Decision-making process for substation renovation and equipment end of life assessment

C. Neumann (Germany)

2009 IEEE Substations Committee Meeting, Kansas City
Decision-making process for substation renovation and equipment end of life assessment

1. Introduction (German EHV grid)

2. Basic methodology

3. Ascertainment of actual condition

4. Determination of other c - parameters

5. Assessment of end of service life

6. Combination of parameters for decision making

7. Conclusion
Introduction

- Fundamental changes in the regulatory framework of the electricity market in the last decade
- Intensified efforts of the grid operators for an optimized utilization of their networks with respect to technical and economical aspects
- At the same time the grid operators have to assure a sufficient power quality & reliability
- Substations are the nodes of the grid substantially affecting the reliability & availability of the grid in total
- Substations represent an essential part of the grid assets
- Of particular interest with regard to optimization of the grid costs, i.e. investments & operational expenditure – CAPEX & OPEX

⇒ Methodology and decision making process for substation renovation and equipment end of life assessment
### German EHV grid

**Operational areas of German Transmission System Operators**

<table>
<thead>
<tr>
<th></th>
<th>RWE</th>
<th>E.ON</th>
<th>VET</th>
<th>EnBW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network length 380 kV [km]</td>
<td>5,200</td>
<td>5,400</td>
<td>6,700</td>
<td>1,936</td>
</tr>
<tr>
<td>Network length 220 kV [km]</td>
<td>6,100</td>
<td>5,300</td>
<td>2,865</td>
<td>1,721</td>
</tr>
<tr>
<td>Served area [1000 km²]*</td>
<td>73.1</td>
<td>139.4</td>
<td>109.0</td>
<td>34.6</td>
</tr>
<tr>
<td>Annual transmission [TWh]</td>
<td>175</td>
<td>138</td>
<td>k.A.</td>
<td>76</td>
</tr>
<tr>
<td>Share load [%]**</td>
<td>38</td>
<td>30</td>
<td>19</td>
<td>13</td>
</tr>
</tbody>
</table>

* in Germany  
** Renewable Energy Act load compensation 2005
German EHV grid

Operational areas of German Transmission System Operators

- EON
- VET
- EnBW
- RWE

380 kV transmission lines
220 kV transmission lines
## German EHV grid

### Operational areas of German Transmission System Operators

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>380 kV circuits</td>
<td>5,200 km</td>
</tr>
<tr>
<td>220 kV circuits</td>
<td>6,100 km</td>
</tr>
<tr>
<td>380 kV substations</td>
<td>62</td>
</tr>
<tr>
<td>220 kV substations</td>
<td>110</td>
</tr>
<tr>
<td>110 kV substations</td>
<td>121</td>
</tr>
<tr>
<td>380 kV transformer</td>
<td>235</td>
</tr>
<tr>
<td>220 kV transformer</td>
<td>145</td>
</tr>
</tbody>
</table>

- **380 kV transmission lines**
- **220 kV transmission lines**
Information for decision making process

- AM ⇔ qualified information of the system and the equipment installed for the decision making process.

- In case of larger population difficult to provide key information manually; therefore reasonable
  - application of data based systems
  - development of algorithms

- Algorithms and method for
  - determining near-term action and annual business planning
  - forecasting the technical and financial effect due to system ageing

- Approach based on condition and importance
Assessment of condition and importance parameters (1)

Assessment of condition parameters

1. Equipment level regarding equipment specific condition parameters, assessment by school marks

   - **static condition quantities**: technology, type related service experience (e.g. after sales service quality, maintenance costs), individual failure rates

   - **dynamic condition quantities**: age of equipment, individual condition ascertained by inspection and condition checks, interval to next planned maintenance activity

2. Equipment condition parameters accumulated on bay level, weighted according the value of different equipment

3. Assessment on station level → bay condition parameters and on system level → station condition parameters, weighted average mean value
Assessment of condition parameters on different levels

System level

Substation level

Bay level

Equipment level

Condition parameters

Static quantities

Dynamic quantities

Subst. A..Z

Subst. A

Subst. B

transf. bay 1 bay 2 subst. contr. UPS infrastruct.

