total installed capacity of 1,338.4 MW. At present the complex is operating at 922 MW (69 percent of installed capacity), with plans to reach full capability by 2025. The two hydropower plants are located on the Niger River in a cascade, 100 km apart with the Kainji dam situated upstream of Jebba. The total storage capacities of the two reservoirs are 15 billion m$^3$ and 3.8 billion m$^3$, respectively.

#### Age and condition of the facilities

When MESL took over operation of the Kainji hydropower plant in 2013, the plant could not be operated. At present (2019), four of the eight units are in operation at nearly 100 percent availability, generating an output of 440 MW. Rehabilitation of units 1G5, 1G6, and 1G12 was funded by the World Bank under the Niger Basin Water Resources Development and Sustainable Ecosystem Management Project, while repair of Unit 1G11 was funded by MESL. Ongoing rehabilitation and modernization work on Unit 1G7 by General Electric will add 80 MW of additional capacity by 2020. Full recovery of the remaining units is planned within the company’s capacity recovery plan, which is expected to be completed by 2025.

MESL took over operation of the Jebba hydropower plant in 2013, with 460 MW of its installed capacity of 578 MW available. Currently five out of six units are operating with an available capacity of 482 MW. Unit 2G6 is currently unavailable due to a major fire that occurred prior to the acquisition by MESL; recovery of the unit is underway through the capacity recovery plan. Of the five operable units, four will require overhaul and modernization to further enhance their performance.

#### Availability

Since acquisition by MESL, Kainji-Jebba hydropower facilities have increased their performance, with availability rates exceeding 99 percent from 2014 to 2018, with a forced outage rate of only 0.53 percent (Table 3.2).
### 3.2 O&M strategy and contractual models

**Contractual O&M model**

Kainji and Jebba HEPs are operated under a concession model (Model 3) in which all aspects of operation and maintenance are the responsibility of MESL as the private concessionaire. The Nigeria Electricity Power Sector Reform Act (2005) established provision for private participation in the Nigerian electricity market, so that private companies that could assume the functional responsibilities, assets, and liabilities of defunct public utilities. It also developed a competitive electricity market with the establishment of the Nigeria Electricity Regulatory Commission (NERC). MESL was incorporated and licensed as a power generating company in 2011 and acquired Kainji and Jebba Hydro Power Plants (HPP) under a concession agreement through a competitive process led by the Bureau of Public Enterprises (BPE), with a target of restoring the installed capacity (1,338.4 MW) of the two power plants and operating and maintaining these facilities in a safe and efficient manner.

**Overall O&M principles**

Some of the key O&M principles implemented within MESL include:

1. **Strive for continuous improvement by applying the Deming’s Cycle Concept** through:
   - daily hydrology and operations review meetings to plan water utilization for optimal energy production
   - daily review of maintenance activities undertaken for continuous improvement
   - root-cause analysis of failures to avoid recurring corrective maintenance issues.

2. **Strive for international standards in O&M through key performance indicators (KPIs) of plant availability and reliability**, including the KPIs described in Table 3.3 and the examples shown in Table 3.4.

3. **Implement and sustain a robust health, safety, and environment policy and related procedures**, to achieve zero accidents (as of November 2018, MESL achieved four million man-hours without a lost-time incident).

4. **Control the performance of operation and maintenance in an efficient and safe manner**, to optimize reliability and energy production.

---

**Table 3.2: Availability of Kainji-Jebba complex**

<table>
<thead>
<tr>
<th>KEY PERFORMANCE INDICATORS</th>
<th>TARGET</th>
<th>ACHIEVED AS OF OCTOBER 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability factor (%)</td>
<td>&gt;95</td>
<td>99.13</td>
</tr>
<tr>
<td>Forced outage rate (%)</td>
<td>&lt; 0.75</td>
<td>0.53</td>
</tr>
<tr>
<td>Energy generated factor (%)</td>
<td>100</td>
<td>98.69</td>
</tr>
</tbody>
</table>

Source: MESL.

---

7 Energy generated factor = actual energy generated/projected energy based on 100 percent availability
8 Deming’s PDCA cycle (plan–do–check–act or plan–do–check–adjust) is an iterative four-step management method used in business for the control and continuous improvement of processes and products.
9 Reliability measures the ability of generating units to perform their intended function. Availability measures are concerned with the fraction of time in which a unit can provide service.
5. Conduct continuous training and sensitization of staff on the importance of safety, preservation of the environment, and adherence to the company and regulator’s policies and guidelines, to prevent environmental incidents.

6. Perform routine inspection and monitoring activities using modern equipment that optimizes equipment reliability and efficiency.

7. Ensure that support documents and procedures are available during work execution.

8. Hire consultants and O&M experts for technical assistance on critical and challenging tasks, e.g., repair of a damaged stator, rehabilitation of specific generator and turbine components, runner blade cavitation repairs, supply of spillway hydraulic cylinders, etc.

9. Adopt the 5S methodology (sort, set in order, shine, standardize, and sustain) which is a standardized process to create and maintain an organized, safe, clean, and efficient work place.

### TABLE 3.3 | Key performance indicators

<table>
<thead>
<tr>
<th>INDICATORS</th>
<th>FORMULA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forced outage rate</td>
<td>Forced outage hours / forced outage hours + service hours; represents the number of hours a unit was in unplanned outage state</td>
</tr>
<tr>
<td>Availability factor</td>
<td>(Available hours / period hours) * 100; represents the fraction of a given operating period in which a generating unit is available without any outages</td>
</tr>
<tr>
<td>Generation unit cost (N/KWh)</td>
<td>Total expenditure / total energy delivered</td>
</tr>
<tr>
<td>Capacity utilization index (%)</td>
<td>Available capacity / installed capacity</td>
</tr>
<tr>
<td>Generation utilization index (%)</td>
<td>Actual generation / available capacity</td>
</tr>
<tr>
<td>Water utilization index (Mm³/MWh)</td>
<td>Volume of water utilized / total energy generated</td>
</tr>
<tr>
<td>Staff productivity index (MWh/employee)</td>
<td>Energy delivered / number of employees</td>
</tr>
<tr>
<td>Breakdown maintenance index</td>
<td>Number of defects rectified / number of defects reported</td>
</tr>
</tbody>
</table>

Source: MESL.

### TABLE 3.4 | Sample of KPI data for Kainji and Jebba plants

<table>
<thead>
<tr>
<th>KPI</th>
<th>OCT 17</th>
<th>NOV 17</th>
<th>DEC 17</th>
<th>OCT 18</th>
<th>NOV 18</th>
<th>DEC 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kainji Jebba</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forced outage rate (%)</td>
<td>0.62</td>
<td>0.56</td>
<td>0.61</td>
<td>0.65</td>
<td>0.59</td>
<td>0.60</td>
</tr>
<tr>
<td>Availability factor (%)</td>
<td>83.31</td>
<td>96.5</td>
<td>97.24</td>
<td>98.8</td>
<td>98.53</td>
<td>97.8</td>
</tr>
<tr>
<td>Energy generated factor (%)</td>
<td>0.956</td>
<td>0.933</td>
<td>0.931</td>
<td>0.981</td>
<td>0.991</td>
<td>0.981</td>
</tr>
</tbody>
</table>

Source: MESL, O&M report.

