New Approach Regarding the Electroerosion Estimation of the Circuit Breakers Contacts

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Abstract: - In the estimation of the circuit breakers technical state, it is very important to knows its contacts electroerosion. The electroerosion depends on the following main parameters: switching number realised, currents values that have been switched, existence time of electric arc at each switching. Electroerosion estimation of the contacts realised in operation leads to an overestimation inducing a supplementary maintenance. Thus it is necessary an evaluation of short-circuit currents in the mounting place of circuit breakers from electrical installations and a reconsideration of switching number at short-circuit of its. In this paper is shown an experimental model of an embedded intelligent system for the technical state evaluation of the switchgears contacts, from electroerosion point of view. This approach has the advantage that the architecture can be used, also, for the monitoring of the some cinematic parameters for the operating mechanism, like as: closing/opening velocity, closing/opening time, the stored energy in the operating mechanism and others.

Key-Words: - Circuit breaker, Contacts electroerosion, Contacts wearing, Intelligent system, Microcontroller.

1 Introduction

The costs of maintenance activities of the circuit breakers are important parts of delivery cost of electrical energy.

In order to make a maintenance activity with low cost we should make a predictive maintenance, [1]. The predictive maintenance implies to realise a diagnosis of the technical state of the equipment before take the decision to make the maintenance.

The diagnosis for the circuit breaker requires knowing some parameters (electrical, mechanical, thermal) which offer us information about the technical condition of equipment.

The thermal stresses of the switchgear contacts are given, in special mode, by the electric arc effect. The electric arc, which burns between contacts at the disconnection of the circuits crossed by the current, is an autonomous discharge characterised through: high current density and high conductivity, high temperature, reduce potential gradient etc

During of electric arc a part from the energy developed in its column is ceded to contacts. This will heat till the temperatures, which can reach their melting temperatures, respective volatilisation of the contacts materials. In this way appears the contacts electroerosion which increases at high energy developed in the arc column. The electroerosion depends on the thermal and electrical proprieties of contact's materials.

In the technical state evaluation of the switchgears, it's very important to know the contacts' quality, from the point of view of their electroerosion.

The electroerosion depends on the switching number and the currents values at which these switching have been realised, the arc time of each switching, but not only. Also, the thermo-physical parameters of the contacts' materials, the environment type from the arc extinction chamber and the ambient temperature have a great importance in the technical state evaluation of the switchgears contacts, [2].

In the case of DC switchgears, in order to avoid to contacts electroerosion, is enough to use materials with high melting temperature.

For AC switchgears, the usage of some materials with very high melting temperature has the disadvantage that maintains, in current's delay, a high temperature of the contact which creates favourable conditions for arc re-ignition in the next semi-period. From this reason, the wolfram usage, as material in construction of contacts circuit breakers is recommended only if it is associated with a high speed of the movable contact, in order to decrease the electric arc temperature through its stretching.

2 Estimation methods for the contacts electroerosion

2.1 Mass wearing's analysis of the contacts

The electric arc between circuit breaker contacts makes a contacts electroerosion (material transportation from cathode) which depends on the current and the developed energy in column of arc, respectively, [3].

The material's volume evaporated from cathode is direct proportional with the power developed at cathode and inverse proportional with the latent melting and vaporisation heat of the material:

$$V = k\frac{u_k \cdot i}{\lambda_m + \lambda_v}, \quad (1)$$

where: u_K is voltage drop at cathode, i- current intensity through electric arc, λ_m, λ_v- latent melting and vaporisation heat, k- proportionality factor.

For a known material, the parameters k, u_k, λ_m, λ_v are constants, while the relation (1) for the time t_a (the existence time of electric arc), will have the shape:

$$V = k\int_0^{t_a} i \cdot dt, \quad (2)$$

where: i is the interrupted current in [kA], t_a– the existence time of the electric arc in [ms], k-material constant.

For silver, Holm establishes that k = 123.10^{-12} [m^3/C]. A part form the vaporised material will remain on contact, because of metal steams condensation.

Considering the total wearing of the both contacts affected by the electroerosion, V_{tw}, the behaviour time of switchgear (circuit breaker) represented through the switching number N, it determinates with relation:

$$N = \frac{V_{tw}}{v_s} = \frac{V_{tw} \cdot \gamma}{m_s}, \quad (3)$$

where v_s is the volume of migrated material at a switching, (it will considers just the electroerosion caused by the disconnection), m_s- material's mass (mass wearing) migrated at a switching, γ- mass density of contact's material.

In the case of HV circuit breakers for which the extremities of the electric arc remain practically fixed on the surface of moveable and stationary contacts on the existence time of the electric arc, the mass wear m, expressed in [mg], is given by the relation:

$$m = a \cdot I^b \cdot t_a, \quad (4)$$

where: I is the RMS value of the breaking current in [kA], t_a– the existence time of the electric arc in [ms], a, b-constants that depend on the contacts' material (for example, in the case of copper-wolfram contacts, a=0,274, b=1,81; copper - a=2,15, b=1,58).

Fig. 1 shows the evolution of mass electroerosion, m, for Cu-W contacts of a circuit breaker, considering the existence time of electric arc as being one, two or three semi-periods., [4].