prot. circuit breaker disconn. inst. transf. arrester infrastructure

Condition assessment
Assessment of condition and importance parameters (2)

- Assessment of importance parameters
  - Reliability analysis of the different substations
  - Derived from short circuit power of the station in question
    weighted by a factor reflecting the relevance of the station in the system

Condition and importance parameters normalised to 100
Condition and importance on equipment level

Example: Circuit breakers

- Replacement necessary
- Need for action to be checked
- Maintenance according to strategy
Condition and importance parameters of a population of 380 kV stations

The diagram shows a scatter plot with two axes: 'importance' on the x-axis and 'condition' on the y-axis. The data points are color-coded and categorized as follows:

- **C tot**: Red squares
- **C pri**: Blue triangles
- **C sec**: Green diamonds
- **C pri >50**: Purple circles
- **C sec >50**: Orange circles

The points are grouped into three regions labeled A, B, and C:

- **Region A**: Points with high importance and high condition.
- **Region B**: Points with high importance but lower condition.
- **Region C**: Points with lower importance but higher condition.

The diagram provides a visual representation of how condition and importance are distributed among a population of 380 kV stations.
Condition on station level and bay level
– condition above 50 –
Decision-making process for substation renovation and equipment end of life assessment

1. Introduction

2. Basic methodology

3. Ascertainment of actual condition

4. Determination of other c - parameters

5. Assessment of end of service life

6. Combination of parameters for decision making

7. Conclusion
Qualified assessment of actual condition of switching equipment

- Qualified condition assessment needs knowledge of the equipment under consideration and the physical background ⇒ experienced and highly skilled personnel.

- In case of a large amount of different pieces of equipment and of different types ⇒ high expenditure for training of specialised personnel

⇒ New approach: Application of an “automated, user instructed and data based inspection and diagnosis system” (ADS)

- ADS system in use for HV CBs since several years, for DSs under development
Basic design of “ADS“ system
(automated, user instructed and data based inspection and diagnosis)

Contact resistance
static & dynamic

1), 2), 3) adaptive sensors

Contact travel

1) SF₆-Check
diagnosis plug
control & supervision of
switching process & drive

diagnosis box
process control
data acquisition
data transfer

User assistance
Maintenance expert may control and supervise the process by remote access

UMTS

RWE Transportnetz Strom 08-2008 PAGE 17
ADS Features

- Diagnostic box → four inputs to record different diagnostic quantities
- Sequence of the inspection process is automated:
  - After input of the general data of the breaker to be inspected → maintenance personnel instructed what actions are to be done
  - All quantities are measured & analysed automatically, all results are stored in a data base
  - ⇒ Reliable, objective & qualified assessment of the actual condition of the equipment under consideration
- Depending on the measuring results and the condition check → information, if and what corrective measures have to be taken.
Results of ADS diagnosis on a 245 kV CB with two interrupter units
Data recorded and analysed by a single shot

- The following data can be recorded and analysed by a single shot:

- Static and dynamic contact resistance

- Operating (making or breaking) time of the main and the auxiliary contacts

- Contact travel, i.e. velocity and damping

- Current and time characteristic of the tripping coil

- In case of an hydraulic drive pressure drop of the hydraulic pressure

- All measured results are recorded and analyzed automatically and afterwards stored in a data base.
Decision-making process for substation renovation and equipment end of life assessment

1. Introduction

2. Basic methodology

3. Ascertainment of actual condition

4. Determination of other c – parameters
   - Maintenance,
   - after sales service

5. Assessment of end of service life

6. Combination of parameters for decision making

7. Conclusion
Average overall maintenance costs of 420 kV CBs per CB-year

<table>
<thead>
<tr>
<th>CB Type</th>
<th>Average Overall Maintenance Cost (in % of new CB cost)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A80s</td>
<td>0.15</td>
</tr>
<tr>
<td>B80s</td>
<td>0.25</td>
</tr>
<tr>
<td>C63s</td>
<td>0.30</td>
</tr>
<tr>
<td>D63s</td>
<td>0.35</td>
</tr>
<tr>
<td>E63s</td>
<td>0.40</td>
</tr>
<tr>
<td>F63s</td>
<td>0.45</td>
</tr>
<tr>
<td>G63s</td>
<td>0.50</td>
</tr>
<tr>
<td>H63s</td>
<td>0.55</td>
</tr>
<tr>
<td>I63s</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Legend:
- **Red**: major event
- **Pink**: minor event
- **Blue**: special measure
- **Green**: planned maintenance
- **Cyan**: condition acquisition