### 3.3 O&M human resources

#### O&M staffing at MESL

MESL manages all O&M activities within the following organizational structure (Figure 3.2):

- O&M activities are divided into separate Operations and Maintenance Departments, each with a dedicated manager who reports directly to the Chief Operating Officer (COO).
- The Operations Department supports operations and water management decisions in both the Kainji and Jebba plants, reporting to the Operations Manager. The Operations Department
comprises of 61 staff (60 local and 1 foreign expert) who have responsibility for the management of operations to achieve a high level of safety and performance and to develop and maintain safe and sustainable water management strategies in the Kainji/Jebba complex, while optimizing generation.

■ The Maintenance Department undertakes maintenance activities for both Kainji and Jebba as well as planning maintenance activities. A technical support unit (TSU) and dam safety unit report to the Maintenance Department Manager. The Maintenance Department comprises of 103 staff (102 local and 1 foreign expert) with responsibilities for coordination and execution of plant-wide maintenance programs, to optimize unit availability and avoid forced outages.

■ The Project Management Department has two staff while the Quality Health Safety and Environment Department has ten staff.

**FIGURE 3.2** Kainji-Jeba organogram

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**O&M staff recruitment and training strategies**

MESL has instituted a plan for staff recruitment and retention, with the following features:

1. **Promotion within the organization for knowledge transfer**: Staff members are promoted to higher level positions with additional responsibilities either laterally or vertically. Promotion boosts staff morale and increases productivity, while encouraging staff retention. Internal postings encourage staff to consider new roles.

2. **Robust and innovative training programs (local and international)**: Training programs are designed to build staff capability and improve productivity. Staff in supervisory roles are mandated to go on company-sponsored external training and conferences, to provide exposure to current trends related to their job. On-the-job training is also provided through coaching and mentoring.

3. **Collaboration and alliance with training institutes and other companies**: MESL collaborates with companies in similar business streams for in-plant knowledge transfer and training programs, e.g., Volta River Authority (VRA) Ghana, NAPTIN, ITF, ICOLD, POYRY, JICA, and Glomac, etc.

4. **Progressive on-boarding system**: MESL enhances employee’s first experiences in the company through an induction program, and continuous engagement and evaluation of staff experience, which includes the following activities:
■ digital control system and human machine interface training by experts from Power China
■ operation procedure of mechanical-hydraulic and electro-hydraulic actuators by experts from Power China
■ governor system proportional–integral–derivative (PID) controller tuning and changing of parameters by experts from Power China
■ 2G4 Turbine runner hub cavitation repair by experts from Andritz, Austria
■ generator overhaul by Hitachi/Andritz, Japan/Austria
■ repair of damaged generator stator core by Hitachi Hydro, Japan.

3.4 O&M financial resources

The cost estimate for annual O&M activities varies from year to year, dependent upon which specific projects are carried out. For example, in 2018, the cost estimate for annual O&M activities was N636.2 M (USD 1.8 M), compared to 2017 where the O&M cost was N428 M (USD 1.2 M). In this case, the fluctuation in annual O&M cost was principally due to the quantum of maintenance activities in year 2018, which included procurement of essential spares for the generating units and the auxiliaries.

The governance process is geared toward ensuring the company prioritizes and achieves its annual goals and objectives and also reconciles its annual expected revenue against expected expenditures.

The governance process used to manage MESL’s annual O&M budget is:
■ preparation and submission of budget estimates by O&M departments
■ presentation to the Budget Committee
■ review and presentation of the Budget Committee to MESL Board for approval
■ execution/implementation
■ audit evaluation; carried out by the business risk and internal audit department.

3.5 Lessons learned from the implementation of the O&M strategy

Some of the challenges MESL has faced in implementing their O&M program include:

■ **Noncompliance with market rules by some market participants.** The Nigeria government recently directed the market regulator, Nigerian Electricity Regulatory Commission (NERC) to enforce the market rules and sanction defaulters.

■ **Instability in the Nigerian electricity market.** This is due to the inability of distribution companies to collect all accrued revenue from consumers, resulting in incomplete payments to the generation companies. This is being mitigated by the Nigerian Electricity Bulk Trader (NBET), a government agency that serves to arbitrate disputes between the generators and the distributors.

■ **Grid instability issues;** resulting in excessive vibration, reduced generation capacity, and cavitation of turbine blades. The Nigerian grid controller is enforcing the operation of all the generators on free-governor mode to stabilize the system grid frequency.

■ **Water resources management challenges;** largely related to greater climate extremes; MESL has invested in the installation of IFS/OPT software to optimize the management of water resources.
Difficulties in sourcing spare equipment due to obsolescence. MESL is currently collaborating with a major equipment manufacturer to ensure timely supply of critical parts or upgrades the obsolete parts.

Conflicts of interest with the downstream water users and riparian communities. To mitigate conflict with the downstream water users, MESL is implementing a more effective flood warning and sensitization program. MESL also organizes stakeholder meetings to discuss concerns with the affected communities.

Emergence of a more competitive electricity market. The Nigerian electricity market is becoming more competitive and MESL is taking steps to maximize market opportunities by signing bilateral agreements with eligible customers within the West Africa Power Pool (WAPP) electricity market of which MESL is a utility member.

3.6 Challenges and future direction

MESL has planned the following measures to implement overall improvement in the O&M processes and practices at the Kainji-Jebba hydropower complex including:

- Implementation of computerized maintenance management system (CMMS), an O&M optimization tool, to assist maintenance management in planning and executing routine and corrective maintenance activities, maintaining technical information, budgeting and cost control, etc.

- Implementation of reliability-centered maintenance (RCM), a widely accepted methodology that optimizes asset availability and minimizes maintenance costs. RCM studies will be developed for those assets considered critical due to their high operating costs, high maintenance costs, or which could result in severe consequences to safety and the environment; e.g., oil containment systems.

- Achievement of ISO 9001 certification. MESL has put in place measures geared toward obtaining certification under ISO 9001. A consultant is engaged to implement measures to achieve certification.

- Optimization of the inflow forecast system and operation tools for more accurate flood management and generation projections.

- Better understanding and coordination of operations with the downstream water users, through stakeholder meetings held monthly with the downstream users and coordinated by the Energy Ministry.

- Ongoing discussions with the supervising ministry to gain a better understanding of MESL operations, constraints, and prospects. Recently, high-level discussions were held to request the grid controller to allow MESL more flexibility to manage its operations for effective flood control, specifically during the white flood (early in the rainy season) inflow.