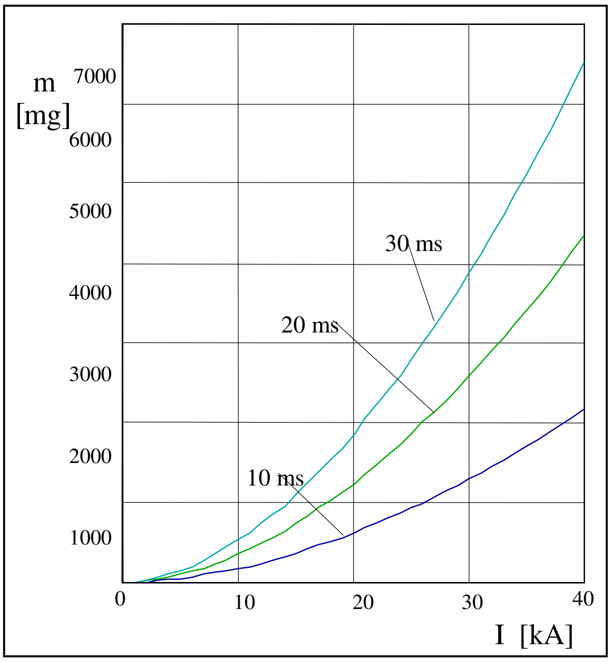


Fig. 1 Mass wearing

2.2 Linear wearing's analysis of the contacts

The maximum linear wearing (W_l) of some SF_6 circuit breakers contacts is approximately 7 mm, and it is reached after the admissible number of switching at a certain value of short-circuit current (for example 8 switchings at rated short-circuit current of 40 kA).

In order to calculate the contact electroerosion it can use the relation:

$$W_l = \sum_i c \cdot I_i^d \cdot t_{ai}, \qquad (5)$$

equivalent with relation (4), where c and d are constants that depends on the contacts' material and their shape, I_i- RMS value of interrupted current at disconnection i, t_{ai}-the existence time of electric arc at disconnection i.

Taking in consideration the maintenance diagrams, Fig. 2 and Fig. 5, for the SF_6 circuit breakers of H14P40 type, results for the constants c and d the values: c = 0,1562; d = 1,5396. These values are obtained considering the existence time of electric arc of 20 ms, conform with the technical features of the circuit breaker [2].

Table 1 Relative electroerosion of SF_6 circuit breaker of H14P40 and H17P40 types

U*		I_{SC} [kA]							
		40	35	30	25	20	15	10	5
N	5	0,651	0,530	0,418	0,316	0,224	0,144	0,077	0,026
	10	1,303	1,061	0,837	0,632	0,448	0,288	0,154	0,053
	15	1,955	1,592	1,256	0,948	0,672	0,432	0,231	0,079
	20	2,607	2,123	1,674	1,264	0,897	0,576	0,308	0,106
	25	3,259	2,653	2,093	1,581	1,121	0,720	0,385	0,132
	30	3,911	3,184	2,512	1,897	1,345	0,864	0,463	0,159
	35	4,563	3,715	2,930	2,213	1,570	1,008	0,540	0,185
	40	5,214	4,246	3,349	2,529	1,794	1,152	0,617	0,212
	45	5,866	4,776	3,786	2,846	2,018	1,296	0,694	0,239
	50	6,518	5,307	4,186	3,162	2,243	1,440	0,771	0,265
	55	7,170	5,838	4,605	3,478	2,467	1,584	0,849	0,292
	60	7,822	6,369	5,024	3,794	2,691	1,728	0,926	0,318
	65	8,474	6,899	5,442	4,111	2,916	1,872	1,003	0,345
	70	9,126	7,430	5,861	4,427	3,140	2,017	1,080	0,371
	75	9,777	7,961	6,280	4,743	3,364	2,161	1,157	0,398
	80	10,429	8,492	6,698	5,059	3,589	2,305	1,235	0,425
	85	11,081	9,023	7,117	5,376	3,813	2,449	1,312	0,451
	90	11,733	9,553	7,536	5,692	4,037	2,593	1,389	0,478
	95	12,385	10,084	7,954	6,008	4,262	2,737	1,466	0,504
	100	13,037	10,615	8,373	6,324	4,486	2,881	1,543	0,531

