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SC A3 - TRANSMISSION & DISTRIBUTION EQUIPMENT
PS2 / DECARBONISATION OF T&D EQUIPMENT

Improving Human Safety & Environment by Innovative Circuit Breaker Testing

Balasaheb DOIPHODE*
balasaheb.doiphode@scopetnm.com
Shivanand DADDI
shivanand.daddi@scopetnm.com
Yash KULKARNI
yash.kulkarni@scopetnm.com
SCOPE T&M Pvt. Ltd.
INDIA

SUMMARY

Circuit Breaker is one of the important equipment in the electrical network. These Circuit Breakers are tested periodically to assess its continual healthiness. Traditionally contact timings, contact speed, travel, coil current and dynamic contact resistance measurement are conducted on CBs. Off-line Circuit Breaker Analyzers with DCRM are used for these measurements. The testing protocol typically involves taking shutdown on CB & isolating CB with Disconnectors. For personnel safety, CB needs to be earthed from both sides before making test cable connections from Test Kit to CB. The same needs to be removed before conducting test because it creates a parallel earth loop affecting the measurement, as traditionally the Test Kits were not designed to work in such configuration. After the tests, reverse sequence is to be followed.

This frequent connection & disconnection of earthing and need to follow the correct sequence of the same could lead to human error having grave consequences. There have been incidences of severe accidents due to this. Working with both sides earthed continuously during maintenance, without need of above referred connection / disconnection provides for much safer operation and is recommended by authorities & standardization organizations. Increased awareness about overall safety and growing concern for environment mandated innovative technological solutions not only for human safety issue, but also for how we can reduce the carbon footprint of this testing activity.

Indigenous CB Analyzers & DCRM kits are in use in India for more than couple of decades. As the demand for critical tests like Contact Timing & DCRM measurements of CB while earthed from both sides were raised by CTU, Powergrid Corporation of India Ltd. and few provincial EPUs, it became imperative for Test Kit designers to develop techniques for the same.

When CB is earthed from both sides, it creates an earth loop parallel to CB contacts, posing real challenge to measure both closing / opening time along with bounces and capturing signature of dynamic contact resistance. During DCRM test depending on resistance of earth loop, partial test current will pass through this loop and for timings this loop will show permanent closure of CB.

This paper describes the technology developed to dynamically measure & compensate the current flowing through the earth loop and get the correct results. Special intelligent firmware algorithms are developed to compensate this current during high-speed sampling of dynamic contact resistance. Similar technology is used with different algorithms for measurement of contact timings & bounces. Innovative hardware & testing arrangements were evolved to significantly reduce the Test Kit size & to make it multi-channel; reduce length & thickness of cables, and to replace traditional Lead Acid battery (a hazardous component) used for high test current generation for DCRM test, by alternate environment friendly components.

KEYWORDS

Both sides earthed - Contact Timing – DCRM - Earth loop - Safety

1.0 Traditional method of circuit breaker testing & it's limitations with both sides earthed

HV and EHV circuit breakers are tested periodically to measure closing time, opening time, contact travel, contact speed, coil current etc. These tests are carried in accordance to IEC® 62271-100. Dynamic contact resistance measurement is an important non-invasive test to know the health of circuit breaker contacts and its mechanism. The traditional offline Circuit Breaker Analyzers are used to measure these parameters. The shutdown is taken on the line. Circuit breaker is isolated from both sides by opening the disconnectors. Earth switches are connected on both sides of circuit breaker. Ensuring both sides of circuit breaker contacts are properly earthed, before making any connection to the circuit breaker is of utmost importance. Even though circuit breaker is completely isolated from both ends, the induced voltage is present on the breaker contacts due to nearby charged lines and the induced voltages can run up to few kV. For the safety, the circuit breaker contacts are immediately earthed after opening the disconnectors.

In traditional CB Analyzers, measurement of coil current, contact travel and speed is possible without removing the earth switches connected to the breaker contacts. For measurement of contact timings test current is sent from the analyzer and sensed back to understand the status of breaker contact. If both sides of breaker contacts are earthed through earth switch, the contact status is sensed as 'close' by the analyzer, even if breaker is in 'open' condition. That is why, it is not possible for the CB analyzers to measure contact timings if both sides of contacts are earthed. Same is the case with DCRM measurement. For DCRM measurement 100 or 200 A DC is passed through the breaker contacts and during breaker operation the graph of change in contact resistance w.r.t. time is plotted. If both sides of breaker contacts are earthed, the current will pass through the parallel earthing path. In such condition it is not possible to carry out accurate DCRM measurement.