The graph shows the breakdown of maintenance costs for different CB types.
# Assessment of after sales service quality (CBs)

<table>
<thead>
<tr>
<th>Weight [%]</th>
<th>1.8</th>
<th>8.0</th>
<th>8.0</th>
<th>15.6</th>
<th>8.0</th>
<th>11.6</th>
<th>13.5</th>
<th>5.5</th>
<th>9.8</th>
<th>15.9</th>
<th>3.3</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>1-6</td>
<td>1-6</td>
<td>1-6</td>
<td>1-6</td>
<td>1-6</td>
<td>1-6</td>
<td>1-6</td>
<td>1-6</td>
<td>1-6</td>
<td>1-6</td>
<td>1-6</td>
<td>0-100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>Weighting by a decision matrix</th>
<th>Assessment results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type A80s</td>
<td>3 5 1 2 1 3 1 1 1 3 3</td>
<td>Best service 0</td>
</tr>
<tr>
<td>Type B80s</td>
<td>5 5 6 5 5 5 5 5 5 4 5</td>
<td>Worst service 100</td>
</tr>
<tr>
<td>Type C63s</td>
<td>2 2 1 2 1 2 1</td>
<td></td>
</tr>
<tr>
<td>Type D63s</td>
<td>5 5 6 2 1 3 1 1 1 3 3</td>
<td></td>
</tr>
<tr>
<td>Type E63s</td>
<td>3 5 1 3 3 2 2 3 3 2 2</td>
<td></td>
</tr>
<tr>
<td>Type F63s</td>
<td>3 5 1 5 5 2 2 3 5 1 1</td>
<td></td>
</tr>
<tr>
<td>Type G63s</td>
<td>5 5 1 5 5 2 2 3 5 1 1</td>
<td></td>
</tr>
<tr>
<td>Type H63s</td>
<td>3 5 1 5 5 3 3 3 5 3 4</td>
<td></td>
</tr>
<tr>
<td>Type I63o</td>
<td>5 5 6 5 5 5 3 3 5 6 6</td>
<td></td>
</tr>
</tbody>
</table>

### Weighting by a decision matrix
- **Best service**: 0
- **Worst service**: 100
Decision-making process for substation renovation and equipment end of life assessment

1. Introduction

2. Basic methodology

3. Ascertainment of actual condition

4. Determination of other c - parameters

5. Assessment of end of service life

6. Combination of parameters for decision making

7. Conclusion
Average failure rates of 420 kV CBs

Average failure rate per 100 CB-years

- A80s
- B80s
- C63s
- D63s
- E63s
- F63s
- G63s
- H63s
- I63o
Ageing given by related failure frequency (RFF)

Example of a certain 420 kV CB type

- Typical ageing process
  - Linear loss of basic substance
  - Exponentially increasing related failure frequency
  - Worse service experience for older equipment

RFF: Failures per year related to 100 CB years [%]
Related failure Frequency (RFF) of 420 kV CBs

Failure Frequency (RFF) of 420 kV circuit breakers with 95% confidence interval
End of life prognosis due to knowledge of the basic ageing process

In case of accelerated ageing renovation is brought forward, in case of decelerated postponed.
End of life prognosis due to knowledge of the basic ageing process

utilization factor [%] *)

Service time [a]

CBs
DSs
arresters

after 20 a
after 40 a

*) utilization factor => expected life related to nominal service life
End of service life assessment of 380 kV substations*
(equipment with impermissible utilization factor will be exchanged)
Conclusion

- For support of the decision making process for substation renovation the asset management needs simple, but technically justified and effective method for assessment
  
  – of actual conditions of the equipment
  
  – end of equipment life

- Methods and algorithms described provide qualified information
  
  – for determining near-term action and annual business planning
  
  – also for forecasting the technical and financial effect due to system ageing.
Decision-making process for substation renovation and equipment end of life assessment

Thanks for Your attention!