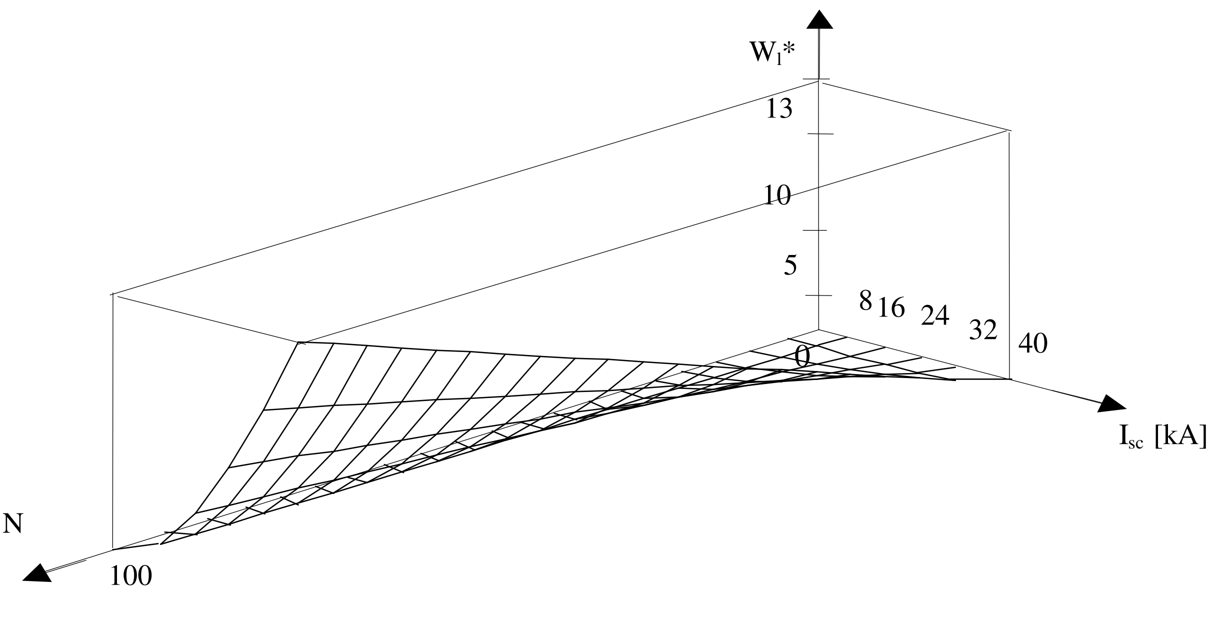


Fig. 2 Evolution of relative electroerosion W_l* vs. switching number at short-circuit and vs. values of fault current

In [3] has been proposed the following expression for the electroerosion in relative units, W_l*, of the breaking contacts:

$$W_l^* = \frac{\sum_i c \cdot I_i^d \cdot t_{ai}}{W_{\max}}, \qquad (6)$$

where W_{max} is maximum electroerosion of contacts.

In Table 1 are presented the values of the electroerosion in relative units W_l* vs. the value of disconnected short-circuit current. I_{sc} and vs. the switching number realised, N. Values of the relative electroerosion W_l* over 1,0 indicates the reaching of the maximum admissible switching at indicated value of the current.

The evolution of relative electroerosion W_l* vs. the same parameters can be observed in Fig. 2.

Fig. 3 shows the evolution of mass (curve 2) and linear (curve 1) electroerosions given by the relations (4) and (5) relative to the electroerosion obtained at the disconnection of a current of 40 kA, for H14P40 type circuit breakers. It observes a very small error between these curves, fact that validates the expression (5) for the estimation of electroerosion.

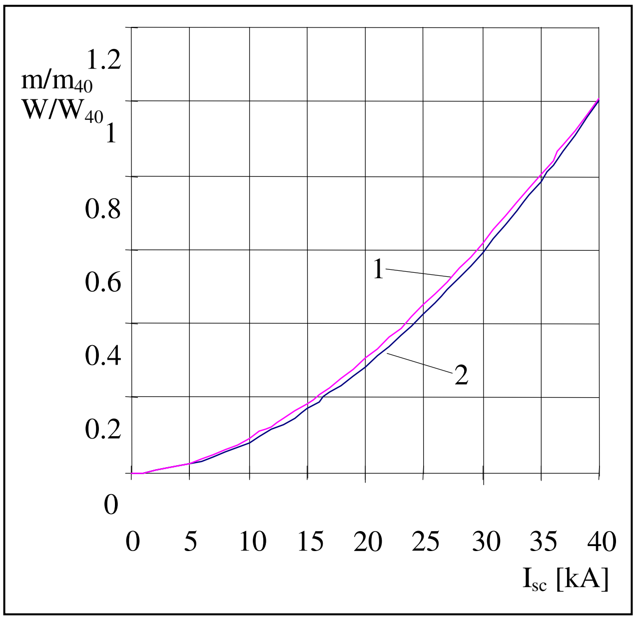


Fig. 3 Mass and linear wearing

2.3 Switching number's analysis of circuit breakers

In order to appreciate the electroerosion effect of contacts and the switching number of circuit breaker, respectively, some relations which don't take in consideration the existence time of electric arc, are used.

In this sense, Fig. 4 shows an equivalent number of breaking operations as a function of breaking current for a SF_6 puffer type circuit breaker.

N_e represents an equivalent number of breaking operations which has the same effect such as a single breaking operation under $0,5I_R$ (where I_R is rated breaking current of circuit breaker and I breaking current).

For values under $0,35I_R$, N_e is calculated with following relations:

$$N_e = 1,83\left(0,35\frac{I_R}{I}\right)^3, \qquad (7)$$

and for values above $0,35I_R$ with:

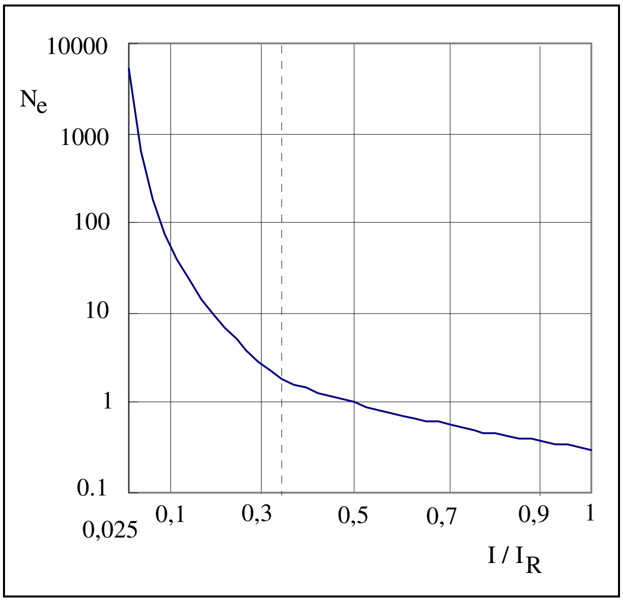


Fig. 4 Equivalent number of breaking operations as a function of breaking current for a SF_6 puffer type circuit breaker

$$N_e = \left(0,5\frac{I_R}{I}\right)^{1,7}. \qquad (8)$$

For the monitoring of contacts electroerosion some electrical equipment constructors give us the maintenance diagrams as functions of breaking current.

