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On-line Capacitor Equipment Monitoring Using a Synthetic Relative Measuring Method

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Abstract

Capacitive equipment in a power system's insulation may be successfully monitored using on-line measurements for dielectric loss angle. The synthetic relative measuring approach not only fixes the problems with the old absolute measuring method, but it also significantly boosts the precision of determining the dielectric loss angle. However, modern studies only discuss the use of a synthetic relative measurement approach based on two or three pieces of capacitive equipment, which lacks the property of universality but is what is being used in practice. The article explains how the synthetic relative measurement concept works. To illustrate the failure judgment matrix for N pieces of equipment, we use an example of application based on three and four pieces of capacitive equipment operating in the same phase as an illustration. These matrices provide for a more generic method of monitoring the failure state of N separate pieces of capacitive equipment. Finally, the study puts out a few issues that need to be addressed and two diagnostic approaches utilized in diagnostic systems to help direct the usage of synthetic relative measurement on local.

1. Introduction

Capacitive equipment, such as current transformers, potential transformers, bushings, and so on, is often used in power systems. Capacitive equipment's stable functioning depends on its being operated safely and reliably [1, 2]. Hence, it will be crucial to keep a close eye on the capacitive equipment's insulation status at all times. The dielectric loss angle is a primary measurable feature of insulating media that reflects its loss characteristics. Power electrical equipment insulation systems may be inspected for global or large concentric local defects by measuring the dielectric loss angle [3, 4]. There are two approaches to determining the dielectric loss angle: horizontal and vertical. The dielectric loss angle of capacitive devices is determined using the PT secondary voltage and the phase difference between the PT secondary voltage and the leakage current through the

capacitive devices is measured [5]. The dielectric loss angle obtained at various times for the same capacitive equipment may be used as a measure of the equipment's insulation. The approach is susceptible to variations in angle at the PT secondary side and other external conditions [6]. The synthetic relative measuring technique is another term for the vertical measuring technique. A collection of relative dielectric loss angles is obtained by randomly sampling the leakage current of comparable capacitive equipment operating in the same phase without reference to the PT secondary voltage angle. It is possible to monitor the insulation of capacitive equipment and identify any defects by looking at the pattern of all observed relative dielectric loss angles [7], [8].

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In the study, a universal diagnostic rule is devised for N pieces of capacitive equipment operating in phase with one another. Several issues that must be addressed on the local level are described, and diagnostic approaches, such as the threshold diagnosis technique and the fuzzy diagnostic approach, are offered to provide a firm basis for the implementation of the concept on the local level.

2. The Basic Principle of Synthetic Relative Measuring Method

If we assume that the dielectric loss angle of each of the N pieces of capacitive equipment deployed in the same phase is denoted by the numbers I and k, then we may interpret i_k as the difference between i and k. To be more precise, $i_k = i - \tan^{-1} \tan i - i$. For any values of i, k, and N, $\tan i_k = \tan i - \tan k$. When the two capacitive devices are functioning properly, we see that i_k and $\tan i_k$ are modest and consistent. When there is a significant change in their worth, it is likely that at least one piece of machinery is broken. If the parameter i_j ($j=1, 2, \dots, N$ and i_j) varies dramatically while k_j ($j=1, 2, \dots, N$ and k_j) remains constant, we may infer that the apparatus with identifier i has insulation flaws. Insulation difficulties in both pieces of equipment numbered I and k may be identified if the angles in and k_j ($j=1, 2, \dots, N$ and i_j) change widely simultaneously while the other $C_{N2} - 2N-3$ relative dielectric loss angles remain stable.

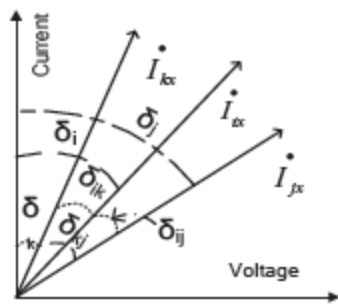


Fig. 1. Phasor diagram of synthetic relative measuring method

Generally speaking, the synthetic relative measuring method is used to calculate relative dielectric loss angle by measuring the angle difference between the leakage currents flowing through capacitive equipment in same phase and according to the change regularity of these obtained values, the diagnostic rule for fault equipment can be found. The phasor principle diagram of synthetic relative measuring method is shown in Fig. 1. Compared with

lateral measuring method, synthetic relative measuring method has some following advantages:

- (1) The synthetic relative measuring method is used according to the leakage current that flows through different capacitive equipment installed in the same phase without considering the reference voltage obtained from the secondary side of PT. Thus, the angle difference caused at PT secondary side can be avoided and the measuring accurate may be improved.
- (2) On local, some capacitive equipment run in the same phase is under the similar electromagnetic environment, the synthetic relative measuring method is utilized to eliminate the negative electromagnetic effect exerted upon the leakage current that flows through the measured equipment. The measuring principle of synthetic relative measuring method is presented in Fig. 2.

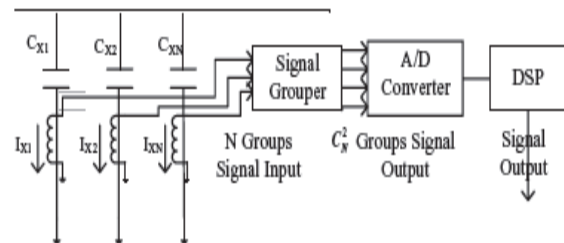


Fig.2. the measuring principle of synthetic relative measuring method

3. The Synthetic Relative Measuring Method Based on N Pieces Capacitive Equipment

It is possible to describe the insulation fault situation of N pieces of capacitive equipment as follows: I of N pieces of capacitive equipment obtains fault. Troubleshooting a Single Capacitive Component (i.e., 3.1) the diagnostic rule in this scenario is shown in Table 1 and it can be simply obtained by using the diagnosis of three different capacitive items of equipment as an example.

Fault diagnosis rule for one, two, or three capacitive devices is shown in Table 1.

Conclusion	δ_{12}	δ_{13}	δ_{23}
No.1 Fault	Change	Change	Unchanged
No.2 Fault	Change	Unchanged	Change
No.3 Fault	Unchanged	Change	Change

In Table 1, the changed dielectric loss angle can be denoted as “1”, and those unchanged can be written as “0”. So a failure judgment matrix can be written as (1).

$$M_3 = \begin{bmatrix} \delta_{12} & \delta_{13} & \delta_{23} \\ 1 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix} \begin{matrix} \text{No.1} \\ \text{No.2} \\ \text{No.3} \end{matrix} \quad (1)$$

In (1), the row labels denote the numbered pieces of capacitive measuring equipment, and the column labels indicate the relative dielectric loss angles between the pieces of gear. The No.1 device is considered to have an insulation issue if both 12 and 13 vary while 23 remains constant. If 13 changes but 12 stay the same, the No. 2 piece of equipment may have an insulation flaw; similarly, if 13 and 23 shift but 12 stay the same, the No. 3 piece of equipment may have an issue. Failure judgment matrices for four and five capacitive devices may be built in the same method, as shown in Equations (2) and (3).

$$M_4 = \begin{bmatrix} \delta_{12} & \delta_{13} & \delta_{14} & \delta_{23} & \delta_{24} & \delta_{34} \\ 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix} \begin{matrix} \text{No.1} \\ \text{No.2} \\ \text{No.3} \\ \text{No.4} \end{matrix} \quad (2)$$

$$M_5 = \begin{bmatrix} \delta_{12} & \delta_{13} & \delta_{14} & \delta_{15} & \delta_{23} & \delta_{24} & \delta_{25} & \delta_{34} & \delta_{35} & \delta_{45} \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 1 \end{bmatrix} \begin{matrix} \text{No.1} \\ \text{No.2} \\ \text{No.3} \\ \text{No.4} \\ \text{No.5} \end{matrix} \quad (3)$$

The insulation state of any one of N pieces of capacitive equipment operating in the same phase

may be diagnosed using the synthetic relative measurement failure judgment matrix provided in (4), which is derived from (2) and (3).

$$M_N = \begin{bmatrix} A_{1 \times (N-1)} & B_{1 \times (C_N^2 - N + 1)} \\ E_{(N-1) \times (N-1)} & M_{N-1} \end{bmatrix} \quad (4)$$

$$A_{1 \times (N-1)} = [1 \ 1 \ 1 \ \dots \ 1]_{1 \times (N-1)} \quad (5)$$

$$B_{1 \times (C_N^2 - N + 1)} = [0 \ 0 \ 0 \ \dots \ 0]_{1 \times (C_N^2 - N + 1)} \quad (6)$$

By N-1 capacitive bits of gear. Finally, the insulation state of each one of N pieces of capacitive equipment may be monitored in accordance with a failure judgment matrix N M. Rule 3.2: Diagnosis using n capacitive sensors (2n-2) here is the diagnostic rule for any two of the four capacitive devices considered, as indicated in Table 2. (Because of constraints on space, the term "Change" has been shortened to "Ch" while the phrase "Unchanged" is shortened to "Unch").

