Statistical analysis of operating times of high voltage SF_6 circuit breakers

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***Abstract*—In this paper the operating times of high voltage SF_6 live tank circuit breakers are tested using standard timing tests. The time measurements obtained have proven to be adequate to the normal distribution. The hypothesis testing methodology is applied in order to determine the mean difference value between the tested phase operating times. The results obtained showed that the time difference between the operating times of the tested circuit breakers is located between - 0.661 and 0.536 ms, which indicates that the operating mechanism of the breakers is still reliable and in good condition.**

Keywords: SF_6 circuit breaker, normal distribution, hypothesis testing, timing test.

I. INTRODUCTION

High voltage SF_6 (Sulphur Hexafluoride) gas circuit breakers have proven to be highly reliable as a result of excellent arc quenching cabilities; relatively short breaking time and simple interrupting mechanism [1, 2]. These technical qualities dictate the suitability and popularity of SF_6 high voltage circuit breakers (HVCB) in transmission as well as in distribution switchgears [3 - 5]. Therefore, in accordance with the international council of large electric systems (CIGRE) technical survey [6], the operating mechanisms of circuit breakers represent 52% of major causes of failure. Common operation mechanism - related problems are such as: lubrication deficiency, damaged or burned trip coil...etc. Therefore, on-site condition monitoring of HVCB is recommended as condition - based maintenance (CBM). The analysis of the operating times of SF_6 HVCB is key information to the condition assessment of the operating mechanisms of the main contacts of circuit breakers. The acceptable standard time difference between the opening or closing of the main contacts of breakers is 5 ms [7]. In this study, 40 similar brands of three-phase SF_6 live tank breakers (LTB) high voltage circuit breakers commissioned around the same time and being operated in open - air switchyards or substations and disseminated around the countryside of South Africa, are on-field tested using the SA10 Switch Analyser. The measured operating times obtained in the pole-phases of the circuit breakers have shown good fitness to the normal statistical distribution. Therefore, the mean and the standard deviation values are determined in order to statistically analyse the operating time difference between the pole-phases with the aid of the two-tailed test statistic of the hypothesis testing methodology. The results obtained show that the timing graphs obtained per breaker's contact tested meet standard requirements. However, at 95% confidence level the operating times of the main contacts observed are not similar, and time difference obtained falls within the safety margin. This therefore indicates that the operating mechanism of the SF_6 circuit breaker's are still in adequate condition.

II. METHODOLOGY

The on-field testing of SF_6 high voltage circuit breakers is conducted for the purpose of recording the operating times. The cumulative distribution function (CDF) of the normal distribution is plotted following the test results. Based on the calculated descriptive parameters of the obtained distribution, the hypothesis testing technique is therefore applied.

A. *Field Testing of SF_6 Circuit Breakers*

Timing or commonly referred to as speed contact tests of 40 identical 72.5 kV SF_6 high voltage circuit breakers are performed on field using the SA10 Switch Analyser and other auxiliary components such as: the connecting cables, remote operation enabler and an external visual display unit. The SA10 Switch Analyser consists of an advanced tool capable to perform timing and several other field tests on circuit breakers, relays and other switchgear equipment [8, 9]. This device provides 12 x 2 main contact timing channels, 6 auxiliary contact channels, 3 analogue and 3 digital transducer inputs and one RS 232 communication port. The connecting cables are used to link circuit breakers under test to the SA10 Switch Analyser as well as to establish the earth loop. For safety purpose, the remote operation enabler unit is connected in order to facilitate remotely handling of the device within a distance of 100 metres. The external visual display unit consisted of a portable computer connected to the SA10 Switch Analyser through the RS 232 communication port, and loaded with BTS SA10 software application. For the purpose of this test, a 100 mA DC current is impressed through the breaker's trip coil to force the main contacts to open. The timing courses of the current signals are therefore recorded and subsequently downloaded and saved in the portable computer. The operating or opening times per phase are easily obtained at the current interruption point on the timing diagrams or graphs. The test set-up of the opening times of SF_6 high voltage circuit breakers is shown in figure 1. Therefore, upon a trip shot being executed the main contact time and the trip coil current are recorded.

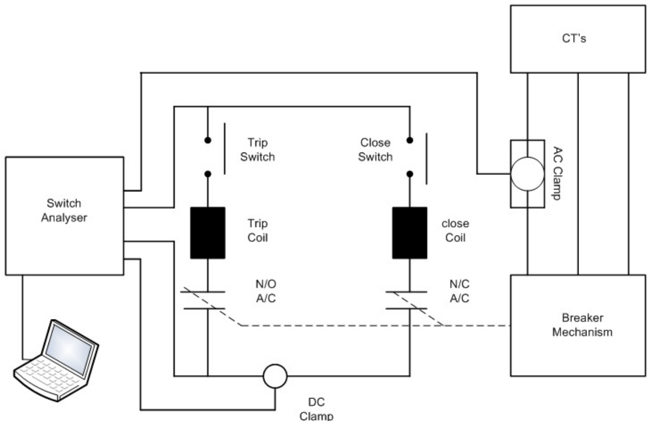

Fig. 1. HV SF_6 Circuit Breaker Test Set up

B. Statistical Hypothesis Testing

The operating times measured from 40 SF_6 circuit breaker's main contact A and B show good fitness to a normal statistical distribution. Therefore the CDF of the operating times can be determined using the following equation [8]:

$$F(t, \mu, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \exp - \left(\frac{t-\mu}{2\sigma}\right) \tag{1}$$

