A NOVEL APPROACH FOR WIDE AREA REAL TIME HEALTH CONDITION ASSESSMENT OF THE POWER CIRCUIT BREAKERS

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ABSTRACT
This paper presents a new approach to centralized health assessment of circuit breakers (CBs) in real time. The basis of the health assessment method is measurement of CB important operational parameters on site with electronic device IED-Q0. By using wide area CBs monitoring system – SMCBC - the measured data are collected from IEDs and forwarded to an Enterprise Asset Management System for further processing, e.g. health condition calculation. The paper also presents a brief overview of CB’s important parameters needed for the health assessment.

INTRODUCTION
Maintenance of today’s power circuit breakers in relay substations is a challenging task. To successfully determine health condition of a CB one must take into account multiple important parameters and include them into Asset Health Index (AHI) calculation. Some of the parameters (i.e. offline parameters) are measured by maintenance crew during CB revision process, however in order to get detailed information about CB health condition, some parameters must be measured in real time when CB is operating (i.e. online parameters). Measuring online and offline parameters gives a good basis for optimization of revision processes and leads into transition from Time Based Maintenance (TBM) to Condition Based Maintenance (CBM) which enables CBs asset management in real time.

The implementation of real time CBs asset management requires four main components:
- Regular CB revisions – for measuring offline parameters.
- Real time CB measurement system – for measuring online parameters.
- Communication and data concentration system – for collecting and transferring data to EAM.
- Enterprise Asset Management (EAM) system – for using the acquired data to calculate AHI.

The big challenge in the area of CBs maintenance today is the lack of reliable, affordable and vendor independent CB measurement systems that could measure online parameters of a CB. Most of the measurement systems in the market today are tied to CB vendor, which presents an issue if an electrical substation contains multi-vendor CBs. In this case costs of implementation of such online measurement systems are highly increased. In addition when using multi-vendor equipment complexity of integration with EAM can become a difficult task. With the presented approach implemented with Intelligent Electronic Devices IED-Q0 and System for Measuring Circuit Breaker Condition (SMCBC) developed at Milan Vidmar Electric Power Research Institute (EIMV) we wish to fill this gap.

IMPORTANT PARAMETERS FOR DETERMINING CB HEALTH CONDITION

The mathematical methods for determining CB health index are not subject of this paper, so they will be only briefly overviewed. To determine CB health index, it’s recommended to use one of the methods described in [1] and [2]. Although there are various methods to calculate CB health index, it’s important to realize that all the methods aim to the same goal i.e. assessment of CB current condition and its ability to continually operate without interruptions due to faults of CB internal nature. For that reason it makes sense to measure the parameters, which will have the most impact on health index calculation. This gives us not only great flexibility of implementation and simplicity in the measurement process (since we’re measuring only important parameters), but also enables to acquire the most information possible about CB condition, with the least measurement processes, which is important, if we’re designing vendor independent measurement/sensor system, that must not interfere with CB mechanical structure. In addition measuring parameters with the most impact on health index calculation is found useful, since the methods for CB health index calculation are continually being changed updated. In general every CB consists of next four parts:
- Interrupter chamber with main contact system.
- Supporting and insulation pole.
- Driving mechanism.
- Electrical signalling and insulation gas density sensor.

Each of this CB parts has parameters, which will show technical condition of the part. All parameters are theoretically measurable in online mode i.e. real time, but in practice that is not the case. In addition this parameters can be further categorized by method of measuring, whether they are measured invasively (interfering with
CB internal structure or structure of the relay protection for CB) or noninvasively.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement method</th>
</tr>
</thead>
<tbody>
<tr>
<td>maximum disengaging current</td>
<td>noninvasively / invasively</td>
</tr>
<tr>
<td>sum of maximum disengaging current</td>
<td>calculated value</td>
</tr>
<tr>
<td>number of disengaging operations</td>
<td>noninvasively / invasively</td>
</tr>
<tr>
<td>time of disengaging single pole</td>
<td>noninvasively / invasively</td>
</tr>
<tr>
<td>time of engaging single pole</td>
<td>noninvasively / invasively</td>
</tr>
<tr>
<td>time asynchronism between poles</td>
<td>calculated value</td>
</tr>
<tr>
<td>insulation gas pressure</td>
<td>invasively</td>
</tr>
<tr>
<td>temperature of the interrupter chamber</td>
<td>invasively</td>
</tr>
<tr>
<td>time of driving mechanism reaction</td>
<td>invasively</td>
</tr>
<tr>
<td>dynamics of contact kinematic parts</td>
<td>invasively</td>
</tr>
<tr>
<td>abrasion of contact system</td>
<td>invasively</td>
</tr>
<tr>
<td>coil energization time</td>
<td>invasively</td>
</tr>
<tr>
<td>operating time of driving mechanism</td>
<td>invasively</td>
</tr>
<tr>
<td>CB age</td>
<td>noninvasively</td>
</tr>
<tr>
<td>resistance of contact parts</td>
<td>invasively</td>
</tr>
<tr>
<td>condition of insulation system</td>
<td>noninvasively</td>
</tr>
<tr>
<td>condition of CB concrete foundation</td>
<td>noninvasively</td>
</tr>
</tbody>
</table>

Table 1: Important parameters for CB AHI calculations.