- MESL is increasing the overall plant capability beyond the original target of its capacity recovery plan and aims to add 200 MW by 2023. The Kainji facility was originally designed for 12 generating units; to date only eight (8) units have been installed. For the remaining units, the intake gates, penstock, foundation, and civil structure at the machine hall level are constructed. The 200 MW capacity extension would be completed in about five years, with commercial operation expected to start at the end of the year 2023.

Note: The present case study strictly focuses on O&M approaches for the Kainji-Jebba hydropower plants. It does not seek to address any potential dam safety issues that might exist or not at these sites. It is understood that Nigeria presents dam safety concerns affecting different categories of dams, which stands as a larger challenge not addressed in this report.
4. New Bong Escape Hydropower Project, Pakistan

Laraib Energy Limited (LEL) is a subsidiary of the Hub Power Company (HUBCO), the first hydropower Independent Power Producer (IPP) in Pakistan, and owner and developer of the 84 MW New Bong Escape (NBE) Hydroelectric Power Complex on the Jhelum River in Azad Jammu and Kashmir (AJ&K). HUBCO owns 75% shares in LEL and has a portfolio of over 2,900 MW within the country. Figure 4.1 shows the structure of HUBCO.

**FIGURE 4.1 | HUBCO company structure (percent of shares in HUBCO)**
4.1 Status of existing fleet

Description of facility

As described in Table 4.1, the 84 MW New Bong Escape (NBE) hydropower project is a run-of-river facility, comprising of four units of 21 MW each, with a total installed capacity of 84 MW. The NBE hydropower complex uses the regulated flow releases from the Mangla powerhouse, 7 km upstream, less any diversion flows allocated to the Upper Jhelum Canal (UJC), based on the irrigation demand downstream of Mangla dam. The inflow at NBE is primarily screened with very little sedimentation in the intake channel.

Age of facility

The NBE hydropower complex was commissioned on March 23, 2013, and has been operational for almost seven years (Figure 4.2).

Availability

The power purchase agreement (PPA) for NBE was signed for a period of 25 years and allows for 480 hours of scheduled outages and 133 hours of forced outages per unit annually, with a benchmark

<table>
<thead>
<tr>
<th>TABLE 4.1</th>
<th>New Bong Escape characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DESCRIPTION</strong></td>
<td><strong>DETAILS</strong></td>
</tr>
<tr>
<td>Project name</td>
<td>84 MW New Bong Escape (NBE) Hydro-Electric Power Complex</td>
</tr>
<tr>
<td>Contributing organization</td>
<td>Laraib Energy Limited (LEL), subsidiary of the Hub Power Company</td>
</tr>
<tr>
<td>Type of project</td>
<td>Existing facility/EPC</td>
</tr>
<tr>
<td>Location</td>
<td>Jhelum River, Village Lehri, Mirpur District, AJ&amp;K</td>
</tr>
<tr>
<td>Age of facility</td>
<td>Seven years old; commercial operation achieved on March 23, 2013</td>
</tr>
<tr>
<td>Type of facility</td>
<td>Existing—run-of-river</td>
</tr>
<tr>
<td>Installed capacity</td>
<td>4 units @ 21 MW, total 84 MW</td>
</tr>
<tr>
<td>Average annual generation (GWh/yr)</td>
<td>470 GWh</td>
</tr>
</tbody>
</table>

Source: Laraib Energy Limited.

FIGURE 4.2 | Aerial view of New Bong Escape

Source: © Laraib Energy Limited.
availability target of 93 percent. LEL has implemented modern O&M practices at NBE, such as opportunity-based maintenance (e.g., maintenance scheduled during low river flows), optimization programs, a target of zero forced outages, and a phased-in program for condition monitoring, to attain optimum performance and reliability. As a result of this strategy, the NBE hydropower complex has achieved availability levels at greater than 98 percent for the last three consecutive years, with the seventh-year availability currently at 99.98 percent.

During the first year of operation, a number of reliability issues were experienced which led to lower overall availability, including: stator winding flashover, generator circuit breaker flashover, oil head housing leakages, and failure of intake stoplog hatch covers. However, after these issues were addressed, availability has improved.

### 4.2 O&M strategy and contractual models

**Contractual O&M model**

Laraib Energy Limited currently owns the 84 MW NBE hydroelectric power plant developed under the build-own-operate-transfer (BOOT) mechanism. The project will be transferred to the government of Azad Jammu and Kashmir at the end of the 25-year term of the PPA.

O&M Model 3, in which the owner/concessionaire delegates virtually all aspects of O&M planning and implementation to an O&M operator, is currently being used by Laraib for NBE. However, as the O&M is being carried out by an in-house O&M group (Hub Power Services Limited), albeit under an arm’s-length agreement, it has many similarities to Model 1B.

The company had initially signed an O&M agreement with TNB REMACO Pakistan in May 2011, a subsidiary of TNB Malaysia in accordance with the lender’s requirement. The O&M agreement was terminated in March 2018 after which Hub Power Services Limited (HPSL)10 took over the role of O&M operator. The initial O&M agreement had a provision to terminate the O&M agreement after the first five years of operations.

In line with HUBCO’s philosophy to manage O&M of its power assets through a wholly owned subsidiary, HPSL took over as the O&M operator in order to enhance safety, and improve availability, reliability, and generation of the power assets. The process of taking over O&M of the facility was achieved using a systematic approach for the transition of the key activities, as described below:

- All employees of TNB REMACO (Ex-O&M operator at NBE) who were already part of the O&M team at NBE since construction were retained by HPSL; these employees had received training from the EPC Contractor (SAMBU) and had been operating and maintaining the power plant since 2013.
- Training Needs Analysis (TNA) was also performed for all employees, and appropriate training was assigned according to their competencies.

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10 HPSL has a diversified and a highly experienced team with O&M experience from other hydroelectrical power plants and two thermal plants in Pakistan. NBE (84 MW) is the third addition to HPSL’s O&M portfolio.
LEL’s technical team was also retained as part of HPSL and received training from the EPC contractor (SAMBU); the technical team remained directly involved in construction, commissioning, testing, and operation of NBE over the last seven years.

A joint steering committee was formed between HPSL and TNB REMACO Pakistan to ensure the transition was done efficiently, whereby equipment verification was carried out, employee communication sessions were held, roles were explained, and engagement events were organized for the employees.

The O&M agreement with HPSL for operation, maintenance, testing, and inspection of the complex is a cost-plus arrangement on a continuing term basis, with fees fixed for a period of 12 months. Although HPSL is a group company, it was ensured that the agreement was on an arm’s-length basis.

### TABLE 4.2  Example of HSE KPIs

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>FISCAL YEAR (20XX-20XX)</th>
<th>EOR (REASON FOR VARIANCE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe man-hours (million)</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>Total recordable injuries</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Total recordable injury rate</td>
<td>0.46</td>
<td></td>
</tr>
<tr>
<td>Lost work injury</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Fatality</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Source: Laraib Energy Limited.

