MONITORING AND DIAGNOSTIC SYSTEM FOR HIGH VOLTAGE CIRCUIT BREAKERS

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***Abstract* – On-line monitoring of a big number of circuit breakers parameters, in order to diagnostic, is mostly of the traditional circuit breakers, difficult to realises, for technical and economical considerations. The paper presents a monitoring and diagnostic system for high voltage (HV) circuit breakers which allows information regarding: thermal stresses, cinematic characteristics, contacts electro-erosion, reliability in operation, and also the prediction of intervention date at monitored equipment. The novelty of this monitoring and diagnostic is that it uses some parameters which can be obtained from the existing technical documents, and also just load current and pressure from the acting mechanism.**

Keywords: *HV circuit-breaker, monitoring, diagnostic, reliability.*

1. INTRODUCTION

The maintenance policy of the switchgears (circuit breakers) is based, presently, on the corrective maintenance applied after the appearance of the fault, on scheduled preventive maintenance, respectively, that it is done after predetermined criteria (time or switching number).

In the case of planed preventive maintenance, it consists that the equipment's state is good, in general, but the maintenance costs can be prohibitive, in the conditions in which some revisions aren't necessary and through another, deficient realized, it affects the technical state of the equipment.

To avoid these difficulties it resorts to the predictive preventive maintenance, which involves, firstly, to realises a diagnostic of equipment's technical state before starting their maintenance. The diagnostic of equipment's technical state involves the monitoring of some characteristics and parameters that can offers the information about their state.