Fig. 5 shows the maintenance diagram for the 123 kV circuit breakers with SF_6, type H14P40, where they are: n-the number of switching; I_R-rated breaking current. It remarks that the limit number of switching at I_R of 40 kA is 8, [4].

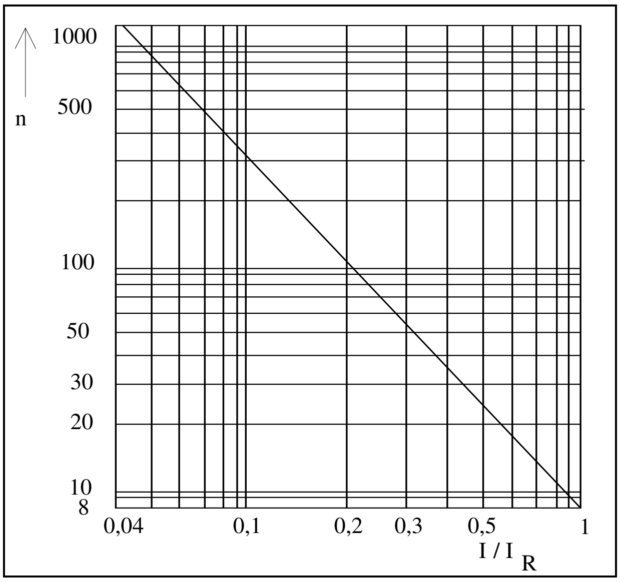


Fig. 5 Maintenance diagram for the HV circuit breaker with SF6 type H14P40

If we know exactly the existence time of electric arc and evolution of breaking current, we may have a very good knowledge about the contacts electroerosion. Starting from this aim we have proposed a method to estimates these parameters.

3 New possibility to estimate the contacts electroerosion

Fig. 6a shows the place of circuit breaker in electrical substation, while Fig. 6b shows the equivalent electrical scheme, [5].

The current through circuit breaker is monitored using a current transformer T_C. In the case of short-circuit, the image of this in the secondary winding of transformer is affected by error, Fig. 7, caused by the saturation of magnetically circuit.

The short-circuit current is:

$$i_k(t) = \sqrt{2} I_k \left[\sin(\omega t - \alpha) + e^{-\frac{t}{T}} \sin \alpha \right], \qquad (9)$$

where: I_k - the RMS value of permanent short-circuit current; α- the switching angle; ω=2πf, f - the current's frequency; T - the time constant of electrical circuit.

By derivation of relation (9) it obtains:

$$\frac{di_k}{dt} = i_k^{'}(t) = \sqrt{2} I_k \left[\omega \cdot \cos(\omega t - \alpha) - \frac{1}{T} e^{-\frac{t}{T}} \sin \alpha \right] \qquad (10)$$

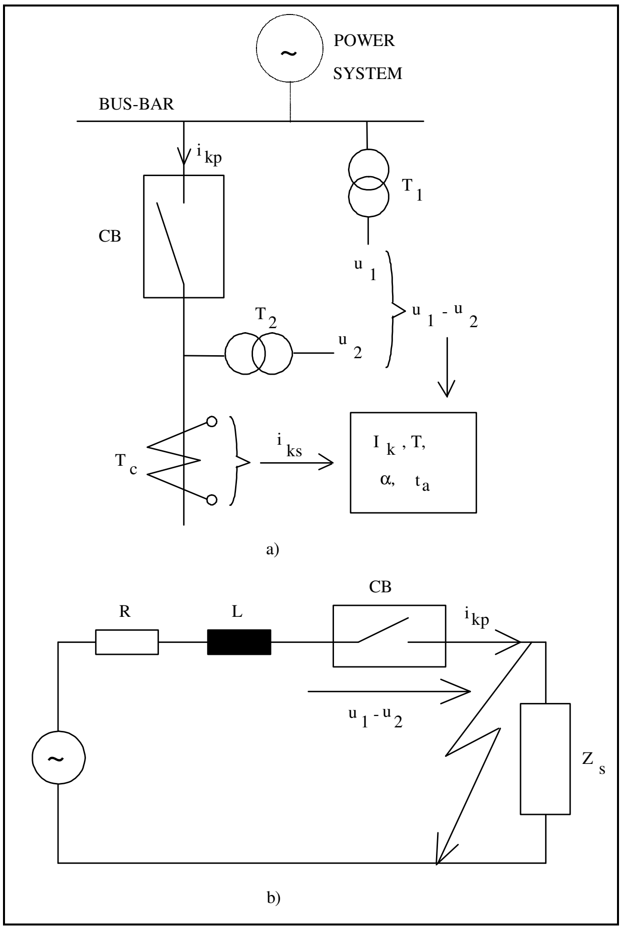


Fig. 6 Place of the circuit breaker in electrical substation

Adding relation (9) with T•(10) we have:

$$i_k + T \cdot i_k^{'} = \sqrt{2} I_k [\sin(\omega t - \alpha) + \omega T \cos(\omega t - \alpha)] \qquad (11)$$

We supposed a small pre-established value i_o of current which isn't affected by the saturation of magnetically circuit and we measured the time intervals t_1, t_2, t_3 between the beginning moment of short-circuit current and the touching moment of i_o current, when $di_k / dt > 0$, Fig.7.