Where: $F(t, \mu, \sigma)$ is the CDF, $\mu = \left(\frac{1}{n} \cdot \sum_{i=1}^{n} t_i\right)$ is the mean value and σ is the variance of the normal distribution given in (2), and t is the operating time.

The variance is obtained from the following equation:

$$\sigma = \frac{1}{n-1} \cdot \sum_{i=1}^{n} (t_i - \mu)^2 \tag{2}$$

Where n is the number of tests conducted.

In order to statistically quantify the time difference between the operating times measured in the breaker's contacts A and B, the hypothesis testing technique is applied. Therefore the following hypothesis formulation and subsequently validation or rejection procedures are followed:

1) The Null hypothesis: this suggests that the mean time difference between the two distributions is zero. Thus the following:

$$H_o : \mu_1 - \mu_2 = 0$$

Where: μ_1 and μ_2 are the mean values of the operating times for contact A and B, respectively.

2) The alternative hypothesis: this suggests that the mean time difference between the two distributions is different from zero. Thus the following:

$$H_a : \mu_1 - \mu_2 \neq 0$$

3) The test statistic: is based on the z value which is obtained from the following equation:

$$z = \frac{\mu_1 - \mu_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{3}$$

Where: $s_1 = \sqrt{\sigma_1}$ and $s_2 = \sqrt{\sigma_2}$ are the standard deviations for respective operating times, n_1 and n_2 are the number of tests.

4) The acceptance or rejection region: based on the central theorem limit whereby the two-tailed test condition is applied at 95% confidence in order to validate or reject either the null or the alternative hypothesis. Therefore the acceptance or rejection condition is determined using the following:

$$H_o \text{ is true} \Leftrightarrow z < -1.96 \text{ or } z > 1.96$$

TABLE I
DESCRIPTIVE PARAMETERS OF NORMAL DISTRIBUTIONS

Contact A	Values	Contact B	Values
μ_1	22.845	μ_2	**22.9075**
σ_1	2.001475	σ_2	**1.993636**
s_1	1.397376	s_2	**1.414001**
n_1	40	n_2	**40**

The confidence limits of the time difference between the operating times measured in breaker's contact A and B could be determined using the following equations:

$$UCL = (\mu_1 - \mu_2) + 1.96\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}} \tag{4}$$

Where: UCL is the upper confidence limit.

The lower confidence limit (LCL) is determined as follows:

$$LCL = (\mu_1 - \mu_2) - 1.96\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}} \tag{5}$$

The upper and lower limits such as described in equations (4) and (5) are determined at 95%.

III. RESULTS AND DISCUSSION

The graphs of the current signals obtained during field testing of HV SF_6 circuit breakers mostly revealed that the pattern indicated in figure 2. These graphs show that the operating times per contact of the breakers tested are not always equal.

The descriptive parameters (mean, variance and standard deviation) of the normal distribution indicated in figures 2 and 3 are determined and shown in table 1.

The CDF of the operating times for breaker's contact A and B such as obtained with the aid of equation (1) are plotted in figures 3 and 4.