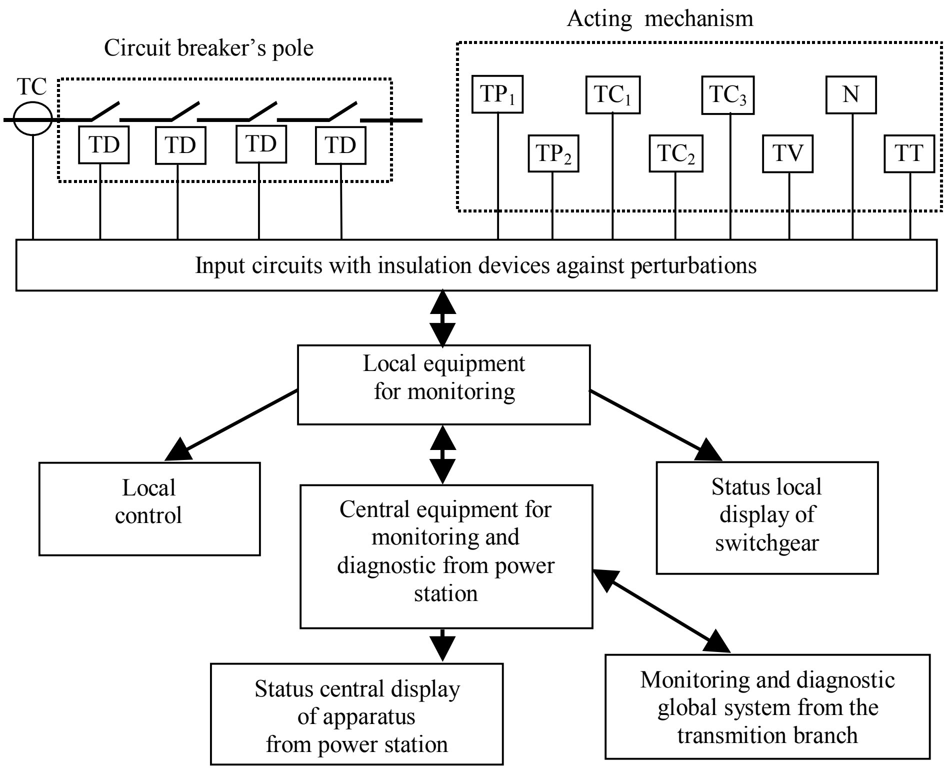

Figure 1: General structure of a complex monitoring and diagnostic system

2. GENERAL STRUCTURE OF A MONITORING AND DIAGNOSTIC SYSTEM

The technical monitoring and diagnostic is realised with the help of some monitoring and diagnostic systems, having the role to controls the main functions of the equipment and to compare the measured values of some parameters with standard values corresponding to good conditions equipment or with anterior values recorded on the same equipment.
General structure of a complex monitoring and diagnostic system, of a circuit breaker, Fig.1, contains traductors for the monitoring: of the current through the circuit breaker (TC); of the mobile contacts moving of the circuit breaker (TD); of the static and dynamic pressure (TP_1, TP_2); of the currents through the motor and the acting electromagnetic coils (TC_1, TC_2, TC_3); vibration fingerprint (TV); the acting number (N); the operating voltage (TT), [1], [3]. The signals from traductors are delivered using the input circuits (electro/optical converters, optical fibres, opto/electric converters etc.) to local monitoring equipment. The local device can be integrated into a more complex hierarchical system, organised on much more levels, [3]. At the inferior level the system allows the connection of the local devices to a high speed local network (Ethernet, Powerlink, Profinet etc.), on the next level are the computers from the control room of the power station, but on the superior level, through Intranet and Internet connections, the communication is realised.
The efforts of technical and economical nature, necessary for the implementation of thus system, mostly in the case of traditional switching techniques, are very great. Thus, the paper presents a monitoring and diagnostic system which uses, in principle, the existing infrastructure from the power stations.

3. MONITORING AND DIAGNOSTIC SYSTEM

The proposed structure for the monitoring and diagnostic system of the circuit breakers technical state includes four boxes which monitor: thermal stresses, cinematic characteristics, contacts electroerosion and the operating reliability, Fig. 2. The novelty of this monitoring and diagnostic is that it uses some parameters which can be obtained from the existing technical documents, and also just load current and pressure from the acting mechanism.

3.1. Thermal stresses

For the realisation of a technical state diagnostic of electrical equipment is necessary to know their thermal stresses. An increased level of thermal stresses influences the good operating of the electrical equipment, the maintenance activity becoming more

