WS8-Method for Evaluating Reliability of Tidal Stream Devices (TSD)

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“When one recognises how much the sum of our ignorance exceeds that of our knowledge, one is less likely to draw rapid conclusions.”

Louis de Broglie
21\textsuperscript{st} century Tidal Stream Devices

• >50 TSD technologies around the world, few will be viable;
• TSDs can be horizontal or vertical turbines or oscillating hydrofoils;
• Which are the most reliable architectures?
Problems Evaluating TSD Reliability

- Data not in public domain;
- TSDs incorporate both structural and machinery components;
- Equipment definition, particularly for auxiliaries, only available in generic terms;
- In absence of in-service reliability data it has been impossible for developers to evaluate prospective technologies;
- Need a system-reliability method to evaluate different architectures;
- To determine which is potentially most reliable.
4 off 1-1.5 MW TSDs Evaluated

Figure 1: Horizontal axis TSDs [3]
Reliability Evaluation Method

• Top-down approach;
• Establish schematic diagram for each device, down to same sub-assembly level, showing interdependencies;
• Classify & name sub-assemblies using a robust method;
• Derive Reliability Block Diagram (FBD) from schematic;
• Populate RBD with reliability data from surrogate sources;
• From surrogate data establish lower & upper bound failure rates for each sub-assembly;
• Adjust surrogate surrogate lower & upper bound failure rates to tidal environment;
• Evaluate total device reliability assuming sub-assembly failures are random, ie bottom of bathtub;
• Complements bottom-up design approach in WS8.
Reliability Prediction Model

\[
\lambda(t) = \rho \beta e^{-\beta t}
\]

\[
R(t) = e^{-\lambda t}
\]

\[
\lambda_a = \frac{\text{Total number of failures}}{\text{Turbine Population}} \text{ Operating Period (years)}
\]

TSDs should be here

Early Life \((\beta < 1)\)

Useful Life \((\beta = 1)\)

Wear-out Period \((\beta > 1)\)

Time, \(t\)

Failure Intensity, \(\lambda\)
Surrogate Data Sources

- European onshore WT databases:
  - WMEP database, 14,400 turbine years data over 13 years;
  - LWK database, 5,800 turbine years over 14 years;
- Petrochemical industry database OREDA 1984-2002;
- Generic databases
  - NPRD-95
  - MIL-HDBK 217F
- Adjust data to represent tidal environment:

Table 1: Environments of Surrogate Data Sources used in the model

<table>
<thead>
<tr>
<th>Surrogate Data Source</th>
<th>Naval, Unsheltered: Severe Environment NU</th>
<th>Naval, Sheltered: Normal Environment NS</th>
<th>Ground, Fixed: Severe Environment GF</th>
</tr>
</thead>
<tbody>
<tr>
<td>LWK WMEP OREDA NPRD-95</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>MIL-HDBK217F</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

Most TSD sub-assemblies here
| But some here

Note: The table highlights the environments of each surrogate data source used in the model, with X indicating the presence of data for that environment.
Surrogate data is study backbone because no reliability data yet available for TSDs. Architectures and core technologies of wind turbines are similar to TSDs.
Schematic for TSD1
Predicted 1-1.5 MW TSDs Failure Rates

The graph shows the total number of sub-assemblies per device, $N_{tot}$, for different TSDs and failure rate estimates. The x-axis represents the TSD types and their percentages (TSD 3, TSD 1, TSD 2, TSD 4) and device types (100%, 50%). The y-axis represents the total number of sub-assemblies per device.

- TSD 3, 100%: 10 sub-assemblies
- TSD 1, 100%: 20 sub-assemblies
- TSD 2, 50%: 30 sub-assemblies
- TSD 4, 50%: 40 sub-assemblies
- TSD 2, 100%: 50 sub-assemblies
- TSD 4, 100%: 60 sub-assemblies

The total failure rate estimate for 1-1.8 MW WTs is shown in the graph with the red horizontal line, indicating the range of expected failures per year.

- One turbine:
- Two turbines:
Predicted Survivors after 1 yr Service

![Graph showing predicted survivors after 1 year service for different device types. The x-axis represents the device type (TSD 3, TSD 1, TSD 2, TSD 4) with variations in percentage (100%, 50%). The y-axis represents the reliability survivor function, R(t year) (%). The graph compares two conditions: FREconv and FREenv.]
Conclusions

- Methodology for analysing TSD reliability devised;
- Simple architectures give best reliability results;
- Preliminary failure rates are high, survivor rates low;
- Sub-assembly failure rates similar to bottom-up predictions;
- Failure rates need drastic reduction;
- Analysis shows sub-assemblies where effort needed;
- 1 year TSD operation as non-repairable system with no maintenance will give unacceptable survivor rates;
- Lower failure rates & better access will achieve better survivor rates;
- Array size and redundancy will raise TSD reliability;
- Perhaps moorable, detachable devices have potential?