A new Approach to Predictive Maintenance of High Voltage Switching Devices

Emil Lazarescu, Flaviu Mihai Frigura-Iliasa,
Mihaela Frigura-Iliasa
Power Systems Department
Politehnica University
Timisoara, Romania
emil_lazarescu@yahoo.ro, flaviu.frigura@upt.ro

Petru Andea,
Doru Vatau
Faculty of Electric and Power Engineering
Politehnica University
Timisoara, Romania
petru.andea@upt.ro, doru.vatau@upt.ro

***Abstract*—Predictive maintenance of high voltage devices is a major issue for all power providers, due to costs and complexity. This article provides some theoretical and experimental principles which can be useful for all maintenance operations performed on high voltage switching devices and some simple methods applicable for assessing the status of all their contacts. Some of the aspects described here are applicable to other high voltage devices like insulators, surge-arresters etc. An original model based on fuzzy-logic algorithms is performed in order to determine the main elements and issues of the predictive maintenance. All these algorithms are integrated into powerful software tools for all types of high voltage equipment maintenance. It could prove the idea of obtaining a higher service efficiency for existing pieces of equipment, with very low costs.**

Keywords—predictive maintenance, high voltage switches, fuzzy logic

I. Generalities

Maintaining the service capacity of high voltage equipment involves:

- Performing and optimizing all procedures;
- Increasing its service availability;
- A permanent monitoring procedure for a better knowledge of all faults and service particularities.

This article wants to present some operations, which could be mandatory in order to ensure a normal service capacity of the high voltage equipment, part of the maintenance procedure of the power equipment involved. As we know from literature, maintenance can be:

- curative - detection and elimination of any accidental faults;
- preventive - prevention of all faults by performing periodic service interventions;
- predictive - forecast of some faults in order to avoid their apparition;

All these types of maintenance have as main objective the improvement of technical management and the optimal service of the high voltage power equipment, objective which could be achieved throughout some monitoring and diagnosing techniques.

When speaking about monitoring, we present an action of assessment, measurement and automatic comparison of some specific parameters, having certain referential values, for an industrial process or equipment, which is based on a set of methods for diagnosis and analysis of faults appearing there.

This operation is performed by using a set of sensors. Their choice procedure, their number and type, their location and the associated measuring schemas conceived for assessing the influence of the monitored parameters offer us the solution of this all time actual issue.

As a simple definition, a performant system of monitoring – diagnosing the state of a high voltage device must have the following characteristics:

- to be able of independent service;
- to be very flexible and versatile, compliant to the user's needs;
- to not interact and not affect the service capacity of the equipment or any aspect of its reliability;
- to be integrated in a control and automation system belonging to that process/equipment (like SCADA ones).

The approach to the monitored system could be made either throughout optimizing the classic problem of monitoring – diagnosing following different criteria or throughout using artificial intelligence and expert systems [2]

All types of high voltage switching devices (SIT) are the largest piece of equipment except transformers, and their work is crucial for the continuity of electric power supply, essential for all consumers.

The main objective of the SIT predictive maintenance strategy involves:

- the acquisition, analysis and process of all data concerning the most important service parameters of the equipment;
- the construction of diagnosis data bases concerning the SIT status in order to identify and to prevent the apparition of faults;
- the reduction of equipment unavailability in order to make service capacity more effective;

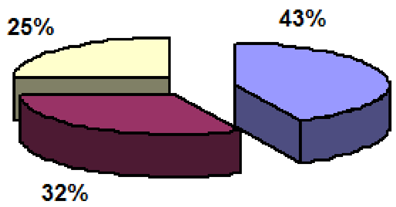
978-1-5090-6406-9/17/$31.00 ©2017 IEEE

All the faults of SIT are depending on:

- their type of construction (oil or SF6);
- their voltage level,
- their position inside the power grid;

According to some statistic research performed at TRANSELECTRICA Romania S.A., the distribution of all main sources for faults on SIT is:

- a high increase of the contact electric resistance measured on the ON (closed) status of the equipment;
- mechanic or dielectric breaking of the support and active insulators;
- other out of work causes, with a percentage presented in Figure 1;



43% - improper materials and adjustments faults
32% - breaking of insulators
25% - other causes

Fig. 1. Percentage of faults' causes on 110 kV switching devices in Romania

TRANSELECTRICA S.A., the National Romanian Power Transporter takes seriously in consideration all the causes of modifications for the electric resistance of contacts belonging to high voltage switching devices.

