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Performance Evaluation of Circuit Breakers under Asymmetrical Fault Condition (Test Duty T100a)

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Abstract

Among several switchgear equipment largely used in high voltage Transmission systems, which change the grid configuration, isolates faulty parts from the grid, etc. circuit breaker is a remarkable one. For the reason to analyse the interrupting capabilities, a circuit breaker has to undergo various test duties according to IEC 62271-100 among which Test duty T100a is considered as the most onerous one. During this test the breaker has to prove its Interrupting capability during maximum arc energy condition. This article focuses on the Performance evaluation of circuit breaker under asymmetric condition Test duty T100a.

Keywords: Asymmetrical Fault, Circuit Breaker, IEC 62271-100, Luminous Electric Discharge, Test Duty T100a

1. Introduction

With the goal to integrate in the smart cities, the safety of electrical equipment by fast disconnection of the power supply in case of fault events like short circuit, electrical arc, over current or overvoltage is taken care through switchgear such as circuit breakers, etc. When the contacts of a circuit breaker are separated under the fault conditions, there is a luminous electric discharge between these two contacts known as 'Arc'. This arc may continue until the discharge ceases. The production of arc may delay the current interruption process and generate enormous heat which may cause serious damage to system or to circuit breaker itself as it produces severe stresses. Especially while clearing the fault, the operating mechanism is subjected to mechanical stresses and the interrupting contacts and current carrying parts are subjected to thermal stresses. Due to the magnitude and duration of the arc the insulating and metallic materials in the neighborhood of the arc are subjected to high thermal stresses. Thus the operating mechanism and the interrupter of the circuit breaker should be able to perform their functions effectively by sustaining the maximum arc energy under fault conditions.

In order to verify whether a circuit breaker can break the fault current during such unfavorable conditions or not, Test duty T100a is to be performed on the breaker.

2. Test Duty T100a

2.1 Asymmetry Criteria

Test-duty T100a is only applicable when the minimum opening time *Top* of the circuit-breaker, as stated by the manufacturer, plus the relay time is such that the d.c. component at the instant of contact separation is to be greater than 20 %. The concept of percentage of asymmetry at contact separation is only valid if the d.c. time constant of the actual short-circuit current (in service or during tests) is equal or close to the rated d.c. time constant of the rated short-circuit breaking current. The d.c. component at contact separation is determined by the following equation:

$$\%dc = 100\ x\ e^{\frac{-(T_{op}+T_r)}{\tau}}$$

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where,

- % dc percentage of d.c. component at contact separation;
- T_{op} minimum opening time declared by the manufacturer;
- T_r relay time (0,5 cycle; 10 ms for 50 Hz and 8,3 ms for 60 Hz);
- τ d.c. time constant of the rated short circuit breaking current;

2.2 Test Procedure

The most unfavorable conditions for a breaker will be those where the contact separation occurs during a minor current loop and where the duration of arcing time is just short of minimum arcing time required for arc extinction by that particular design of the breaker. The interrupting capability of a breaker should be evaluated in such severe fault conditions where it undergoes maximum arcing time and also experience severe thermal stress due to asymmetrical fault current. Since the severity of the tests for this duty can vary widely depending on the moment of contact separation, a procedure has been developed in order to arrive at realistic stresses on the circuit-breaker under test. The intention is to arrive at a series of three valid tests. The initiation of the short-circuit changes 60° between tests in order to transfer the required asymmetry criteria from phase to phase. Test-duty T100a consists of three opening operations at 100 % of the rated short-circuit breaking current with the required asymmetry criteria regarding the peak and duration of the last major loop and the related arcing time conditions as described below and a transient and prospective power frequency recovery voltage under symmetrical conditions. The duty is said to be satisfactory if following conditions are met. There is no preferred order to demonstrate the three valid tests.