Under these conditions from relation (11) we may obtain the equations system:

$$\begin{cases} i_0 + T \cdot i_1^{'} = \sqrt{2} I_k (\omega t_1 - \alpha + \omega T) \\ i_0 + T \cdot i_2^{'} = \sqrt{2} I_k (\omega t_2 - \alpha + \omega T), \\ i_0 + T \cdot i_3^{'} = \sqrt{2} I_k (\omega t_3 - \alpha + \omega T) \end{cases} \qquad (12)$$

where:

$$i_j^{'} = \left.\frac{di_k}{dt}\right|_{t=t_j}, \qquad j = 1, 2, 3. \qquad (13)$$

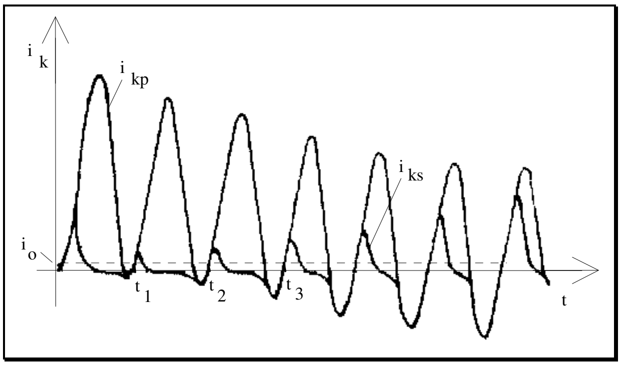


Fig. 7 Short-circuit current and its image in the secondary winding of current transformer

After solving the equation system (12) we obtain I_k, T, α and considering the transformer ratio of T_c we will obtain the evolution of short-circuit current in the primary winding of current transformer.

Fig. 8 shows some results for comparison the evolution of short-circuit current determined experimental respectively the numerical results after using the presented method.

The existence time of electric arc is determined knowing the beginning moment and extinction moment of electric arc, [6]. The beginning moment isn't discerned from the current curve but is possible by monitoring of the differential voltage u_2 - u_1 from secondary windings of voltage transformers T_2, T_1, Fig. 6a. The extinction moment is simultaneously with the breaking of short-circuit current.

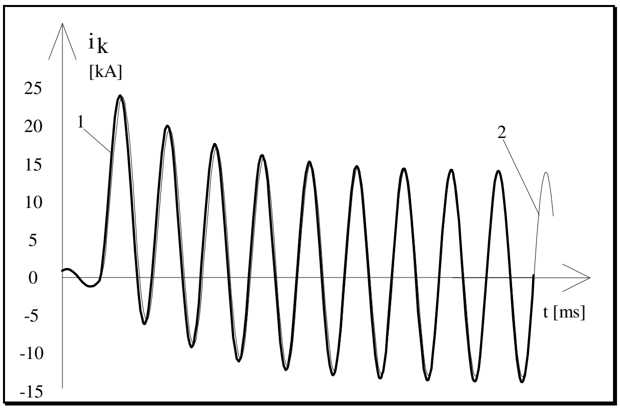


Fig. 8 Evolution of short-circuit current: 1-experimental, 2-numerical

Using determined parameters it is possible to know more exactly the arc contacts electroerosion at an interruption and the energy developed in the column of electric arc.

4 Requirements of an intelligent system

Through an embedded intelligent system it means an object (device, equipment) manufactured which interacts with its environment. For this interaction, it takes the required energy from environment that will be converted in mechanical energy and heat, or it manipulates information, [7], [8].

The intelligent systems interact with their environment using some inputs (information, energy, material, mechanical action of the environment to equipments) and some outputs (information, energy, actions executed by the equipments to the environment).

The intelligent structures can operate individually or connected in other systems. In this last case, the global performances of those systems are better than sum of performances of each equipment included.. Also, the intelligent structures can operate autonomous, without a total human control, but with the possibility to collaborates with this.

From different types of intelligent structures, the most adequate is that of network type, shown in Fig. 9.

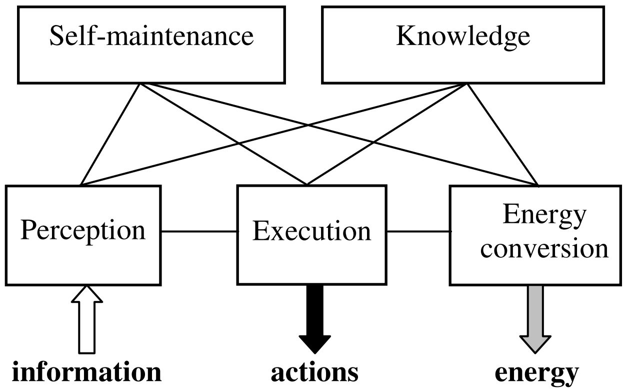


Fig. 9 Intelligent system's architecture

This architecture has the functions set which is included in every intelligent system. Thus, an intelligent system has the following basic subsystems::

- *perception subsystem*, which has the task to acquires, save, process and delivers the information about the status of structure and of environment where it operates;

- *knowledge subsystem*, which evaluates the acquired information by the perception subsystem and plans the structure's actions;
- *execution subsystem*, responsible with all equipment's actions, on the base of those two subsystems. After how it can see in Fig. 10, the received instructions from the knowledge subsystem determinate the planned behaviour, while the information received from perception subsystem determinate the reactive behaviour. Generally, the last is predominant.
- *self-maintenance subsystem*, has the role to maintains the equipment in good conditions of operation. This subsystem ensures an intermittent monitoring of equipment's behaviour in order to prevent eventual failures (preventive self-maintenance) or to alarm immediately when its appear (self-diagnostic). In particular cases the self-maintenance could means even self-repairs.

