On-line condition monitoring of a 230 kV minimum oil circuit breaker

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A previous project completed in 2000 had installed five on-line monitoring systems on a newer 230 kV SF6 breaker with hydraulic drives. Conclusions at the end of three years of monitoring confirmed the extremely repetitive operation of that particular type of breaker, and provided participating utilities a justification for reducing the maintenance costs by increasing the maintenance intervals. At the time, the project concluded that the monitoring technology had not reached maturity, and its implementation may not be economical.

The current project shifted the monitoring focus to an older design, high maintenance breaker, and used an emerging monitoring system. The OLM2, manufactured by Elcon International, combines extensive data analysis capability with a cost that can start making on-line monitoring economically defendable. A wide array of parameter calculations can be setup for monitoring different breaker technologies and designs.

The target breaker, ASEA HLR with BLG352-C mechanisms is a 1970s vintage, minimum oil design, with spring actuated drives and independent pole operation. Higher failure rates, and a long history of increased maintenance have been primarily associated with mechanism problems. Life extension of this breaker in a condition-supervised mode has a positive economic potential. Monitoring aimed to identify different failure modes and the potential for early detection by an on-line system. Breaker location was in a filter-bank switching position, in the 230 kV AC switchyard of a large converter station.

System installation

Three OLM2 modules were supplied in prewired temperature-controlled cabinets, which also housed current transducers and some temperature sensors. Fig. 1 shows a general view of the breaker, and the monitoring installation close to the main control cabinet.

Digital incremental encoders were used to measure rotation. Current off-line testing procedures use the non-intrusive measurement of rotation at T1. The angular travel is then translated to model the linear contact travel vector (T2), on which all motion parameters are calculated. The on-line system derives the Contact Travel in a similar fashion, from a rotation measurement taken elsewhere on the linkage mechanism.

Translation tables are provided by the system manufacturer for common monitoring applications. Once selected in the setup, their use is transparent.

System

<table>
<thead>
<tr>
<th>System</th>
<th>Measurement</th>
<th>Transducer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contacts/</td>
<td>Travel</td>
<td>Digital Encoder</td>
</tr>
<tr>
<td>mechanism</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Close coil</td>
<td>Current</td>
<td>CT</td>
</tr>
<tr>
<td>Open coil</td>
<td>Current</td>
<td>CT</td>
</tr>
<tr>
<td>Motor</td>
<td>Current</td>
<td>Shunt</td>
</tr>
<tr>
<td>(charging)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>Voltage</td>
<td>Direct Input</td>
</tr>
<tr>
<td>voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line</td>
<td>Current</td>
<td>Pick-up coil</td>
</tr>
<tr>
<td>Cabinet</td>
<td>Temperature</td>
<td>PT100</td>
</tr>
<tr>
<td>(mechanism)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient</td>
<td>Temperature</td>
<td>PT100</td>
</tr>
</tbody>
</table>

A view inside the monitoring cabinet is shown in Fig. 2. Two coil current measurement CTs, and a shunt for the charging motor current are placed at the bottom.

Transducers

Only a subset of the available monitoring inputs has been used in the test installation. These measurements are listed in Table 1. Three sets of transducers connected the three phase mechanisms to the respective monitors. Other breaker technologies, or a larger monitoring scope (SF6 density, spring travel, voltages) can be accommodated by the additional channels.

Contact and mechanism travel

The OLM2 system accommodates both analog and digital travel sensors.
be accommodated at a time. Contact monitoring was performed on all three phases for the first 1½ years. The Phase B travel measurement was then switched to dashpot monitoring for a trial period of one year. Both travel transducers are shown in Fig. 4.

**Wireless Network**

The server is a central component in the OLM2 system architecture (Fig. 5). In a typical installation the host PC would be placed in the substation, and connected to both Internet and a local RS485 monitoring network. However, wiring this network for the needs of a temporary project would be an inefficient use of resources, with little side benefits. It was decided to replace it with a spread-spectrum wireless link. Direct gains were the cost savings, hands-on experience with this technology, reusability, and bypassing the administrative approval process to setup an ftp server for monitoring purposes.

Three radio modems provided point-to-point communication between the OLM Server and the Monitors shown in Fig. 6. These 900 MHz transceivers operate in a wide spectrum, frequency-hopping mode. No licensing is required for the featured maximum radiated power of 1 W. Maximum communication speed is 115 kbps on the RS232 interface in half duplex mode.

Data was transmitted in a first instance 500 yards from the breaker to the station, then relayed for another 16 km to the Research Centre. The same type of modem was used for this second leg, with two Yagi 6 dB directional antennas at each end (10 - 25 m above ground level).

