Benchmarking tool for small hydropower operations and maintenance

- Christie Burger & Henk Hattingh
- Project Engineer & General Manager
- REH Operations & Maintenance
- South Africa
Application rather than Perfection

“All models are wrong but some are useful”
– George E.P. Box
Hydropower Plant Operations & Maintenance

How to use O&M as the leveraging factor to increase generation revenue by making reference to a WMO benchmarking technique and world class practices.
Background on REH

- REH is the only hydro-group in South-Africa to develop, own, and operate its hydro-plants.
- REH has been active since 2003 and raised R500 million in project financing to date.
Current Assets

Sol Plaatje – 2.3 MW

Merino – 3.7 MW

Stortemelk – 4.5 MW
# REH Asset Summary

<table>
<thead>
<tr>
<th>Power Plant</th>
<th>COD</th>
<th>Installed Capacity</th>
<th>Generation</th>
<th>M&amp;E Contractor</th>
<th>O&amp;M Contractor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sol Plaatje</td>
<td>Nov-09</td>
<td>2.3 MW</td>
<td>16 GWh</td>
<td>BFL (India)</td>
<td>REH O&amp;M</td>
</tr>
<tr>
<td>Merino</td>
<td>Aug-10</td>
<td>3.7 MW</td>
<td>25 GWh</td>
<td>BFL (India)</td>
<td>REH O&amp;M</td>
</tr>
<tr>
<td>Stortemelk</td>
<td>Jul-16</td>
<td>4.5 MW</td>
<td>28 GWh</td>
<td>Andritz (Austria)</td>
<td>REH O&amp;M</td>
</tr>
</tbody>
</table>
Integrated Hydro Model

Project Development

Greenfield-Potential

Operations & Maintenance

Technical Design

World Class O&M (WMO Benchmarking)

Hydro Power Assets

PROFIT
Weighted Maintenance Objects (WMOs)

The WMOs concept is based on the principle that the complexity of the technical assets of a Hydropower Plant is the primary O&M cost driver.

The WMO analysis allows comparison between different sized and technology Hydropower Plants on an equal basis.
WMO Complexity Assessment

TECHNICAL CONTRIBUTORS
- Generator Capacity
- Turbine Speed
- Run-of-River vs. Reservoir Design
- Number of Switchgear
- Number of Gates
- Distance of Transmission Line etc.

OTHER CONTRIBUTORS
- Altitude
- Climate
- Catchment
- Accessibility etc.

Hydro Power Plant (HPP)

WMO model algorithm weighs the inputs

NUMERICAL WMO VALUE FOR THE HPP
WMO Benchmarking Technique

The WMO Benchmarking Technique bridges the inherent complications when comparing unique Hydropower Plants.

\[
\text{Costs associated with O&M} \div \text{Hydro Power Plant WMO Score} = \text{Benchmark Score (kUSD/WMO)}
\]

- Field Operations
- Technical Operations
- Finance & Administration
- Refurbishments

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Benchmarking Graph

TOTAL O&M COST PER WMO

KUSD/WMO

Hydro Power Plant

11.6 12.9 13.5 13.9 15.2 16.1 18.2 19.9 21.9 36.6 62.9

Average: 23.2

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Bethlehem Hydro – Benchmarked

• An external audit and technical capacity building program was initiated by Norfund and REH in 2015.
• The audit indicated a benchmarking score for REH O&M of **13.2 kUSD/WMO** for the operation of Bethlehem Hydro (April 2015).

The O&M performance, based on a benchmarking score of **13.2 kUSD/WMO** and annual availability of **98%**, was regarded as “**Almost a World Class Organization**” according to the Norwegian Consultant.
Benchmarking Results

TOTAL O&M COST PER WMO

REH O&M
(Bethlehem Hydro)

KUSD/WMO

Hydro Power Plant

Average 23.2

62.9

36.6

21.9

19.9

18.2

16.1

15.2

13.9

13.5

12.9

11.6
Benchmarking Results

Now that we can quantify our O&M performance, how do we improve?
What is world class O&M?

