New possibility for the electroerosion estimation of the circuit breakers contacts

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Abstract: - Electroerosion estimation of the contacts realised in operation leads to an overestimation inducing a supplementary maintenance. In this paper is shown an architecture with microcontroller 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 speed, opening speed, closing time, opening time, the energy accumulated in the operating mechanism and others.

Key-Words: - contacts electroerosion, circuit breaker, architecture, microcontroller, embedded system.

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. 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 to know 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 a 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.

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 Estimation methods for the contacts electroerosion
The electric arc between circuit breaker contacts makes a contacts electroerosion which depends on the current and the developed energy in column of arc, respectively, [1].

The material’s volume resulted under the influence of the current interruption is calculated with:

\[ V = k \int_{0}^{t_a} i \cdot dt, \]  

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

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:
\[ m = a \cdot I^b \cdot t_a, \]  

(2)

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, \( a=0.274, b=1.81 \)).

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. 1 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 \( 0.5I_R \) (were \( I_R \) is rated breaking current of circuit breaker and \( I \) breaking current).

For values under \( 0.35I_R \), \( N_e \) is calculated with following relations:

\[ N_e = 1.83 \left( 0.35 \frac{I_R}{I} \right)^3, \]  

(3)

and for values above \( 0.35I_R \) with:

\[ N_e = \left( 0.5 \frac{I_R}{I} \right)^{1.7}, \]  

(4)

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

Fig. 2 shows the maintenance diagram for the 123 kV circuit breakers with SF\(_6\) manufactured in Romania where they are: \( n \)-the number of switching; \( IR \)-rated breaking current. It remarks that the limit number of switching at IR of 40 kA is 8, [3].

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. 3a shows the place of circuit breaker in electrical substation, while Fig. 3b shows the equivalent electrical scheme.

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. 4, caused by the saturation of magnetically circuit.

The short-circuit current is:

\[ i_k(t) = \sqrt{2}I_k \left[ \sin(\alpha t - \alpha) + e^{-\frac{t}{\tau}} \sin \alpha \right], \]

(5)

where: \( I_k \) - the effective value of permanent short-circuit current; \( \alpha \)- the switching angle; \( \omega=2\pi f \),
f - the current frequency; T - the time constant of electrical circuit.

![Diagram of a power system with a circuit breaker.](image)

By derivation of relation (5) it obtains:

$$\frac{di_k}{dt} = i'_k(t) = \sqrt{2}I_k \left[ \omega \cdot \cos(\alpha - \alpha) - \frac{1}{T} e^{-\frac{t}{T}} \sin \alpha \right].$$  \hspace{1cm} (6)

Adding relation (5) with T\(\cdot\)(6) we have:

$$i_k + T \cdot i'_k = \sqrt{2}I_k \left[ \sin(\alpha - \alpha) + \omega T \cos(\alpha - \alpha) \right].$$  \hspace{1cm} (7)

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 \(\frac{di_k}{dt} > 0\). Fig. 4.

Under these conditions from relation (7) we may obtain the equations system:

\[
\begin{align*}
    i_0 + T \cdot i'_1 &= \sqrt{2}I_k (\omega t_1 - \alpha + \omega T) \\
    i_0 + T \cdot i'_2 &= \sqrt{2}I_k (\omega t_2 - \alpha + \omega T) \\
    i_0 + T \cdot i'_3 &= \sqrt{2}I_k (\omega t_3 - \alpha + \omega T),
\end{align*}
\]

where:

$$i'_j = \frac{di_k}{dt} \bigg|_{t=t_j}, \quad j = 1, 2, 3.$$  \hspace{1cm} (9)

After solving the equation system (8) we obtain \(I_k, T, \alpha\) and considering the transformer ratio of \(T_c\) we will obtain the evolution of short-circuit current in the primary winding of current transformer.

![Diagram showing short-circuit current and its image in the secondary winding of current transformer.](image)

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![Graph showing the evolution of short-circuit current: 1-experimental, 2-numerical.](image)

Fig. 5 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 electrical arc is determined knowing the beginning moment and extinction moment of electric arc. 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. 2a. The extinction moment is simultaneously with the breaking of short-circuit current.

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 electrical arc.

4 Architecture with microcontroller for electroerosion estimation

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, [4].

![Fig. 6 Principle scheme of the embedded system](image)

In order to obtain an improved resolution of the measurements received from the transformers, these have been amplified using LM324N operational amplifiers, having a specific amplifying rate for each channel.

5 Conclusion

The proposed architecture, realised under the shape of an embedded system, has the advantage that can be used for electroerosion estimation and also, for the monitoring of the some cinematic parameters for the operating mechanism like as: closing speed, opening speed, closing time, opening time, the energy accumulated in the acting mechanism and others. Through this approach, it is possible the local display of the monitored parameters and their transmission at a PC for an ulterior processing.

References:


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