Universal CB measurement device that is also vendor independent is currently not available in the market today. Some measurement systems provide measuring of some parameters shown in table 1 [1], [2]. These systems are dependent on the vendor of the CB they are measuring and usually are using invasive methods. As said if substation contains multi-vendor CBs and the measurement devices are not measuring all important parameters, this presents a huge problem for AHI calculation and disables carrying out Reliability Centered Maintenance (RCM) methods.

**IED-Q0 MEASUREMENT DEVICE**

**The most important parameters for CB technical condition determination**

Common practice with CB maintenance among Transmission System Operators (TSOs) and Distribution System Operators (DSOs) is TBM with revision processes where key parts of CB are inspected. This updates the information about technical condition only when the CB is not operating, but unfortunately technical condition of CB is decreased during operation, which can lead to unexpected faults and additional expenses. Most faults on CB occur in the interrupter chamber as an abrasion of contacts due to high current disengaging or increased number of manipulations. Therefore this two problems can be identified as the critical parameters to be monitored in real time. For high current disengaging it’s possible to measure peak currents during disengaging process and for increased number of manipulations a device must monitor the number of disengagements. Maintenance instructions of many CB vendors, such as ABB [3], VATECH [4] and AREVA [5] are showing I-N curve, where technical condition of CB contact system in the interrupter chamber is determined by the sum of maximum disengaging currents (I) vs. number of disengaging operations (N). If certain value of I and N is reached CB interrupter chamber must undergo maintenance procedure. Device IED-Q0 is designed for measuring exactly these two parameters (sum of maximum disengaging currents and number of disengaging operations) in real time. As the device is meant to be independent, we used noninvasive method of measuring for both parameters.

**Measurements of disengaging currents and number of operations with IED-Q0**

IED-Q0 was designed as autonomous electronic measurement device, which is integrated locally inside relay houses on site. Currents measurements are taken on secondary protection core windings of the current measurement transformer in order to obtain peak values of disengaging currents. This measurement is done for each pole of the CB, therefore three measurements of disengaging currents are made (I1, I2 and I3) and an additional measurement of neutral wire (I0). As mentioned these measurement are done noninvasively, which means the sensors IED-Q0 is using to acquire values of the currents are not interfering with CB and relay protection mechanical or electrical structure nor do they have any feedback on them. IED-Q0 is using miniature current clamp sensors that are mounted on existing relay protection circuits. Relay protection circuits are connected to the secondary protection core windings, which are used by protection relay system for overcurrent protection of the CB. As such, the currents that are flowing through relay protection circuits, where sensors are measuring are reduced by the current measurement transformer ratio, which is usually from 1:600 to 1:1000. In Slovenian power grid most common measurement transformer ratio is 1:1000, on CB we can expect realistic disengaging currents up to 20 kA, anything more than that would destroy the CB after 20 to 30 manipulations. For IED-Q0 current clamp sensors we used Talema AC-1020, which are nominally operating at 20 A in linear area at proper loading of the clamp output [6]. Since the device will be operating in high voltage substations, EMI can occur. For that reason current clamp sensors are protected with robust case which is mounted at the base of the sensor and shielded cables are used for connection to IED-Q0 as shown in figure 1.
Also IED-Q0 itself is protected from EM interferences. All sensible electronics are placed in sealed metal box which acts as Faraday cage. IED-Q0 was successfully field tested in one of the Slovenian 110 kV relay substations.

Measurement of the currents in IED-Q0 is triggered by external CB disengagement trigger signal that comes from relay protection. Figure 2 shows integration of IED-Q0 in substation measurement system.

The trigger signal from relay protection starts about 60-80 ms after the fault happens, this is the time necessary for relay protection to characterize the fault. When this is done, trigger signal triggers sampling of the current by IED-Q0 microprocessor at time $t_0$. The current is then sampled for period of $t_0 + 300$ ms, which is the duration of disengagement process of the CB. During this period contacts in the interrupter chamber are moving apart, which causes an electric arc that is damaging the contacts and thus shortens CB lifetime. Most of the high current spikes during fault are happening in the first 100 ms of the disengaging process, depending on the type of CB. The currents have a frequency of 50 Hz, so values are sampled with sampling frequency of 5 kHz, which enables peak precision detection. For detecting current peaks the microcontroller program is using modified bubble sort algorithm, to obtain peak values while sampling, this is more efficient from the standpoint of microcontroller memory usage.