World Class O&M can be defined as the following:

• Zero Lost Time Injuries
• More than 98% technical availability
• A never-ending chase for revenue/cost margins
• No breaches to internal and external regulations
• Plans, analysis and documentation for core activities
• A WMO cost level at, or below Nordic average
• ...year after year after year after year after year.
The Path to Best Practice/World Class O&M

1 to 3: Mainly preventive maintenance
Routine to repair or replace on a fixed frequency
Reacting to current conditions and fix
Firefighting—Fix when it breaks-repeat

2. Reactive

3. Preventive

4. Preventive

5. Preventive + Q + KPI

6. (5) + Predictive/CBM

7. (6) + CMMS

8. (7) + RCM “light” + IMS

9. Leveraging Best Practices
Leader Bottom line

10. WC /BP Recognized

6 to 8: Almost WC organization
Use of predicative techniques (e.g. oil analysis, RCM “light”, PdM)

9 to 10: “WC/BP organization”
World Class O&M

ASSET MANAGEMENT PLAN

BUSINESS PLAN

Asset Management Plan
Introduction
Process
Planning Framework
Life Cycle Management
Plan
Performance Planning

KPI
GWH
%AVAILABILITY
%RELIABILITY
$/WMO
RISK & ASSET CONDITION
LEVEL
HSE KPI
LEGAL COMPLIANCE

RAV
RISK AND VULNERABILITY ASSESSMENT

CMMS
COMPUTERIZED MAINTENANCE MANAGEMENT SYSTEM

RCM
RELIABILITY CENTERED MAINTENANCE
OPEX OPTIMIZATION

RCA
ROOT CAUSE ANALYSIS

LCCA
LIFE CYCLE COST ANALYSIS (TOOLBOX)
CAPEX OPTIMIZATION

Refurbishments/Upgrading

GENERATION & TRANSMISSION ASSETS
Example

CONDITION ANALYSIS
VISUAL INSPECTION
OPERATING CONTROLS
OFF LINE TEST
ON LINE MEASUREMENT
CORRELATION ANALYSIS

RISK ASSESSMENT

ABILITY TO
MONITOR
POWER
GENERATION

REFURBISHMENTS/
UPGRADING - NEEDS??

Y

N

COMPLY WITH
OPERATIONAL STANDARDS

OPERATE & MONITOR
POWER GENERATION

PLAN UNAVAILABILITY

REFURBISHMENTS/UPGRADING - NEEDS??

Y

N

IMPACT

< 70% Very High
70% - 79% High
80% - 89% Medium
90% - 99% Low
> 99% Very Low

IMPLICATION

Minor
Major
Critical

RISK ASSESSMENT

KPI
GWH
%AVAILABILITY
%RELIABILITY
$/WMO
RISK & ASSET CONDITION
LEVEL
HSE KPI
LEGAL COMPLIANCE

Asset Management Plan
Introduction
Process
Planning Framework
Life Cycle Management
Plan
Performance Planning
**Business Plan ➔ Asset Management Plan (AMP)**

The AMP shall include overall processes required for managing the assets.

- Business Management Documentation System (BMDS) - (Integrated Management System)
- Business Plan
- KPI/Goals
- Operation and Maintenance Strategy
- HSE in an Operational phase.
- Risk And Vulnerability Assessment (RAV)
- Root Cause Analysis (RCA)
- Reliability Centered Maintenance (RCM)
Choosing the correct maintenance strategy has a direct impact on cost effective operations and directly influences the asset’s useful life.

- REH adopted the “Reliability Centred Maintenance Strategy”
- Consequence Matrix, to determine the probability and severity of failure.
- Maintenance may take a condition based, preventative, or to failure approach.
# Reliability Centred Maintenance

