Economic evaluation of IOT-based maintenance in offshore wind energy: A case study in Taiwan

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Area: 36,193 km²
Population: 23,313,517
Population Density: 644 people/km²
GDP(PPP): $ 977 billion
GDP(PPP) per capita: $41,581
Worldwide CO2 Emissions per capital by region

Source: International Energy Agency (IEA), 2015
Percentage of Wind Energy in Taiwan is still low

Source: Bureau of Energy, Ministry of Economic Affairs (July, 2014)
Why offshore wind energy?

- Abundant, free and clean with advantage of available space.
- High wind resources:
  - Onshore wind energy: 1600 MW
  - Offshore wind energy: 3200 MW
The challenge behind the “Green Effect”

- Offshore wind turbines break down from time to time.
- Location hard-to-reach

Maintenance cost is high ➔ uncertainties of the economic benefit
2. Literature review

Maintenance Strategies

Before a defected fault

Preventive maintenance (PM)
- Time-based Maintenance
- Predetermined Maintenance

Condition based Maintenance

Predictive Maintenance
- Inspection

Corrective maintenance (CM)
- Deferred
- Immediate

Condition Monitoring System

IoT

Cloud-based concept
Why IOT-Based Maintenance?

- IOT is a competitive trend in predictive maintenance technology
- Avoid unnecessary maintenance
- Ensure turbine reliability
- Minimize turbines downtime
- Avoid catastrophic failure
<table>
<thead>
<tr>
<th></th>
<th>IOT-based maintenance</th>
<th>Traditional Maintenance</th>
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</thead>
<tbody>
<tr>
<td><strong>Goal</strong></td>
<td>Improve production and/or maintenance efficiency</td>
<td>Ensure the reliability of machine operation</td>
</tr>
<tr>
<td><strong>Data</strong></td>
<td>Data stream (time varying features). Multiple data sources</td>
<td>Very limited time varying features</td>
</tr>
<tr>
<td><strong>Scope</strong></td>
<td>Component level. System level</td>
<td>Parts level</td>
</tr>
<tr>
<td><strong>Approach</strong></td>
<td>Data driven</td>
<td>Model driven</td>
</tr>
<tr>
<td><strong>Tasks</strong></td>
<td>- Failure prediction, - Fault/failure detection &amp; diagnosis - Maintenance actions</td>
<td>- Failure prediction (prognosis). - Fault/failure detection</td>
</tr>
<tr>
<td></td>
<td>recommendation, etc.</td>
<td>&amp; diagnosis (diagnosis)</td>
</tr>
</tbody>
</table>
CONTRIBUTIONS:

- This paper covers new trends in predictive maintenance with IOT
- Estimate the potential of using IOT-based maintenance
- Analysis the failure rate with probabilistic method
- Propose an approach to analyze the levelized cost of offshore wind system using IOT in maintenance
- Estimation of energy generation under the real weather in Taiwan
3. IOT-Based maintenance

- **SENSORS TECHNOLOGY**
  Embedded in the turbines and connected to information networks

- **INFORMATION NETWORKS**
  Data acquisition and using cloud based concept is to achieve multilateral communication and give maintenance decision making
3. IOT-Based maintenance
Levelized cost of energy (LCOE) is the cost of generated energy for a energy project.

\[
LCOE = \frac{TC}{P_{op} \times hour} = \frac{I + \sum_{i=1}^{n} \frac{C_i}{(1 + r)^i}}{\sum_{i=1}^{n} \frac{E_i}{(1 + r)^i}}
\]

\[
P_{op} = \frac{1}{2} C_p \eta_1 \eta_2 \eta_3 v_{ref} \left( \ln \frac{h}{z_0} \right)^3 \pi R(R + 2l) \frac{\varphi}{GT} \left( -\frac{gh}{GT} \right)
\]

\[
TC = \text{total cost (NT\$)}
\]
\[
P_{op} = \text{power output (W)}
\]
\[
I = \text{capital cost (NT\$)}
\]
\[
E_i = \text{generated energy in year } i \text{ (kWh)}
\]
\[
r = \text{discount rate (%)}
\]
The cost model without using IOT–based maintenance

\[ TC_{wo} = I_{wo} + \sum_{i=1}^{N} \sum_{j=1}^{K} F_{ij} \times \left( C^j_{CM} + C^L_{CM} + D \times C^i_{trans} + P_{op} \tau_{CM} P_i^e \right) \left(1 + \frac{\lambda_j}{100}\right) \times \frac{\gamma}{100} \]

The cost model with IOT–based maintenance

\[ TC_w = I_w + \sum_{i=1}^{N} \sum_{j=1}^{K} F_{ij} \times \left[ \left( C^j_{PM} + C^L_{PM} + D \times C^i_{trans} + P_{op} \tau_{PM} P_i^e \right) \times \left(1 + \frac{\lambda_j}{100}\right) + \left( C^j_{CM} + C^L_{CM} + D \times C^i_{trans} + P_{op} \tau_{CM} P_i^e \right) \left(1 - \frac{\lambda_j}{100}\right) \right] \times \left(1 + \frac{\gamma}{100}\right) \]

- \( TC_{wo} \) = total cost without using IOT-based maintenance
- \( TC_w \) = total cost with using IOT-based maintenance
- \( I_{wo} \) = capital cost without sensors (NT$)
- \( I_w \) = capital cost with sensors (NT$)
- \( F_{ij} \) = number failure of component \( j \) in year \( i \)
- \( C^j_{CM} \) = replaced equipment cost of component \( j \) in a corrective maintenance occasion (NT$)
- \( C^j_{CM} \) = replaced equipment cost of component \( j \) in a preventive maintenance occasion (NT$)
- \( C^L_{CM} \) = labor cost if a corrective maintenance task is done (NT$)
- \( C^L_{PM} \) = labor cost if a preventive maintenance task is done (NT$)
- \( C^i_{trans} \) = transportation cost ($/km)
- \( D \) = distance to offshore wind farm from seashore (km)
- \( P_i^e \) = market electricity price in the year \( i \) (NT$/kWh)
- \( \tau_{CM} \) = time of a corrective maintenance occasion (hour)
- \( \tau_{PM} \) = time of a preventive maintenance occasion (hour)
Generated power at 12 locations monthly under real-weather condition in Taiwan

Wind speed impacts most severely to the efficiency of the offshore wind system’s power generation

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<th>Parameters</th>
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<td>Swept Area</td>
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<td>Tower height</td>
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Parameters of Vesta V82 offshore wind turbine

- Diameter: 82 m
- Swept Area: 5281 m²
- Tower height: 78 m
- Rated Power: 1.65 KW
- Cut-in wind speed: 3–5 m/s
- Cut-out wind speed: 25 m/s
- Nominal wind speed: 12 m/s
IOT technology could improve the maintenance efficiency and reduce the cost for maintenance.
The benefits of using IOT technology in maintenance offshore wind system are evaluated and compared to the traditional maintenance method without using IOT technology.

IOT technology could improve the maintenance efficiency by reducing the cost for maintenance.

The levelized cost of the offshore wind system with IOT–based maintenance is higher than the offshore wind system without IOT–based maintenance.

In future, when the cost for sensor and processing data is reduced as the development of technology, IOT–based maintenance will be very promising for offshore wind system.
References

Thank You!

Q & A