Corrosion protection of offshore wind turbines

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Wind Power R&D seminar – deep sea offshore wind, Trondheim, 21-22 January 2010

Offshore wind turbines – Challenges

- High corrosivity (marine environment)
- Erosion impacts due to salt particles and water droplets
- Mechanical loads due to floating ice
- Mechanical loads due to biofouling in submerged zone
- Variation in weather conditions
- Wind
- Waves
- Reduced accessibility
- Long and irregular inspection intervals
- High maintenance and repair costs

Corrosion protection – necessary from the very beginning

- Safety reasons
- Regularity in energy production

Environmental conditions

- Atmospheric zone
- Splash zone
- Sub-merged zone
- Inside the tower

Design of the structure

- Rotor blades
- Nacelle
- Tower
- Sub-structure
- Mooring

How can the turbine be protected?

Application of protective coating systems

- Steel tower
  - Sub-structure
  - Cathodic protection
  - Inside the tower
    - Keeping the internal environment dry
- Blades
  - Corrosion resistant composite materials
  - Nacelle
  - Corrosion resistant materials
  - Keeping the internal environment dry

Protective coatings – offshore oil & gas experience

- NORSOK M-501 specifies
- Pre-treatment quality
- Generic type of coatings
- Film thickness and number of coats
- Inspection during construction and service
- Experience indicates shorter lifetime of coatings recommended for the atmospheric zone than the 20 years designed life for offshore wind turbines

<table>
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<tr>
<th>Exposure conditions</th>
<th>Typical coating system</th>
<th>Life time expectancy</th>
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</thead>
<tbody>
<tr>
<td>Atmospheric zone</td>
<td>Epoxy primer + UV resistant topcoat</td>
<td>20 years</td>
</tr>
<tr>
<td>Splash zone</td>
<td>2-coats polyester</td>
<td>20 years</td>
</tr>
</tbody>
</table>

Rules and regulations

- International standards
  - IEC 61400 developed to ensure safety for systems and components
  - DNV DNV-OS-J101 is based on existing oil & gas standards and experience, synchronised with IEC
- National standards
  - Denmark
  - Germany
Are extended coating lifetimes possible?

- To ensure a lifetime corresponding to design life with a minimum maintenance requirement, DNV recommends
- Use coating systems with documented performance
- Prequalification (NORSOK M-501)
- Control that specified surface preparation and application conditions are followed

Challenges for offshore wind turbines

- Keep costs low
- Higher energy output
- Improved foundation technology
- Enhanced wind turbines
- Steel foundations seem to be competitive to concrete
- 50 years design lifetime is possible for steel structures
- What about the corrosion protection?

Coating systems in use

Offshore wind parks

- Zinc duplex systems
- Thermo-sprayed zinc-epoxy system
- Paint system

- Inside
  - Main paint coat alone
  - TSZ specified in splash zone on some towers
  - Generally limited information on coatings and coating performance

Corrosion protection on new projects

Hywind
- Coating systems on substructure based on
  - NORSOK M-501
  - Statoils experiences from offshore oil & gas
  - Standard tower/turbine
  - Not known, but probably according to ISO 12944, class C5-M
  - Tower and nacelle
  - Climate inside controlled by dehumidifiers

Sharingham Shoal wind park
- Substructure
  - Paints according to NORSOK M-501 in above splash zone
  - Cathodic protection (sacrificial anodes) only in submerged zone
- Tower
  - ISO 12944, class C5-M

- Below the air-tight deck
  - No coating applied inside
  - 6 mm corrosion allowance added

Corrosion protecting coating systems for offshore wind turbines

Demands
- Rapid production
- Low investments costs
- Low costs in service
- Long lifetime compared to lifetime experienced for offshore oil & gas installations
- Maintenance-free coating systems

Alternative protection systems today

Conventional coating system
- Experiences from offshore oil and gas installations
- First maintenance after 6-9 years

- According to Hempel
  - Existing NORSOK M-501 qualified coating systems have 20-25 years lifetime
  - A minor increase in the dry film thickness may increase the lifetime to 25 - 30 years

Including metalization
- Already used on offshore wind turbines
- Used by the Norwegian Public Roads Administration since 1965
- Rombak bridge showed no corrosion after 40 years
- Coating system
  - Thermally sprayed zinc (TSZ)
  - Corrosion protection paint
Our recommendations – existing coatings

- Recently, a life cycle cost analysis has been performed for
  - Conventional three-coats system
  - TSZ duplex systems
  - Metallization
  - 30-50% cost increase in construction
  - 30% LCC saved by avoiding maintenance

We recommend

- TSZ duplex system
- Atmospheric and splash zone
- Combined cathodic protection and epoxy coating in submerged zone
- Reduced application costs
  - Automation of coating application
  - Reduce the number of paint coats

New coating technology

- Self repairing coatings may improve corrosion performance of a coating system
  - Healing agents release from microcapsules
  - Chemical inhibiting species release in connection to coating damages

- Before such coatings can be used on offshore wind turbines we need further
  - Evaluation
  - Optimization

Thank you for your attention!