Modern Techniques for Monitoring Circuit Breakers by using Microcontroller System

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Abstract **- The paper deals with experimental monitoring system, developed by the authors, by using a microcontroller within the 8051 family, Dallas DS87C550. This micro-system has two main parts: the acquiring and transfer module and the user interface developed using the facilities specific to Graphic User Interface of Matlab®. The achievement such a way implies designing a hardware structure that meets the proposed functions in a versatile approach and programming of controller using its facilities. The electrical equipments, being characterized by small time constants and high risk, impose major efforts in order to develop competitive monitoring systems. On the other hand, the costs involved by such systems need to be as low as possible, without cutting the imposed performances. The possible functions of the experimental system are related to the monitoring of IO breaker using modern diagnostic methods: monitoring of the contacts condition, the computation equivalent switching number, the estimation of the insulating oil quality, monitoring the achieved service, the diagnostics of the weaken contact by vibration analysis technique and the dependence of voltage versus temperature on contact. The results are presented as graphical user interfaces developed by using the facilities of the software MATLAB. The interface is versatile and with ease allows the tracking of results after data processing.**

Keywords: *monitoring circuit breaker; microcontroller system; user interface.*

I. INTRODUCTION

The modern electric equipment includes performing on-line monitoring and diagnosis systems based on microcontrollers. The electrical equipment, being characterized by small time constants and high risk, impose major efforts in order to develop competitive monitoring systems.

This micro-system has two main parts: the acquiring and transfer module and the user interface, developed by using the facilities specific to Graphic User Interface (GUI) of Matlab®.

For the fastest and efficient behavior to the user's demanded functions, the acquiring and transfer module was programmed in assembling language, by using the complex interrupting system of the controller.

II. THE HARDWARE ARCHITECTURE

The hardware part of the monitoring system is centered on the Dallas micro-controller DS87C550. This type of micro-controller is code fully compatible with the 8051 family controllers, being equipped with many integrated peripherals that make it suitable for embedded applications.

More than that, being equipped with the high speed core specific to the Dallas controllers, the performances achieved by the hardware subsystem based on this module make it very suitable for the on-line monitoring of the high speed electrical equipment.

The acquiring and transfer module consists of the blocks: Sources, Controller, Local console, Inputs, Outputs and Serial communication interface (Fig.1) [1]

By the way of three precise voltage regulators, the Sources block supplies the regulated voltages to the micro system.

The Controller block is the core of the module and consists of the controller itself, the full duplex RS485 serial interface, connector to the 7 digits display, digital open collector output, that can be used for commanding a power element (relay), non-volatile serial EEPROM with 32 bytes, for saving adjusting parameters or essential events, 8 micro switches for possible changes of the system's functionality, LED for signaling the state of the system [2].

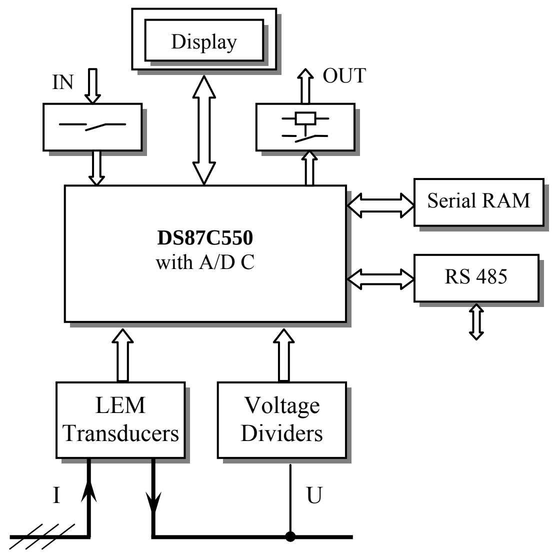

Fig. 1. The hardware structure of the experimental acquiring and transfer module.

In Fig.2 is presented the hardware subsystem [3].

In order to integrate the mentioned component in the hardware subsystem of the monitoring structure, specific to the electrical equipment, special transducers must be used.