**Sample monitoring results**

Odd operation recordings have been observed shortly after the monitoring commissioning, while installation problems (recording triggering and synchronization) were still being worked out of the system. Analysis of these events concluded that the unlikely picture emerging was that of unpredictable and unrepetitive breaker operation. Most of the events had a few, very important features in common. Due to their random incidence, failure modes were hard to diagnose using traditional maintenance procedures, making the help of a monitoring system essential to identify their pattern of occurrence.

### Breaker Events

A breakdown of the failures experienced, by the originating system is presented in Table 2. All events, with the exception of dashpot failures, were flagged at the time of analysis by the monitoring system. All failures required the breaker to be taken out of service for repairs.

<table>
<thead>
<tr>
<th>Mechanism Release</th>
<th>Breaker/Station Control</th>
<th>Charging/Operating Mechanism</th>
<th>Failure Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Individual phase delays;</td>
<td>4. Continuous assertion of the Close command in specific modes of breaker failure.</td>
<td>5. Broken bridge guides. Failure during maintenance outage (A Phase)</td>
<td>3. Failure to close;</td>
</tr>
<tr>
<td>2. Failure to close;</td>
<td>6. Broken charging chain, failure in operation.</td>
<td>8. Dashpots replaced a number of times on different phases, and affecting all of them, spanning the entire monitoring duration.</td>
<td>7. Broken safety pin on the charging motor gear (2x).</td>
</tr>
</tbody>
</table>

Table 2: Breakdown of failure.

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**Fig. 3**: Motion sensor location on the HLR breaker.

**Fig. 4**: Phase B travel transducers.

**Fig. 5**: Typical monitoring configuration.

**Fig. 6**: Actual installation, including a radio link.

**Fig. 7**: Operations during and after maintenance.
The first two failure modes were of particular interest. They have been observed at the same time on different phases. Both defied repeated interventions that aimed to fix the problem. System impact was different between the two, but the root cause analysis pointed to the same component (Fig. 9). The monitoring data was key to achieving this understanding, and suggesting solutions.

**Intermittent phase A delay**

Fig. 7 shows two consecutive operations, the first one being the last test operation during the monitoring installation. The second chart is the first operation of the energized breaker (phase currents not displayed). The Phase A motion delay can be correlated with a longer coil operation time. This failure mode’s characteristics were:

- Delayed operations alternated with normal ones, although the prevailing mode was Delayed.
- Random but sustained occurrence since the beginning.
- A burned coil replacement and repeated coil gap adjustments were unsuccessful in correcting the problem.

The problem was initially assessed as not critical, as the delay was not long enough to engage the phase discrepancy protection.

**Phase C failure to close:**

Unpredictable breaker response to the close command has been experienced in the form of:

- Breaker trips free on the close command.
- Unexplained operation 10 - 15 seconds later, without operator intervention.
- Breaker may not respond to close command.
- Breaker will respond differently to commands issued from different control centers.

Consecutive recordings provided by the monitoring system are presented in Fig. 8. The top one shows identical three phase coil energization, and the lack of C phase motion. In the second chart this phase is re-energized, 12 seconds later, and maintained so indefinitely. The result could be either illegitimate single-phase operation, or a burned-out coil. Both events were alternately recorded.

These types of operations:

- Did not result in catastrophic system failure.
- Increased system stress due to asymmetrical/incomplete breaker closure.

**Resulted in reduced contingency.**

Repeated coil burnouts and several maintenance outages could not isolate the problem. Maintenance went to the root of the problem and corrected it in November 2001. Major repair work was required, involving the latch assembly and dashpot replacement.

**Phase A delay compared to phase C failure:**

In comparison to the phase A delay, the C phase uncontrolled closing was more severe, visible at the operation control level, and having a higher impact on the switched apparatus.

Both problems were due to a flattened roller with different degrees of deformation. The roller had in turn been distorted by high impact operations associated with the prior failure of the hydraulic dashpot damper.

Fig. 9 shows the progress of this failure mechanism. It also shows the most likely sequence of repairs, which would be naturally followed by a maintenance team.

The end result is the breaker’s failure to close due to a burned coil. Repeated coil replacement during consecutive forced outages may not address the root of problem, which is the flattened roller. Replacing the roller will also be insufficient without corrective work to the dashpot operation.

Phase delay detection by online contact monitoring could trigger maintenance at an early stage, thus avoiding undue system stress and more extensive damages at a later time. Choosing to perform dashpot travel monitoring instead of contact, would be even more beneficial, prompting for repairs before damage is done to the closing assembly and the closing roller.

**Dashpot monitoring**

Preliminary conclusions attributed more than 50% of failures to prior drive deterioration. Dashpot monitoring was accordingly implemented in phase B in November 2002, with more than 70 operations recorded over the following nine months.

Fig. 10 shows the off-line measurement procedure for damping time (top chart) and the on-line substitute method. Automatic calculation of a damping time parameter was setup in the online system directly on the rotation vector. Note that this recording’s duration is shorter, at 250 ms. The damping time calculation will be exact for operations shorter than 250 ms, and will only gauge the beginning of dashpot action in longer recordings. The loss is not significant, the damping time assessment rule being “not shorter than 75 ms”. Lack of amortization will show entirely in the 250 ms timeframe, while changes in the longer recordings will affect the travel/time gradient in the observation window.

