UNBALANCED MAGNETIC PULL AND AIR-GAP MONITORING FOR LARGE HYDROGENERATORS

AN INNOVATIVE MEASUREMENT DEVICE FOR THE MONITORING OF STATOR AND ROTOR MAGNETIC CIRCUITS

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1. OBJECTIVES
Large low speed hydrogenerators have a very small
specific air-gap/stator bore diameter ratio making it
impossible to have a perfect centering of the elements
during the assembly process. Therefore the machines
are operated with an eccentricity that though small is
not negligible, and is the cause of undesirable effects:
considerable unbalanced magnetic pulls, vibrations,
additional losses. It is consequently important to
assess the eccentricity and even more to check its
trend to guarantee a safe operation and prevent any
serious damage.

The purpose of the UMP Monitoring device
(Unbalanced Magnetic Pull Monitoring) is to detect
synchronous machine stator and rotor circuit defects.
These defects, of mechanical origin (wrong positioning
of the rotor, mechanical unbalance, mechanical
deforation…) or electromagnetic origin (partial short-
circuit in field coils, magnetic circuit defect…), may
engender important magnetic strains between the
stator and the rotor giving rise to vibrations and in the
worst case a rubbing of the rotor and the stator.

Early detection of air-gap anomalies eases the
maintenance task by giving the user time to plan for
repairs before scheduled outages. Prediction of long
term evolution of air-gap, stator and rotor shape can
be used in operational and rehabilitation planning.

Knowing the magnitude of the magnetic pull between
rotor and stator can inform the operator of the need to
remove a machine from service before serious
damage such as a rotor stator rub occurs.

2. ELEMENTS OF THE EQUIPMENT
The equipment comprises :
- devices to measure the magnetic flux in the air-
  gap of the machine;
- data acquisition units;
- data processing tools to extract the parameters
  related to stator and rotor magnetic circuit defects.

2.1. Sensors to measure the magnetic flux in
the air-gap
The magnetic flux in the air-gap of the machine is
measured using coils distributed on the periphery of
the stator, each one between two ventilation ducts.

These sensors may be put in place by the
manufacturer of the machine; for generators already in
operation their installation is relatively easy not
requiring an access to the rotor. For measurements of
limited duration (such as an unique diagnostic of the
machine) the sensors are easy to remove.
For generators already in operation, sensors are put in place from the back of the stator yoke using a simple and efficient method. The installation of 15 sensors takes only a few hours.

2.2. Data acquisition units

A standard device for data acquisition with 12 or 16 bits resolution and 5 kHz sampling rate is used with a straight connection to the PC (fig. 3).

![Figure 3. UMP Monitoring equipment.](image)

2.3. Data processing tool

This part of the UMP-Monitoring device consists in a PC for real time processing. The results are issued from calculations based on the induced voltages measured on each sensor (fig. 4).

![Figure 4. Induced voltage in the sensors.](image)

3. MEASUREMENT MAIN FEATURES

The measurement is performed in real time over a complete revolution of the rotor. Consequently, the period between two successive measurements depends directly on the rotation speed of the generator.

Analysis of the measurements provides the complete information regarding the condition of the magnetic circuits related to the air-gap:

- deformation of the stator magnetic circuit;
- relative effective static and dynamic eccentricities;
- magnitude and direction of static and dynamic magnetic pulls;
- air-gap magnetic flux.

The UMP-monitoring equipment provides a numerical and graphical representation of the rotor magnetic circuit state, stator deformation, and the combination of these two states as well as a harmonic analysis of the deformations.

4. BENEFITS FROM AN INDUCTIVE AIR-GAP MONITORING

4.1. Sensors

Type of sensor
- simple and very low cost

Sensor set-up
- easy with minimal intervention on the machine;
- no direct access to the air-gap necessary;
- no gluing;
- no mechanical disassembling / reassembling;
- fast with simple tools;
- easy to remove.

4.2. Measuring equipment

- measurement of voltages in an unproblematic range (between 3 and 6 V);
- several methods of data acquisition possible.