To overcome this situation while testing with traditional CB analyzers, the earth switch connected to CB contacts is removed after making connections between CB contacts and analyzer. The induced voltage on the circuit breaker is bypassed to the earthing connected to analyzer through the low impedance path provided in the analyzer. This is shown in Fig 1

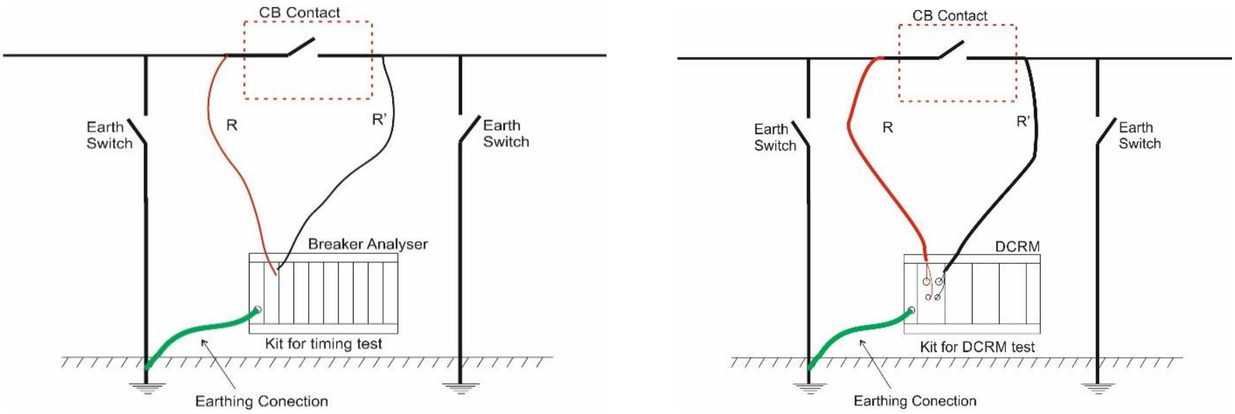

Fig 1: Connecting Analyzer to CB with both side Earth Switch open, for timing & DCRM measurement

2.0 Safety Concerns in traditional method of circuit breaker testing

As we understand, opening of earth switch from both sides is mandatory for testing circuit breaker using traditional analyzers. This raises a safety concern, as user need to follow certain sequence actions while making and removing connections from Analyzer to CB. The sequence of connections to be followed is as mentioned hereunder:

a. Open disconnectors after opening the circuit breaker (after shut-down).
b. Connect earth switch on both sides of CB contacts.
c. Connect earthing cable between master earthing of analyzer and grid earthing.
d. Then make connection between analyzer and breaker contacts.
e. Ensure firmness of all connections, especially earthing of analyzer.
f. Disconnect earth switch before starting the actual testing.

While removing or changing any connections to the breaker contacts, again following sequence needs to be followed:

a. First connect both side earth switches to breaker contacts.
b. Remove or change the breaker contact connections.
c. Disconnect earth switch, if test is to be continued again.
d. Otherwise remove breaker contact connections.
e. Disconnect breaker analyzer.

The user has to be always alert during the testing process. As earth switches are disconnected during testing, all the safety interlocks related to earth switch are disabled. Many times, earth switch control and disconnector (Isolator) control are present in same marshalling box. By mistake operator can operate disconnector instead of earth switch. Such human error has grave consequences for safety of operator and for the equipment used for testing the CB. There have been incidences of severe accidents due to this.

In the standard EN-50110-1 (Operation of Electrical Installation) the standard operation procedure and working procedure is given. The present testing method doesn't comply this standard completely. This safety concern is the source of innovation of new method of testing circuit breaker. In the new method the circuit breaker is tested with keeping earth switch on both sides of CB connected throughout the testing process. This paper illustrates the new method of testing developed & implemented and successfully tested on EHV CBs of all ratings for timing as well as DCRM tests.

3.0 Working principle of new method of circuit breaker testing

The objective of new method of circuit breaker testing is to measure following parameters of circuit breaker, keeping earth switches on both sides of CB in continuous close condition.

- Closing time, Opening time, C-O time and no. of bounces & bounce duration during closing.
- DCRM signature & measurement of static contact resistance from DCRM graph

Obviously, the present method of testing is not going to work as both sides earth is going to create a parallel short circuit path across the breaker contact. In the new method the high current source is used to detect the change in contact status by compensating the current flowing through the earth path.