Trending of the damping time parameter indicates repetitive breaker operation in the test interval. The method is confirmed as sensitive enough to pickup seasonal variations, four odd coil operations (highlighted), and recording noise on three occasions.
Conclusions

**Monitored breaker**

- Several failure modes specific to the HLR breaker have been identified.
- The monitoring system illustrated a high-impact type of failure that may develop gradually, offering the possibility of early detection.
- Most failures experienced by the breaker could only be picked up by on-line measurements. Irregular problems such as phase discrepancy, failure to close, and failure to latch closed may go unnoticed during off-line testing, but were flagged by the on-line system.
- Important limitations of the present breaker command logic were evidenced in the system control interface to the monitored breaker. It became evident, in the process of understanding and troubleshooting a particular failure mode, that an illegitimate closing command will be released and maintained, resulting in a potentially hazardous situation. Availability of monitoring data played a key role in the root-cause fault analysis.
- Fifty percent of the recorded breaker failures were linked to potential prior degradation of the dashpot performance, leading to subsequent failures elsewhere in the system. Monitoring of the dashpot damping is particularly recommended for the BLG-352 mechanism.

**Breaker-monitoring system combination**

- Independent pole operation of the monitored breaker at 230 kV requires a set of 3 monitoring units per breaker.
- The HLR monitoring needs could be completely satisfied by a system with the capability to accommodate dashpot travel analysis (>50% of failures). Both contact and dashpot travel measurements can be accommodated by the existing hardware, but relevant motion analysis can only be performed on one of them at a time. Since this conclusion was formulated the OLM2 system has been modified to accommodate concurrent dashpot and contact travel analysis.

**Monitoring system**

- The monitoring package had a good overall performance, with respect to installation, data handling, data analysis and adaptability.
- Setup and operation of the system was not demanding.
- There is a learning curve to achieve a comfort level in the operation of any monitoring system, and the OLM is no different in this respect from other test equipment. There are however clear benefits.
- Contact wear estimation was by means of calculating an \( \text{I} \times \text{t} \) breaking duty coefficient. The accuracy of this calculation relies on the correct evaluation of arc time from the contact travel and phase current recording traces. The system showed consistent accuracy in this assessment.
- The monitoring system’s flexibility of configuration allowed the change of monitoring focus with minimum effort. The system has been adapted to measure and calculate dashpot motion and related damping parameters. Except for a different travel sensor location all the changes were made in software.
- The system can accommodate novel SF6 density sensors with direct measurement of the gas density, as well as the more traditional measurement of gas pressure and temperature.
- Important condition evaluation parameters are calculated from the coil current measurement. The system was developed to differentiate between two possible sources of signal (CT or shunt) and apply the correct calculation algorithms according to the specific implementation. It has been recognized by the project that making the original coil current traces available to the end-user is an important feature.
- The OLM software has been under continued development, and several upgrades were issued throughout the project. At the same time, this singular breaker model implementation provided continued positive feedback to the manufacturer. The system’s general ability to accommodate a few unique monitoring requirements confirmed a robust monitoring platform.
- Recording synchronization between the three phases was lost at times, in the absence of server polling. This situation may be encountered during longer shutdowns of the monitoring server or the communication link.
- Remote access to the monitoring data is an important feature of the system. Recordings and status points are instantly uploaded to an ftp server, which can be accessed by different authorities in real time, over the Internet.

**Wireless network**

- The addition of low cost wireless communication directly from the breaker bay location adds significant flexibility to the deployment of on-line monitoring systems in existing switchyards. This proof of concept had direct application in the current installation, but can be extended to other type of monitoring equipment or apparatus.
- The 900 MHz license-free wireless modems performed well in the 230 kV and HVDC switchyard environment found at the converter station.
- Remote interrogation and data download using off-the-shelf digital radio transceivers proved to be technically viable, and an ideal economic alternative to a hard-wired link. Additional benefits of the wireless technology are:
  - Provides connectivity to new monitoring installations at a minimum incremental cost per extra location. It is also possible to relocate existing monitoring equipment to virtually any other breaker location in the switchyard, without the need to install new communication cables.
  - It is possible to remotely program any wireless unit in the network so as to serve different communication needs in different instances. For more than a year the network has been expanded to serve two different projects. Automatic reconfiguration of the wireless has been setup, so that switching from one monitoring system to the other is transparent to the user.

Over the two years of monitoring, the manufacturers of both breaker and the monitoring system, provided excellent support and were able to resolve most issues through software upgrades, typedata changes, or firmware changes for the monitoring DAU. It is significant that no hardware modifications were required, indicating a mature hardware platform.