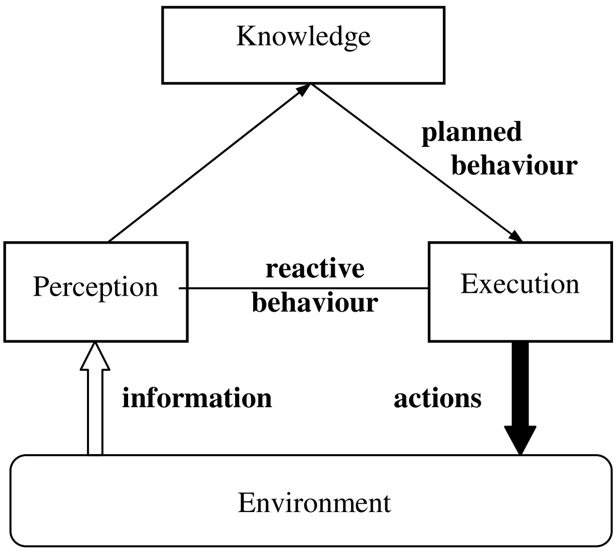


Fig. 10 Reactive and planned behaviour

- *subsystem of energy conversion* ensures the quantity and the shape of required energy in order as all subsystems to operates in good conditions. The real components from those subsystems are sensors, actuators, microprocessors, communication networks, input/output devices, energy sources etc.

Having in view those above presented, Fig. 11 shows the basic functions of an intelligent hardware/software structure.

It doesn't exist general methods to determinate the boards between perception, knowledge and execution. These distinct functions of an intelligent structure are not compulsory implemented as real components or different subassemblies.

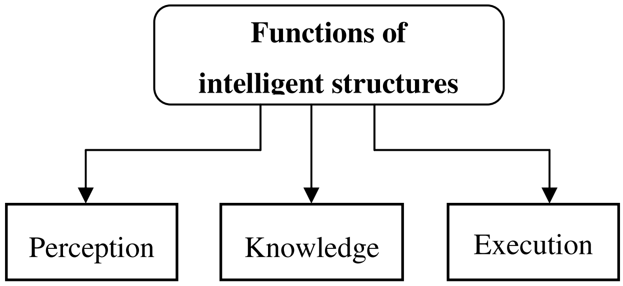


Fig. 11 Basic functions of an intelligent system

The perception function ensures the required information about the status of the system and environment where this operates. In order to realise this function the sensors and data acquisition are used. The acquired data are organised and pre-processed in order to reduce the incertitude regarding the status of equipment and environment.

The knowledge function has the purpose to plan and initiate the equipment's actions, taking in consideration the information ensured by the perception. The knowledge has in view to takes some decisions regarding the actions which will be realised by the equipment In any moment, the knowledge subsystem is in front of a multitudes of future possible stages of the equipment. Through this function, it choice the best evolution of the equipment, which to ensure the advantages on long term (having various expressions as minimum cost of material, resources, energy, minimum risk of failure etc.).

The execution function initiates, control, carry on and finish the equipment's action, on the base of information received from knowledge and perception. The equipment's actions represent its interaction with its environment.

In the structure of execution subsystem can be used elements having static switch (semiconductors components, static contactors) or dynamic (actuators, electromagnetic contactors etc.).

5 Embedded intelligent system

The RISC (Reduced Instructions Set Computer) microcontroller is a powerful tool that provides a highly flexible and cost-effective solutions to many embedded monitoring and diagnostic systems, [9], [10].

The architecture has been made around of an Atmel ATmega128 AVR microcontroller, [11]. with principle scheme presented in Fig. 12.

Fig. 13 shows the experimental model of the proposed intelligent system which can acquire the parameters required for the electroerosion evaluation.

