Integrated monitoring system for power transformers and hydro generators as an asset management and "smart grid" component

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Monitoring - Definition

• On-line **monitoring system** (MS) is a system which continuously monitors asset parameters by measuring or estimating them automatically.
Monitoring system features

- **Measurement** of certain parameters
- **Protection functions** related to continuously monitored parameters
- **Diagnostic function** - continuous or intermittent
- Comparison of actual parameter values with the values from the history (trend)
- **Comparison** between actual measured parameters with values given by model
- Tracking **process values** related to the interpretation of working conditions
The monitoring system has specific tasks during the whole lifetime of the equipment:

- **During the normal state** - insight in the state of asset and its real-time service conditions
- **During the fault progress** - to make the correct diagnosis and to warn the user (to enable fault prevention)
- **After the fault** – support for fault cause analysis
Implementation considerations

Monitoring system can be installed on a new or an existing generator or transformer (retrofitting)
Implementation criteria are:

• Risk analysis
• Importance in the grid
• Generator/transformer condition, age and size
• Working conditions
• Fault frequency
• Cost-benefit analysis – failure cost vs. MS price
## Risk analysis

**Risk = (Probability of an accident) x (Losses per accident)**

<table>
<thead>
<tr>
<th>LOSSES</th>
<th>PROBABILITY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>often</td>
</tr>
<tr>
<td>catastrophic</td>
<td>A</td>
</tr>
<tr>
<td>critical</td>
<td>A</td>
</tr>
<tr>
<td>medium</td>
<td>A</td>
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<tr>
<td>negligible</td>
<td>A</td>
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</tbody>
</table>

- A – high risk → high priority
- B – medium risk → medium priority
- C – low risk → low priority
Failure analysis for hydro generators

ENEL failure study on 1200 hydro generators (5 years period).

Causes of generator failure

- loosening slot: 16,3%
- rotor interturn fault: 12,2%
- bearing overheating: 12,2%
- PD damage: 10,2%
- shaft current: 9,2%
- local overheating: 8,2%
- lubrication circuit damage: 8,2%
- insulation damage by core vibration: 6,1%
- winding connection break: 6,1%
- breakdown of rotor insulation: 6,1%
- loosening magnetic wedges: 6,1%
- loosening core pressure: 2%
- end winding vibration: 2%
Failure analysis for transformers

**Location of transformer failure**

- OLTC: 41%
- Windings: 19%
- Core: 3%
- Bushings: 12%
- Tank and oil: 13%
- Accessories: 12%

CIGRE survey, 1983
Substation transformers with OLTC
Failures with forced and scheduled outage
Monitoring structure

• What type of sensors can be fitted:
  – Built-in (magnetic flux, air gap, partial discharge, temperature for generators, bushing CT, optical fiber thermometer for transformer …)
  – Add-on (vibration, relative displacement, speed for generator, gas in oil, Pt-100 into existing pocket, matching impedance for transformer …)

• Modularity – possible upgrades and different configurations (installed SW and HW)

• Connectivity
  – Remote access
  – Data exchange
Typical PC based MS

- Sensors / Transducers
  - Installed on the object
  - Measure physical, chemical and electrical signals

- Data acquisition unit
  - Signal conditioning
  - Analog to digital conversion

- Communication link
  - Fiber optic, wireless
  - LAN/WAN, dial-up

- Computer
  - Data processing
  - Archiving
  - Visualization
  - Link to SCADA

Remote point
Sensors / Transducers

- A device that converts a physical or mechanical phenomenon (e.g. temperature, vibration, speed) into a measurable electrical signal
- Standard sensor output signals are 4 to 20 mA DC current, 0 to 10 V DC
- Nonstandard signals 0 to 20V, current transformer 0…5 A AC, Pt-100 etc.
- Often in form of an IED (Intelligent electronic device)
  - Performs measurement, A/D conversion and data processing
  - Transfer of the measuring signal via digital communication protocols
Typical generator sensors

- Air gap
- Magnet flux
- Partial discharge

- Vibration (accelerometers)
- Relative displacements
Typical transformer sensors

- Loading current
- Gas and moisture in oil
- Voltage
- Winding temperature
- Partial discharge
Data acquisition unit

• Performs:
  – Signal conditioning (sometimes):
    – Analog to Digital Conversion - digitizes incoming analog signals so the computer can interpret them
  – Other functionality:
    • analog output,
    • digital I/O, counter/timers,
    • triggering and synchronization
  – Data processing (sometimes)
Data acquisition unit with auxiliary equipment

Generators

Transformers

- Monitoring controller
- Fuses
- Over-voltage and over-current protection device
- Ethernet switch and media converter
- UPS
- Conditioning equipment
- ...
Communication link

- Media:
  - Copper cabling / twisted pair cabling - short distance (25/100m), low EMI (Electro Magnetic Immunity)
  - Optical fiber – Ethernet to fiber convertor on both ends of optical fiber – distance up to 80 km, excellent EMI
  - Wireless (Bluetooth, WiFi – Wireless Local Area Network (WLAN)) – easy to install, short range, security issues
Communication protocols