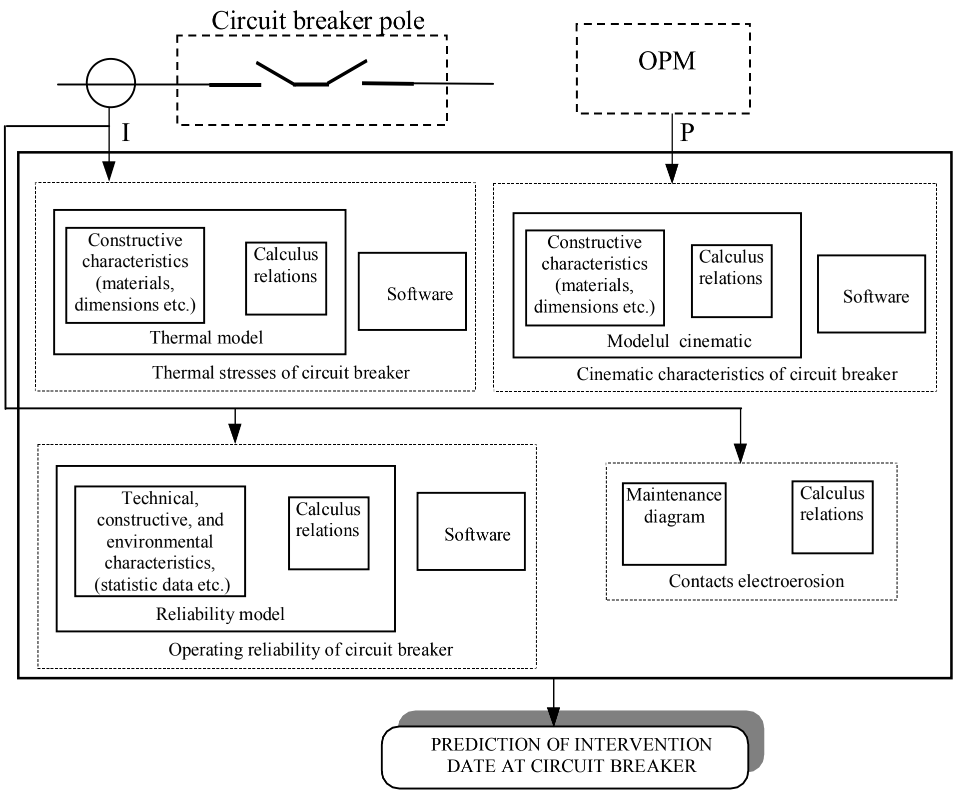

Figure 2: Monitoring and diagnostic system of HV circuit breaker

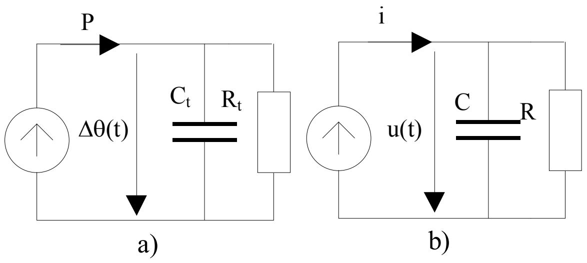

Figure 3: R-C parallel circuits

intense and decrease the operation time. For the thermal stresses monitoring of the equipment from the power systems presently it uses an installation which detects the infrared radiation level emitted by the monitored equipment. The actual technical and economical possibilities for an extended monitoring (as time and number of equipment), of thermal stresses, are reduce. In this context, it propose a possibility of thermal stress monitoring of a circuit breaker through the monitoring of the current that flows through it and through the knowledge of the contact resistance measured at the last maintenance of the circuit breaker. For this the thermal stresses are modelled using the R-C circuit elements because of the similitude between the equations which describe the transient states of the processes of thermal and electrical nature. It considers the thermal and electrical circuits from Fig.3.

The equations which describe both circuits are:

$$P = mc\frac{d\vartheta}{dt} + \alpha_t S\vartheta, \qquad C\frac{du}{dt} + \frac{1}{R}u = i. \quad (1)$$

It observes a similitude between both equations with the following correspondence of the parameters:

$\vartheta(t)$-overtemperature ⇔ $u(t)$-voltage;
P-thermal power (flux) ⇔ i-current intensity;
$R_t=1/\alpha_t S$-thermal resistance ⇔ R- electric resistance;
$C_t=mc$-thermal capacitor ⇔ C- electric capacitor, and thus it can assign for the thermal scheme from Fig.3a with an electrical scheme from Fig.3b tacking in view the anterior correspondences.

Knowing the constructive structure of the equipment (which it allows the calculus of thermal resistances and capacitors), and the installing conditions (to appreciates more precisely the global thermal transitivity-α_t), it obtains a thermal model which, converted into an electrical scheme, having as input parameters the current and contact resistances, respectively, it will allows to determinates the thermal stresses in different conditions.

For example, in Fig.4, it is given the overtemperature, in the mobile contact zone, versus the contact resistance and current through the circuit breaker (I_n=630 A), being drawn the isotherms in accordance with 10, 20, ..., 60 °C. The above points of 50 °C isotherm correspond of some operation parameters of the circuit breaker (contact resistance and current) which leads at the appearance of an overtemperature over the admissible value in contact zone.

This monitoring possibility of the thermal stresses can be applied at any type of switchgear (oil, vacuum, SF_6) if the equivalent thermal model is realised, [1].

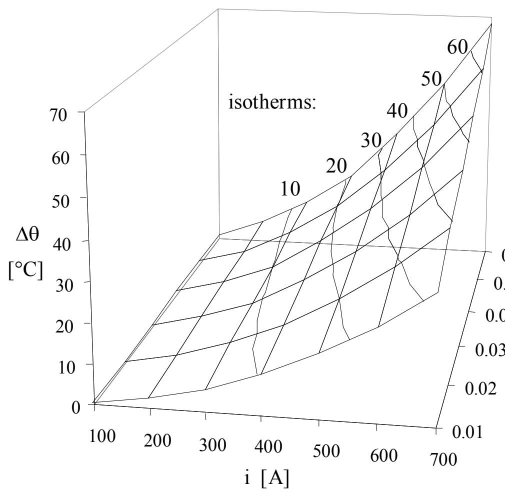

Figure 4: The overtemperature in the mobile contact zone

3.2. Cinematic characteristics

The cinematic parameters of the circuit breakers (total moving, moving in contact, closing/opening speed, closing/opening time, unsimultaneity time between poles, between the chambers of the same pole, respectively) have a great importance regarding the technical state of them, [2], [5]. By the cinematic parameter are strongly linked the contact electroerosion, of blowing nozzle (for SF_6 circuit breaker), ignition chamber wearing, the quality deterioration of the insulation and ignition environment of the electric arc etc.