Rule for diagnosing failure in two out of four capacitive devices is shown in Table 2.

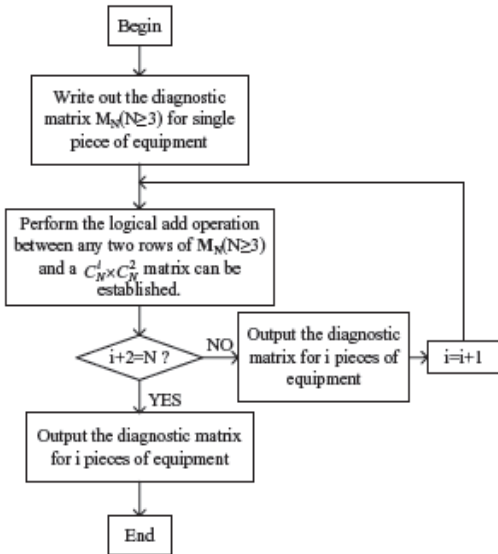
Conclusion	δ_{12}	δ_{13}	δ_{14}	δ_{23}	δ_{24}	δ_{34}
No.1, 2 Fault	C	C	C	C	C	U
No.1, 3 Fault	h	h	h	h	h	nch
No.1, 4 Fault	C	C	C	U	C	C
No.2, 3 Fault	h	h	nch	h	h	h
No.2, 4 Fault	C	U	C	C	C	C
No.3, 4 Fault	U	C	C	C	C	C

Fault condition diagnosis procedures for any two of the four capacitive items of equipment are

summarized in Table 2. Meanwhile, we may get (7), our 2 2 C4 C4 diagnostic matrix, by any two rows of (2) are subject to a logical addition operation that is repeated 2 4 C times.

$$M_{C_4^2} = \begin{bmatrix} \delta_{12} & \delta_{13} & \delta_{14} & \delta_{23} & \delta_{24} & \delta_{34} \\ 1 & 1 & 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} \begin{matrix} (1,2) \\ (1,3) \\ (1,4) \\ (2,3) \\ (2,4) \\ (3,4) \end{matrix} \quad (7)$$

Row labels (1, 2) in (7) represent the total number of pairs of capacitive devices with an insulation problem, etc. The equation in the matrix form for Table 2 is (7). When there are N pieces of capacitive gear, there is a 2 2 Using a logical add operation between any two rows of the N M matrix, we may get the N N C C matrix 2N C M needed to evaluate the insulation between any two of N pieces of equipment. Consequently, a matrix of dimension 3 2 N N C C, 3N C M, may be obtained by performing the same process on 2N C M 2 N C times. After i-1 iterations of this process, a failure judgment matrix (i, 2N, C, C) is provided that may be used to assess the insulation state of i (iN2) items of capacitive hardware. The process's algorithmic flowchart is shown in Fig. 3.



Algorithm flowchart an insulating condition may be verified by N devices, and the maximum order of the

matrix is determined by the number of N-2 devices that are deemed faulty. Rule 3.3: Testing and Diagnosing N+2 Capacitors If we have N broken capacitive devices, then the diagnostic matrix may be written as (8), where N-1 or N is the matrix order (1 2N C).

$$M_{C_N^{N-1}} = M_{C_N^N} = \begin{bmatrix} 1 & 1 & \cdots & 1 \end{bmatrix}_{k \times C_N^2} \quad (8)$$

From (8), we may infer that the insulation on at least N-1 of the N pieces of capacitive equipment is damaged. Since 2 N C values of dielectric loss angle are subject to fluctuate, the precise amount of malfunctioning devices that cannot be identified. There is a negligible chance that N or N-1 pieces of capacitive equipment mounted on the same phase and in the same or a nearby location are both malfunctioning at the same time.