Triggering of the current measurements is done with trigger signal cables from relay protection. These are DC signals, that are set to logic 1 (230 V), when CB is opened or in the process of opening, or logic 0 (0 V) when CB is closed. It is important, that these signals do not have common ground (0 V) with the CB, but ground is separated, therefore IED-Q0 must not have any feedback effect on ground potential of relay protection.

For that reason IED-Q0 has optical isolated channels for each trigger signal, that galvanically separate trigger signals from relay protection from the rest of the electronics in IED-Q0. Each optical isolated channel has a breakdown voltage of 5 kV and is protected against voltage spikes with surge diodes.

Each trigger signal represents information about number of disengaging manipulations of the CB. This is counted in IED-Q0 every time when opening manipulation takes place.

**Local data displaying and communication with remote devices**

Device IED-Q0 has built in LDC display, to enable maintenance engineers on site reading of the measured values. The display can show four different screens with values of:

1. The last measured maximum disengaging currents per pole ($I_{L1}$, $I_{L2}$, $I_{L3}$) [A].
2. The sum of all measured maximum disengaging currents per pole ($\text{sum} I_{L1}$, $\text{sum} I_{L2}$, $\text{sum} I_{L3}$) [A].
3. The last maximum neutral disengaging current ($I_N$) [A].
4. The number of disengaging manipulations per pole ($N_1$, $N_2$, $N_3$).

Simple user interface can be found on the device front right panel. Pushbuttons offer options to backlight LCD, change between screens or delete all measured data, if a user provides an administration key. Back panel of the device has power switches, inputs for trigger signal cables, inputs for current clamp sensors, USB port for programming of microcontroller and an Ethernet port for TCP/IP communication with data concentrators or other remote devices. IED-Q0 front panel is shown on figure 3.
One of the features on IED-Q0 is also preprogrammed measurement data for CBs that are already operating in the grid. Even though CB historical condition data may not have been monitored, there are backwards interpolation methods that can approximate technical condition from revision measurements. This enables that even CBs, which are in operation for several years can be monitored with IED-Q0. Sending data to remote devices is crucial since, all the AHI calculations are usually done in IT systems, e.g. EAM system. IED-Q0 uses Ethernet communication module Wiznet W5100, which receives data from microcontroller via SPI protocol and sends it forward through Ethernet using TCP/IP protocol. In case of IED-Q0 the remote device on the other side is a data concentrator which receives the measured data from multiple IEDs.

**SYSTEM FOR MONITORING CIRCUIT BREAKERS CONDITION**

Devices IED-Q0 monitor each CB individually and locally. However when there is a need for monitoring multiple CBs across multiple substations, data collection can become more challenging. For that reason SMBC has been designed as a wide area monitoring and data collection system. Each substation has relay houses that contain all electronic measurement and protection equipment for CBs, including devices IED-Q0. Usually there is a fiber optic connection from these relay houses to substation’s local data servers in central communication room. IED-Q0 uses Ethernet port to transfer its data to the nearest Ethernet-to-Fiber media converter, which is mounted inside relay houses and forwards the data to concentrator located in central communication room. The data between IEDs and data concentrator are sent in an XML message format. The data concentrator collects measurements from all IEDs in the substation and sends them to remote EAM system (usually located in a data center) using standard SOAP protocol for Web Services. The transport layer in communication is TCP/IP all the way from IEDs to EAM. Figure 4 shows integration of IEDs and SMBC with an EAM.

When integrating system like SMBC with existing information systems the cybernetic security policy has to be taken into account. Such integration enables collection of wide are CB condition data in EAM, which can further execute AHI calculations in real time. This is the basis for CBM and RCM maintenance of CBs, where a CB has predetermined importance index depending on its significance to the power network. Based on CB technical condition and its importance index, it can be determined when the CB will need a revision or when it needs to be replaced. This ultimately reduces maintenance costs and prevents unwanted CB faults [7].

**CONCLUSION**

IED-Q0 was tested as a single device in laboratory (with CB simulator) and also in a relay substation under real conditions. All tests were successful, the parameters were measured correctly and data was sent to remote data concentrator. This concludes that the system is ready for long-term testing on CBs and to be integrated with an EAM system.

IED-Q0 doesn’t measure all the important parameters listed in table 1 yet, but the parameters that are currently implemented provide good estimation of when a CB should undergo revision, maintenance or replacement procedure, which is the core functionality of CBM. IED-Q0 is a first step to vendor independent device to online measurement of CB important parameters. With further development IED-Q0 will be upgraded to measure more CB condition parameters and using standard substation communication protocols, such as IEC 61850.

**REFERENCES**