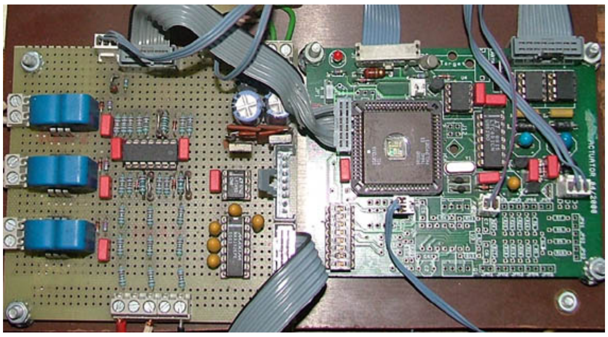

Fig. 2. The hardware subsystem.

III. Monitoring Methods of the Breaker Condition

When a fault occurs, the current must be interrupted quickly and reliably to avoid personal injuries and minimize damage. If a breaker fails to break the circuit, the resulting damage can be very serious indeed. Moreover, a needlessly large section of the power grid will have to be disconnected in order to interrupt the fault current.

A circuit breaker is the active link in the fault clearance string. Even though circuit breakers are comparatively reliable, faults can and do occur. Circuit breakers must thus be tested and maintained to ensure operation when a crucial need arises.

During its 40+ year service life, a circuit breaker must be constantly prepared to do its duty. Long periods of pause often elapse during which the breaker's mechanical parts never move. There are many reasons to maintain and test a circuit breaker. Friction and wear can affect the performance of movable parts. Leaks can occur in the valves and the seals used in arc extinguishing chambers, damping devices, pneumatic and hydraulic operating mechanisms. Faults can occur in electrical control circuits thus increasing the risk of excessive heat generation [10].

A circuit breaker should not be seen as a single component. It consists of several components including control circuits, interrupters, drive mechanisms, insulation and a wide range of ancillary equipment. Because circuit breakers can vary so much in design and application, it is essential to understand and identify certain circuit breaker properties to apply the proper testing, troubleshooting, and diagnostic and monitoring techniques.

The selection of monitoring methods for circuit breakers should be based on engineering and economic principles. Suitable monitoring can be selected by considering failure modes and their effects on the circuit breaker and on the power system, the degree of risk or criticality associated with failure, and the economics associated with each type of failure [9].

A. Monitoring of the contacts condition

In order to evaluate the technical condition of medium voltage circuit breakers it is important to know the electro-erosion state of the contacts. The value of the electro-erosion depends on the switching number and the values of the currents that were switched but also the duration of the electric arcs.

For medium voltage circuit breakers the electro-erosion mass m [mg] can be estimated with:

$$m = a \cdot I^{b} \cdot t_{a} \tag{1}$$

where,

I - the RMS of the disconnected current [kA];

t_a - the electric arc duration of the switching [ms];

a and *b* – the constants that depend on the nature of the material (example: copper - wolfram: a= 0.274; b = 1.81; copper: a = 2.15. b = 1.58).

The Table 1 presents the values for the electro-erosion mass m [g], the total electro-erosion mass m_t [g] and overestimation of the electro-erosion mass Δm [%] for the IO 12/2500 type breakers (1600 A rated current and 31.5 kA rated breaking current).

TABLE I.
ELECTRO-EROSION PARAMETERS FOR THE IO 12/2500 BREAKERS

I/N [kA/nr. switches]	m [g]	m_t [g]	Δm [%]
31.5/5	3.817	19.086	0
30/5	3.494	17.473	8.452
28/5	3.084	15.422	19.199
26/5	2.697	13.486	29.342
24/5	2.333	11.667	38.872
22/5	1.993	9.967	47.779
20/5	1.677	8.387	56.053
18/5	1.386	6.931	63.683
16/14	1.120	15.682	17.837
14/14	0.879	12.315	35.478
12/14	0.665	9.316	51.187
10/14	0.478	6.698	64.907
8/14	0.319	4.472	76.568
6/40	0.189	7.591	60.225
4/40	0.091	3.644	80.906
2/40	0.025	1.039	94.554
1.6/500	0.017	8.674	54.551

With the experimental system, the results of this monitoring method are presented in Fig. 3. The method can be accessed by activating the “Electro-erosion contacts” button.