4. Some Problems Needs to be noticed in Using the Synthetic Relative Measuring Method

The same issues must be addressed in order to make the synthetic relative measurement approach useful on a local scale First, a representative sample of the leakage currents passing through the apparatus being monitored must be taken simultaneously. Instant [9] in time. The angle of dielectric loss is known to be quite minimal, and its relative magnitude is also well understood.

$$\Delta\delta_{ijs} - \sqrt{\sum e^2} \leq \Delta\delta_{ijmes} \leq \Delta\delta_{ijs} + \sqrt{\sum e^2} \quad (9)$$

$$\Delta\delta_{ijmes} \geq \Delta\delta_{ijs} + \sqrt{\sum e^2}$$

$$\Delta\delta_{ijmes} \leq \Delta\delta_{ijs} - \sqrt{\sum e^2} \quad (10)$$

In this expression, ijs is the reference value for the relative dielectric loss angle, ijmes is the value that was actually measured, and e is the measurement error due to all of the interference components. On top of that, Margin should be left, and its value determined, based on factors such as location and prior experience. If conditions (9) and (10) hold, the diagnostic system may determine that the relative

dielectric loss angle has not changed and record this as a state of "0"; if conditions (10) and (11) hold, the relative dielectric can be determined to have changed and be recorded as a state of "1". In order to evaluate the insulating state of capacitive equipment, a set of failure condition judgment matrices has been constructed.

Method of Fuzzy Diagnosis

In reality, if condition (9) holds, diagnosing insulation faults in capacitive equipment is difficult; if conditions (10) and (11) hold, the insulation is not guaranteed to be in good shape. Fuzzy set theory may be used to examine the fuzziness introduced by "this and that" [14]. It is necessary to first construct a membership function of the form (x) a (12). Next, plug δ_{ijmes} into (x) A to determine the likelihood that a fault may occur in the insulation of the capacitive equipment being tested. Finally, a failure judgment matrix may be developed based on the aforementioned likelihood value.

$$\mu_A(x) = \frac{(\Delta\delta_{ijmes} - \Delta\delta_{ijs})^2}{(\Delta\delta_{ijmes} - \Delta\delta_{ijs})^2 + \sum e^2} \quad (11)$$

The function figure of membership function (x) A can be shown in Fig. 4.

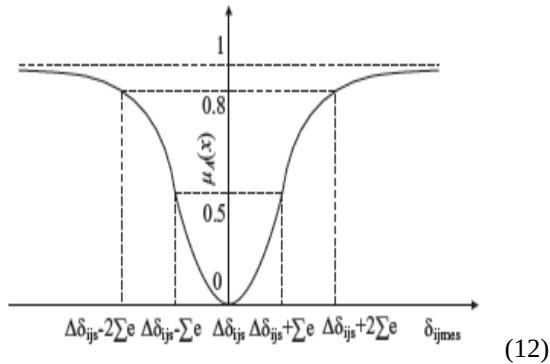


Figure 4: The (x) a function diagram

When (x) 0 a holds, as seen in Fig.4, then (x) δ_{ijmes} holds. That is to say, the capacitive equipment is in great insulation condition since the relative dielectric loss angle remains stable; Probability of equipment fault is less than 0.5 when $\Delta\delta_{ijmes} - \Sigma e \leq \Delta\delta_{ijmes} \leq \Delta\delta_{ijmes} + \Sigma e$ holds, we can find out 0 (x) 0.5 A; if the probability is more close to 0.5, the relative dielectric loss can be considered change and should be accordingly recorded as "1" in failure judgment matrix and simultaneously the diagnostic system can be able

6. Conclusion

Since the synthetic relative measuring technique suggested in this study eliminates the need to deal with voltage signals obtained from the secondary side of PT and significantly reduces electromagnetic interference imposed on the tested capacitive equipment, it is widely regarded as superior to the conventional techniques now in use. Conventional lateral technique of measurement. This work presents a theoretical basis for the implementation of the approach by proposing a generic diagnostic rule based on N pieces of capacitive equipment that operate in the same phase utilizing the synthetic relative measurement method. Two diagnostic approaches utilized in the diagnostic system are described, along with certain field-care issues that need to be addressed; this provides important guidance for implementing the method in the local context.

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