FAULT RECORDER APPLICATION IN CALCULATING OF I^2t DISTRIBUTION CIRCUIT BREAKERS MAINTENANCE CRITERION

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Abstract

In the maintenance of switching equipment transition from time-based to condition-based maintenance is evident. The main objective is to avoid very expensive and often unnecessary dismantling of arc extinguishing chamber and overhaul of operating mechanism. The experience of many utilities in the world has shown that opening of arc extinguishing chamber in some cases can reduce the availability of circuit breaker because of badly done work. Due to this reason the application of monitoring and diagnostic techniques in order to determine breaker state is used more and more.

On-line monitoring systems most often are not economically justified for distribution breaker technologies. Due to that reason, in this paper the application of digital fault recorder in the determining of i^2t contact wear criterion is analyzed. Fault recorders are intended for many specific analysis – short-circuits, relay protection operation, power quality analysis and so on. But, if some technical and organizational conditions are met, they can serve as maintenance support tool. In this paper it is presented how it can be done.

1 NEED FOR MONITORING OF ARCING CONTACT WEAR

High voltage substation components are subject to ageing and wear during their service life. Lifetime of switching equipment is difficult to estimate in advance, because it depends on many factors as the manufacturing technology and temperature, electrical, ambient conditions and mechanical stresses. The continuous monitoring of switching equipment is considered as more and more valuable tool for

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maintenance management. Maintenance management systems are expected to give answer to questions concerning [1]:

- The actual condition of the equipment,
- Its future trend with reference to certain maintenance schedules, and
- The optimum maintenance level.

Main objectives for switching equipment monitoring are as follows:

- Supporting maintenance and lifetime assessment,
- Ensuring information on the equipment state,
- Receiving warning signals in order to prevent failure,
- Achieving optimum equipment operation, and
- Reducing times and cost of commissioning.

The basic objective of contact wear monitoring is the maintenance support. The continuous monitoring of switching equipment especially in case of circuit breakers will create possibilities to carry out maintenance works much more effectively and efficiently. It is well known from practice that after carrying out a circuit breaker overhaul it often appears that it is was not necessary. In many cases, after dismantling of arc extinguishing chambers to check the state of contacts and taking apart operating mechanisms the general condition and performance of the circuit breaker is very often worse due to inadequate work.

By providing a support for maintenance, condition monitoring systems may induce a reduction of maintenance cost in reducing maintenance programs and improving availability. The application of monitoring can help to reduce systematic component replacements for components that are not known as suffering from time based wear and tear. For such components, the gathered information helps to evaluate their real condition and then replace them at the right time. Optimization of maintenance programs thanks monitoring may allow reducing all resources needed for maintenance and the corresponding costs. Also, monitoring enables a better knowledge about real current state of apparatus. Maintenance can be focused on problematic equipment. At the same time, unnecessary work on good component is avoided.

Defects are detected by inspection, diagnostic testing, monitoring and through malfunction. A data archiving system is required to discover which defects are systematic. The system could consist of an advanced computerized and remote-controlled system and must take into account information on specific and systematic failures and defects. Stresses are commonly archived by monitoring systems, protection systems, SCADA systems or other log systems. In this paper using of digital fault recorder in accumulation of electrical and mechanical stresses in maintenance of circuit breaker is proposed. Essentially, these devices are primarily devoted to short circuits analysis, but can be employed for circuit breakers maintenance support in a systematic way.

2 STRESSES IN SERVICE

Circuit breakers in service are permanently subject to various stresses [2]. For overhaul as most expensive part of circuit breakers maintenance work the most important are mechanical stresses due to common operation and electrical stresses due to regular network conditions, switching operations and also failure conditions. The third overhaul criterion in many cases is duration in operation because of possibilities of insulation degradation. Criteria for overhaul are most frequently expressed as number of operations, arcing contact wear and duration of operation. Of course, these are criteria concerning dismantling of arc extinguishing chambers and detailed overhaul of operating mechanism.