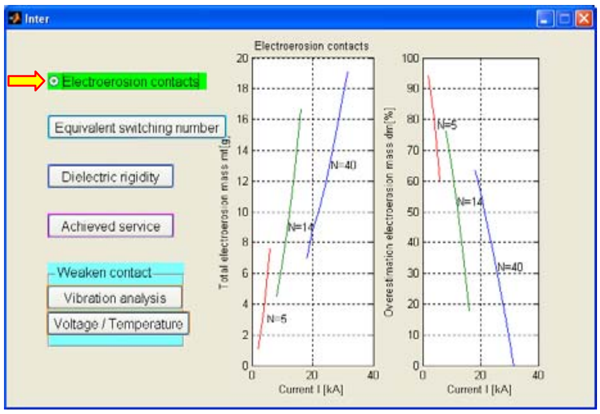

Fig. 3 The interface component “Electro-erosion contacts”.

B. The Equivalent switching number

The equivalent switching number can be calculated based on the ratio of disconnected current and breaking current. For medium voltage IO breaker type, the estimation of the equivalent switching number (N) can be done by using the relation [5]:

$$N = c \cdot \left(\frac{I_R}{I} \right)^d \qquad (2)$$

where,

I_R – the rated breaking current;

I – the disconnected current

c, d - the specific constant of the breaker type. For the IO 24/1250 breaker, $c = 6.77$, $d = 1.81$.

The results of the monitoring system after processing the experimental data are presented in graphical user interface plotted in Fig. 4. For activate this component of the interface, the "Equivalent switching number" button must be pressed.

Calculation of the Equivalent switching number depends on the breaker type. The supervision electro-erosion of the contacts is based on the maintenance diagram and based on the technological documentation for the sulfur hexafluoride (SF_6) breaker.

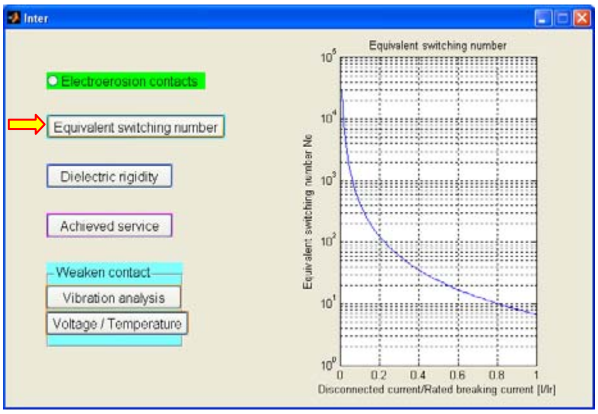

Fig. 4 The interface for the Equivalent switching number

C. The estimation of the insulating oil quality

Some factors that lead to failures during breakers operation include the quality depreciation of the insulating oil.

Therefore, decreasing the quality of the oil can be selected as the criterion for estimating the depreciation of the breakers performances. The main phenomenon which determines the quality depreciation of the oil is the electric arc during switching processes.

The value of the dielectric rigidity of the oil diminishes following an exponential allure, depending on the number of switches:

$$\frac{E_{d\ initial}}{E_{d\ x}} = e^{k \cdot N_x} \qquad (3)$$

where,

$E_{d\ initial}$ - the initial dielectric rigidity;

E_{dx} - the dielectric rigidity after N_x switches;

N_x – the number of switches;

k – the numerical factor which depends on the value of switched current.

For determining the k factor it must be taken into account that the ratio between the initial dielectric rigidity and the final dielectric rigidity corresponds to the estimated switching number of short-circuit current:

$$\frac{E_{d\,initial}}{E_{d\,final}} = e^{k \cdot N_e} \Big|_{I_{SC}} \qquad (4)$$

The relationship (4) allows the calculation of the k factor if are known the initial dielectric rigidity (example, 140 kV/cm), the final dielectric rigidity (example 60 kV / cm) and the estimated number of switching calculated with the relationship:

$$N_e = c \cdot \left(\frac{I_{r\,n}}{I_{SC}} \right)^d \qquad (5)$$

where, c and d are constants, specific to each type of breaker [4].

