APPLICATION OF RELIABILITY CENTERED MAINTENANCE TO DISTRIBUTION HIGH VOLTAGE CIRCUIT BREAKERS

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Abstract

The paper shows the principles of the reliability centered maintenance of distribution circuit breakers. This method takes into account the condition of the breaker and the importance of the breaker in the substation. The original method of weighting of condition and importance parameters is presented in the form in which it can be used in Serbian distribution utilities.

1 INTRODUCTION

Electricity distribution utilities are faced the competitive environment now. There is a need to move to asset management and to improve their maintenance strategies. Economic considerations point out the need to extend the lifetime of equipment and substations using, among others, the most effective maintenance strategy. One of very important tasks of the utilities is to select the equipment which should be maintained, and to make ranking of the equipment. This will enable to select that equipment which should be maintained first. The reliability centered maintenance is the way that ranking can be done most efficiently.

There is several maintenance strategies used in the electricity distribution utilities. In a corrective maintenance strategy, replacement or repair is performed only if a failure occurred. This procedure may results in the lowest overall costs only in the case of equipment costs are low and a fault will have only a minor effect. This maintenance strategy is abandoned by electricity distribution utilities many years ago due to high social importance of electricity. Corrective maintenance actions will be

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necessary as many failures and defects can not be prevented by the time based maintenance actions. Corrections are required for the failed circuit breaker.

Age is one of the factors leading to a certain deterioration of components. This factor is taken into account by time based maintenance. Stress based maintenance accounts for the usage as another stress factor. For the circuit breaker, apart from age, well known stress factors are the number of operating cycles, the number of short-circuit currents interrupted, the accumulated short-circuit currents interrupted and the number of capacitive or inductive current interruptions. In the practice, time and stress based maintenance procedures are mainly combined into one maintenance strategy, so called time based maintenance.

The most frequent applied maintenance strategy is time based maintenance, based on the age (and stresses) of the equipment. The intervals between inspections, diagnostic tests, other maintenance activities and overhaul are predetermined according to manufacturer's recommendations and the utility's experience. In our country this strategy is applied most frequent also. This approach generally produces satisfactory results, but it is not the most cost-effective option in all cases, since the equipment will not usually remain in operation up to the end of the lifetime which is possible. Information files for the collection of the maintenance experience are very valuable, if any, and offer the possibility to adapt the predetermined time intervals. There are some versions of so called adaptive time based maintenance practices.

Since some years, however, there is a shift from time-based maintenance toward condition-based maintenance. This strategy is based on the technical condition of the equipment. All major parameters are considered in order to determine the technical condition with maximized accuracy. The detailed in formations via diagnostic methods or monitoring systems are needed in this strategy. Condition-based maintenance explicitly relates maintenance actions to the condition of the apparatus. The condition of the circuit breaker is estimated by inspections, diagnostic tests, monitoring systems or dismantling one sample.

The fourth maintenance philosophy is reliability centered maintenance, which takes into account the condition of the equipment and the importance of the equipment in the network. The importance of the circuit breaker in the network describes the consequence of the breaker failures on the network and on the economy. The condition of the breaker must be evaluated on the very subjective criteria. In essence, the main goal of application of this strategy is the ranking of equipments to be maintained due to insufficient resources (money, staff, spare parts, end so on) or due to saving financial efforts without reducing system availability. Ranking can be made about importance of the circuit breaker in the network, about breaker's failure modes and about maintenance methods should be applied.

2 RELIABILITY CENTERED MAINTENANCE

There are two basic reliability centered maintenance: the system approach and the equipment approach [1]. The system approach analyses all equipment within a specified system. A system is a group of equipment that all have a common function, for example, supplying power to customers in distribution network. The other method is the equipment approach, which analyses similar equipment as a group. The group could be equipment of one manufacturer or one type of circuit breaker. Reliability centered maintenance is very difficult task at this moment because it is absolutely new method in the world. It needs many special data about diagnostics criteria and reliability data. This is a reason why experts propose very careful application of this promising method, first of all, step by step. Because of method's inherent complexity, the author of this paper propose as a first step the equipment approach to be used in Serbia. Advantages of equipment approach are:

- The equipment method is "lighter" for defining and application,
- Very detailed analysis of each equipment can be gained, and
- Allows integration of an accurate knowledge to the application of method.

Both methods result in the determining of preventive maintenance schedules. The final schedules are not very different. The equipment method necessarily requires at least a brief analysis of the equipment failure modes. It is mostly oriented to equipment as a part of system and on its importance in the network. On the other side, system approach as its central issue has system reliability and function.

A reliability centered maintenance combines the two aspects of condition and importance [2]. This maintenance strategy requires the following procedure:

- The condition of the circuit breaker has to be determined,
- The importance of the breaker must be determined, e. g. influence of a breaker failure on the reliability of supply, and
- Both inputs must be combined in some way in order to determine critical breakers for maintenance schedule.