### TABLE 4.3  Example of operational KPIs

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation (GWh)</td>
<td>470</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Availability (%)</td>
<td>93</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load factor (%)</td>
<td>63.9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Laraib Energy Limited.

### O&M strategy

NBE is the world’s first hydropower facility to implement the globally renowned DuPont Safety Management System and is the first hydropower project in Pakistan registered with the UNFCCC as Clean Development Mechanism (CDM) Project.

Laraib Energy Limited monitors the overall O&M plan using a number of key performance indicators (KPIs) on an annual basis. Annual budgets are then defined, and the targets are assessed periodically (Tables 4.2 and 4.3). Targets are set in the following areas:

- Health, Safety, and Environment (HSE)
  - Total Recordable Injury Rate (TRIR) benchmark—based on 1 recordable injury per year
  - DuPont safety management system implementation—phase wise
  - Ensure compliance with applicable National Environmental Quality Standards (NEQS) requirements
Operations

- availability (planned against previous outlook and the PPA target)
- generation (planned against previous outlook and the PPA target)
- load factor (planned against previous outlook and the PPA target)
- plant improvement projects and other special projects
- corporate social responsibility (CSR)—well-being of local communities (health, education, livelihood, and community physical infrastructure).

4.3 O&M human resources

A total of 69 staff are working at the plant site, comprised of a Station Manager, the Head of Operations and Maintenance, 8 section managers and 59 O&M staff. The Operations, Mechanical/Civil Maintenance, Electrical/Control and instrumentation Maintenance and Projects and Engineering report to the head of O&M. The head of O&M, and managers of health, safety and environment, human resource, finance and administration report directly to the Station Manager, as shown in Figure 4.3.

**FIGURE 4.3** Organogram of O&M staff at NBE

Source: © Laraib Energy Limited.
A brief description of the organizational structure at NBE is as follows:

1. **Health, safety, and environment (HSE)**
   The HSE section ensures implementation of safe work practices as well as compliance to all environmental regulations. The HSE department is implementing the DuPont safety management system.

2. **Operations and maintenance**
   The operations team is responsible for maintaining reliable operation of the power plant, while ensuring technical parameters and the operating limits of the hydropower equipment are met. Operations is also responsible for issuing permits to the maintenance teams and ensuring correspondence with different stakeholders. The maintenance team consists of mechanical, civil, electrical, controls, and instrumentation teams responsible for carrying out scheduled and forced outages in the most effective and time efficient manner.

3. **Projects and engineering**
   The projects and engineering team is responsible for analyzing plant performance, leading plant improvement projects, carrying out root cause analysis, reporting as per regulatory and lenders’ requirements, consolidating periodic reports, performing gap analysis with reliability-centered maintenance (RCM) best practice, ensuring documentation control, and providing technical support to the O&M business development team.

4. **Human resources**
   The human resources team oversees all O&M staff activities at the power plant including merit-based performance reviews, employee engagement and engagement activities, staff training and development, compliance to company policies pertaining to but not limited to salaries, wages, benefits, and ensuring effective succession planning.

5. **Finance**
   Finance is responsible for controlling the O&M budget of the power plant. It also ensures tax compliance, processing of invoice payments from the operating budget, and preparation of annual budgets as part of the annual plan submitted to the owner.

6. **Business support**
   Business support oversees the provision of support services which includes procurement activities and procedures as well as maintaining the warehouse. It ensures inventory management for timely utilization of spare parts and consumables during maintenance outages. Technology and IT services are also covered by this department.

7. **Administration**
   Administration at NBE is responsible for facility management inclusive of the office and the residence. This pertains to, but is not limited to administrative matters, food, allied services, gardening, project-based assignments with regards to the complex upkeep, etc. Administration also liaisons with government departments, especially the labor department.

LEL’s salaries are benchmarked against comparable positions in leading companies in Pakistan, through a study conducted every year by Mercer, a global leader for trusted HR and related financial advice, products and services. LEL is acknowledged as one of the best employers in the market because of its corporate culture, environment, policies, and procedures.
**O&M training**

An Employee Training Need Analysis (TNA) is performed annually for technical and soft skills development. On the basis of TNA, a training calendar is designed for all staff members. Moreover, specific need-based training is also conducted within the year for O&M, using a variety of venues including classroom type training, expedition training, etc. Engineers are sent on maintenance planning and RCM training, while operators/technicians and millwrights, are involved in on-site training. As well, all staff attend training sessions on a variety of skill development topics including: leadership skills, negotiation skills, communication skills, project management, etc.

Employees are kept informed of the latest technologies via external and in-house training, including digitalization improvements or advancements in condition monitoring. LEL has signed a Technical Services Agreement (TSA) with Andritz Hydro, which provides access to training related to hydropower projects, knowledge and learning sessions, and sharing of root cause analysis and improvement projects carried out at similar facilities.

To reach out to the global community, the team utilizes the Asset Management Knowledge Network of International Hydropower Association (IHA) and attends webinars to stay updated of the latest trends in the hydropower sector. In addition to in-house training opportunities, O&M staff are involved in a number of corporate activities that are designed to build and enhance their skills, including employee engagement surveys, reward initiatives linked with performance and potential of the employees, and frequent team building activities, along with communication sessions with senior management, job training, mentorship, and coaching.

A succession planning system is also well established. The succession planning system is in place for building and developing a healthy and sustainable talent pipeline through on-the-job training, mentorship and coaching, short-term assignments, cross functional activities, etc. The presence of a strong succession planning system has prevented any problems from occurring as the substitutes are always present within the team.

### 4.4 O&M financial resources

An annual plan is submitted by the O&M operator to the owner/concessionaire, and based on this an operating budget is prepared and approved by the lenders. The annual plan incorporates the anticipated O&M upgrades associated with plant improvement projects. Thereafter, the corporate plan is prepared and approved by the Board of Directors. Quarterly stewardship and board meetings are organized to analyze performance and steer the implementation of the corporate plan. At the end of the year, the annual budgets are reconciled against quarterly expenses and compared against the annual plan approved at the beginning of the year.

The O&M budget ranges between USD 2.5 to 3.0 million per annum which represents 1.1 percent to 1.3 percent of the NBE project cost.
4.5 Lessons learned from implementation of the O&M strategy

Hubco’s corporate philosophy of managing its assets through HPSL resulted in significant positive impacts on the operation and maintenance practices at the NBE Power Complex, including:

- improvements in overall plant reliability
- achieving excellence in operations through various continuous improvement initiatives being implemented at all levels
- improved employee engagement and retention
- 100 percent of previous operator’s staff employed by HPSL
- implementation of the safety management system (DuPont)
- achieving synergies with operations, human resources, finance, and IT by leveraging expertise at head offices and various sites
- improvements in compliance with lenders and other regulatory bodies due to better coordination with the O&M team
- HPSL’s O&M team gained valuable experience from two other power plants in Pakistan: Hub Power Plant (oil fired—1,292 MW) and Narowal Power Plant (oil fired—225 MW)
- HPSL has strengthened its team by attracting, hiring, and retaining highly competent and experienced professionals from within Pakistan.