TABLE II.
PARAMETERS FOR DIFFERENT TYPES OF BREAKERS

Breaker type	*c*	*d*
IO- 12/630	3.785	1 .329
IO- 127 1250	4.151	1 .229
10-12/2500	6.246	1.345
10-24/630	4.71	1.525
IOM-24/630	3.3	2.06
10-24/1250	6.77	1.817
IUPM- 12/360	3.077	1.409
IUPM- 12/1 000	2.93	1.516
IUPM-24/630	4.224	1.355

The equation (3) shows that the depreciation of the insulating oil has not a linear dependency. So, if the breaker switches only the short-circuit current, the first breaking determines a strong decrease of the dielectric rigidity, the following switches having lower influence.

The processed experimental results are presented in the interface plotted in Fig. 5. The interface component is activated by pressing the "Dielectric rigidity" button.

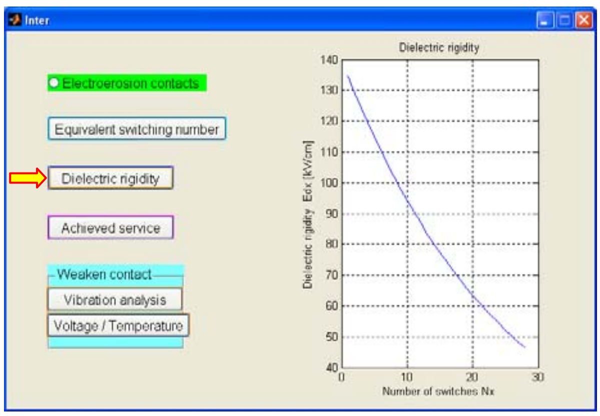

Fig. 5. The component interface "Dielectric rigidity".

D. Monitoring the achieved service

Based on Standard Operating Service indicated by the manufacturer, the disconnections of the breaker can followed by recording for each pole the value of the disconnected current. By using this value, the life time of the breaker can be reevaluated.

For the monitored breaker having the rated values: U_n = 12 kV, I_n = 2500 A, nominal breaking capacity I_{nr} = 25000 A, the Standard Operational Service gives the data shown in Table 3 [5].

TABLE III.
STANDARD OPERATIONAL SERVICE

Disconnected Current [% Inr]	X/R	Switches Number
15...20	3	28
45...50	7	20
90...100	14	10
Total switches		58

In accordance with the ANSI (Standard C37.61 - 1973) the equivalent services of the breaker can be calculated rising the RMS value of the interrupted current by the power 1.5.

Taking into account the allowed number of interruptions, based on the data in Table 3, breaker Equivalent Service (Table 4) can be calculated [5]:

TABLE IV.
BREAKER EQUIVALENT SERVICE

Current [A]	Equivalent Service / switch	Switches Number	Equivalent Service
5000	$5000^{1.5} = 35.3 \cdot 10^4$	28	$988.4 \cdot 10^4$
12500	$12500^{1.5} = 139.7 \cdot 10^4$	20	$2794 \cdot 10^4$
25000	$25000^{1.5} = 395.2 \cdot 10^4$	10	$3952 \cdot 10^4$
Total Equivalent Service			$7734.4 \cdot 10^4$

The total acceptable switches number for fault current can be estimated by considering the Total Equivalent Service from Table 4. So, for a fault current of 5000 A the total switches number is:

$$\frac{7734{,}4 \cdot 10^4}{35{,}3 \cdot 10^4} = 220 \text{ Switces} \tag{6}$$

Respectively,

TABLE V.
TOTAL SWITCHES NUMBER

Current [A]	Total switches number
5000	220
12500	55
25000	19

The monitoring of the achieved service refers to the dependency switching number vs. interrupted current (Fig. 6) for “Standard Service” and “Equivalent Service”. For any other value of interrupted current between 5000A and 25000A system allows determining the total switching

The component of Matlab interface is activated by pressing the “Achieved service” button (Fig. 6) [6].

E. The diagnostics of the weaken contact

Following a weaken contact, the strangulation of the current when passing through contact pieces becomes more accentuated. The heat through the electro caloric effect in the strangulation points, where high current density has values, causing local deformations that are manifested in the form of low amplitude vibration harmonics consist of integer multiples of the frequency power supply.

