Risk based distribution system asset management - looking ahead

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CIGRE Seminario Internacional on Asset Management
Regente Palace Hotel
Some improvement options

- Transparency in efficiency sharing with customers
- Improved grid state indicators - improved condition monitoring
- Improved reliability and power quality management in decision processes
- Increased utility service and customer satisfaction focus
- Additional objectives and key performance indicators – in addition to short term profit
- Opens for improved multi criteria risk based grid management
- To utilize all the data that are out there - in a more holistic and coordinated way
Ongoing work - Looking ahead

The RISK DSAM project
  - Risk-based Distribution System Asset Management

Project main objective:
  - Improved management of the risk exposure for a distribution company, on planning, operative and physical level as well as on strategy level - related to maintenance and reinvestment strategies
  - Improved concepts, work flows, methods, tools and competence
Project Research Partners and user Participation

- National Research Partners:
  - SINTEF Industrial Management, Dept. of Safety and Reliability
  - NTNU, Faculty of Information Technology
    - Dept. of Electrical Power Engineering
    - Dept. of Mathematical Sciences
  - SNF – Institute of Research in Economics and Administration

- International Research Partners:
  - University of Porto/INESC        Portugal
  - Lappeenranta University of Technology    Finland
  - EdF – Electricité de France R&D     France

- National User Participation (DNOs):
  - Hafslund Nett AS
  - Lyse Nett AS
  - Fredrikstad Energiverk/Energi 1
  - Statkraftalliansens Nettgruppe (BKK, TEV, Agder, Skagerak og Istad)
Six RISK DSAM aspects

1. Distribution system risk management concept
2. Recommended work flow
3. Support system relationships
4. Objectives - Parameters - Indicators
5. Tools
6. Competence building
Concept (IEC)
IEC 60300-3-9 Dependability management Part 3 Application guide
Section 9 Risk analysis of technological systems


<table>
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<th>Risk Management</th>
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<td>Risk Assessment</td>
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<td>Risk Scenario Identification</td>
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<td>Risk Estimation</td>
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<td>Risk Treatment</td>
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<td>Risk Avoidance</td>
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<td>Risk Optimization</td>
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<td>Risk Transfer</td>
<td></td>
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<tr>
<td>Risk Retention</td>
<td></td>
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<tr>
<td>Risk Acceptance</td>
<td></td>
</tr>
<tr>
<td>Risk Communication</td>
<td></td>
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</tbody>
</table>
Classifying risk

Consequence classification

- Economy
- Quality of supply
- Vulnerability
- Occupational/Public Safety
- Environment
- Political/PR
- Regulations Contracts
Concept/workflow

Study planning

Identification

New distribution system

History-trends
Environmental stress/loading
Maintenance/renewal

Threats/Triggering mechanisms

Present state of the distribution system

Unwanted events
Unwanted consequences

Consequence classification

Economy
Quality of supply
Vulnerability
Occupational/Public Safety
Environment
Political/PR
Regulations/Contracts

Modelling and decision making

Consequence metrics and indicators

Risk estimation
Risk evaluation

Risk criteria

Risk treatment
Risk optimization

Improved distribution system

Study motivation
Stakeholder(s) and stakes
Objectives and restrictions
System boundaries
Terminology

SINTEF Energy Research
Ongoing work:
Key Performance Indicators
Key Performance Indicators give Asset Management Decision Support
Example from a Norwegian Utility Prototype

Network Information System (NetBas)
- Documentation, GIS, topology
- Analysis (load flow, short circuit)
- Reliability
- LCC
- Maintenance management
- Fault data management
- Health, environment and safety

Other data sources and systems
- ERP (Economy System)
- CIS (Customer Information System)

Grid company:
- Company strategy
- Focus areas
- Preferences

Analysis
- Criteria
- Weighing
- Categories

NetBas visualization of results
- Electrical rating
- Technical condition
- Availability
- Economy
- Health, environment and safety

Decisions to be made:
- Identify problem areas
- Budget
- Propose solutions and actions
- Cost benefit

KPI

NIS used for presentation of results
Aggregated grid state indicators per distribution transformer –
- **bad**
- **medium**
- **good**
- **missing data**
Quantitative and qualitative parameters

- Transformation into predefined states by comparing current values with a pre-defined set of criteria