For the **First valid operation** the initiation of short circuit and the setting of the control of the tripping impulse should be such that:

a) arc extinction occurs in the first-pole-to-clear at the end of a major current loop in the phase with the required asymmetry criteria and with the longest possible arcing time.

The longest possible arcing time t_{arc1} for the first-pole-to-clear is achieved, when following condition is met:

$$t_{arc1} = \left(t_{a100s} - T \text{ x } \frac{d\alpha}{360^{\circ}}\right) + \Delta t_{a1}$$

where,

- T is the duration of one cycle of rated frequency;
- t_{a100s} is the minimum of the arcing times of any first pole-to-clear during the breaking operations of test-duty T100s;
- dα = 18°;
- $\hat{I}$ is the p.u. value of the peak current of the first-pole-to-clear, the last-pole-to-clear for *k*pp = 1.5 related to the peak value of the symmetrical short-circuit current;
- Δ_{t1} is the duration of the major loop of the first-pole-to-clear;
- Δ_{ta1} is the time interval between the moment of current interruption in the first-pole-to-clear after a major loop with the required asymmetry and the moment of the first preceding current zero;

The Following Figure 1 shows possible first valid asymmetrical breaking operation.

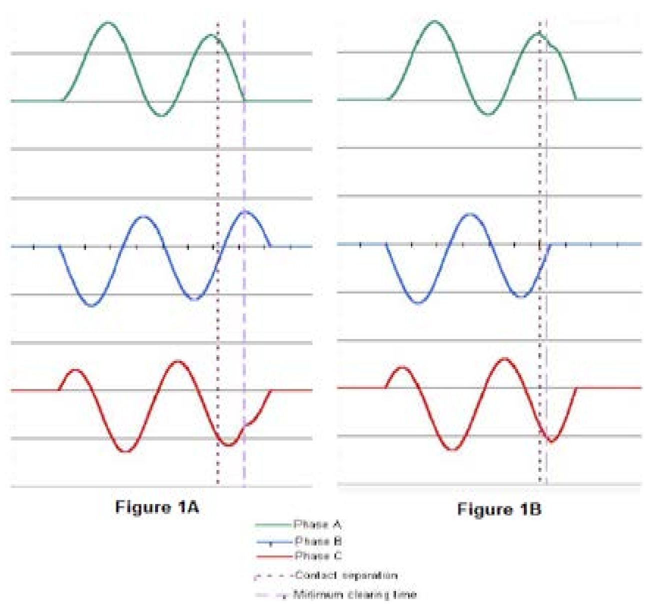

Figure 1. Possible first valid asymmetrical breaking operation.

For the **Second valid operation** the initiation of short- circuit should be advanced by 60° and the setting of the control of the tripping impulse should be such that:

a) arc extinction occurs at the end of an extended major current loop in the last-pole-to-clear or in the second-pole-to-clear with the required asymmetry criteria and with the longest possible arcing time.

The longest possible arcing time t_{arc2} for the last-pole-to-clear for circuit-breakers rated for $k$pp = 1.5 is achieved, when following condition is met:

where,

$$t_{arc2} = \left(t_{a100s} - T \text{ x } \frac{d\alpha}{360^{\circ}}\right) + \Delta t_{a2}$$

Δ_{t2} is the duration of the extended major loop of the last-pole-to-clear for $k$pp = 1.5;

Δ_{ta2} is the time interval between the moment of current interruption in the last-pole-to-clear after an extended major loop with the required asymmetry for $k$pp = 1.5 and the moment of the second preceding current zero;

To perform a valid second test the following actions has to be taken into consideration

- if the first operation was valid as shown in Figure 1A, because the arc extinction occurred in the phase with the required asymmetry criteria after a major loop, the setting of the control of the tripping impulse should be advanced by approximately 130° with respect to the first valid operation.

- if the arc extinction occurred in the phase with the required asymmetry criteria after a major extended loop as shown in Figure 1B, then the setting of the control of the tripping impulse should be advanced by approximately 25°.