Generally, the determination methods of the cinematic characteristics are methods used in the maintenance activities of the circuit breakers and its follow the validation of some of these activities (for example, the replacement of a high pressure pipe, can leads to a supplementary hydraulic resistance and thus, at the modification of cinematic parameters). Its aren't methods dedicated for cinematic characteristics monitoring of the circuit breaker when them are over

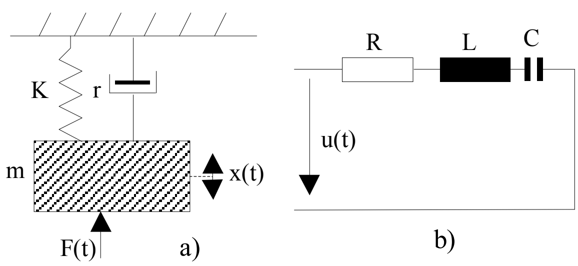

Figure 5: Linear mechanical system-a; RLC series electrical circuit-b

voltage.
Because of this fact it presents a possibility of cinematic characteristics monitoring based on the monitoring the pressure evolution into control system on the acting duration of the circuit breaker. The method based on the modelling of the mechanical system of moving transmission with the help of the systems of electrical nature, with RLC elements, [1]. It be the linear mechanical system with a single freedom degree, RLC series electric circuit, respectively, from Fig.5.
The equations that describe both systems are given by the relations:

$$m\frac{d^2x}{dt^2}+r\frac{dx}{dt}+Kx=F(t),\ L\frac{d^2q}{dt^2}+R\frac{dq}{dt}+\frac{1}{C}q=u(t). \quad (2)$$

It consists a similitude between both differential equations with the following correspondence between parameters:
u(t)-supply voltage ⇔ *F(t)*-the excitation force of the mechanical system;
q(t)- electric charge ⇔ *x(t)*- mechanical shift;
R- electric resistance ⇔ *r*- amortisation coefficient;
L- electric inductance ⇔ *m*-mass;
1/C- capacity's opposite ⇔ *K*- elasticity constant, and therefore it can assign for the mechanical system from Fig.5a the electrical scheme from Fig.5b, on the base of established correspondence.
Knowing the constructive structure of the circuit breaker, it allows to obtains a reduce mechanical system, which then it is converted into an electrical scheme, having as input the voltage. Through the monitoring of the pressure evolution on the acting duration of the circuit breaker and the introducing in electrical scheme of a voltage in correlation with this, is possible the monitoring of cinematic parameters of equipment.
Fig.6 shows the mobile contact motion of a HV circuit breaker, type IO, during the closing operation, experimental and numerical obtained, respectively. It

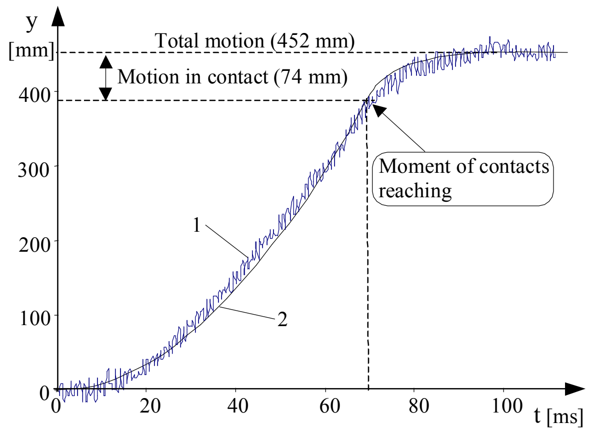

Figure 6: Mobile contact motion during the closing operation, experimental recorded (curve 1) and numerical, respectively (curve 2)

observes a good similitude between the experimental characteristics and those given by the model.

