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Mechanism Assessment of Air Circuit Breaker and Identification of Faults by Testing Method

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Abstract: Air Circuit Breakers (ACBs) are popularly used for low voltage application in many industries and distribution panels. ACBs possess fault interruption capabilities such as high making and breaking capacity. ACB operates on the mechanism of sensing current through Static Release (SR) action which results in Free Return Charging Device (FRCD) being operated. The reliability greatly depends on the smooth mechanism operation of ACB. This paper illustrates root causes of various faults on ACB during its lifespan using Ishikawa diagram. ACB serves a vital part of the protection of power system, it's reliability gains importance. The testing of ACB in the company is carried out as per International Electrotechnical Commission (IEC) codes using on field fault conditions which ensures its reliability in market as guaranteed by the organization. The industry carries out testing on test bench by creating on field fault condition such as overload, short circuit, earth fault which is based on the principle of primary and secondary injection methods. The reliability of ACB can be predicted by detailed analysis of testing results.

Keywords: Air Circuit Breaker, Free Return Charging Device, Microprocessor based Static Release.

I. INTRODUCTION

ACBs are electromechanical protection devices used to protect the electric circuit from damage caused by faults. Proper installation and maintenance according to IEC standards will ensure that the breakers render a longer lifespan of trouble-free service. ACB operates on a principle of making or breaking circuit in the medium of air at atmospheric pressure (760 mm Hg). It works as a switching current interrupting device. ACBs being a major safety equipment on which the reliability of the connected system depends. Testing of ACB is based on the principle of primary current injection and secondary current injection. Secondary injection technique is widely used in industries and commercial application for purpose of ACB testing.

Larsen and Toubro (L&T) is India's largest manufacturer of low tension switchgear which produces wide range ACBs. These breakers are designed for industrial environment and robust body. L&T ACBs are classified as U Power and C Power depending upon the market specifications. ACBs are identified by their current ratings. L&T manufactures a wide range of ACB ranging from 400A, 640A, 800A, 1000A, 1250A, 2500A, 3200A, 4000A, 6300A.

II. OPERATING MECHANISM OF ELECTRICAL ACB

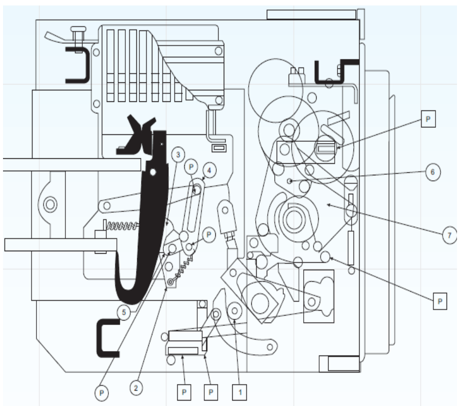

Fig. 1 Mechanism of Electrical ACB

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P) Pins

1) Roller Assembly
2) Pole Latch Spring Retainer
3) Stainless Steel Profile
4) Slotted Guide
5) Pole Latch Nylon Rollers
6) Crank

7) Plate

This type of breaker incorporates electrical motor operated spring charged (stored energy type) mechanism. The universal motor mounted on the breaker charges the spring through FRCD. This device converts the rotational motion of the motor into linear motion of the spring. It consists two clutches each allowing the rotation of the FRCD shaft in only one direction. This device also cuts the motor supply when the spring is fully charged. When the spring gets fully charged and closing signal is given to the breaker, an electromagnet releases the latch through mechanical links. As the latch gets released, the spring gets discharged. But at the same time the spring force is applied on the main shaft of the breaker and this force acts on the poles via connectors and the breakers gets closed. After the ACB closes, the spring gets automatically charged for the next closing operation.

A motor charges the closing mechanism spring. The supply to the motor gets disconnected by a limit switch at the end of the charging operation. The closing electromagnet, when actuated, discharges the spring and closes the breaker. Spring condition is indicated by a mechanical indicator visible through a transparent window on the front facia. In case of control supply failure to motor, the operating handle can be used to charge the spring.