The Following Figure 2 shows possible second valid asymmetrical breaking operation.

For the **Third Valid Operation** the initiation of short-circuit should be advanced by further 60° and the setting of the control of the tripping impulse should be such that the required conditions of a) and b) are to be fulfilled in a third operation, arc extinction may occur at the end of a major current loop for first-pole-to-clear conditions, or of an extended major current loop for last-pole-to-clear conditions for circuit-breakers rated for $k$pp = 1.5. To perform a valid third test the following actions has to be taken into consideration:

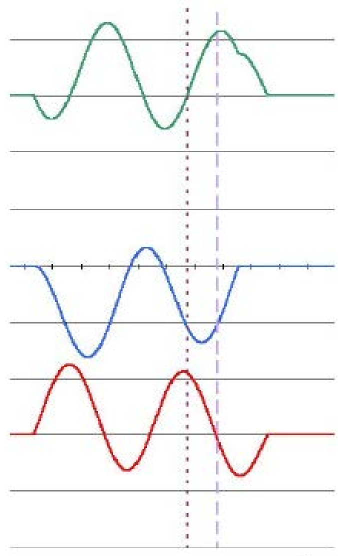

Figure 2. Possible second valid asymmetrical breaking operation.

- during second test if the arc extinction occurred in the phase with the required asymmetry criteria after a major loop as shown in Figure 2, the setting of the control of the tripping impulse should be advanced by approximately 130°;

- if the arc extinction occurred in the phase with the required asymmetry criteria after a major extended loop, then the setting of the control of the tripping impulse should be advanced by approximately 25°;

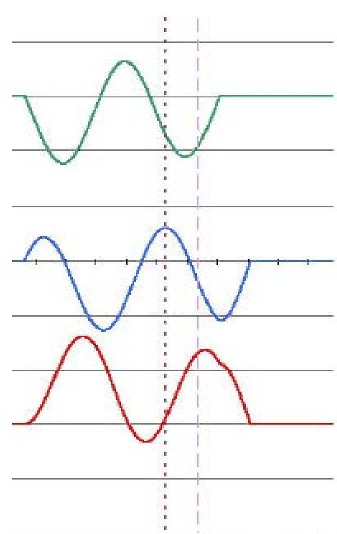

Figure 3. Possible second valid asymmetrical breaking operation.

There are no further requirements regarding arcing times.

A test where the circuit-breaker clears at the end of a reduced major current loop or a minor loop in the phase meeting the asymmetry criteria is invalid. But some circuit-breakers will not clear at the end of a major loop. Arcing then continues during the subsequent minor current loop and becomes a last pole-to-clear. However, this test is considered valid if, during a subsequent test, it is proven that the longest possible arc-duration was achieved.

Some circuit-breakers will not clear at the end of a major loop after the required arcing time. However, this test is valid if the circuit-breaker cleared the subsequent minor current loop and it is proven that the longest possible arc-duration was achieved as shown in Figure 4. If the behavior of the circuit-breaker is such that the required conditions of a) and b) are not fulfilled, the relevant tests shall be continued by changing the tripping of the circuit-breaker in steps of 18°. If during tests the required arcing times are not achieved because of minimum arcing times differing from t_{a100s} the maximum achievable arcing times shall be demonstrated. The total number of tests is limited to 6, when attempting to meet the above mentioned requirements. After 6 tests the test duty is valid regardless of which arcing times have been obtained.