4.6 Challenges and future direction

NBE is a relatively new facility with the latest technology and monitoring equipment installed. However, plant aging may be a major challenge in the future. Work is being carried out proactively and discussions are underway with global automation leaders to devise a predictive approach to address this.

An advanced condition monitoring approach, using expert systems and predictive analytics, will include diagnostics of failure in specific components. This approach will result in early detection of potential equipment failure and will ultimately avoid unplanned outages by providing better risk management strategies.

Currently, expertise for the SF6 switchyard is not readily available and if major maintenance is required, external technical assistance would be required. Similarly, major overhauls would also require outside expertise. To mitigate this issue, a technical services agreement (TSA) has been formalized with OEM Andritz Hydro to provide the technical assistance as and when required.

LEL, developer and owner of the NBE Hydroelectric Power Plant, is the first hydropower IPP in the country which has already paved way for further development in the private sector hydropower plants. Several hydroelectric power plants are under development and in construction phase in the region, and it is expected that by 2025, between 8,000 to 10,000 MW of power generated through hydroelectric power plants will be added to the national grid. Laraib Energy Limited, being a key player in the power sector of Pakistan, is actively exploring opportunities to invest in renewable energy projects including run-of-river/mid-sized hydro, wind, solar, and wind-solar hybrid projects.
5. Nalubaale-Kiira Hydropower Complex, Uganda

Uganda Electricity Generation Company Ltd. (UEGCL) has executed a 20-year operational, management, and maintenance concession to Eskom Uganda Limited (EUL), for the Kiira and Nalubaale Power Stations (Table 5.1 and Figure 5.1). Eskom sells the electricity it generates to the Uganda Electricity Transmission Company Limited.

<table>
<thead>
<tr>
<th>NAME OF SITE</th>
<th>TYPE OF FACILITY</th>
<th>LOCATION</th>
<th>AGE OF FACILITY (YRS)</th>
<th>INSTALLED CAPACITY (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nalubaale</td>
<td>Existing run-of-river</td>
<td>White Nile River system near to its source at Lake Victoria</td>
<td>65</td>
<td>10 units @18 MW, total 180 MW</td>
</tr>
<tr>
<td>Kiira</td>
<td>Existing run-of-river</td>
<td>White Nile River system near to its source at Lake Victoria</td>
<td>19</td>
<td>5 units @ 40 MW, total 200 MW</td>
</tr>
</tbody>
</table>

Average annual generation (GWh/yr) 1,424 GWh/yr

Source: Eskom (U) Ltd.

5.1 Status of existing fleet

Age and condition of facility

The generating units at Nalubaale hydropower site were installed between 1954 and 1968 and were refurbished between 1990 and 1996. Currently, a substantial number of components are obsolete and are difficult to replace due to unavailability of spares. In the most recent modernization of the Nalubaale plant, oil circuit breakers were replaced with SF6 breakers, new modular protection relays were installed on all units, and feeders and all DC power supply systems were refurbished.

The generating units at the Kiira facility were installed between 2000 and 2006. Most of the equipment installed was considered up to date at that time. However, due to rapidly changing technologies, most
of the current electronic equipment will become obsolete within about 10 years and will need to be replaced due to the lack of spares for these components. A number of components have already been replaced including unit protection, unit excitation, unit governors, and part of the SCADA system.

**Joint operation of Nalubaale-Kiira hydropower complex**

The operation of the Nalubaale-Kiira hydropower complex is dependent on the quantity of regulated outflow released from Lake Victoria. Because Lake Victoria is a natural reservoir shared between Uganda, Kenya, and Tanzania, the Directorate of Water Resources Management is responsible for determining the flow releases for power generation. Existing water release treaties with downstream countries including Egypt have to be complied with when allocating water releases. Once the water permit is issued, the allowable flow release is used to determine the amount of generation to be dispatched in order to satisfy day-ahead load requirements.

In Uganda, all power from generating plants larger than 5 MW must be sold to Uganda Electricity Transmission Company Limited, the transmission entity. Typically, the Nalubaale plant is operated more frequently than Kiira power station, because it is comprised of 10 Kaplan units which have additional capability to match the daily load profile, as opposed to the Kiira facility, with only 5 fixed-blade units. The joint operation is largely a manual process which favors the use of the Nalubaale Power Station unless it is unavailable due to outages.

**Availability**

Contractually, availability for the Nalubaale and Kiira complex has been maintained between 94 percent to 97 percent. The combined average annual energy production of the Nalubaale-Kiira complex is 1,424 GWh per year. The capacity factor for Nalubaale HPP is 48 percent to 55 percent, and for the Kiira HPP it is 35 percent to 40 percent.
5.2 O&M strategy and contractual models

Contractual O&M model

The Ugandan government, working with the Uganda Electricity Generation Company (UEGCL), awarded a 20-year operational, management and maintenance concession to Eskom Uganda Limited (EUL), a subsidiary of Eskom, the South African energy company, to cover both the Nalubaale Power Station and the adjacent Kiira Power Station. The concession agreement commenced in 2003, with the electricity generated being sold to the Uganda Electricity Transmission Company Limited (UETCL); the agreement expires on April 1, 2023.

In this Model 3 concession arrangement, all O&M responsibilities are assumed by EUL, the private operator, for a fixed duration. UEGCL supervises the asset health and assumes all risks that are deemed to be catastrophic in nature. The owner reports to Electricity Regulatory Authority (ERA) to enforce performance standards, especially during the periodic renewal of generation license performance targets.

EUL, the O&M operator, assumes all operational risks and mobilizes all the required capital funding to keep the assets in good condition under an investment incentive structure, based on a 12 percent return on investment on all verified investments during the contract period. “Utility Prudent Practices” are generally the yardstick upon which the assets are to maintain. To date, no specific details of these practices have been defined in the existing contract between EUL and UEGCL due to the broad definition of prudent practices.

Overall O&M strategies

The general approach adopted by EUL for maintaining the Nalubaale-Kiira hydropower complex is as follows:

- General maintenance and overhauls take place during a 30-day outage over a 36-month cycle for each unit. This involves all major repairs/replacements and modifications which would have been scoped and planned during previous outages. The type of work in this category includes complete subsystem overhauls as well as heavy mechanical work such as replacing Kaplan blade seals.
- Detailed inspections are completed during a 15-day outage over an 18-month cycle on each unit subsystem, to establish the unit condition, which in turn determines the priorities for the 36-month maintenance schedule. During the shorter outages, detailed technical assessments are completed for activities such as rotor pole re-insulation.