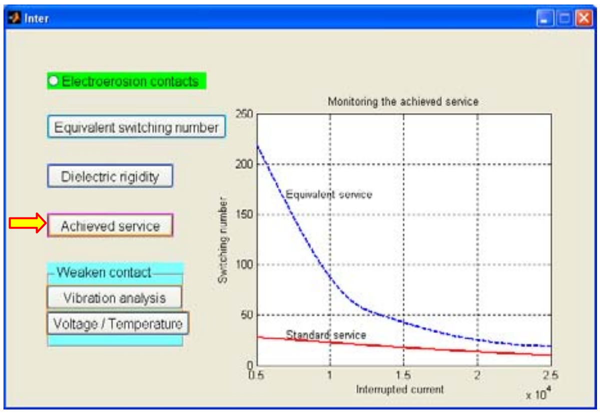

Fig.6. The interface of component “Achieved service”.

In order to determine the contact state, the vibrations that occur in the area of the contact are measured by using vibration sensors which are mounted on the cases of the contact assembly. The obtained signal is then processed by a frequency analyzer.

The corresponding component of the Matlab interface is “Weaken contact – Vibration analysis” (Fig. 7) [5] [7].

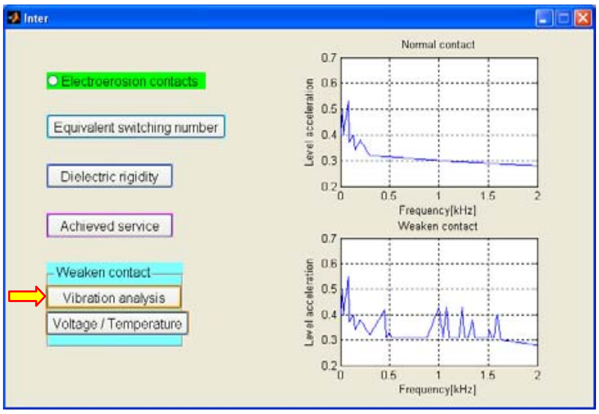

Fig.7. The interface of component “Weaken contact - Vibration analysis”.

There is a relationship between the energy of vibrations and contacts voltage. Table VI shows the dependency of the voltage drop on contact by the temperature of the metals that compose the electrical contact.

According to the measurements, the vibration energy is characterized by a step and indicates abnormal condition for the voltage about 0.1 V. Comparing this value with those in Table VI, one see that the step corresponds to the softening state of the metal. This moment precedes the instant when melting points (areas) occur on contact.

The corresponding component of the Matlab interface is “Weaken contact – Voltage / Temperature” (Fig. 8) [5].

F. The acoustic diagnosis of mechanical defects

The methods of monitoring the condition of circuit breakers is based on analysis and processing according to certain criteria of provenance records the acoustic - the acoustic signature - that records obtained by mechanical vibration of switching (inrush - tripping) followed breaker. This "signature" is compared to the reference considered,

TABLE VI.
VOLTAGE DROP ON CONTACT BY THE TEMPERATURE

Metal	Softening		Melting		Vaporization	
	Voltage [V]	Temp. [°C]	Voltage [V]	Temp. [°C]	Voltage [V]	Temp. [°C]
Al	0,1	150	0,3	600	-	2300
Fe	0,21	500	0,9	1539	-	2740
Ni	0,22	520	0,65	1452	-	2730
Cu	0,12	190	0,43	1083	0,97	2600
Zn	0,1	170	0,17	419	-	906
Mo	0,25	900	0,75	2620	1,1	4800
Ag	0,09	180	0,37	960	0,67	2000
W	0,4	1000	1,1	3390	2,1	5930

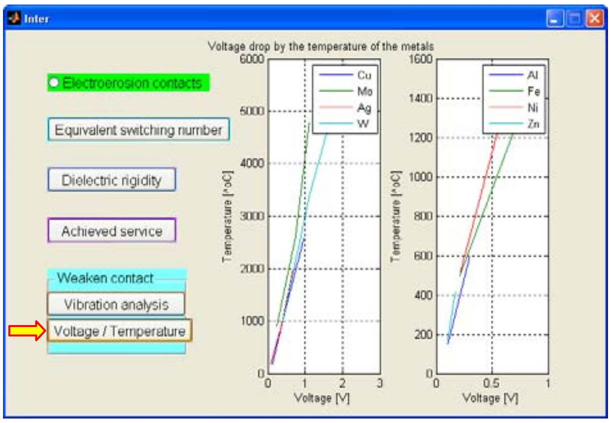

Fig.8. The interface of component "Weaken contact – Voltage / Temperature".

both in time and frequency domain to enable the highlighting of breaker abnormal operation.