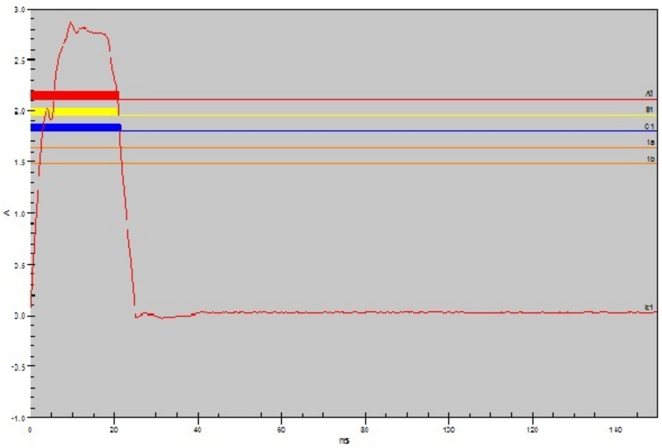

Fig. 2. Current Signal through the breaker's coil

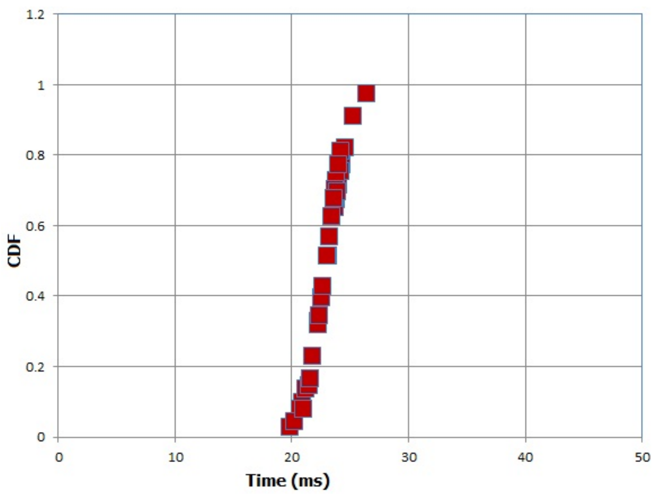

Fig. 3. CDF for Breaker's contact A

Applying the hypothesis testing leads to the determination of the statistic test value using equation (3). This proves to be: z = - 0.205. It could therefore be observed that the z-value obtained did not obey the acceptance condition, which consequently translated to the rejection of the null hypothesis. The rejection of the null hypothesis ultimately validates the alternative hypothesis. Applying equations (4) and (5) yield the LCL and the UCL to be - 0.661 and 0.536, respectively. This indicates that the obtained z-value can actually be located between the upper and lower limits. Therefore, the time difference between the operating times of contact A and B of the tested HV SF_6 circuit breakers is different from zero. The alternative hypothesis is therefore accepted over the null hypothesis. The applied two-tailed acceptance or rejection of the hypothesis testing at 95% confidence level is shown in figure 5.

The rejection of the null hypothesis suggests that there is no or unacceptably insignificant probability of having no time difference between the operating times of the tested HV SF_6

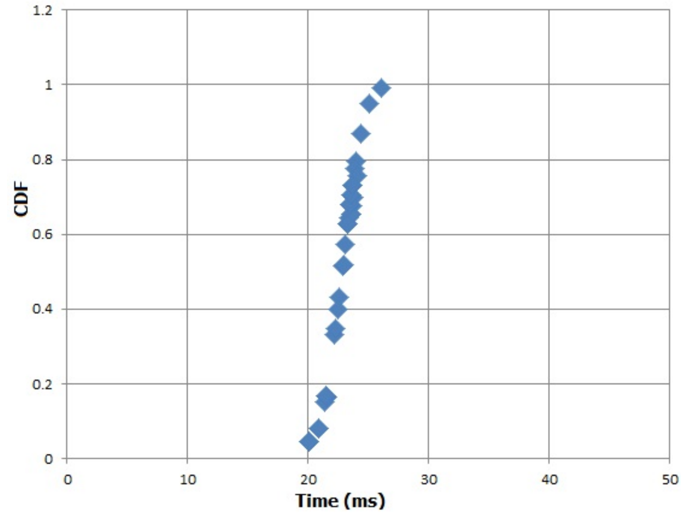

Fig. 4. CDF for Breaker's contact B

circuit breakers.

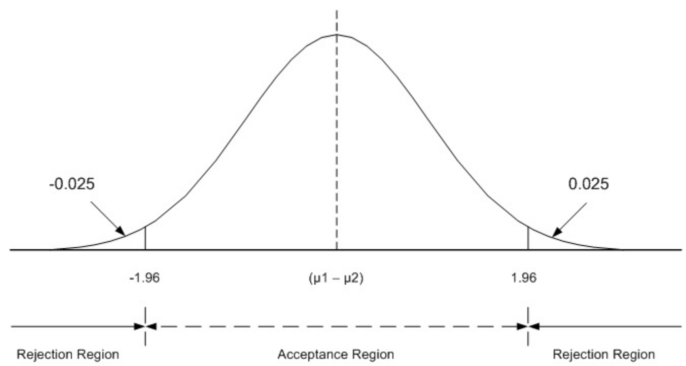

Fig. 5. Two - tailed graph of the hypothesis Test

IV. Conclusion

Condition assessment of HV SF_6 circuit breakers requires amongst others: a reliable test performance of the interruption mechanism of these important switchgear equipment. The operating times of several HV SF_6 circuit breakers are tested using the SA10 Switch Analyser. The time difference between the breaker's contacts A and B are evaluated using the statistical hypothesis testing methodology. The resultats obtained indicate the following:

1) The operating times of the HV SF_6 circuit breakers tested in this study show good fitness to the normal statistical distribution.

2) The time difference between the operating times of the HV SF_6 circuit breaker's contacts may be unequal.

3) At 95% confidence, the time difference between the operating times of the HV SF_6 circuit breaker's contacts

tested in this study lies between the following time interval: - 0.7 and 0.5 ms.

From the field testing perspective, the timing courses obtained meet the requirements for the operating mechanism of SF_6 circuit breakers, which are therefore deemed healthy. However, This finding is confirmed with the use of the statistical hypothesis testing on the determination of the time difference between the main breaker's operating times. It is however envisaged in the future to predict maintenance time for these switchgar equipment using the results obtained in this study.

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