Number of operations is a very useful parameter for diagnostic purposes, especially when combined with experience with the breaker considered. Majority of utilities takes this parameter into account when assessing what type of diagnostic testing to carry out and when to do it, and also when planning invasive maintenance. Wear and tear of mechanical systems increase with use. The number of operations a switching device has performed can be taken as a very general measure of the overall condition of the device and a higher failure rate. This is one of prime factors determining the maintenance intervals.

Arcing contact wear is extremely important as a criterion for planning of dismantling of arc chamber [1]. All maintenance work concerning circuit breakers can be divided on the first part during which all noninvasive procedures (without dismantling of arc chamber and mechanical linkage) have to be done, and the other – dismantling of chamber with repair of mechanism. In is believed that in most utilities and for all voltage classes maintenance expenditures for circuit breakers make 40 % of all substation maintenance expenditures. Also, 60 % of circuit breaker maintenance is addressed to overhaul, which is much rarer then all other activities. This is very good reason to prolong unnecessary overhaul as much as possible.

Switching arc in both low-oil and SF6 circuit breaker interrupters with insulating nozzle is placed inside the nozzle between arcing contacts. In vacuum interrupters the arc is also placed between contacts, but there is not a nozzle. During the switching process, the arc causes erosion of the arcing contacts and ablation of the nozzle, resulting with failure of the circuit breaker after a certain number of switching operations. The mass loss of the tungsten/cooper arcing contacts before the failure can be observed as a critical quantity which determines contact life. Measuring of the mass loss without interrupter dismantling is practically impossible and makes that parameter useless on site. For that reason, critical mass loss of arcing contact is assessed by so cold "measure of thermal stresses", which is determined by adequate test procedure. The method is presented in detail in [3]. The method is based on the experimentally verified issue that the sum of the time integrals of squared short-circuit current for opening operations $\int_{t_{arc}} i^2 \cdot t$, where t_{arc} is the accumulated arcing time, is a good measure of the arcing contact wear. The great majority of circuit breaker manufacturers developed intensive test procedures to determine the number of operations to overhaul based on this criterion. But, for this method the current must be measured as a function time.

Third criterion for determining of overhaul schedule is (apart from vacuum breakers) time interval between major overhaul (dismantling) as given in the manufacturers manuals. This is well known that these intervals were initially determined by great caution. Experience has shown that intervals in many cases can be greatly enlarged.

There is one very important issue concerning mechanical and electrical wear of breakers parts. In [2] very important conclusions of international enquiry on stresses in service of high voltage breakers (greater than 63 kV) are presented. But, it could believe that conclusions are valid for distribution circuit breakers also because of the same nature of processes. The most important conclusions are:

- Most of the short-circuit currents interrupted have rather low amplitudes. The average is 20 %, as the 90 % percentile is about 35 % of the rated short-circuit current of the circuit breaker;
- The average value of the expected maximum short-circuit current in a substation is about 50 % of the rated short-circuit current of the circuit breaker;
- More than 90 % of all short circuits in transmission network occur on the overhead lines;
- The average is 1.7 short circuit per year per overhead line;
- Between 70 % and 90 % of all faults are single phase faults;
- About 80 % of the faults disappear before the first auto-reclosing,
- There is a 70 % reduction of the number of short circuits for the breaker, related to 3-phase faults and for full operating sequences (O-CO-CO), and
- The average number of operating cycles per year is about 80 cycles for 90 % of all circuit breakers. This means that more than 90 % of all breakers will only reach 2000 operating cycles in a 25 years lifetime.

From issues mentioned above, it is evident that have the great possibility to reduce the numbers of unnecessary overhauls and to save a big amount of money and labour.