TABLE 1

Indicator Display	Spring Condition
Yellow	Charged
Black	Discharged

TABLE 2

Indicator Display	Breaker Condition
Green	ON
Red	OFF

III. REPRESENTATION OF FAULTS BY FISHBONE (ISHIKAWA) DIAGRAM

Ishikawa diagram cause effect matrix and pareto analysis were used to examine the root causes of failure in ACB which has maximum impact on its mechanism. Four primary causes that lead to the effect of ACB's tripping action is represented in the Ishikawa diagram. The failures along with the various causes can be effectively determined with the help of Fishbone diagram. as represented in the Fig. No.2. Four key faults (Short circuit fault, Overload fault, Earth fault and improper SR setting) have maximum impact on ACB performance. To avoid or minimize the extent of these fault proper handling and appropriate maintenance of ACB is essential.

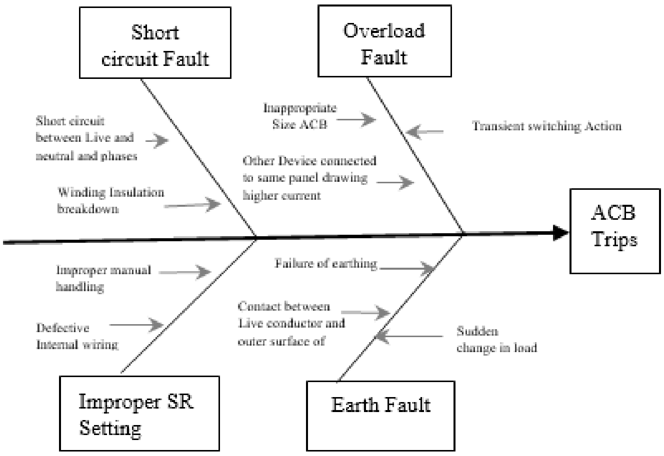

Fig. 2 Fishbone diagram representation

In abnormal conditions, current is diverted from its intended path, this defect in the electrical circuit is called as fault. This faults causes reduction in insulation strength of conductors. Severity of the faults decides the extent of damage.

Severity of fault depends on the amount of excessive current flowing through the circuit and also depends on sudden drop of the impedance of conductors due to short circuit between conductors or between the conductor and ground. The probability of failure of heavy equipments is more on power lines because they are subjected to the action of atmospheric disturbances. It is beneficial to have some ideas of various causes of faults and frequency of all fault occurrences in power links.

TABLE 3

Sr. No.	Causes	Percentage (%) of total failure
1	Lightning	12
2	Sleet, wind, Mechanical breakdown	20
3	Apparatus failure	20
4	Switching to fault	20
5	Atmospheric condition	28

Types of faults that widely occur on the system are discussed below.

3.1 Short Circuit Fault

Most common and severe fault that occurs in power system is the Short Circuit fault. They occur due to the breakdown of insulation which results into Short Circuit between phases as discussed above. Short Circuit faults are L-L; L-L-L Probability of occurrence of frequent kinds of short Circuit faults is given in the table 4.
The transient phenomenon lasts for short duration (3-5 seconds). The zone in which abruptly current rises and falls at high rate then it is called Sub transient state. Then current reduces gradually which comes under Transient zone. After the transient period, steady state current flows through the circuit. Constant short circuit current flows in steady state region after transient period.

TABLE 4

Sr. No.	Types of Faults	% of Occurrences
1	L-G	70
2	L-L	15
3	L-L-G	10
4	L-L, L-G	20.3
5	L-L-L-G	20.3
6	L-L-L	20.3

3.2 Overload Fault

Short Circuit and the overload is discriminated from each other because Short Circuit occurs due to the fault between the lines whereas overload means equipment draw the excess current from supply. The term Overload is related to circuits or devices. When more than desirable load is applied to the circuit then it is said that the system is overloaded. Most probably the causes of overload are malfunctioning of the equipment or faulty circuits. In case of overload faults the voltage at load end diminished to a very low value (not zero). The current in this case is high but considerably lower than the S. C. current. The effect of overload is that it results in increase the temperature which causes breakdown and hence damage the equipment. Overload conditions can occur at the service feeder or branch-circuit level of electrical power distribution system.

Mechanically overloaded motor is also responsible for overcurrent which is caused by excess friction within its internal bearing surfaces, excess heat. The Overcurrent situation can be controlled in this situation because of low magnitude of current.

3.3 Earth Fault

An Earth fault current is a current that flows through earth due to faulty system installation and has a magnitude which depends on the method of system earthing. Earth faults may occur for a number of reasons which are mentioned in Fig. 2.