## REH Operations & Maintenance: Consequence Matrix (Sol Plaatje)

<table>
<thead>
<tr>
<th>Likelyhood</th>
<th>Very High</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
<th>Very Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>More than once a year</td>
<td>More than 70%</td>
<td>Between 30% to 70%</td>
<td>Between 5% to 30%</td>
<td>Below than 1%</td>
</tr>
<tr>
<td></td>
<td>Once/1 to 3 years</td>
<td>Once/3 to 20 years</td>
<td>Between 1% to 5%</td>
<td>Once/20 to 100 years</td>
<td></td>
</tr>
<tr>
<td></td>
<td>More than once a year</td>
<td>More than 70%</td>
<td>Between 30% to 70%</td>
<td>Between 5% to 30%</td>
<td>Below than 1%</td>
</tr>
<tr>
<td></td>
<td>Once/1 to 3 years</td>
<td>Once/3 to 20 years</td>
<td>Between 1% to 5%</td>
<td>Once/20 to 100 years</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IMPACT</th>
<th>Small</th>
<th>Moderate</th>
<th>Major</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Safety</strong></td>
<td>Injury/illness with minor absence or short temporary disability</td>
<td>Injury/illness with extended temporary disability</td>
<td>Injury leads to permanent disability</td>
<td>Event leads to fatality</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td>Minor on-site damage</td>
<td>Minor off-site damage. Restitution time &lt; month</td>
<td>Moderate off-site damage. Restitution time &lt; year</td>
<td>Major off-site damage. Restitution time &gt; year</td>
</tr>
<tr>
<td><strong>Reputation, CSR, ethics</strong></td>
<td>Moderate local impact. May cause project delay or require disciplinary action.</td>
<td>Major local impact, moderate regional impact. May cause project cancellation or production stop. May lead to criminal charges against local senior management.</td>
<td>Major national impact. Threaten position of company in country. May lead to criminal charges against senior management or widespread fraud by local management.</td>
<td>Criminal proceedings against REH top managers. May effect possibility to continue as company.</td>
</tr>
<tr>
<td><strong>Direct Cost</strong></td>
<td>&lt; 10 kUSD</td>
<td>10 - 15 kUSD</td>
<td>15 - 25 kUSD</td>
<td>&gt; 25 kUSD</td>
</tr>
<tr>
<td><strong>Availability</strong></td>
<td>&lt; 200 MWh</td>
<td>200 - 350 MWh</td>
<td>350 - 600 MWh</td>
<td>&gt; 600 MWh</td>
</tr>
</tbody>
</table>

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## Maintenance Strategy

<table>
<thead>
<tr>
<th>Component</th>
<th>Maintenance Type</th>
<th>Action</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator</td>
<td>CBM</td>
<td>Vibration tests Infrared scanning Oil Analysis</td>
<td>Adapt measurement frequency according to condition.</td>
</tr>
<tr>
<td>Transformer</td>
<td>CBM</td>
<td>Gas schematic</td>
<td>Adapt measurement frequency according to condition.</td>
</tr>
<tr>
<td>Turbine Hub</td>
<td>Preventative</td>
<td>Seal replacement Oil exchange</td>
<td>Scheduled replacement</td>
</tr>
<tr>
<td>LOS Filters</td>
<td>Preventative</td>
<td>Filter Replacement</td>
<td>Scheduled replacement</td>
</tr>
<tr>
<td>Cooling water pump</td>
<td>Run to Fail</td>
<td>Visual nspection</td>
<td>Spare pump in stock</td>
</tr>
<tr>
<td>Cabling</td>
<td>Run to Fail</td>
<td>Inspection</td>
<td>Readily available</td>
</tr>
</tbody>
</table>
Condition Based Maintenance

Gas Schematic Analysis

Tests:
- PCB’s
- Furan
- Water
- kV
- Acidity
- DGA
# FURAN Analysis (Transformer)

<table>
<thead>
<tr>
<th>Substation</th>
<th>Transformer</th>
<th>Serial No</th>
<th>Sample Date</th>
<th>Furan (mg/kg)</th>
<th>Predicted DP</th>
<th>% Life Used</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>MERVINO</td>
<td>TX1</td>
<td>T1403</td>
<td>16/02/2016</td>
<td>0.12</td>
<td>741</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>SOL PLAATJE HYDRO</td>
<td>AUX</td>
<td>R1406</td>
<td>15/02/2016</td>
<td>0.09</td>
<td>770</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>SOL PLAATJE HYDRO</td>
<td>TX1</td>
<td>R1405</td>
<td>15/02/2016</td>
<td>0.04</td>
<td>878</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