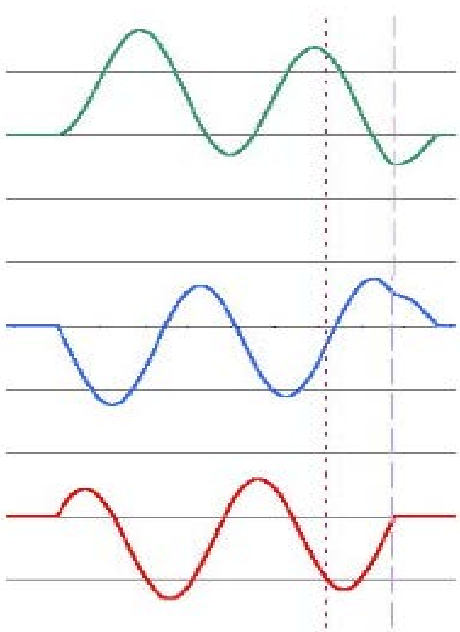

Figure 4. Possible fourth valid asymmetrical breaking operation.

The breaking operations are valid if the prospective current meets the following asymmetry criteria:

– The peak short-circuit current $\hat{I}$ during the last loop prior to interruption is between 90 % and 110 % of the required value and

– The duration of the short-circuit current loop Δt prior to interruption is between 90 % and 110 % of the required value.

3. Empirical Results

Test duty T100a has been conducted as per clause no 6.106.5 of IEC 62271-100 on various medium voltage circuit breakers rated 12kV and breaking current up to 44kA at 1250 MVA short circuit testing station (Station-1), STDS, Bhopal. The following Figure 5 shows the test circuit diagram for Test Duty T100a. Severity of test duty T100a on a circuit breaker while evaluating its performance can be seen in following case studies.

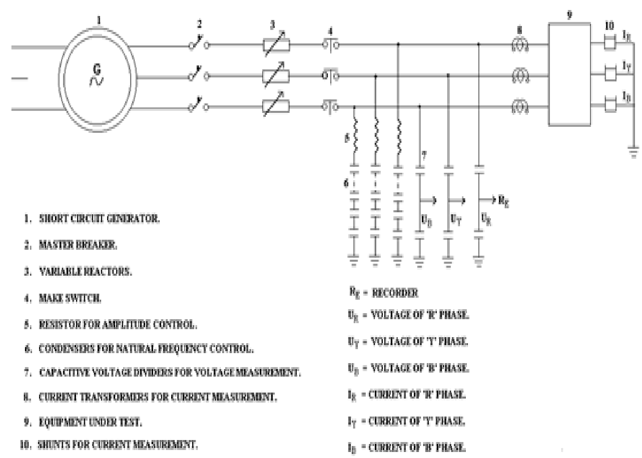

Figure 5. Test circuit diagram for Test duty T100a.

3.1 Valid Operations of Test Duty T100a

Figure 6 represents the recording of oscillogram of 12kV, 40kA circuit Breaker upon which Test duty T100a has been carried out at CPRI, Bhopal. As stated under 2.1, the minimum clearing time for this breaker was found to be 45msec. It was made to interrupt the rated breaking current 40kA at rated voltage 12kV , with $k$pp = 1.5, during which last pole to clear with major extended loop with required asymmetry in R phase was observed as shown in figure which met the condition (b) as stated under 2.2 making it a valid first break shot. During this shot arcing time was calculated as per stated under section 2.2 of this paper, which was found to be 16.5msec.

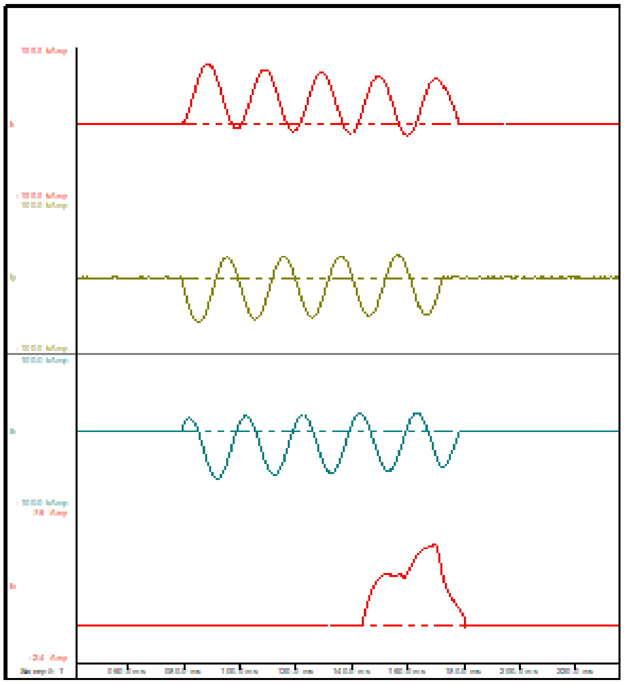

Figure 6. 1st valid break shot.