**Categorization of low-level indicators in one out of 4 possible states**

<table>
<thead>
<tr>
<th>State</th>
<th>Description</th>
<th>Criteria</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHITE</td>
<td>Inadequate input data</td>
<td></td>
<td>$\alpha_{\text{White}}$</td>
</tr>
<tr>
<td>GREEN</td>
<td>No actions necessary</td>
<td>$U &gt; 218$</td>
<td>$\alpha_{\text{Green}}$</td>
</tr>
<tr>
<td>YELLOW</td>
<td>Fulfills functional requirements, but actions may be necessary</td>
<td>$U &lt; 218$</td>
<td>$\alpha_{\text{Yellow}}$</td>
</tr>
<tr>
<td>RED</td>
<td>Does not fulfill functional requirements, actions required</td>
<td>$U &lt; 207$</td>
<td>$\alpha_{\text{Red}}$</td>
</tr>
</tbody>
</table>

$U$ – Lowest measured (or calculated) voltage in the low-voltage network [V] (230 V system)

**Relative weighting of the 4 possible states.** Based on an intuitive assumption that ”red” indicators are more important than ”yellow” and ”green”, the 4 states have been given different relative weight (white indicators are not included, and have $\alpha_{\text{White}} = 0$).
Relative weighing of indicators

Relative weighing of the low-level indicators. These different low-level indicators may have different importance (weight) when assessing the actual component. The weighting can be based on a subjective assessment.

### Aggregated component indicator:

\[
PI_{Parti} = \frac{\alpha_{Green} \sum_{j,Green} w_{i,j} + \alpha_{Yellow} \sum_{j,Yellow} w_{i,j} + \alpha_{Red} \sum_{j,Red} w_{i,j}}{\sum_{j,Green} w_{i,j} + \sum_{j,Yellow} w_{i,j} + \sum_{j,Red} w_{i,j}}
\]

### Table 2: Examples of low-level indicators for a transformer

<table>
<thead>
<tr>
<th>Low-level indicator</th>
<th>Value</th>
<th>Red</th>
<th>Yellow</th>
<th>Green</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Technical solution</td>
<td>Orient. core</td>
<td>-</td>
<td>Non-ori. core</td>
<td>Orient. core</td>
<td>(w_{i,1})</td>
</tr>
<tr>
<td>2. Age</td>
<td>30 years</td>
<td>(\geq 45) years</td>
<td>(\geq 35) years</td>
<td>(\leq 35) years</td>
<td>(w_{i,2})</td>
</tr>
<tr>
<td>3. Technical condition</td>
<td>40</td>
<td>(\leq 25%)</td>
<td>(\leq 50%)</td>
<td>(&gt; 50%)</td>
<td>(w_{i,3})</td>
</tr>
<tr>
<td>4. Degree of utilization</td>
<td>92</td>
<td>(\geq 100%)</td>
<td>(\geq 90%)</td>
<td>(&lt; 90%)</td>
<td>(w_{i,4})</td>
</tr>
</tbody>
</table>
Experience

- Choose sensible indicators
  - That reflect important company strategies
  - That utilize current information; data quality and data availability will partly be present due to regulatory requirements

- Detailed studies must follow before decisions are made, but network indicators will tell where to put effort
Ongoing work:
Life time models - Failure models for network components as a basis for asset management
To better understand fault mechanisms and failure modes are important in a risk based asset management approach,

Multi fault state Markov process
Modelling objective

For a specific component (type) and failure mechanism:
- Estimate residual lifetime
- Estimate the failure probability for each year

Basis for
- Condition monitoring, maintenance and renewal (0-5 years)
- Analysis of reinvestment needs (5 years ->)
Life curve (simplified)

<table>
<thead>
<tr>
<th>State</th>
<th>Description (EBL Handbooks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No indication of deterioration.</td>
</tr>
<tr>
<td>2</td>
<td>Some indication of deterioration. The condition is noticeably worse than as new.</td>
</tr>
<tr>
<td>3</td>
<td>Serious deterioration. The condition is considerably worse than as new.</td>
</tr>
<tr>
<td>4</td>
<td>The condition is critical.</td>
</tr>
<tr>
<td>5</td>
<td>Failure.</td>
</tr>
</tbody>
</table>
Main state modeling

- Assumption: $T_k \sim \text{gamma}(\alpha_k, \beta_k)$

$$f(t) = \frac{1}{\beta_k^\alpha_k \Gamma(\alpha_k)} \cdot t^{\alpha_k-1} \cdot e^{-\frac{t}{\beta_k}} dt$$

Technical condition

State $k$: 1 2 3 4 5

Failure

$T_1$ $T_2$ $T_3$ $T_4$

gamma($\alpha_1$, $\beta_1$) gamma($\alpha_2$, $\beta_2$) gamma($\alpha_3$, $\beta_3$) gamma($\alpha_4$, $\beta_4$)
Main state model → Markov chain

- Gamma distributions are transferred into a chain of exponential distributions.
1. Component description