3.3. Contacts electroerosion

In the estimation of the circuit breaker technical state, a great importance is the knowledge of its contacts electroerosion. The electroerosion depending on the switching number and on the current values in accordance with the realised switching and also depending on the existing time of the electric arc at each switching. The mass wearing *m*, expressed in [mg], is given by the relation:

$$m = a \cdot I^b \cdot t_a, \quad (3)$$

where: I is effective value of the switched current in [kA], t_a-the ignition time of the switching electric arc in [ms], and *a*, *b*-constants depending on the materials nature (for example in case of contact made from: copper-wolfram - a=0.274, b=1,81; copper - a=2.15, b=1.58), [4].
Because the existing time of the electric arc is difficult to measure, in electroerosion estimation of the circuit breaker contacts it is recommended to use the relation, [6]:

$$\sum_{i=1}^{n}\alpha_i \cdot I_i \le K, \quad (4)$$

where: I_i is effective value of the switched current at switching *i*, α_i - constant that depends by the effective value of the switched current, and *K* – constant specific of each type of circuit breaker and at it reaching the contacts replacement is recommended (K = 420 kA, in the case of SF_6 circuit breakers, type H14P40, H17P40, [6]).
On the base of maintenance diagram and electroerosion calculus relations, it can estimates the real electroerosion of the circuit breakers contacts, thus being possible to indicates the moment of contacts replacement and the decreasing of unjustified costs induced by the maintenance realised at maximum electroerosion

3.4. Reliability in operation

The proposed system is equipped and with the possibility of technical state monitoring of the switchgears on the base of its reliability in operation.
The estimation of switchgears reliability is made using a reliability model of equipment, model which is obtained on the base of some data that can be easily monitored and on the base of the existing technical documents from the producing, transport and distribution energy companies, respectively.
The circuit breaker presents a certain switching reserve and operation, respectively, thus at each operation or switching operation of the equipment, these reserves are consumed. At its behaviour can intervenes the

Figure 7: Circuit breaker's reliability diagram

following primary faults, considered as independent random events: progressive faults induced by the consumption of switching and operation reserves, unexpected faults, manufacturing faults (constructing and assembling) and faults given by the cumulus of some variables (called explicative) like as equipment's age, the emplacement, the equipment manufacturer, loading degree, the contact resistance value etc.

In circuit breaker's reliability diagram five subsystems have been serried, Fig.7, [1]: the acting mechanism subsystem (AM) where progressive faults induced by the consumption of operation reserves can appears, ignition chamber subsystem (IC) where progressive faults induced by the consumption of switching reserves can appears, UF subsystem where the expected faults can appears, MF subsystem where the manufacturing faults can appears and VF subsystem where faults induced by the explicative variables can appears.

Each component subsystem can has just two states: operation status (success) and non-operation status (unsucces). In accordance with this, and circuit breaker will has just these two states. As result, the circuit breaker's component subsystems can be characterised through the behaviour probability $P_i(t)$, while the circuit breaker is characterised also through the behaviour probability $P(t)$. In this case, the circuit breaker's behaviour probability it's obtained through the multiplication of behaviour probability corresponding to these five components subsystems:

$$P(t) = P_{AM}(t) \cdot P_{IC}(t) \cdot P_{UF}(t) \cdot P_{MF} \cdot P_{VF}, \quad (5)$$

where: $P_{AM}(t)$ represents behaviour probability of the acting mechanism without the consumption of operation reserve; $P_{IC}(t)$ behaviour probability of the ignition chamber without the consumption of switching reserve; $P_{UF}(t)$, behaviour probability of the circuit breaker without unexpected faults; P_{MF}, behaviour probability of the circuit breaker without manufacturing faults; P_{VF} behaviour probability of the