These modifications are caused by [3], [4]:

- the diminution of the pushing force on the contact as a result of normal stress and fatigue of all types of springs used, due to a large number of commutations performed by that equipment;
- the reduction of the physical contact area, as a result of oxide pollution and fatigue on contact pieces;
- the improper maintenance performance;

Their effect is also an increase in the voltage drop while in service, for all contacts, more above the admissible values [3].

II. DIAGNOSIS OF SWITCHING DEVICES CONTACTS

One method used for on-line monitoring the status of contacts in SIT is performed by using optic fibers installed from the beginning, by the constructor of the equipment, inside the switch and connected to an interface for data capturing and processing.

It consists in processing some thermal images previously captured and informing the maintenance staff on the evolution of the contact resistance R_c in order to prevent faults. By monitoring the stationary over-temperature of that contact, τ_c ($\tau_c = \theta_c - \theta_{amb}$) and the intensity of the permanent service regime current, I, function of the physical nature of the superficial material used of the two contact pieces (copper or even silver alloys), we can determine the voltage drop, U_c,

It is given by:

$$U_c = R_c \cdot I = \xi \cdot \tau^{1/2} \quad (1)$$

And, by consequent, the contact resistance, R_c

$$R_c = \xi \cdot I^{-1} \cdot \tau_c^{1/2} \quad (2)$$

which have to be compared with the admissible limits.

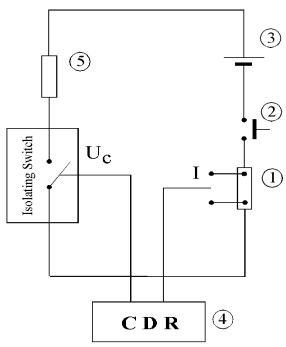
Table I [5] present those limits for couples of contact pieces of the same material (silver–silver or cooper–cooper in air, at normal temperature, the critical voltage drops for those contacts (when plasticization of materials is possible) as well as the values of ξ factor:

TABLE I. PHYSICAL PROPERTIES OF STANDARD CONTACT MATERIALS

Material	Critical temperature θ_{cr} [grdCelsius]	Critical voltage drop in contact U_{cr} [mV]	ξ [$V \cdot grd^{-1/2}$]
Silver–silver	180	93.6	$7.44 \cdot 10^{-3}$
Cooper-cooper	190	94	$7.40 \cdot 10^{-3}$

By taking in consideration relations (1) and, respectively, (2), we noticed that the modification of the conduction status and the decrease of the contact surfaces, in service state, due to impurification with insulating pellicles, and, respectively, the decrease in the pushing contact force, may cause an increase of the contact temperature. So, diagnostic could be done by monitoring, either directly the contact over-temperature, or the voltage drop on it, in order to appreciate with maximum economic efficiency, through predictive maintenance, the proper moment of the next maintenance works for the contact and its' sub – assemblies on the SIT.

Another method used for diagnosing the status of main SIT contacts, which does not need equipment for thermal vision and could occasionally (on-line) or periodically (of line) assess the status of contacts, is based on measurements of the contact electric resistance of the equipment, according to the diagram shown in Figure 2, [1].



1 co-axial shunt
2 mono polar contactor
3 12 V, 66 Ah battery
4 CDR
5 limiting resistance.

Fig. 2. Block diagram of Contact Disturbance Recorder

This method needs complete disconnecting of the installation where the measurements are done. A current of 100 – 1000 A is injected through contacts, and both the voltage drop U_2 between the two pieces and the current I, passing through these closed contacts are measured.

A dedicated CDR (Contact Disturbance Recorder) acquisition interface is used to record, compute, analysis and transmission of all data to the maintenance management points and stores information obtained throughout the measurements, according to the principle diagram in Figure 2, recording at the same time also the number of commutations N made by the switching device between two successive acts measurements.