Key performance indicators include availability, reliability, lost time injury rate, oil spills, waste disposal, water quality, security, and annual profits. These key performance indicators are reviewed, and on a monthly and yearly basis a report is sent to the regulatory authority to track the performance of the business against key strategic initiatives, such as compliance to licenses, innovation, sustainability,

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11 Any capital replacement made by Eskom (U) Ltd is recovered through asset depreciation plus a 12 percent return on investment.
etc. The intent of the periodic review is to move continuously toward a maintenance environment that ensures that assets are maintained in an optimal manner.

5.3 O&M human resources

Maintenance staff are in charge of general maintenance and modification implementation, while specialized work such as machining of turbine runner hubs and replacement of entire subcomponents is outsourced to international companies due to lack of experienced contractors within the local market. Around 120 local staff on average are permanently employed by EUL. The ratio of technical staff to support staff is currently about 80 percent, technical and 20 percent support, which is considered to be a reasonable staff distribution within power stations.

The technical staff are organized in directorate format with a technical director who has maintenance, operations, and project managers as direct reports. The managers respectively have engineers, technicians, and artisans in their teams with staff dedicated to performing operating or maintenance activities.

The maintenance staff are divided into three sections, electrical, mechanical, and civil, which are led by section heads reporting to the maintenance manager. Engineering staff work within the maintenance sections and are responsible for the planning, troubleshooting, modification designs, etc. Routine maintenance is mainly undertaken by the technicians and artisans.

Training and recruitment strategies

The main recruitment strategy within UEGCL is to work closely with the local university and other regional training facilities; e.g., the Kafue Gorge Regional Training Centre is one of the most respected training centers in Africa, with the necessary facilities to train shift charge operators.

Succession planning is utilized for knowledge transfer, and training needs assessments are carried out to formulate training plans for O&M staff. To ensure a transfer of skills from more senior staff to new entrants, the Electricity Regulatory Authority (ERA) has introduced a training program to recruit and offer training for three years to 10 trainees from Nalubaale HPP and 10 trainees from Kiira HPP. While the ERA training initiative has only run for two years, some postgraduate trainees have successfully completed the program and have gained permanent employment with EUL.

Staff are given exposure to the parent company (Eskom South Africa) with assignments under the supervision of senior personnel. These are referred to as ‘stretch’ assignments and cover most of the key supervisory responsibilities, including the annual budgeting process involving the trainee in key strategic meetings. Delegation of leadership and supervisory responsibilities is also encouraged.

5.4 O&M financial resources

The operator, Eskom Uganda Ltd. (EUL) (who is also the concessionaire in this agreement) submits an O&M plan and budget to ERA every four years, which is reviewed and approved. This plan is confirmed
annually and agreed upon between the operator and the regulator. The overall annual O&M budget estimate is on average USD 7 million dollars per year. This is approximately 1 percent of the capital cost of the two projects, assuming USD 2,000 per kW construction cost.

5.5 Lessons learned from implementation of the O&M strategy
Under the current 20-year O&M contract with Eskom Uganda Limited, UEGCL has experienced both challenges and successes. Some of the positive aspects of the current O&M strategy include:

■ Transfer of knowledge—Eskom Uganda Limited has facilitated knowledge and skills transfer to a number of trainees from academic institutions as part of the usual industrial practice of internships programs.
■ Modernization—The operator has modernized some of the critical plant systems, albeit at a slower pace than what was anticipated at contract signing. These improvements reduced the number of forced outages at the Nalubaale Power Plant.

5.6 Challenges and future direction
Some of the major challenges in the current O&M arrangement include:

■ Due to the generic definition of prudent practices, the success of the O&M contractual arrangement with EUL cannot be fully appraised in the absence of appropriate qualitative or quantitative assessment. Discussions are ongoing to amend the contract to improve the contractual performance measures with a focus on asset management.
■ Due to rapidly advancing technologies and long procurement lead times, there is an ongoing requirement to stock spare components to avoid lost generation due to forced outages.
■ Alkali Silicate Reaction (concrete expansion) at the Nalubaale HPP has been (and continues to be) a technical issue since 1964 when the first crack appeared, resulting in a significant reduction in the expected life of the civil structure. Therefore, a program has been undertaken to carry out a comprehensive rehabilitation of the power station, beginning with the feasibility study already underway.
■ Skills retention continues to be a challenge due to ongoing industrialization where skilled staff are in high demand by competitors. Therefore, there is a need to continuously provide on-board training and competitive salaries to retain skilled workers.

In general, the emergence of private sector–led investment in other forms of renewable energy, mainly from solar PV and other small hydropower projects on seasonal rivers, has resulted in an increase in peaking requirements and start/stop cycles for the large hydropower projects on the Nile River. This additional demand for peaking will ultimately lead to a reduction in the design life of the hydro units, particularly for Kiira HPP which was designed for baseload conditions. The impact on Nalubaale units is not seen to be as significant because the units are Kaplans and can easily follow demand; i.e., each unit has an operating range from as low as 6 MW up to 18 MW, providing a healthy margin of spinning reserve.

Looking ahead to the above challenges, a modernization plan for the Nalubaale–Kiira hydropower complex is in preparation, focusing mainly on the optimization of the two power plants to improve their plant factor, and to find a permanent solution to concrete expansion problems at Nalubaale Power Plant.
6. Salto Grande Hydropower Complex, Uruguay/Argentina

The Comisión Técnica Mixta de Salto Grande (CTMSG) is a binational facility, jointly owned by Uruguay and Argentina. Under this arrangement, the complex operates in an integrated fashion, with two separate load dispatch centers. The O&M program is carried out by the staff of the CTMSG.

Table 6.1 outlines the general characteristics of the Salto Grande complex; the average annual energy generated is divided equally across the two countries.

**TABLE 6.1** Salto Grande Hydropower Complex plant characteristics

<table>
<thead>
<tr>
<th>NAME OF SITE</th>
<th>TYPE OF FACILITY</th>
<th>LOCATION</th>
<th>AGE OF FACILITY (YRS)</th>
<th>INSTALLED CAPACITY (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salto Grande</td>
<td>Existing storage hydropower</td>
<td>Uruguay River, located near Concordia, Argentina, and Salto, Uruguay; shared between the two countries</td>
<td>40</td>
<td>14 units @ 135 MW, total 1,890 MW</td>
</tr>
</tbody>
</table>

Average annual generation (GWh/yr) | 8,542 GWh/yr

Source: Salto Grande Hydroelectric Complex.

6.1 Status of existing fleet

*Age and description of facilities*

The CTMSG was created by the República Argentina and the República Oriental del Uruguay to operate the Salto Grande Hydropower Complex on the Uruguay River in the area of Salto Grande (Figure 6.1).
Since the creation of the commission in 1946, it has been responsible for all studies and projects. From 1974 to 1979, CTMSG was responsible for the construction and commissioning of the Salto Grande Hydroelectric Complex, the first hydropower binational project in Latin America.