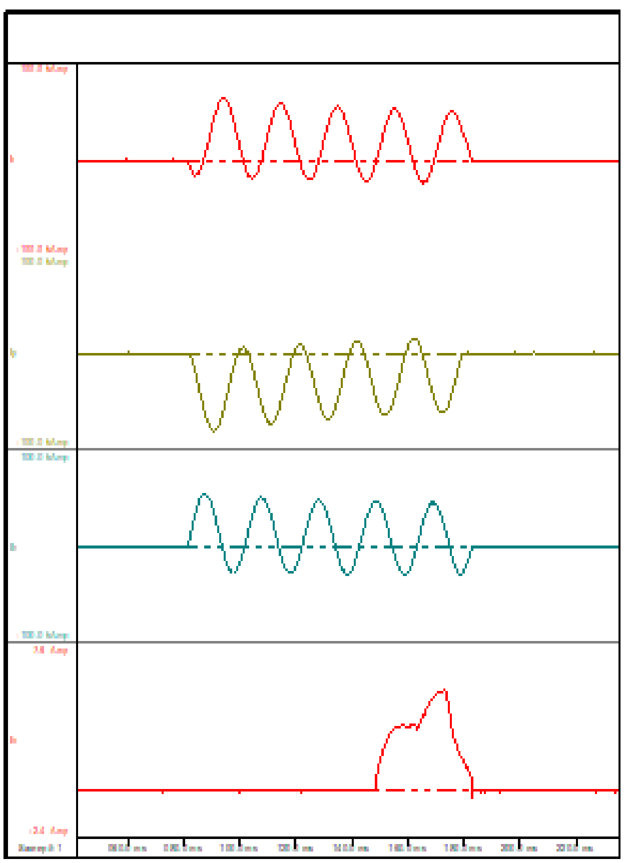

Figure 7. 2nd valid break shot.

Then when proceeded for second break operation by advancing the initiation of the short circuit by 60 degree and the tripping pulse has been shifted by 25 degree, breaker experienced asymmetrical condition on Y phase and interrupting the fault current as first pole to clear with major loop satisfying the valid operation a). During this shot arcing time was calculated as per stated under section 2.2 of this paper, which was found to be 9.8msec The Figure 7 shows the valid second break shot of the breaker.

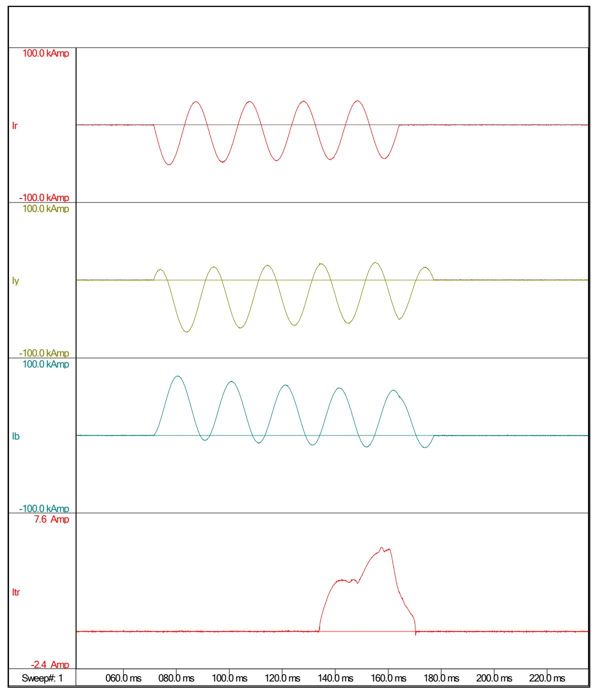

Figure 8. 3rd break shot.