IV. PRINCIPLE OF TESTING OF AIR CIRCUIT BREAKER

When a machine is manufactured in industry as per the particular design, testing is required to determine whether the performance of machine is as per the IS and IEC standards. If the operation of machine is not as per the IEC standards, then variations in actual values and desired values are determined and the differences are recorded and checked whether they are within the permissible limits specified by IEC or IS standards or not. Testing of circuit breakers is more difficult as compared to other electrical equipments because fault current is very large and this can cause major damage to the circuit. Therefore, testing holds a vital role in the proper trouble free operation of an ACB.

4.1 Testing Methods

4.1.1 Primary Injection Method

This principle employs high voltage and high currents used in testing. Mostly this method is seen to be followed at large electrical installations such as control circuits, industries and substations etc. In case of testing of an ACB, a high magnitude current depends on the system specifications and test requirement is injected directly on primary side. During fault condition to identify the operation of CB at various levels of load current this method of testing is followed.

The major disadvantage of primary injection method is the error in detection of sensor wiring problems. This method is not feasible as well as relatively expensive service. To overcome such difficulties, the Secondary Injection method is widely used in the industry.

4.1.2 Secondary Injection Method

Similar to Primary Injection Method, Secondary Injection method of testing is followed in the industries to serve the purpose of correct functioning of circuit breakers. This method works on low voltage principle due to which the testing of ACBs is done at low voltage which prevents the breaker from damage and also helps in the safe operation of testing. The person working on the test bench or testing equipment will not get shock due to some technical fault issues as it follows low voltage principle. It consists auxiliary relays, protective relays and circuit, metering devices, communication and control systems etc.

This method of testing not only comprises proper functioning of ACBs but also verifies all the circuits connected in secondary protection system for correct functioning and maintenance inspections. The main shortcoming of these tests is that only the solid state trip unit logic and components are tested. Test connections are made directly at solid state relay because they are universally equipped with test plug terminals for testing. A simulated CT secondary current is allowed to be injected for checking the trip circuit in secondary injection method. In secondary injection method of testing, solid-state relay unit can perform the secondary test in various test modes depending upon the desired accuracy and output of the tests.

4.2 IDMT Characteristics

The CBs follow Inverse Definite Minimum Time (IDMT) characteristics during the fault condition. The testing of breakers is based on this characteristic. Therefore, the brief explanation about IDMT characteristics holds significance in this paper. In many instances of overcurrent, the protective devices will not allow such high current to pass through the breaker for safety and reliable operation of system.

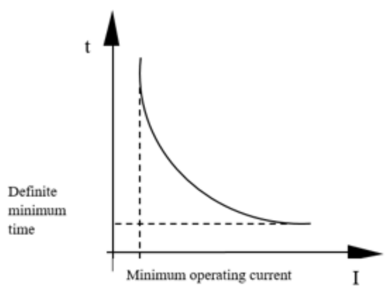

Fig. 3 IDMT Characteristics

The protective devices (SR Release, DN Release) based on IDMT characteristics to provide overcurrent protection. IDMT characteristics have particular behavior for high amount of overcurrent as the time required to trip the circuit is less and for low current value the time required is more. As compared to other characteristics IDMT characteristics have a faster response. Hence it is reliable to follow these characteristics for protection of ACBs.

V. TESTS PERFORMED ON ACB

5.1 Short circuit test

The capacity of CB should be such that it can carry maximum short circuit current momentarily and should have ability to interrupt this high magnitude current. In short circuit test, CB is subjected to sudden short circuit so that testing equipment can note its contact performance at the time of Short circuit and the graphical results are recorded. These results are studied with reference to the breaking and making currents. Symmetrical and asymmetrical restriking voltages are tested at rated conditions. Simultaneously poles are energized by current which is 4 times greater than rated current. The condition for test is that the breaker should trip within 200ms after passing short circuit current through any one phase of ACB by blocking other two phases.
Test current through single phase of ACB =1.2 × 2 CT

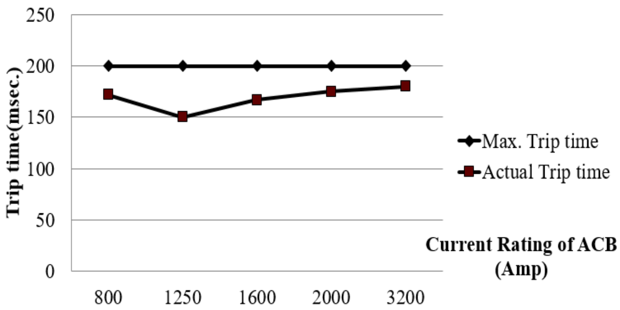

Fig. 4 Short circuit test result

Test bench based on secondary injection method is installed at L&T. Fig. No.4 shows the short circuit test results are verified and tested by L&T Test bench.