The Salto Grande Complex (SGC) is located a few kilometers upstream from the cities of Concordia (Argentina) and Salto (Uruguay), 470 km from Buenos Aires, the capital city of Argentina, and 520 km from Montevideo, the capital city of Uruguay. The SGC is comprised of 14 Kaplan turbines rated at 135 MW per unit for a total installed capacity of 1,890 MW. It also includes a 500-kV interconnection ring, with 350 km of transmission lines and four substations, with 1,300 MVA of transformation capacity from 500 kV to 132 kV or 150 kV. The total reservoir volume for the complex is 5.5 km³ (4,500,000 acre-ft). On occasions, when a country requires less electricity, and the other country requires more, the facility can work as an international interconnection, allowing for electricity trade between the two countries.

**Availability of hydropower equipment**

As of 2018, the Salto Grande Hydroelectric Complex supplied 191.5 GWh to the Argentine electricity grid and 126.5 GWh to the Uruguayan grid. While energy is allocated equally between both countries, Uruguay typically has surplus energy, which it sells to Argentina.

Over the past two years, the average annual availability has been 94.3 percent (2017) and 95.6 percent (2016), with an overall average availability (1983–2017) of 93.4 percent.

Periods of lower availability are attributed to planned maintenance outages of two hydroelectric units per year (13 of 14 units available for 5.5 months) and other scheduled maintenance outages (four to five days each). Other outages are required for trash-rack cleaning to mitigate hydraulic losses that affect available head and power.

Some of the unique features of the SGC are:

- The site and equipment are jointly owned by both Uruguay and Argentina.
- Energy generated, and power are divided in equal parts between the two countries.
Salto Grande operates in an integrated coordination between both load dispatch centers.

Electrical networks of both countries are interconnected by Salto Grande’s transmission lines.

Salto Grande makes a significant contribution to primary and secondary frequency control for both countries.

Operation and maintenance are carried out with a binational team.

### 6.2 O&M strategy and contractual model

The O&M program at Salto Grande is structured as per Model 1A for O&M, involving a public binational agreement between both countries, Uruguay and Argentina. The Salto Grande Complex is 100 percent publicly owned, sharing state ownership in equal parts. O&M is carried out using internal resources with some support from small contractors for special works (metallurgical work, general cleaning, etc.).

**O&M strategies**

Over its 40 years of experience, Salto Grande has historically shut down two units per year for planned maintenance during the low flow season. Additionally, a scheduled maintenance plan consisting of shorter outage periods (four to five days) is coordinated, also to coincide with low flow periods. Predictive maintenance plans and monitoring are undertaken based on a variety of metrics including: online vibrations, partial discharge control, thermography, oil analysis, temperatures and pressures trending, turbine index test, nondestructive testing for the metallic critical zones including liquid penetrant testing, magnetic particle inspection, and ultrasound inspection.

All assets are managed by an enterprise asset management system (EAM-Infor), a platform that has helped Salto Grande optimize its asset records and asset intervention analysis, and ensure environmental and human safety, while decreasing time and costs in work and license permits for workers. The EAM studies are complemented by reliability-centered maintenance (RCM) analysis of critical equipment, HydroAMP condition assessment (see Figure 6.2), and evaluations made by turbine and generator manufacturers. The planning of scheduled maintenance, improvement projects, and equipment upgrades is managed with a tool for integrated planning, with the participation of all the team members.

The HydroAMP guide, “Hydropower Asset Management Using Condition Assessments and Risk-Based Economic Analyses,” has been used to assess the condition of the hydroelectric equipment and prioritize investments.

As shown in Figure 6.2, the equipment condition index indicates values between 0 and 10, where 0–3 is “Poor,” 3–6 is “Marginal,” 6–8 is “Reasonable,” and 8–10 is “Good.”

Salto Grande has taken as a basis, recommendations made by agencies specialized in critical infrastructure of both countries, and international best practices, developing an action plan aligned with the controls established in NIST CSF (ISO/IEC 27001: 2013, COBIT 5, NIST 800-53 rev. 4). It is also interesting to note that an Emergency Action Plan (EAP) has been put in place, through which any worker must notify the Chiefs of Operation Shift if they observe an alarm or risk situation, which triggers communication and mitigation actions.

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12 The goal of hydroAMP is to create a framework to streamline and simplify methods for objectively evaluating the condition of hydroelectric equipment, for the purpose of supporting asset and risk management decision making.
Modernization of the Salto Grande complex

A multiyear modernization program has been underway at SGC since 2003, with an investment of approximately USD 86 million in the last 15 years. The following equipment modernization is already completed:

- main breakers and unit excitation systems
- plant ventilation system
- plant sewer treatment system
- generator protection
- new main transformer group and acquisition of a replacement unit
- sluice gates
- refurbishment of drainage system
- new management systems (hydrology, maintenance, management)
- renovation of hydrometeorological stations.

Some of the major components in the long-term plan (with a budget of USD 80 million for the next five years) to be refurbished include:

- digitalization of plant control and supervising system, integrating all the control and monitoring equipment
- replacement and modernization of governors

**FIGURE 6.2** Example of HydroAMP condition assessment
- replacement of excitation transformers
- renovation of bridge crane and gantry crane
- main transformers
- replacement of pumps for the drain system
- refurbishment and modernization of diesel emergency generator.

6.3 O&M human resources

**O&M staffing**

Currently, the total staffing levels for both O&M stands at 150, comprised of:

- 84 maintenance personnel made up of 9 mechanical engineers, 6 electrical and electronic engineers, 8 technological engineers, and 61 technicians.
- 66 operating personnel made up of 13 operation engineers, 2 technological engineers, 3 full-time technicians, and 48 technicians on 24/7 shifts.

In addition, there are also personnel in Transmission (84), Information Technology and Communications (25), Hydrology, Dams, Reservoir, Environment and Asset Management (42), Accounting, Acquisitions and Facility Management, and Staff General Departments.

**O&M staff recruitment**

Recruitment is undertaken using open (internal or external) job offers based on qualifications in specific areas of expertise. In order to improve the qualifications and skills of future employees, agreements have been established with technical schools and local universities where courses, technical visits, internships, and projects are promoted. Seminars are given in educational institutions in order to inform students of the qualifications required for employment at Salto Grande.

Maintenance training on a variety of topics is offered, including certification of crane operators, certification of welders, certification in non-destructive testing, visual inspection, vibration analysis, turbine technology courses, environmental management, and industrial safety.

Operational training is offered to new personnel, who are paired with experienced operators for a minimum period of five months. Shift teams include a trainee position. Responsibilities are allocated according to competency, based on qualification. Additional tests must be passed before operators are promoted to positions with greater responsibility.

The strategic relevance of SGC as an industrial leader to both countries, supplying the energy needs of Uruguay and Argentina equally, generates a sense of loyalty within the company, a value which is always considered and enhanced in the organizational culture. Reasonable wages and benefits are offered as an incentive for employee retention. As well, support for national and international training, congress participation, seminars, and technical visits to other facilities are encouraged within SGC.
Knowledge transfer within SGC, although not implemented systematically, is achieved through annual internal workshops led by experienced personnel on specialized systems, e.g., governors, pressurized oil systems, sluice gates, seals, bearings, non-destructive tests, welding, etc.