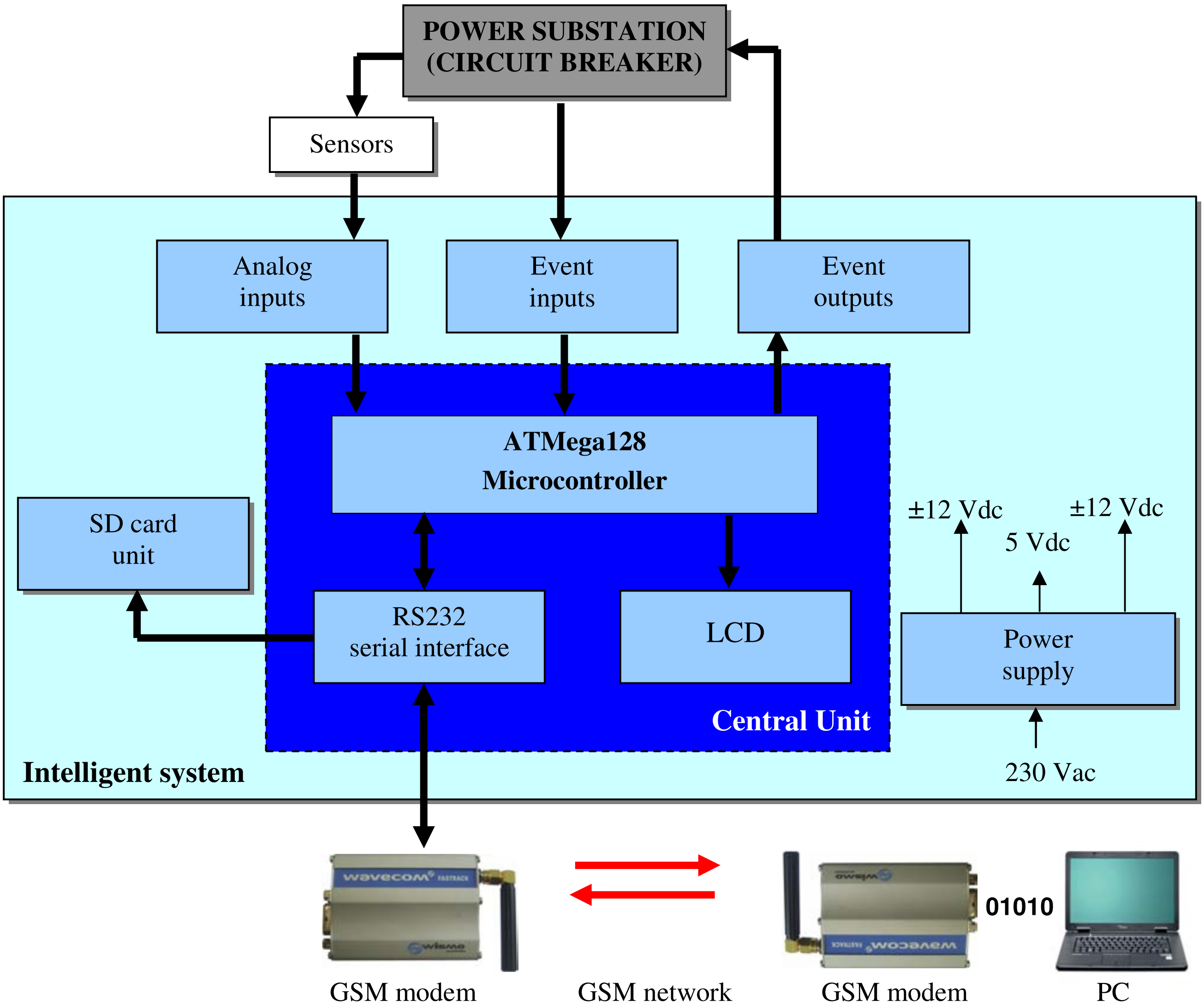


Fig. 12 Principle scheme of embedded intelligent system

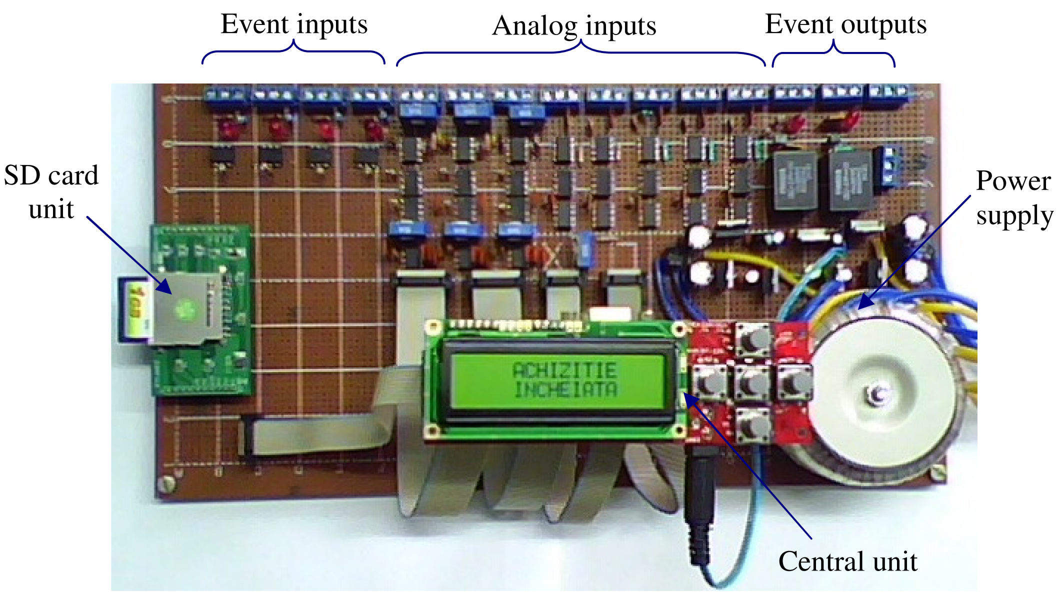
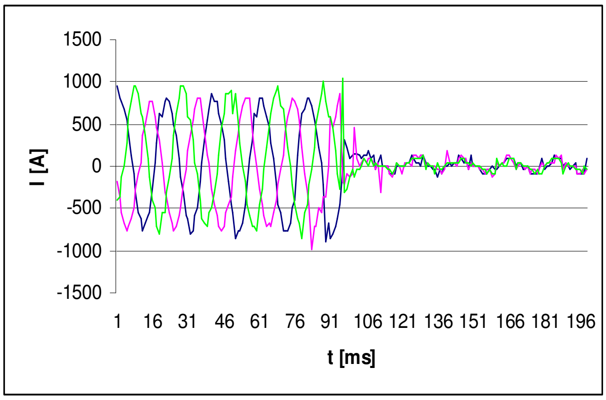


Fig. 13 Experimental model



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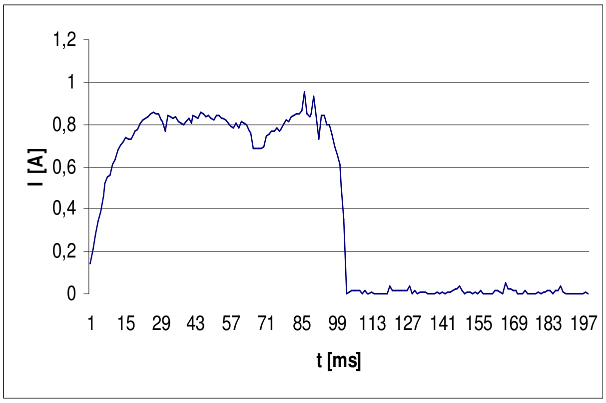