Reliability centered maintenance is first of all based on condition based strategy because of need to know circuit breaker state very accurately. Determining of breaker state is first step in defining maintenance strategy and schedule, but it also can be second step because defining of importance and defining of breaker state are absolutely independent. Results of breaker's state and breaker's importance are to be combined at the end of procedure. It is very important to note that, as can be seen in several newest references [1-9], the method of defining of breaker state and importance is quite arbitrary in any case. Because of that, the method is not unique and no practical user's guide through method is given. The utility must define own reliability method based on utilities experience and accepted maintenance procedures. This paper is trying to explain the essence of this method and to propose the first procedure which can be improved later by utility maintenance staff.

The first step in defining of method is to propose determining of circuit breaker's state.

3 ANALYSIS OF THE CONDITION OF THE CIRCUIT BREAKER

Condition monitoring and diagnostic techniques are presented in detail in [3] and [4]. Failure modes and reliability data very useful for defining the reliability centered method presented in this paper are given in [5].

The purpose of condition check is to reveal the condition of the breaker and thereby define the maintenance need. Implemented in a proper way it will also indicate the development of the condition (trend) until the next check. The main question is when the margin of accepted availability of breaker be reached? The most important issue in this task is to choice the parameters that are to be included in the condition check and to find the parameters that are really important for the maintenance work.

In [5] the main major circuit breaker's failure modes are defined:

- Does not close on command,
- Does not open on command,
- Closes without command,
- Opens without command,
- Does not make the current,
- Does not break the current,
- Fails to carry the current,
- Breakdown to earth (internal),
- Breakdown to earth (external),
- Breakdown between poles (internal),
- Breakdown between poles (external),
- Breakdown across open pole (internal),
- Breakdown across open pole (external).
- Other failures necessitating intervention within 30 min.

Major failure of a circuit breaker is [5] complete failure of a breaker which causes the lack of one or more of its fundamental functions. Minor failure is a failure other than major failure. To avoid these major, as well as minor failures, it is needed to determine circuit breaker state during regular maintenance work. This work is without arc chamber dismantling and it is to be done approximately once a year (inspection, cleaning, greasing, counter reading, SF6 humidity and pressure, oil insulation medium dielectric check, and so on) or once in 4-5 years (linkage adjusting, and so on).

The parameters which can be monitored during maintenance work are presented as follows. Beside of parameters presenting, the original method of defining of circuit breaker condition is introduced.

1 Dielectric parameters:

1. SF6 gas density is very important parameter because it represents quantity of insulating and breaking medium. Due to its importance this quantity is monitored by density monitor in practically all cases. Decreased SF6 gas density can decrease dielectric withstand and breaking capacity. If it is lowered, a signal “filling” can arise. At this level the availability of the breaker is jeopardized. If gas leakage continues, the blockade of breaker can be induced automatically. Proposal of author of this paper is to assign “points” to severity of some parameter that departure from permitted range. Weighting of departures is quite arbitrary process. It is accepted that all departures from rated values or values defined by manufacturer are weighted linearly in four steps for all measured values during diagnostics test or monitoring. For example, as a matter of SF6 gas concerned, for one 110 kV breaker rated pressure at 20°C is 0.42 MPa and “filling” signal is at 0.36 MPa. The range 0.06 MPa is to be divided by 4.

Table 1: Table of severity factors (“points”) for pressure departure

Pressure range at 20°C in MPa	Severity (points)
0.42-0.405	1
0.406-0.390	2
0.391-0.375	3
0.375-0.36	4

It must be enabled if pressure reach 0.36 MPa, the word “urgent” to be fill in the table because maintenance work is urgent and must not be delayed. For this quantity this information is got by density monitor automatically, but this may be a principle in other cases.

2. Oil in low-oil breakers is of major importance in oil breakers. Quantity of oil need to be checked and, if level is insufficient, oil must be filled in. Quantity of dielectric oil can be measured by well-known procedure described in IEC 156/1963. Manufacturer has a duty to describe the range of dielectric withstand for breakers. For example, domestic manufacturer define the withstand voltage (IEC 156/1963) of 25 kV (rms value) as a good value. Oil changing is needed at 15 kV. The range of 25-15=10 kV must be divided by 4.

Table 2: Table of severity factors (“points”) for dielectric withstand departure

Dielectric withstand kV	severity
25-22.5	1
22.49-20	2
19.99-17.5	3
17.49-15	4

3. Insulator must be clean. It can be cleaned during maintenance work and it is not of importance for condition determining.