3.1 Timing Measurement:

When the test is started, current is passed through the circuit. The current starts flowing through the earth loop, if breaker contacts are open. The current through the earthing path is sampled and kept for compensation during the closure of contact. Then the close command is issued to the circuit breaker. During the operation current passing through the earth path, total current and voltage drop across the breaker contact are sampled.

The proper software algorithms are developed to compensate the current flowing through the earth and find out the actual current flowing through breaker contacts. Then using these current samples and voltage drop samples, breaker closing time with accurate bounces and bounce duration is calculated. In the same way, breaker opening time is also calculated.

3.2 DCRM Measurement:

Similar method is used with 100A or 200A current source to carry the DCRM test. The 100A or 200 A current is passed through the circuit. As the circuit breaker is in open condition, majority of current passes through the earth loop. This current passing through the earth is sampled and kept as reference signal for further compensation of current during actual operation of circuit breaker. Then C-O command is executed on the circuit breaker. During the operation current passing through the earth path, total current and voltage drop across the breaker contact are sampled. After the operation, powerful software algorithms are applied on the sampled data to properly compensate the earth current and actual DC current passing through breaker contacts and resistance graph with all the variations are plotted as DCRM graph. Fig 2 explains the working principle of new method.

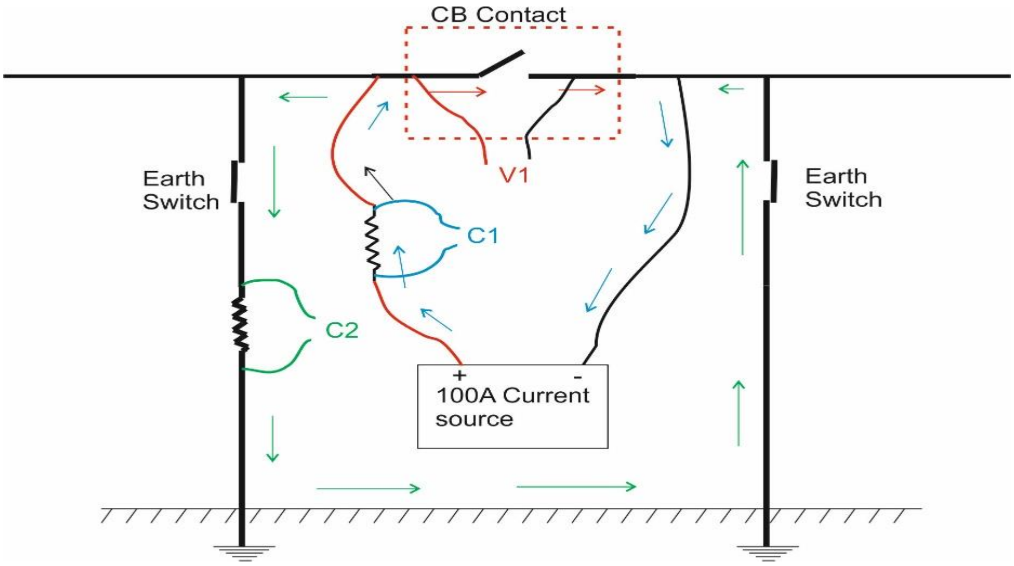

Fig 2: Working Principle of new method of testing circuit breaker

100A or 200A current source is used to inject the current through the CB. The source has internal shunt to measure total current (C1) flowing through the circuit. When breaker is in open condition all possible current will flow through the earthing loop (C2). When close command is issued to the breaker, during closing operation current will be divided. As the CB contact resistance is lesser (in the range of micro-ohms) as compared to earth resistance (in the range of milli ohms to ohms), major current will flow through breaker contacts. But still considerable amount of current will flow through earth loop. Test instrument continuously samples C1, C2 as well as V1, voltage drop across the breaker contacts during the complete operation of circuit breaker. After the operation, the analysis on sampled data is done and compensation of current through the earth loop is carried out on sampled data. This is done through specially developed software algorithms. Using compensated current data and sampled voltage drop (V1) data, the data for change in resistance of contact is generated. This is plotted as DCRM graph. The same process is followed with smaller current for calculating closing and opening time.

4.0 Lab simulation of new method

To establish the above working principle, the required hardware prototype is developed. Circuit breaker is simulated with a lower rating Contactor. Both ends of contacts of contactor are connected to earth and experiments are carried out on this simulated setup in the lab. Along with this required firmware and software is developed. Details of hardware and software are explained here. The block diagram of prototype hardware is shown in Fig 3.