When proceeded for 3rd break shot by advancing the initiation of short circuit by 60 degree and shifting the tripping pulse by 130 degree, breaker experienced asymmetrical condition on B phase and interrupted the test current as last pole to clear with minor loop. The Figure 8 shows the valid break shot meeting the condition as shown in Figure 4.

To obtain the valid operation c) as stated under 2.2, break operation performed by advancing the initiation of short circuit by 60 degree and shifting the tripping pulse by 130 degree. The Figure 9 shows that breaker experienced asymmetrical condition on R phase with first pole to clear with major loop satisfying third valid operation. Last current loop parameters under all the valid break operations were calculated with formulae mentioned

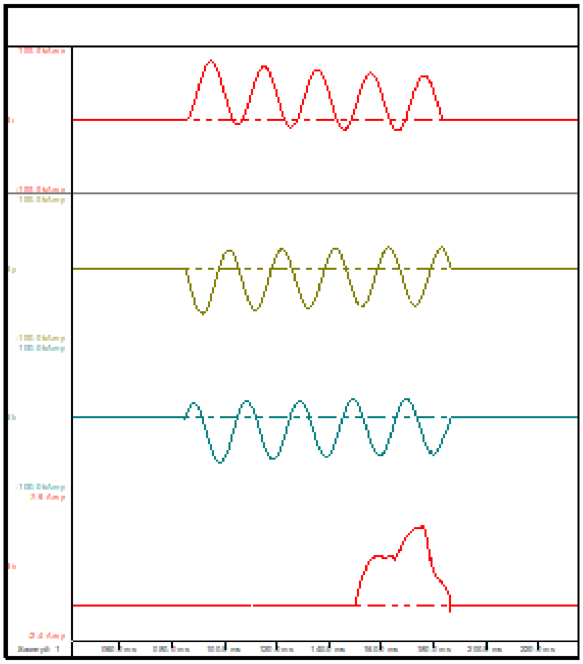

Figure 9. 3rd valid break shot.

under section 2.2 and listed in the table mentioned below which were well meeting with requirements of table 39 of IEC 62271-100,2017 [1], for a clearing time of 45msec, under three phase tests of Test duty T100a for 50HZ operation.

4. Case Study of Breakers Failed During Test Duty T100a

4.1 Case Study 1

Test duty T100a conducted on 12kV, 2000A, 40kA breaker. During 1st break shot, breaker could not clear the fault and current flow for the full duration. The fault current was interrupted by the Master breaker of the Short circuit laboratory. Contact of the circuit breaker found welded while checking the continuity. Hence further test discontinued. The recording of oscillogram of the test is shown in the Figure 10.

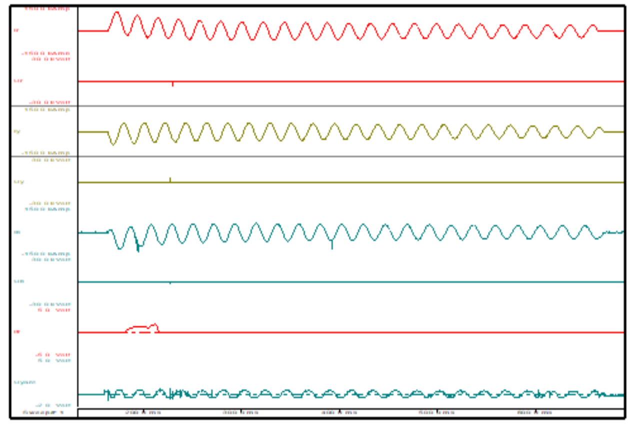

Figure 10. Recording representing the breaker not clearing the fault during Test duty T100a.