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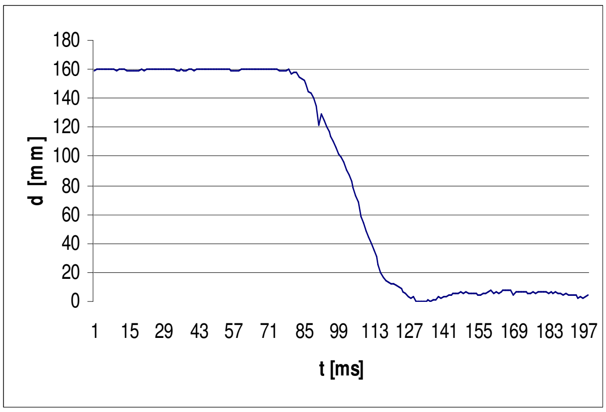
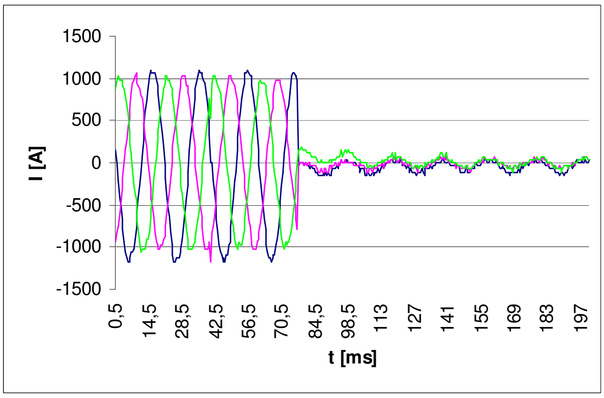


c)

Fig. 14 Acquired parameters using the experimental model: a) phase currents; b) current through trip coil; c) travel curve at the opening of the circuit breaker

The intelligent system is capable to acquire and other parameters necessary for the monitoring and diagnostic of a circuit breaker. It has been tested on a MV circuit breaker with rated voltage of 24kV and rated current of 1250A. In Fig. 14 are shown some of the parameters recorded by the intelligent system at the trip command.



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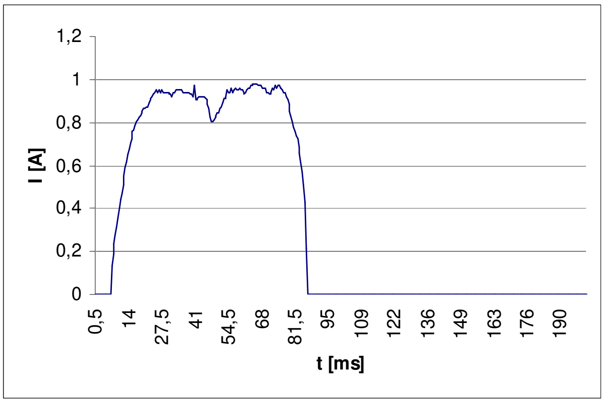

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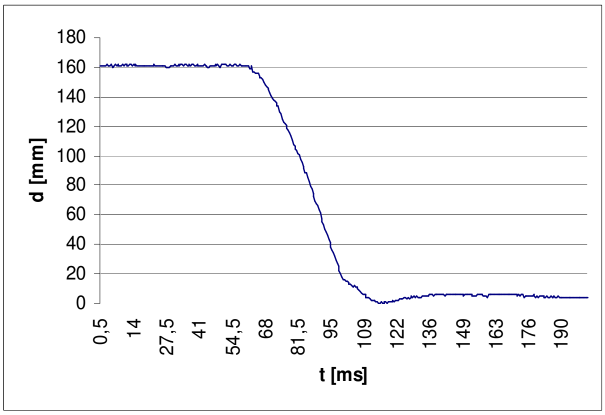

c)

Fig. 15 Acquired parameters using BCM 200 system: a) phase currents; b) current through trip coil; c) travel curve at the opening of the circuit breaker

In order to estimates the performances of the intelligent system, the same parameters have been acquired on the same circuit breaker using BCM 200 system made by Hathaway (USA), Fig.15.

Analysing the acquired data, it can observes a good similitude between both systems.

The embedded intelligent system allows to saving the curves on an SD card for ulterior processing. Also, it is capable to transmit alarms and information regarding the status of circuit breaker using a wireless communication (GSM modem in this case).

This approach has the advantage that the architecture can be used for the monitoring of the some cinematic parameters for the operating mechanism like as: closing speed, opening speed, closing time, opening time, the stored energy in the operating mechanism and others, [12].

6 Conclusion

The estimation of contacts electroerosion is realised in operation knowing the switching number, but it don't takes in consideration the RMS value of short-circuit currents The maintenance required by the contact replacement will be realised much more frequent, because the electroerosion isn't always at the maximum admissible value.

Thus, it is necessary an evaluation of short-circuit currents in the mounting place of circuit breakers from electrical installations and a reconsideration of switching number at short-circuit of its.

The paper presents few methods for electroerosion estimation (mass wearing's analysis, linear wearing's analysis, switching number's analysis) and also a new method which allows to determinate the short-circuit current's parameters and the existence time of electric arc. In order to acquire these parameters, an experimental model of an embedded intelligent system has been proposed.

This approach has the advantage that the architecture can be used, also, for the monitoring of the some cinematic parameters for the operating mechanism like as: closing/opening velocity, closing/opening time, the stored energy in the operating mechanism and others.

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