3 CRITERIA FOR OVERHAUL OF TYPICAL DISTRIBUTION CIRCUIT BREAKERS IN SERBIAN UTILITIES

In Serbian power distribution utilities the majority of circuit breakers are low-oil breakers, but there are SF6 and vacuum technologies also. For example, in the “Elektrodistribucija Beograd” utility in 2003 year there were following number of breakers [4]:

Table 1: Circuit breakers number in “Elektrodistribucija Beograd”, 2003 year

	Low-oil	SF6	Vacuum
110 kV	37	24	-
35 kV	373	-	-
10 kV	1124	-	344

The SF6 breakers are 110 kV voltage level only. At this time there are 28 SF6 110 kV breakers because one new station is energized in the meantime. Twenty breakers of 24 in the Table 1 are of some older design. In this table four breakers of one new station 110/10 kV (Grcica Milenka) are not included because it is energized after 2003 year. Maintenance conditions for these 20 breakers are [5]:

Table 2: Maintenance conditions

Normal maintenance period	8-12 years
Cumulative short-circuit fault currents up to rated breaking current	500 kA
Interruption of operating currents up to rated current	2000 operations
Mechanical switching operations	5000 operating cycles

It is interesting that number of operations and number of interrupted short-circuits of these breakers is so small that the main criterion would be normal maintenance period, in this case about 10 years. The first of these breakers was opened after about 24 years and it was in as-new condition (arcing contacts and nozzles were excellent).

Many manufacturers on the basis of maintenance experience concluded that overhaul criteria for SF6 breakers precautionary were very short because it was not known how SF6 insulation and breaking medium will behave (decomposition powder, humidity and so on). Arc chamber opening intervals were greatly enlarged and for four newer type 110 kV breakers in station “Blok 20” are:

Table 3: Maintenance intervals of new design SF6 circuit breaker:

Normal maintenance period	15-20 years
Number of operations	2500 operations
I^2 Cumulating short-circuit currents	20000 kA^2

These values are typical. It is accepted also that all interruptions of normal currents doesn’t induce the contact wear and must be treated as a mechanical operation.

It can be concluded that arc chamber opening of these breakers can be greatly prolonged and many money and labor efforts saved. Real data about number of operations made and switched short-circuit currents can be extremely important, especially because the arc chamber opening of these breakers needs very skilled maintenance staff. The fault recorders can enable us such data.

The great majority of breakers in distribution systems in our country consist of 10 kV, 20 kV and 35 kV low-oil breakers. By manufacturer maintenance instructions of these breakers the arc chamber opening, contact and nozzle inspection (change) are defined in [6]. These low-oil breakers can interrupt only 6 times rated interruption current:

Table 4: Interrupting ability of typical low-oil breaker [14]:

Interruption current	I_P	$0.8I_P$	0.5IP	$0.3I_P$
Number of operations	6	8	10	20

where I_P is rated interruption current. Overhaul also must be done after 10-12 years or 5000 close-open operating cycles. After 1000 interruptions of normal currents the insulating oil must be changed.

From these data it is evident that the number of interruptions of short-circuit currents is very small in relation to SF6 (and vacuum) breakers. Due to that reason there would be several arc chamber openings in the breaker lifetime. This is a reason why contact wear monitoring is paramount for these breakers because of a great labor and money can be saved if arc chamber opening are prolonged.

4 THE APPLICATION OF FAULT RECORDER IN THE DETERMINING OF CONTACT WEAR AND NUMBER OF MECHANICAL OPERATIONS

Fault recorder is a multifunctional device intended to analyze short-circuits and other events in substations and industrial plants. Modern digital fault recorders provides several functions [7]:

- Fault recorders for analog and binary channels for recording current and voltage curves in the event of a short-circuit. Additional information is measured and recorded concurrently, for example, circuit breaker positions,
- Power and frequency recorder,
- Mean value recorder for registering the long-term progression of different measured values,
- Power quality recorder,
- Event recorder for switching information and other status information,
- Recorder in industrial plants for monitoring slowly changing process.

It is evident that it can be used for contact and nozzle wear analysis, as well as number of operations decision in order to plan maintenance schedule. It is very important that not only informations about short-circuit oscillograms can be got, but the number of operation of operating mechanism.