5.2 Overload Test

The purpose of this test to ensure that ACB should withstand the overload current flowing through it for minimum 18sec. Fault condition is created by passing current which is equal to twice the rated CT tap connected through one pole (R, Y or B) and other poles are blocked. Condition is that the breaker should trip within 18-28sec. If CB is not tripping within it's specified time then the ACB is proceeded for rework. Thus overload test is conducted on ACBs. Microprocessor based SR setting is provided such that ACB should take minimum time to trip for short circuit.
When compared both overload and short circuit conditions ACB takes more time to trip in overload than short circuit fault condition which results into severe damage due to high magnitude of fault current.

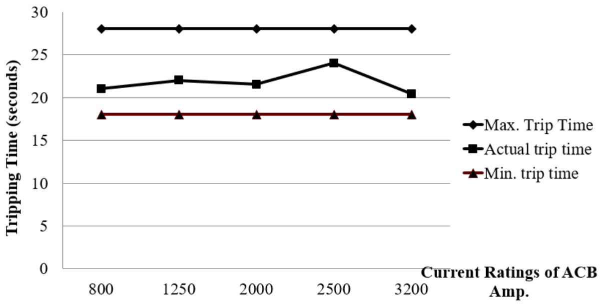

Fig. 5 Overload test result

Overload faults on ACB's are tested on L&T Test bench from tested output as shown in Fig. No.5. we can observe that actual trip time is within maximum and minimum time limits determined on the basis of IEC-60947.

5.3 Earth Fault Test

To check rated capacity of the breaker as per specification decided by IEC-60947, this test is performed on ACB. For Non-Trip test, initially 3 phase balance current is passed through it and then it is checked whether the breaker is tripping or not. The condition is breaker should not trip within 5 sec. Trip test, 3 phase unbalance current is passed through ACB and here the condition is, breaker should trip within 200 msec.

VI. RELIABILITY

Integrated electrical power systems are very complex. In case of interruption of supply to load due to failure hampers the reliability of the system. Consumer's demand of power system reliability is gaining importance which concerns the power industry and society at large. All category consumers such as industrial, commercial and domestic demand a highly reliable supply at economical rates. A reliable CB aids the reliability analysis of the power system. CB must continuously operate under normal service condition and should have the capability to withstand short time overcurrent during abnormal conditions. The reliability in case of normal operating conditions requires the following conditions should be met.

$$\text{Rated current} \geq \text{Actual load current}$$

Reliability being a qualitative parameter is accessed from statistical data. Reliability of ACB cannot be specified in terms of mathematical expression with known certainty. The CB should be properly fixed into the connected system. Instantaneous operation on occurrence of fault gives the reliability of ACB as maximum. Proper maintenance and fault detection process would give reliability analysis of CB at regular intervals. Factors accounting for reliability of ACB are as follows:

1. Careful maintenance.
2. High quality material of contacts.
3. Robustness in construction.
4. Smooth and dust free contacts.
5. Proper settings of SR and DN Release.

VII. CONCLUSION

The Protection device ACB which holds significance in switchgear was analyzed and studied. The operating mechanism of ACB according to its two types viz. Electrical and Manual were studied. The performance of a system relies on its protection system. The failure of an ACB to trip would lead to a delay and overcurrent would damage its contacts and connected circuit. Instantaneous operation of an ACB depends on its operating mechanism, causes of failure and operating condition. The root causes of failure were analyzed in detail with the help of Ishikawa diagram. This method is most significant in determining all the possible causes of failure.

The overload, short circuit, earth fault tests are performed at industries to ensure the reliability. The test procedure includes creating on field condition using test bench. According to the observation the ACB withstood all the fault conditions and tripped the circuit within the specified time limit. The testing results conformed to the IEC standard-60947 and company's testing reference sheet. The cause of failure has been reviewed and accordingly preventive measures were carried out to limit the chances of failure. This method is proven to improve the reliability of ACB.

VIII. ACKNOWLEDGEMENT

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