2 Main circuits:

1. Arcing contacts can be burned off. The consequence can be decreased arcing contact overlapping that can make breaker to fail to interrupt. Fault is developing and can be monitored by numbering of short-circuit interruptions. Manufacturer always give the curve of permissible number of interruptions of short-circuits. For example, domestic manufacturer states that its low-oil breaker can interrupt rated current I_{rated} 6 times or $0.8I_{rated}$ 8 times or $0.5I_{rated}$ 10 times or $0.3I_{rated}$ 20 times. That means if breaker interrupted one time current of 0.5 I_{rated} , it spent $1/10 \cdot 100$ %=10 % of its breaking resource. For several breakings, spent resources must be added. For example, if breaker interrupted one time rated current and one time 0.5 I_{rated} , is spent 26.7 % of breaking resources. Maximum resource is 100 %. This percentage must be divided by 4. If circuit breaker spent 0-25 %, severity is 1, 26-50 % severity is 2, and so on up to 4.

2. Temperature rise can induce melting risk. Symptom is increased resistance and temperature. Commonly resistance is measured. This quantity can be weighted. An increasing or fluctuating resistance is clear indication of abnormalities in the current carrying properties of a device. The range of contact resistance must be known as a criterion for condition determining. This range need to be divided by 4 as in all other cases. Resistance measurements are in many cases a simple, direct, fast and reliable method for verifying the current carrying ability of a breaker. Severities are 1-4 as in other cases. For example, domestic low-oil breakers manufacturer recommends for one of its 10 kV breaker with rated current of 800 A permissible voltage drop measured by DC current of 100 A of 7 mV±25 %. Therefore, all "good" voltage drops are between 5.25 mV and 8.75 mV. How to assign severity points in this (and similar) case? It can be proposed that every 5 % of departure is 1 "point". For example, the table can be:

Table 3: Table of severity factors ("points") for voltage drop departure

Voltage drop	Severity
8.75-9.1	1
9.11-9.45	2
9.46-9.8	3
9.81-10.15	4

Of course, experience of utility can be paramount. Utility's values determined by experience for this type of a breaker can be some other values.

3 General parameter

1. Number of operations is a measure for wear and tear of mechanism parts. Time for maintenance is according to breaker manual. This parameter can be known by counter reading. Condition of mechanism can be assessed by dividing of permissible number of operations by 4. For example, permissible number of operations for one breaker type is 2000 operations. That means that if number of operations is 0-500 severity is 1, 501-1000 severity is 2, 1001-1500 severity is 3 and if number of operations is 1501-2000 severity is 4. This means if severity is 4, more care is needed for this breaker mechanism.
2. Fatigue can induce rupture of component. Breaker fails to operate on command and ruptured component must be changed immediately. Due to this reason (fault is sudden) this parameter is not interest for condition based maintenance.
3. Corrosion can make breaker fail under operation. At this time there is no clear way of assessment of this quantity and it can be assessed only quite arbitrarily by maintenance staff by severity factors from 1 to 4.

4 Contact systems

1. Closing time, if it is changed, means mechanical fault under development. The "good" range must be known by manufacturer recommendations. If parameter is out of range, it can be assessed similar as temperature rise (contact resistance). For example, domestic manufacturer of states for low-oil 10 kV breaker that closing time is up to 80 ms.
2. Opening time – the story is the same as for closing time.
3. Closing speed means insufficient closing capability. It is seldom measured in our conditions. The range of adequate speed can be given by manufacturer. For example, for one breaker type good velocity is 5 m/s ±0.3 m/s. If velocity is greater than 5.3 m/s or lower than 4.7 m/s, velocity is not good and principle as for contact resistance can be implemented.
4. Opening velocity – the same as closing speed.

5 Operation capabilities

1. Closing coil – open circuit: If this failure happens, breaker fails to operate. If the failure is detected during planned maintenance, it must be removed by repair work. The work can not be prolonged. Due to this reason this failure mode is not important for circuit breaker condition assessment.
2. Opening coil – open circuit: the same as for closing coil.
3. Adjustment of link/rod/shaft: If linkage is not adequately adjusted, that means mechanical fault is under development. Adjustment in many cases can be done immediately (during diagnostics test). This failure mod is not interesting for condition assessment.

4. Heater – open circuit. Heater is used against corrosion and condensation. If fault is detected during maintenance work, it must be repaired immediately because heater “works” or not “works”. Nothing between these two states can happen. Due to this nature of a fault, this failure mod is not interesting for breaker condition assessment.
5. Motor current and charging time are very easy to measure and give very useful information about development of some mechanical fault. Motor current as well as charging time range can be known by manufacturer information. If departure of those quantities outside of range, the same procedure as for contact resistance can be applied.

In this way, proposal of one arbitrary condition assessment procedure is made. The essence is to quantify departure from normal range of some important quantities in order to assign severity factor (“points”). In this way detailed data sheet for one breaker can be defined that enables much better planning of maintenance work and ranking of breakers for maintenance. Suppose now that one such data sheet is done, for example, of low-oil distribution breaker. In the Table 3 this data sheet of condition assessment is presented.