4.2 Case Study 2

Test duty T100a conducted on 12kV, 1250A, 26.3kA circuit breaker. During 6th break shot, the recording of oscillogram as shown in the Figure 11 was obtained. After the shot, breaker was not operable on no-load and R & B pole of the breaker found welded. There is no recording of current waveform from Y-Pole.

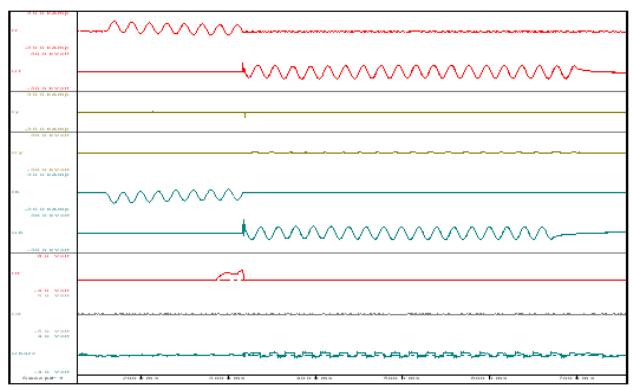

Figure 11. Recording representing the breaker whose contacts got melted during Test duty T100a

4.3 Case Study 3

When Test duty T100a conducted on 12kV, 40kA vacuum circuit breaker, during 2nd shot, heavy arcing noticed,

Required Last current loop parameters (msec)				Obtained parameters during First Valid break shot (msec)		Obtained parameters during Second Valid break shot (msec)		Obtained parameters during Third Valid break shot (msec)	
Δt_1	Δt_{a1}	Δt_2	Δt_{a2}	Δt_2	Δt_{a2}	Δt_1	Δt_{a1}	Δt_1	Δt_{a1}
12.2	3.8	13.7	9.8	15.3	11.5	14.2	4.8	14.1	4.3

Y-Phase cluster contact found melted, hence further test were discontinued. The breaker was operable on no load after the shot. The oscillogram of the recording is shown in the Figure 12.

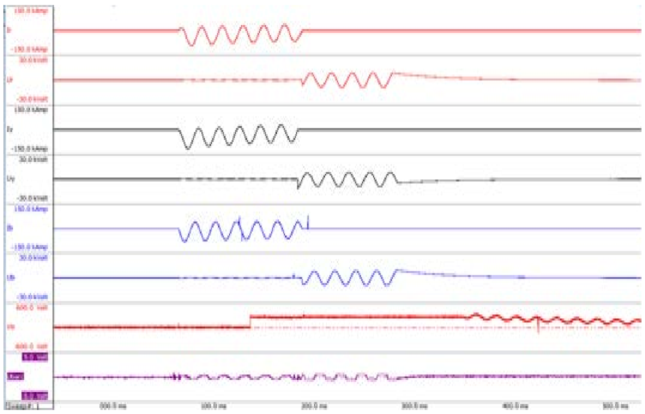

Figure 12. Recording of Oscillogram of breaker where heavy arcing noticed during Test duty T100a.

5. Conclusion

The Test Duty T100a verifies the performance of breaker under mechanical stress due to asymmetrical fault and severe fault interrupting condition, when the interrupter is subjected to maximum arcing time or maximum arc energy input and the breaker operating mechanism at rated breaking operations.

The probability of the failure of the circuit breaker during the basic duty test T100a:

- due to defective trip circuit & auxiliary switch.
- incomplete breaker mechanism travel as operating mechanism of breaker not able to withstand such severe mechanical stress.
- Dielectric material inside the interrupter is out of specification (like low pressure or low temperature) or it might got contaminated, etc. If the interrupter or contacts of the breaker is not able tolerate the arc column temperature then arcing inside the interrupter will likely to cause welding or melting of contacts.

6. Acknowledgement

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7. References

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