If this device is to be used, some of organizational needs must be satisfied:

- All circuit breakers which contacts and mechanism wear is to be planned must be uniquely defined by station and bay name and number because all breakers must be in a special maintenance database,
- Each circuit breaker must have its own database sheet because data about number of operation and accumulated short-circuit currents must be analyzed, stored and saved for the decades,
- Maintenance engineer needs the possibilities to access the station computer remotely (from his office) for example, once a week, and to gather and classify needed data to appropriate breaker sheet in the database,
- Data must be gathered promptly because buffer of the fault recorder fills up due to many events,
- It is the best that data about contact wear are analyzed as soon as possible,
- Instead of manually gathering data from fault recorder, it is possible data to be transmitted to maintenance engineer computer. But, it must be provided that this procedure is safe. In our conditions that can be tricky and simple manual gathering data procedure is preferred,
- The way to determine interrupted current must be as simple as possible.

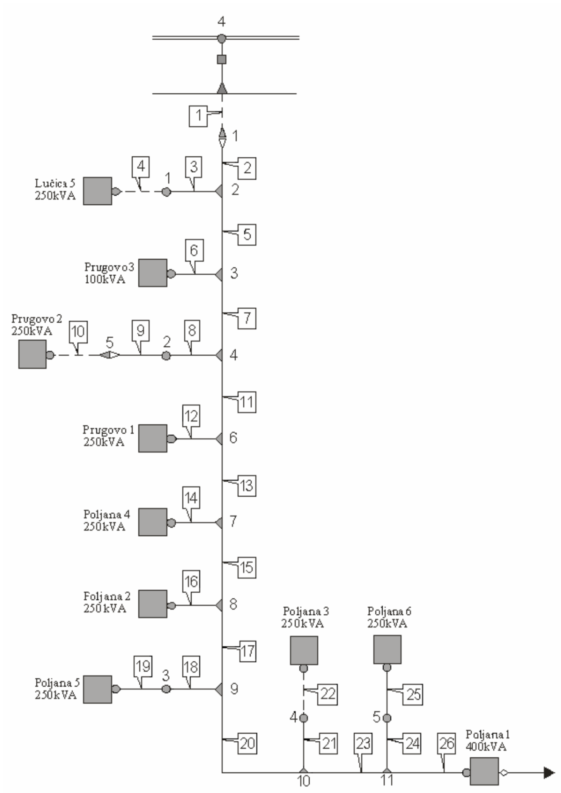

Fig. 1 Bay No. 3 of switching station 35/10 kV "Pozarevac 4"

Fig. 2 Three-phase short-circuit current at the begining of 10 kV line

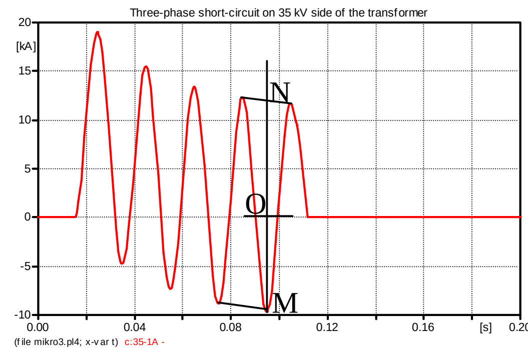

Fig. 3 Three-phase short-circuit on the 35 kV side of transformer

In the Fig. 1 one typical 10 kV feeder is presented. Two short-circuit currents are calculated to demonstrate the application of the fault recorder for maintenance purposes. One is a fault at the beginning of 10 kV feeder, the other is on 35 kV side of a transformer. It can be seen that at the moment of contact parting the short-circuit current is symmetrical (without DC component) and can be calculated simply as apparent value of current. It is supposed that a high-current stage relay (for nearby faults) time is 30 ms, opening time of the breaker is 50 ms and arcing time 16,6 ms. This absence of DC component current in the moment of contact parting (80 ms after fault initiation in this case) is natural for distribution feeders because of very little DC time constant. This also is true for over-current protection where relay action is delayed about 0,4 – 0,5 ms because of selectivity. But, if some DC component at the moment of contact parting is present, as can be see on the Fig. 3, procedure defined by IEC 62271-100 (High-voltage Switchgear and Controlgear-High voltage alternating current circuit breakers, 2001-05) is possible. This procedure enables to calculate assymetrical breaking currents. Percent of DC current and asymmetrical breaking current are:

$$p = \frac{I_{DC}}{I_{AC}} = \frac{ON - OM}{MN} = 10.8\,\%\,,\quad I_{AC\max} = \frac{MN}{2} = 10.883\,\text{kA}\,,\quad I_{assym} = I_{aym}\sqrt{1 + 2p^2} = 7.79\,\text{kA}\,.$$