<table>
<thead>
<tr>
<th>Component:</th>
<th>Operating mechanism / energy storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type:</td>
<td>Hydraulic</td>
</tr>
</tbody>
</table>

2. Fault description

<table>
<thead>
<tr>
<th>Fault mode:</th>
<th>Lack of energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Causes:</td>
<td>Poor gaskets, Corrosion, Defect pumps, etc.</td>
</tr>
<tr>
<td>Fault progress:</td>
<td>Increasing leakage causing lack of energy and stuck breaker</td>
</tr>
</tbody>
</table>

3. Normal operational state

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of couplings</td>
<td>0-10 per year</td>
</tr>
</tbody>
</table>

4. Criteria for assessing the states

<table>
<thead>
<tr>
<th>Main state</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Visible corrosion, sweaty gaskets, minor leakages</td>
</tr>
<tr>
<td>3</td>
<td>Coupling time or tension time significantly changed, Leakage</td>
</tr>
<tr>
<td>4</td>
<td>Major leakage (compressor starts frequently)</td>
</tr>
<tr>
<td>5 (failure)</td>
<td>Insufficient coupling energy (stuck breaker)</td>
</tr>
</tbody>
</table>

5. Duration of state 1-4

<table>
<thead>
<tr>
<th></th>
<th>T_1</th>
<th>T_2</th>
<th>T_3</th>
<th>T_4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical (expected) duration of state 1-4:</td>
<td>time [years]</td>
<td>10</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>10^{th} percentile of the duration of state 1-4:</td>
<td>time [years]</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>
Tool for calculation of failure prob. of a specific component of a certain condition

Based on expert judgment:

- Sub-component: Operating mechanism / energy storage
- Type: Hydraulic
- Failure type: Lack of energy
- Expert: NN
- Company: XX

Technical condition: new | 1 | + | 2 | + | 3 | - | 4 | - | x | MTTF 6,923

Next year

<table>
<thead>
<tr>
<th>year</th>
<th>Failure probability</th>
<th>Cumulative probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0,000329</td>
<td>0,000329</td>
</tr>
<tr>
<td>2</td>
<td>0,010102</td>
<td>0,010432</td>
</tr>
<tr>
<td>3</td>
<td>0,046032</td>
<td>0,056464</td>
</tr>
<tr>
<td>4</td>
<td>0,096251</td>
<td>0,152715</td>
</tr>
<tr>
<td>5</td>
<td>0,134641</td>
<td>0,287356</td>
</tr>
<tr>
<td>6</td>
<td>0,148304</td>
<td>0,435660</td>
</tr>
<tr>
<td>7</td>
<td>0,139832</td>
<td>0,575492</td>
</tr>
<tr>
<td>8</td>
<td>0,118422</td>
<td>0,693914</td>
</tr>
<tr>
<td>9</td>
<td>0,092837</td>
<td>0,786751</td>
</tr>
<tr>
<td>10</td>
<td>0,068732</td>
<td>0,855483</td>
</tr>
<tr>
<td>11</td>
<td>0,048731</td>
<td>0,904215</td>
</tr>
<tr>
<td>12</td>
<td>0,033421</td>
<td>0,937636</td>
</tr>
<tr>
<td>13</td>
<td>0,022337</td>
<td>0,959972</td>
</tr>
<tr>
<td>14</td>
<td>0,014630</td>
<td>0,974602</td>
</tr>
<tr>
<td>15</td>
<td>0,009430</td>
<td>0,984032</td>
</tr>
<tr>
<td>16</td>
<td>0,005940</td>
<td>0,989972</td>
</tr>
<tr>
<td>17</td>
<td>0,003806</td>
<td>0,993778</td>
</tr>
<tr>
<td>18</td>
<td>0,002380</td>
<td>0,996158</td>
</tr>
<tr>
<td>19</td>
<td>0,001479</td>
<td>0,997637</td>
</tr>
<tr>
<td>20</td>
<td>0,000914</td>
<td>0,998550</td>
</tr>
</tbody>
</table>
Application of the method

- Answer to the basic question: What is the probability of failure in e.g. the next 5 years?
- Calculate the expected costs of unwanted events
- Calculate economical utilitarian value of maintenance and re-investment projects
- Document a project’s effect on various “qualitative” elements (health, environment, safety, PR, etc.)
- Quantify the effect of different maintenance strategies
Guidelines for Condition assessment

Condition data + Experts’ evaluations + Operational history

Technical state

Commissioning

Time [yr]

T1 T2 T3 T4 TC1 TC2 TC3 TC4 TC5

Fault

Failure probability

Failure probability

25
To protect against acts of God - still a challenge, but...
the distribution system will be useful for many years.