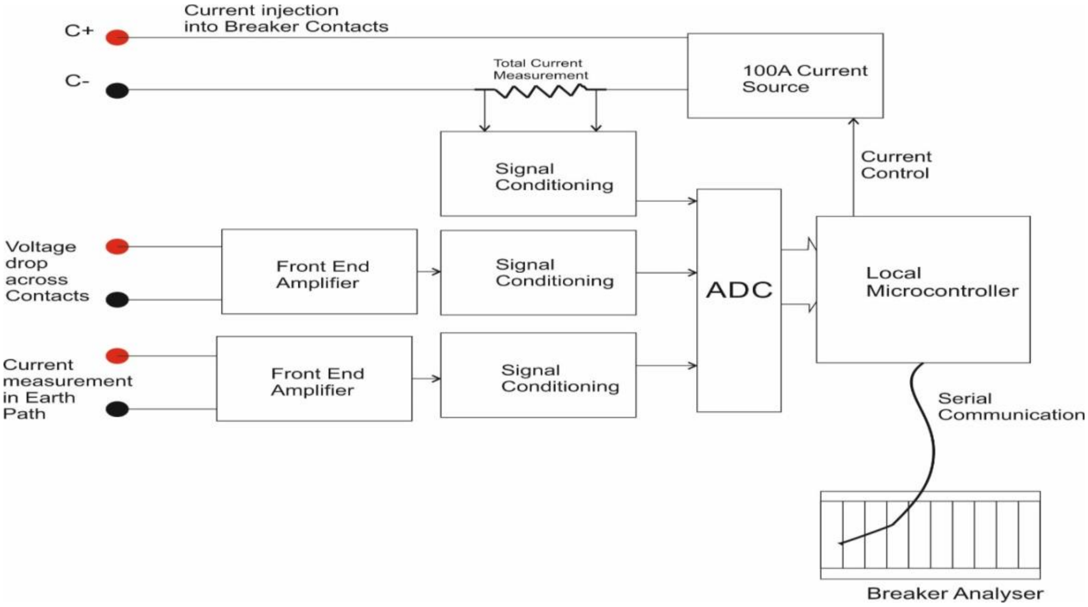

Fig 3: Block Diagram of Hardware prototype

4.1 Hardware:

An add-on prototype hardware module is developed which can be interfaced with existing CB analyzer. First 100A current source is developed using latest technology Super Capacitors. Super capacitors are used mainly to reduce the weight of the power source and to avoid usage of lead acid (an environmentally hazardous component) battery for this large current generation. Three analog channels are designed to sample data of C1 (Total current in circuit), C2 (Current through Earth path) and V1 (Drop across the CB contacts). All the analog signals are conditioned and given to the 24 bit high speed analog to digital convertor. The digitally converted data is then fed to the micro controller.

Here local microcontroller is used to sample analog data at high speed, to communicate with breaker analyzer and to control the current source. On command from breaker analyzer, the microcontroller triggers 100A current source making current pass through the breaker contacts and all three analog channels are sampled at high speed and data stored in micro controller. After finishing the data sampling, the data is sent to breaker analyzer. The software residing in the lap-top (HMI) of analyzer further runs the algorithms on sampled data to compensate the current in the earth loop and find out closing, opening times and DCRM graph. Once the hardware and software are made ready, the contactor setup is made to simulate the circuit breaker in lab. The image of setup is shown in Fig 4