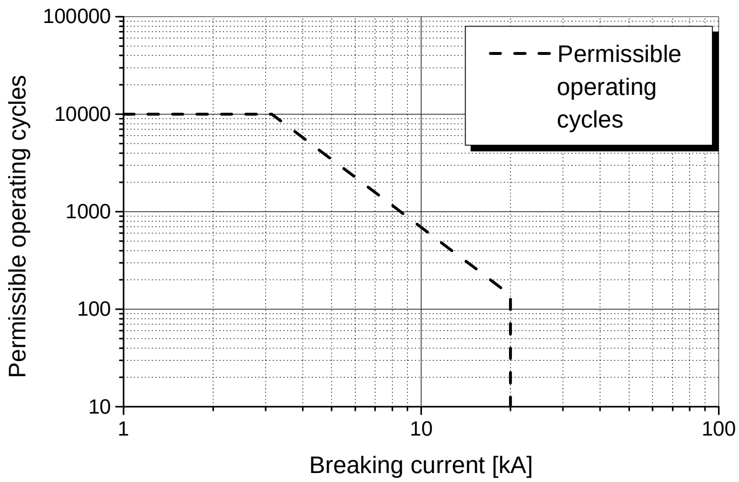

Fig. 4 Permissible operating cycles of vacuum breaker

Typical number of permissible operating cycles curve in manufacturer instructions is presented as in the form presented in Fig. 4. That means this vacuum breaker can interrupt 10000 cycles with current up to rated current 3.15 kA or 140 cycles of breaking current of 20 kA or 3000 cycles of 5 kA current. That means if the breaker interrupted one time 20 kA current, it spent 0.72 % of contact wear capability. Short–circuit currents interrupted are very different due to different fault places in the network, fault type, fault arc resistance and so on. Every time when fault happens, it is needed to calculate percent of spent wear capability and to add to the previous one, up to 100 %, when overhaul is needed.

5 CONCLUSIONS

Several conclusions can be made:

- The main objective is to avoid very expensive and often unnecessary dismantling of arc extinguishing chamber and overhaul of operating mechanism. Due to this reason the application of monitoring and diagnostic techniques in order to determine breaker state is used more and more.
- The basic objective of contact wear monitoring is the maintenance support. The continuous monitoring of switching equipment especially in case of circuit breakers will create possibilities to carry out maintenance works much more effectively and efficiently.
- A data archiving system is required to discover which defects are systematic. The system could consist of an advanced computerized and remote-controlled system and must take into account information on specific and systematic failures and defects. Stresses are commonly archived by monitoring systems, protection systems, SCADA systems or other log systems. In this paper using of digital fault recorder in accumulation of electrical and mechanical stresses in maintenance of circuit breaker is proposed. Essentially, these devices are primarily devoted to short circuits analysis, but can be employed for circuit breakers maintenance support in a systematic way.
- Stresses in service are much less then it is supposed when circuit breaker has designed and tested. It is evident that have the great possibility to reduce the numbers of unnecessary overhauls and to save a great amount of money and labor.
- It can be concluded that the arc chamber opening of SF6 and low-oil breakers can be greatly prolonged and many money and labor efforts saved. Real data about number of operations made and switched short-circuit currents can be extremely important, especially because the arc chamber opening of these breakers needs very skilled maintenance staff. The fault recorders can enable us such data.

- From the organizational point of view, the application of fault recorder in the determining of contact and nozzle wear needs an adequate database because data must be stored, analyzed and saved for several decades.
- Procedure for determining of contacts and nozzle wear presented in this paper is relatively simple and adequate.
- From economical standpoint, the application of fault recorder for maintenance purposes can be justified for 110/10 kV distribution stations. For other stations detailed technical and economical analysis must be done.
- Decision of contacts repair or mechanism overhaul need to be verified by diagnostic techniques.

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