Table 4: Data sheet of condition assessment

Dielectric withstand of oil	2
Arcing contact wear	3
Contact resistance	1
Number of operations	4
Corrosion	1
Closing time	2
Opening time	2
Closing velocity	4
Opening velocity	3
Motor charging time	2

But, in reliability centered maintenance condition of one breaker must be defined by only one number. That defining can be done by infinity ways, that is, the procedure is quite arbitrary. Procedure for assigning one number to breaker’s condition presented in the following is original and is a first step of introducing of this maintenance strategy in Serbia. Principles are:

- “Condition number” need to be derived from Table 4,
- All severities of “1” and “2” are disregarded because these severity factors means relatively good condition (low departure from adequate values),
- Overall number is derived by number of “4” multiplied by weighting factor 0.75 and by “3” multiplied by 0.25 because importance of “4” is much greater then “3” according to formula:

$$\text{Condition number}=0.75\cdot a+0.25\cdot b$$

where *a* is number of “4” severity factor and *b* is number of “3” severity factor.

Table 5 is presented as an example to demonstrate that of major importance is number of “4” (bad condition of breaker), but numbers of “3” enables us to distinguish condition numbers when number of “4” is equal for several breakers. In that case greater number of “3” is worst condition than lower one.

Table 5: Examples of condition number calculations

1	0.75×a+0.25×b=0.75×5+0.25×2	4.25
2	0.75×5+0.25×1	4
3	0.75×4+0.25×2	3.5
4	0.75×4+0.25×1	3.25
5	0.75×3+0.25×2	2.75
6	0.75×2+0.25×2	2
7	0.75×1+0.25×2	1.25
8	0.75×1+0.25×3	1.5
9	0.75×1+0.25×4	1.75
10	0.75×1+0.25×5	2

In this way first part of calculation is done. By second calculation it is needed to define importance of circuit breaker in some distribution station.

4 IMPORTANCE OF THE CIRCUIT BREAKER IN DISTRIBUTION STATION

Defining equipment's importance and assessing the consequences of a fault constitute a practical, but also subjectively determined value. Several different parameters to be considered and weighted from "1" to "4" are:

- Non-availability of the substation,
- Availability of spare parts,
- Interrupted active power,
- Social effects and kind of customers,
- Availability of adequate maintenance staff,
- Failure rate of the equipment.

All of these parameters can be weighted in the same manner as for breaker condition – assigning weighting factors from 1 to 4. The severity "4" means most unfavorable conditions. For example, if availability of spare parts can be done in this way:

- available spare parts in utilities store-room: 1,
- non available spare parts in store-room but they can be got by manufacturer up to 7 days: 2,
- spare parts can be got, but for a long time: 3,
- no spare parts available by manufacturer because of abandoned manufacture: 4.

Other parameters can be evaluated and weighted by classic reliability study. Suppose at this time that weighting factors (severities) are known. All "1" and "2" factors need to be disregarded as favorable case. General assessment now can be done in the same way as condition assessment, because beside this detailed importance assessment it is needed to get only one assessment. For example, let the breaker with condition assessment of 4 has got importance assessment of 3.5. By reliability centered maintenance, these two parameters must be combined. It is proposed that the coordinate system with condition as ordinate and importance as abscissa to be made. In this coordinate system values for all breakers need to be written.

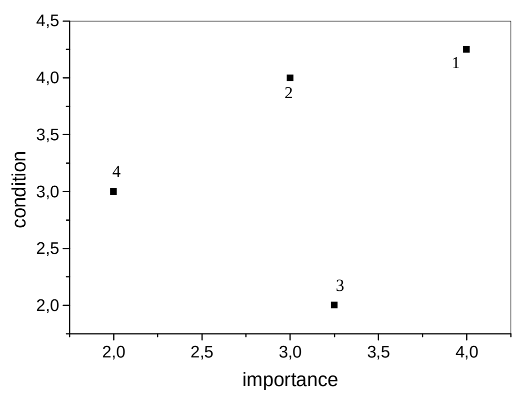

Fig. 1 The graph for 4 circuit breakers

It is evident that breakers in right upper corner are in most unfavorable condition. Breaker No. 1 must be maintained first, breaker No. 2 second and so on.

5 CONCLUSIONS

Several conclusions can be made:

- In this paper basic characteristics of reliability centered maintenance are presented. The base of the method is condition based maintenance, but the importance of breaker and consequences of a fault are taken into consideration,
- The original method of weighting of many condition parameters are introduced,
- Also, method of weighting of importance parameters are given,
- These two parameters are combined through a graph,
- Detailed information about breaker that needs more care is got,
- Maintenance schedule ranking of breakers is done at last.

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