The use of RCM has played a role in knowledge transfer. The analysis of critical equipment is carried out by technicians with various areas of expertise. Tasks are undertaken by teams, including junior and senior technicians to promote knowledge transfer. In operations, experienced personnel who no longer work in the shift teams are typically assigned to training tasks.

### 6.4 O&M financial resources

Table 6.2 summarizes the annual maintenance and operations costs based on an average for a period of the last 3 years (2016, 2017, and 2018).

**TABLE 6.2 | Annual O&M expenditures**

<table>
<thead>
<tr>
<th></th>
<th>MAINTENANCE (annual expenditures in USD)</th>
<th>OPERATION (annual expenditures in USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Assets 2,740,000</td>
<td>Assets 1,270,000</td>
</tr>
<tr>
<td></td>
<td>Functioning 1,580,000</td>
<td>Functioning 280,000</td>
</tr>
<tr>
<td></td>
<td>Personnel 6,034,000</td>
<td>Personnel 4,964,000</td>
</tr>
<tr>
<td></td>
<td>Total 10,354,000</td>
<td>Total 6,514,000</td>
</tr>
</tbody>
</table>

Source: Salto Grande Hydroelectric Complex.

The cost of personnel includes variable costs such as travel allowances and overtime, as well as salaries.

In the last three years, expenditure was around 85 percent of the planned annual budget, partly because it is budgeted in US dollars, and a large part of the costs are paid in local currencies which depreciated. There was also some inefficiency in the procurement process.

The estimated total investment value of the SGC (based on replacement cost) is approximately USD 4 billion. Hence the USD O&M budget of USD 16.9 million represents around 0.42 percent of the capital cost of the project.

**Governance of O&M budgets**

The organization consists of a directorate. Each country government is represented by three delegates that form the Joint Technical Commission (CTMSG in Spanish).

The organization is completed with two general managers (one for each country), and one manager for each of six specific work functions: operations, transmission, and resources (Argentines), and generation, engineering and planning, and accounting (Uruguayans). The O&M budget is shared equally by each owner state; 50 percent Uruguay and 50 percent Argentina.

Figures 6.3a and 6.3b illustrate the organizational structure for operation and generation.
FIGURE 6.3A  Operation organization chart

I Management

II Management

III Area

IV Sector

V Unit

Professional training group

VI Section

VII Specialized

VIII Principal

IX Basic

Source: © Salto Grande Hydroelectric Complex, Salto Grande Personal Resources Area.
Each manager proposes an annual budget of variable O&M costs and capital investments, which is approved by the general management and then raised to CTMSG, who in turn approves the overall budget. The common costs are financed in equal parts by each of the two countries. Maintenance costs for all of the civil works and generating assets, as well as any O&M studies and projects are paid equally by each country. Each country is responsible for the salaries of its staff and any expenses and investments that are not deemed to be common costs.

Funding for common expenses, personnel expenses, and minor investments are provided by the respective governments through transfer of funds to cover the budget, based on the cashflow requirements during the year.

A comprehensive renovation plan was prepared in 2015–2016 by Stantec-Iatasa and financed by Inter-American Development Bank (IDB), in which a detailed diagnosis was carried out, including analysis of opportunities to increase energy production and power. Since investments will take place over a period of 25 years, a loan from IDB was obtained and shared equally between both countries. This initial loan will provide investment for modernization for the first five years.

Financing of the longer term modernization program, required for the 20 years from 2024 to 2043 is a challenge that will be addressed in the next five years with governments, international financial entities, and suppliers.

### 6.5 Lessons learned from implementation of the O&M strategy

**Positive aspects of the current O&M strategy**

The greatest success of the binational organization undertaking O&M of the Salto Grande Project is its ability to achieve technical excellence and the professional attitude of its staff. Additionally, the strategic and economic importance of SGC in the electrical systems of both countries makes it possible to obtain financing from both governments to meet the annual budgets.

Other positive aspects include:

- Primary maintenance practices have improved, supported by procedures and experience from 40 years of operation, providing exceptional knowledge of the equipment and its performance. Monitoring of the aging equipment enables early fault detection.
- Troubleshooting with internal specialized personnel has successfully resolved technical issues.
- Planned maintenance outages have been successfully coordinated to coincide with the annual low flow period of the river (November to March), reducing losses in revenue.

Some of the drawbacks of the current O&M strategy, and which strategies have been explored to deal with these challenges include:

- Long-term planned outages have in some cases not been possible, due to network conditions or other considerations. In these cases, efforts were made to extend working hours through extra shifts or overtime in order to reduce the overall outage duration.
Extended periods of roughly seven years between each planned maintenance outage could result in faults occurring undetected. To prevent this, an extensive set of new predictive monitoring techniques were implemented such as non-destructive tests, on-line vibration monitoring, and partial discharge control.

The current strategy is based on the quality, robustness, and high availability of the generators and turbines, which allows for scheduled outages on a seven-year cycle. The challenge will be to obtain the same quality, robustness, and availability in the new equipment, avoiding the acquisition of lower quality machines that cavitate, vibrate, fissure, overheat, or pollute.

6.6 Challenges and future direction

Some of the main operating challenges SGC deals with periodically include:

- Hydrological variability of the Uruguay River makes it challenging to operate the facility to meet peak demands and avoid spillage.
- Natural flood management to mitigate adverse impacts on downstream communities.
- Sedimentation of the reservoir; this is measured every five years and it has been estimated that 25 hm³ in reservoir volume are lost every year, out of a total capacity of 5,500 hm³.
- Climate change forecasts show a trend toward greater flows out to 2050. Impact of climate change on potential rise of algal blooms will also have to be analyzed and managed adequately.

Some of the technical maintenance issues SGC deals with periodically include:

- Cleaning inlet areas in front of intakes.
- The accumulation of logs and sediments in the intake of the hydro generator unit, mitigated by the installation of a floating boom.
- Spillway gates: structural reinforcement, shield elevation, seal change and conditioning and painting, command and control renewal.
- Conditioning and painting of metal surfaces (gates, stop-log boards, intake trash racks, refrigeration systems piping).

Planning and coordination of the O&M activities during the plant renovation will be challenging, including use of shared resources such as cranes and technical staff. Good coordination between the personnel involved in the renovation with the maintenance personnel is needed to ensure knowledge is shared.

Digitalization of assets poses several challenges, such as maintaining cybersecurity at the same level as existing assets while introducing innovation and new technology (intelligent maintenance, more efficient operation, increased reliability, optimized costs) to maximize the benefits from the facility.

Some of the challenges for the hydropower sector in the region will be the variability introduced by a greater penetration of intermittent renewable technologies such as wind and solar energy. Hydropower is crucial to control the network frequency, providing energy storage and balancing services. With greater variability, Salto Grande will face changes regarding how the plant will be operated, compared with how it has been operated in the past.