All periodic measurements of the contact resistance, which characterizes the technical status of the commutation part of the switching device, are compared with the referential ones, and allow a clear appreciation of the instant technical status of the equipment. References are made based on new equipment behavior or documented incidents.

The next moment for performing maintenance could be established through fixing a percentage limit of a time value U_{cr} (shown in Tab.1) which would be compared with the current value of the contact voltage drop. U_{CN}, as a result of the measurement performed on the contact resistance R_{CN}, (after a number of N maneuvers) and on the current I, operation recorded by the CDR.

An algorithm which could be used for establishing the predictive maintenance period of the contacts on SIT is based on fuzzy logic issues.

All data recorded from the periodic measurements of the contact resistance, after a number of N maneuvers, R_{NC} data base, are used to calculate the normal error $\delta_j(N)$ versus the value of that same parameter, measured at the end of the latest revision, R_{CO}.

$$\delta_j(N) = 1 - \frac{R_{CO}}{R_{CN}} \tag{3}$$

together with the variation of this value after a number of N commutation cycles (between two consecutive periodic measurements) $\varepsilon_j(N)$

$$\varepsilon_j(N) = \delta_j(N) - \delta_j(N-1) \tag{4}$$

By placing δj(N) and εj(N) in fuzzy multitudes, like in Figure 3, after linking them to the 3 fuzzy values SP; MP; LP (short, medium and long period), we can pass to the calculation of the final functions:

$$\mu_j(SP) = \underset{x_i}{MAX}[MIN(\mu(x_i))] \tag{5}$$

$$\mu_j(MP) = \underset{x_i}{MAX}[MIN(\mu(x_i))] \tag{6}$$

$$\mu_j(LP) = \underset{x_i}{MAX}[MIN(\mu(x_i))] \tag{7}$$

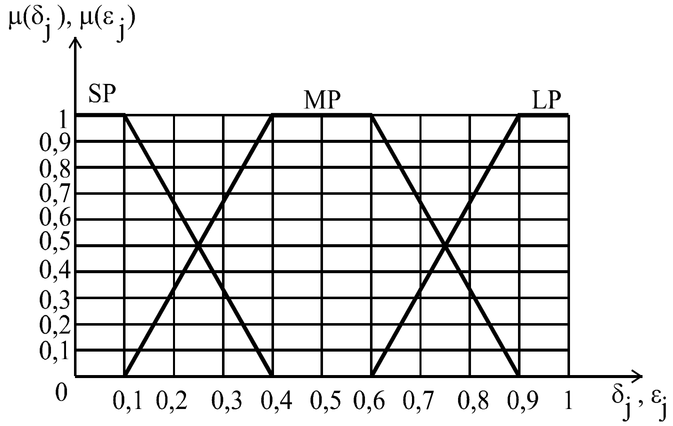


Fig. 3. Fuzzy belonging functions

The computation of the belonging functions $\mu_f(SP)$, $\mu_f(MP)$ and $\mu_f(LP)$ is performed on rules established in table II and table III.

TABLE II. FUZZY INFERENCE RULES

δ_j \ ε	SP	MP	LP
SP	SP	MP	MP
MP	MP	MP	LP
LP	LP	LP	LP

The following step consists in determination of the belonging function μ outputs based on the algorithm shown in figure 4:

TABLE III. TABLE OF FUZZY MULTITUDES AND BELONGING FUNCTIONS

x_i	Input	output		
	$(\delta_j, \varepsilon_j)$	$\mu(x_i, SP)$	$\mu(x_i, MP)$	$\mu(x_i, LP)$
x_1	(SP,SP)	1	0.5	0
x_2	(SP,MP)	0.5	1	0.5
x_3	(SP,LP)	0.5	1	0.5
x_4	(MP,SP)	0.5	1	0.5
x_5	(MP,MP)	0.5	1	0.5
x_6	(MP,LP)	0	0.5	1
x_7	(LP,SP)	0	0.5	1
x_8	(LP,MP)	0	0.5	1
x_9	(LP,LP)	0	0.5	1

$$\mu_{output} = MAX[\mu_f(SP), \mu_f(MP), \mu_f(LP)] \tag{8}$$

When performing a conversion from the linguistic value of μ at output into a real numerical value μ % (in practice it represents the fatigue of the electric contacts, as percentage) and comparing this value with the admissible fatigue, μ_{adm}, ,and it is possible to propose the moment of the next diagnosis test and revision.