Of the causes of shutting down the breakers are mechanical defects: misalignment, disturbances, course overruns, bent levers and rods deformed, cracked, broken, worn.

The reference signature can come from the previous registration at the same breaker or to another of the same type. The wear contacts, the mechanical damage and other abnormal behavior can be detected by changes of the acoustic signature breaker. The acoustic signature of a mechanism may be recorded with the accelerometers mounted on the outside pole and drive mechanism.

The results are easiest to interpret if a reference recording – often referred to as a reference signature– is available. This is simply a recording made when the breaker was known to be in good condition and operating correctly. The reference signature can be readily compared with subsequent recordings, with any significant changes indicating potential problems. If no reference signature is available for the specific breaker under test, the comparisons can instead be made with the reference signature of another breaker of the same type. This is however a compromise, not least because it is very different to be certain that the parameters for tests on two individual breakers – such as the exact placement of the accelerometers – are identical.

Particular vibration patterns are associated with specific mechanical events, such as the closing of the breaker's arcing contacts or main contacts. The time shift analysis looks for differences in the timing of these vibration patterns between the reference signature and the test recording. Deviation analysis looks for differences in the amplitude and frequency spectrum of the events.

Care must be taken in setting up and carrying out the tests if accurate and dependable results are to be obtained. In particular, the positioning of the accelerometers that pick up vibrations from the breaker is critical - changes in position of just a centimeter or two can make a big difference to the results. This also means that the positions used for the reference test must be clearly and indelibly marked, so that the accelerometers can be mounted in exactly the same positions for subsequent tests.

An important advantage is that the noise associated methods have immunity to electromagnetic noise. No external noise, such as from traffic, for example, has no influence, noting that both measurements made in the station, as well as those carried out in laboratory conditions, the signal / noise ratio is 60 dB.

G. Static contact resistance

Static contact resistance is measured by injecting a DC-current through the breaker and measure the voltage drop over the contact or joint that is of interest. The IEC standard requires a current of at least 50 A DC. The ANSI standard says minimum 100 A DC. Some manufacturers recommend 10% of the rated current for the breaker [11].

There are several reasons for using a high test current. At low currents the measured values will be the same provided that the resistance is linear vs. the current. The risk is that low currents might give too high resistance values at some instances.

Such cases can be grease on the contact surface or a polluted contact from rest products from several breaks of rated current. The references values given by the manufacturers are static resistance values.

CONCLUSIONS

The on-line monitoring of the equipments is an actual concern due to the necessity of higher reliability in all the domains of the industry. The electrical equipments, being characterized by small time constants and high risk, impose major efforts in order to develop competitive monitoring systems. On the other hand, the costs involved by such systems need to be as low as possible, without cutting the imposed performances.

If a maintenance strategy that is strictly corrective is adopted, no attempts are made to deal with a developing circuit breaker fault before it becomes fatal. This does not, however, ensure the reliable supply of electric power that consumers are entitled to expect. Short-term savings in maintenance costs will soon be eaten up by the cost of the damage and the cost of correcting faults. In periodic maintenance, a number of specific measures are taken at predetermined times, regardless of the conditions under which a circuit breaker operates. If this method is applied too strictly, however, it may lead to needless intervention.

Disassembling a circuit breaker that has no faults entails needless expense, and it does not improve reliability.

The paper described the main structure of a monitoring system that is mainly composed of two parts: the field systems and the central unit. The field systems are generally dedicated to a certain part of the equipment and consist of specialized sensors, transducers, adapters and signal conditioners that acquire information about the monitored process, digitized it and store in a local computer.

The experimental system was used for the IO 12/2500 breaker monitoring, by using modern diagnostic methods: monitoring of the contacts condition; the equivalent switching number; the estimation of the insulating oil quality; monitoring the achieved service; the diagnostics of the weaken contact by vibration analysis technique. The experimental results were processed and presented in a graphical user interface in MATLAB.

Based on the results of the experimental system, several considerations related to the lifetime of the circuit breaker can be done. Depending on the monitored parameters, the GUI allows the monitoring methodology to be selected.

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