4.3. Data processing unit

- standard PC;
- easy to adapt to specific user wishes;
- possibility to have remote display through internet.

4.4. Innovative features of the system

- low cost sensors;
- insensitivity to external conditions (humidity, temperature, etc.)
- measurement of static and dynamic unbalanced magnetic pull;
- capability to recognize deformation of any shape;
- arbitrary number and disposition of sensors;
- real-time assessment of air-gap condition;
- no influence of the cables on the measurement;
- no need of linearization.
5. EXAMPLES OF MEASUREMENT

5.1. Laboratory prototype machine

The prototype machine (18 kVA) has a rotor and several interchangeable stators to allow the measurement of different defects such as:

- static eccentricity,
- dynamic eccentricity,
- combinations of the above mentioned defects,
- stator deformation (elliptic or triangular shape),
- partial short-circuit of the field coil.

One of the stators allows specific windings (parallel paths, equipotential connections) making possible eccentricity unbalance compensations (fig. 5).

Parameters of the laboratory machine

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated power</td>
<td>18 kVA</td>
</tr>
<tr>
<td>Number of poles</td>
<td>10</td>
</tr>
<tr>
<td>Rated frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>Internal diameter</td>
<td>400 mm</td>
</tr>
<tr>
<td>Length of laminated stack</td>
<td>100 mm</td>
</tr>
</tbody>
</table>

Measurements have been performed with fifteen air-gap sensors. When one is only interested in investigating eccentricity problems, the UMP-monitoring equipment provides the magnitude of the static and dynamic eccentricities as well as the unbalanced magnetic pull (fig. 6).

When one is interested in investigating synchronous machine stator and rotor circuit defects such as:

- wrong positioning of the rotor,
- mechanical unbalance,
- mechanical deformation of the stator,
- partial short-circuit of the field coil, magnetic circuit defect,

the UMP-monitoring equipment provides a numerical and graphical representation of the rotor magnetic circuit shape, stator deformation, and a harmonic analysis of the deformation (fig. 7).

5.2. Power plant of Verbois (Geneva)

Verbois hydroelectric power plant construction lasted from 1937 to 1944; it has been renovated in 1985 and in 2000. It comprises four 33 MVA units. Head is 20 m.
Parameters of the generators

**Generator ABB, 33 MVA**
- Nominal power: 25.75 MW
- Voltage: 9 kV
- Nominal current: 2'117 A
- Power factor: 0.8
- Speed: 136.4 rpm

**Stator magnetic circuit**
- Internal diameter: Ø 5'992 mm
- Total length: 1'371 mm
- Ventilation aperture: 10 mm
- Stacks: 60 mm
- Air-gap: 12 mm

Measurements were performed using sixteen air-gap sensors. On group 2, the diagnostic shows that on the one hand the rotor doesn’t have any noticeable dynamic eccentricity; but on the other hand, it reveals a slightly deformed stator bore as well as a static eccentricity (fig. 9 and 10). The maximum magnetic pull (static and dynamic) reaches 86.5 kN (fig. 11).

On group 3, there is no significant static or dynamic eccentricity (fig. 12). Therefore, the maximum magnetic pull (static and dynamic) is low with only 21.3 kN (fig. 13).
6. CONCLUSIONS

A novel air-gap monitoring system for large low speed hydrogenerators based on inductive sensors has been described; it is tested on a prototype laboratory machine and on three large units. This system is able to measure in real time static and dynamic rotor eccentricities, stator and rotor deformations and partial short-circuits in the field winding. It determines also the unbalanced magnetic pulls in magnitude and direction.

As this system uses inductive sensors, it sees the real distribution of the air-gap flux density. This means that all damping effects coming from the saturation, the rotor damper winding, the parallel current paths and the equipotential connections of the stator winding are taken into account.

The measurement equipment itself is very simple to install and to remove. It is readily available on the market and its price is very low in comparison with a capacitive air-gap monitoring system. The simplicity and the low cost of the inductive sensors used allow the installation of a high number of sensors and therefore make possible the measurement of deformations of higher orders.

References