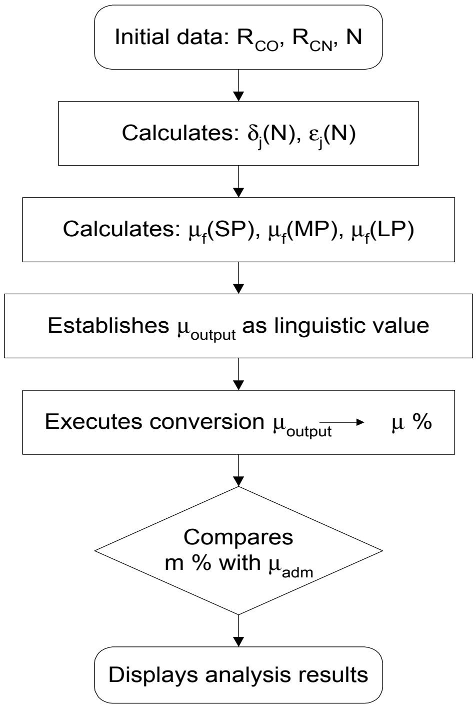


Fig. 4. Block diagram of algorithm for determine the period of predictive maintenance of the electric contacts on a SIT

III. CONCLUSIONS

All those methods described in this paper (the classic ones and the new one) allow a high confidence diagnosis of the technical status for the contacts on the high voltage switching devices of all types, providing detailed information on some parameters like: the electric resistance of the contacts, the fatigue degree of the main contacts and the best moment for the next predictive maintenance operation on the equipment.

As we notice during the last years, in partnership with the Romanian National Grid Operator TRANSELECTRICA S.A., Sibiu Branch, the off-line monitoring system for the contact resistance on the high voltage switching devices applied at one high voltage station (Sibiu South), presented in this paper, allows an increasing efficiency of the activity reducing the periods of unavailability, respectively increasing the all reliability of these equipments.

The application could be extended for a large number of applications, for all type of high voltage equipment, for all levels of high voltage in service. By applying this method to many stations and pieces of equipment, the data base of maintenance parameters could be also extended, in order to improve the fuzzy logic algorithm.

REFERENCES

[1] P. Barkan, J.A. Deni, A. K. McCabe, J.G. Reckleff, H.N. Scherer, and R.C. Woodward, „Monitoring methodology for high voltage switches status - Méthodologie pour la surveillance de l'état des disjoncteurs des haute tension", Rapport 13.04, CIGRE, 1998.

[2] B. Bouchon – Meunier and H. Nguyen, „The incertitudes in intelligent systems - Les incertitudes dans systèmes intelligents", Presses Universitaires de France, Paris, 1996.

[3] P.D. Bourkes, F.A. Kayafs and A.V. Machias, „Specified current in emergency load switches", IEEE Proced., vol.135, Nr.4, p.330-333, 1998.

[4] O. Postolache, T. Poiata, and I. Zaharia, „Use of artificial neuronal networks for monitoring distributed systems" *vol. SIAE, Galaţi*, p.41-45 (in Romanian) 1998.

[5] D. Vatau, F. Surianu and L. Moldovan, „Switch contacts state prediction of high voltages devices" Proceeding of 19th International Conference on Electric Contact Phenomena, Nuremberg, 1999.

[6] D. Vatau, „About Fuzzy assessment of high voltage switches life service - Asupra evaluării Fuzzy a duratelor de viaţă a întreruptoarelor de înaltă tensiune", vol.SIAE, Galaţi, p.416 – 420 (in Romanian), 1998.

[7] D. Wang, Y. Zhu and Y. Wang, „Condition Monitoring and Integrating Platform for Power Transmission and Transformation Equipment Based on IEC 61850", Journal of Automation of Electric Power Systems; No.13, 2013.