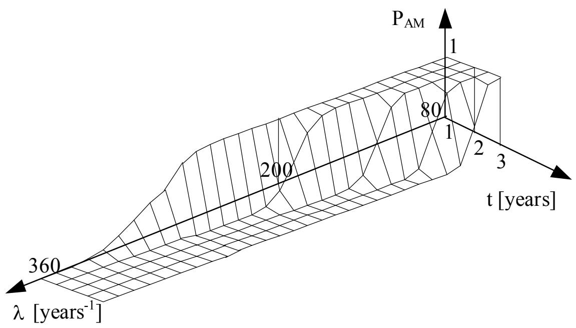

Figure 8: Reliability function evolution of the acting mechanism versus the operation intensity and time duration

circuit breaker without faults given by the explicative variables. The determination of the circuit breaker's reliability function has proposed the anterior calculus of reliability function of each component subsystem. For example, the acting mechanism's reliability function is given by the relation:

$$P_{AM}(t) = \sum_{k=0}^{N-1} P_{N-k}(t) = \sum_{k=0}^{N-1} \frac{(\lambda t)^k}{k!} \cdot e^{-\lambda t}, \quad (6)$$

where: $P_{N-k}(t)$ represents the probability the event appearance (operation) in the range $(0,t)$ of k times (k being a random variable, allocated after Poisson low by parameter λt); λ-operation intensity, while N-operation reserve.

Fig.8 shows the behaviour probability evolution of the acting mechanism for different values of the operation intensity till the 360 and different time durations (1…3 years) considering the operation reserve N=300.

The reliability model has allowed realising predictive maintenance software focused on the reliability monitoring in exploitation of the circuit breakers. The software has as input the explicative variables and also information, like as: date of the last revision, number of realised operations, number of switching operations, values of switched short-circuit currents etc. and offers as result the value o behaviour probability at the final interval of desired analysis and the date when the circuit breaker intervention is recommended, respectively.

4. CONCLUSIONS

To avoid the difficulties induced by the scheduled preventive maintenance it resorts to the predictive preventive maintenance, which involves, firstly, to realises a diagnostic of equipment's technical state before starting their maintenance. The diagnostic of equipment's technical state involves the monitoring of some characteristics and parameters that can offer the information about its state.

The technical monitoring and diagnostic is realised with the help of some monitoring and diagnostic systems, having the role to controls the main functions of the equipment and to compare the measured values of some parameters with standard values corresponding to good conditions equipment or with anterior values recorded on the same equipment.

On-line monitoring of a big number of circuit breakers parameters, in order to diagnostic, is mostly of the traditional circuit breakers, difficult to realises, for technical and economical considerations.

The proposed structure for the monitoring and diagnostic system uses some parameters which can be obtained from the existing technical documents, and also just load current and pressure from the acting mechanism. This includes four boxes which monitor: thermal stresses, cinematic characteristics, contacts electroerosion and the operating reliability of the circuit breaker and also the prediction of intervention date at the monitored and diagnostic equipment.

References

[1] M. Adam, A. Baraboi, R. Ciobanu R, *Monitorizarea şi diagnosticarea întrerupătoarelor de putere*, Editura Gh. Asachi, Iaşi, 2001.

[2] M. Adam, A. Baraboi, C. Pancu, *About the monitoring and diagnostic of the circuit breakers*, The XIIIth International Symposium on High Voltage Engineering, Delft, Olanda, p.4, 2003, ISBN 90-77017-79-8-CD-ROM.

[3] A. L. J. Janssen, W. Degen, C. R. Heising, H. Bruvik, E. Colombo, W. Lanz, P. Fletcher, G. Sanchis, *A summary of the final results and conclusions of the second international enquiry on the reliability of high voltage circuit breakers*. Paper 13.202, CIGRE, 1994.

[4] A. Peicov, P. Tuşaliu, *Aparate electrice*. Editura Scrisul Românesc, Craiova, 1988.

[5] * * *, *User Guide for the Application of Monitoring and Diagnostic Techniques for Switching Equipment for Rated Voltages of 72,5 kV and Above*, CIGRE WG 13-09, 2000.

[6] * * *, *Întreupătoare cu hexafluorură de sulf tip H14P40 H17P40*, Electroputere Craiova.