**Note**

- **DP Range**
  - <200
  - 200-250
  - 250-350
  - 350-450
  - 450-600
  - 600-900
  - >900

**Remark**

1. Test indicates extensive paper degradation exceeding the critical point. Strongly recommend that the transformer be taken out of service.
2. The paper is near or at the critical condition. Recommend that the transformer be taken out of service as soon as possible and thoroughly inspected. Paper samples can be taken for direct DP testing.
3. The paper is approaching the critical condition. Suggest inspection be scheduled and/or re-sample within 1 year to reassess condition.
4. The paper is starting to approach the critical condition. Suggest a re-sample in 1-2 years time.
5. Significant paper deterioration but still well away from the critical point.
6. Mild to minimal paper ageing.
7. No detectable paper degradation.

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## Analysis (Transformer)

<table>
<thead>
<tr>
<th>Transformer Insulating Oil Condition</th>
<th>IEC 60422 Category C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Content:</td>
<td>mg/Kg 3</td>
</tr>
<tr>
<td>Breakdown Voltage:</td>
<td>kV 82</td>
</tr>
<tr>
<td>Acidity:</td>
<td>mg KOH/g oil 0.01</td>
</tr>
<tr>
<td>Interfacial Tension:</td>
<td>mN/m</td>
</tr>
<tr>
<td>Oil Quality Index:</td>
<td>OQIN (IFT/NN)</td>
</tr>
<tr>
<td>Dissipation Factor @ 90C:</td>
<td>DDF</td>
</tr>
<tr>
<td>Resistivity @ 90C:</td>
<td></td>
</tr>
<tr>
<td>Oil Colour:</td>
<td></td>
</tr>
<tr>
<td>Total Polychlorinated Biphenyl:</td>
<td>mg/1 PCB 0.1</td>
</tr>
<tr>
<td>Transformer Oil Temp:</td>
<td>Deg C 40</td>
</tr>
<tr>
<td>Water@20C</td>
<td>mg/Kg 1</td>
</tr>
<tr>
<td>Corrosive Sulfur:</td>
<td>Unknown</td>
</tr>
<tr>
<td></td>
<td>&lt; 30 (Good)</td>
</tr>
<tr>
<td></td>
<td>&gt; 40 (Good)</td>
</tr>
<tr>
<td></td>
<td>&lt; 0.15 (Good)</td>
</tr>
<tr>
<td></td>
<td>&gt; 25 (Good)</td>
</tr>
<tr>
<td></td>
<td>160 (min)</td>
</tr>
<tr>
<td></td>
<td>&lt; 0.10 (Good)</td>
</tr>
<tr>
<td></td>
<td>50 (max)</td>
</tr>
<tr>
<td></td>
<td>80 (max)</td>
</tr>
<tr>
<td></td>
<td>IEC 60422</td>
</tr>
</tbody>
</table>
Preventative maintenance

Scheduled maintenance & inspections

- Visual inspection
- Measuring of clearances
- Oil replacement
- Seal replacement
- Condition monitoring
**Light Analysis**

- Identify equipment as per maintenance strategy
- Method of monitoring (oil analysis, thermal imaging, vibration monitoring etc.)
- Parameters as per manufacturer's specification
- Convert the data into a life curve model
- Data to be summarized into a high level Light analysis Report

<table>
<thead>
<tr>
<th>Overall Plant Condition</th>
<th>Power Plant</th>
<th>Generator</th>
<th>Gearbox</th>
<th>Turbine</th>
<th>Cooling System</th>
<th>Hydraulic unit</th>
<th>Switchgear</th>
<th>Transformer</th>
<th>Intake Structure</th>
<th>Maintenance gates</th>
<th>Intake Structure</th>
<th>Turbine</th>
<th>Gearbox</th>
<th>Generator</th>
<th>Power Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merino</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11/2015</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sol Plaatje</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>04/2016</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Stortemelk</td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</table>
The Bottom Line…

Increase seen in the Ratio of Generational Revenue to Operational Expenditure.