- Monitoring system is usually connected with other systems in the substation

  - Communication protocols:
    - Modbus
    - IEC 60870-5-101/103/104
    - DNP 3.0 (USA)
    - IEC 61850
Remote access to aw MS

- Monitoring systems are almost always accessed remotely.
- KONČAR has implemented secure and efficient remote access via:
  - LAN/WAN
  - Direct dial-up
    - modem + phone network (analogue or ISDN)
    - mobile modem or wireless card + mobile network
Access to the data

TMS Server

Substation LAN

Firewall

WAN

PSTN GSM

TMS Client 1

TMS Client 2

TMS Client 3

SCADA

61850
60870-5-101
60870-5-104
Modbus
Monitoring server

- Industrial PC with:
  - 19” TFT monitor
  - Ethernet 10/100 card
  - HDD 2x320 GB RAID
  - Windows XP OS
- Software
- Database

Visualization can be obtained
- Graphical user interface (GUI)
- Web user interface (WUI)
Monitoring according to the models

• Models perform real-time on-line computation to convert measured data into useful information
• Usually are based on internationally recognized standards (IEC, IEEE), manufacturer calculation algorithms etc.
• Inputs:
  – On-line data – directly measured values
  – Off-line data – asset parameters from factory testing and design
Example of the models for generators

Air gap measurements
- Measurement range 2-100 mm
- Output Sensor - current 4-20 mA, voltage 0-10 V
- Capacitive sensing

![Diagram showing models for generators with labels for rotor, stator, C1, C2, and V, mA.](Image)
Example of the models for generators

- Air gap sensor 1
- Air gap sensor 2
- Air gap sensor 3
- Model according to machine factory acceptance tests
- Roundness of the rotor
- Roundness of the stator
- Eccentricity

- Roundness is an indicator of how the shape resembles a circle
- Eccentricity is the relative position of the approximate geometric center vector of the rotor, relative to the rotating axis of the stator
Example of the models for transformers

Index of bushing capacitance change
Example of the models for transformers

Input data

- Voltages measured on the bushings test tap (3 phase)
- $U_A$
- $U_B$
- $U_C$

Output data

- $F_A = \frac{2U_A}{U_B + U_C}$
- $F_B = \frac{2U_B}{U_A + U_C}$
- $F_C = \frac{2U_C}{U_A + U_B}$

Indexes of relative capacitance change

Index numbers
Visualization of main screen for generators
Orbit plot from generator data base
Visualization of main screen for transformer
Visualization of actual parameter values

- Tap Position: 6.0
- Position of Tap Over Selector: 8
- Position of Change Over Selector*: k+

- Diverter Switch Current U*: 485.7 A
- Sum of Switched Current U*: 3.5 kA

- Number of switchings:
  - Number of Selector Operations*: 7.0
  - No. preselector operations*: 2.0

- Switching operation:
  - Duration of Switching Operation*: 4.3 s
  - No. of unacknowledged alarms: 2

- Logged on server
- Controller OK

- 6.3.2009
- 12:16:49
Visualization of historical parameter values (trend)
Retrofitting and new TMS installation
Sensors installation in hydro generators
Integrated generator-transformer monitoring system
Advantages of integrated monitoring system

- Access to the data of the monitored equipment through common point (server, remote client, etc.)
- Manipulation with the integrated system is simpler (unification of the user interface)
- Easy upgrade and integration of new equipment to be monitored (circuit breaker, instrument transformer, disconnector)
- More effective exchange of the data with the control and smart grid elements of the network
- More effective asset management
Monitoring as cog-weel of smart grid

- Asset management
- On-line monitoring system
- Smart grid
Main tasks of MS and their relation with grid

- The analysis and interpretation of collected data
- Estimation of the condition of the component
- Exchange of data with other systems

Asset management → Asset management
Smart grid
What does interpretation of data enable?

- Warning of faults, trends and possible failure
- Insight into operating conditions and actual state
- Improvement of grid reliability and security
- Improvement of personnel and environment safety
- Enhanced fault cause analysis
- Long-term data archival
What does estimation of condition enable?

- Forecasting different states of monitored component
- Prevention or reduction of fault consequences
- Condition-based maintenance and outage management
- Optimum asset management (overloading, life extension, delayed replacements etc.)
What does exchange of data enable?

- Improvements of the network control and load flows
- Determination and taking appropriate actions autonomously or through operators
- Faster than real-time action
- Computer-aided asset and workflow management
Conclusion–What are the current status and trends?

Today
• Monitoring systems are added to classical electromechanical monitoring and protection devices
• Installed only on key generators and transformers
• Focus on sensor development
• Off line diagnostics
• Time-based and corrective maintenance

In the future
• Most of classical monitoring devices will become obsolete and replaced with digital electronic devices
• Standard equipment for all generators and transformers
• Focus on interpretation
• On line diagnostics
• Condition based maintenance