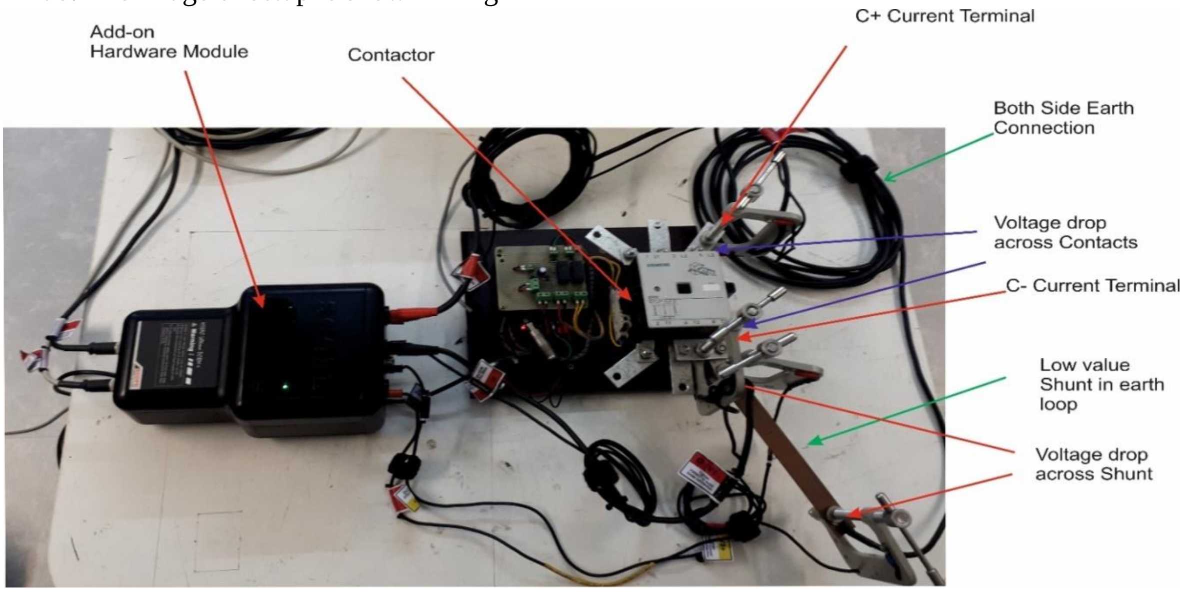

Fig 4: Simulated lab setup of circuit breaker testing with both sides earthed

Out of three phases, one phase contact is used to simulate the circuit breaker condition. Using Ck clamp 100A current is injected through the contact. Both the ends are shorted with a long cable and connected to earth to simulate the both side earth condition. A copper shunt is used in series with this shorting cable, to measure current in earthing path. Communication cable is connected between add-on measuring module and circuit breaker analyzer.

4.2 Software:

For the measurement of contact timing and DCRM, DC current is passed through the circuit. But the earth in influenced by the 50 or 60 Hz signal, due to system voltage. This signal gets mixed with the DC current. Part of this unwanted AC signal is filtered through hardware. Software also consists of powerful AC noise and high frequency noise suppressing algorithms. After studying the nature of variation in current signal and its behavior during breaker operation in different conditions, proper current compensation algorithm is developed. This algorithm derives the current flowing only through the breaker contacts after doing compensation on each current sample. Then the bounces in close operation are calculated by analyzing the voltage drop across the contact and current signal nature. It is also possible to find the exact closing time of the circuit breaker. In the same way using the power of software algorithm it is possible to calculate the opening as well as Close-Open time.

With this setup and software, it is possible to separate the current flowing through contacts and as the voltage drop across the contact is available, further DCRM graph is plotted in normal way.

The experimentation is done on contactor setup and closing and opening time of contactor are calculated by earthing both sides of contacts as well as without earthing both sides. The results were found comparable.

After rigorous trials at lab and with multiple iterations of algorithms, a prototype add-on module for field trial is built and further trials at actual substations are carried out.

5.0 Challenges faced in implementing the new method in field

In actual substation, the earth switches are firmly connected to breaker contacts after shutdown. The structure is rigid. There is no chance to insert the current measuring shunt in the earth loop to measure current flowing through it. This is the main challenge in implementing new testing method in field.

Initial trials were conducted by removing one side earth switch and putting an external earth cable. A current measuring shunt is inserted in this earth cable. However due to varied field conditions, test object geometry with respect to connection points, different earthing arrangements used, it is observed that substation to substation there is vast variation in earth resistance. Effect of 50 /60 Hz noise was also different at different substation. The filter and noise suppression algorithms that worked at one substation doesn’t work in different conditions prevailing in another substation.

The use of Hall Effect sensor was tried in the initial phase of development. But generally the type and sizes of earthing conductor varies. Enough space clearance is not available to inset Hall Effect sensor. Sometimes the earth switch is at a distance. We have made the arrangement of hanging Test Unit near the breaker contacts to reduce the length and weight of test cables. The units are developed to be used in all substations from 11kV to 765kV. Due to these site variables, we have developed a simpler method to use part of earth path near breaker contact to measure the current through the earthing. We are neither using CT nor Shunt to measure the current in the earthing path.

Identification of bounce duration, which are less than 1 mS was a big challenge as the voltage drop signal gets mixed with the noise in the earth. Multiple field trials with the prototypes are carried and the algorithms to calculate breaker timings are improved.

6.0 Field trials with prototype

To overcome the concern of adding current measuring shunt in series with the earth loop, we added one more algorithm, where we sampled the voltage drop in the part of earthing loop and derived the current passing through the earthing loop. With all this a prototype add-on module with breaker analyzer is made ready for field trials. The prototype add-on module was having all the required hardware and facility to make required connections to the CB. For regular operation, data collection and calculations, circuit breaker analyzer was used with its software loaded in laptop.

Fig 5: Add-on prototype hardware module

Fig 6: Connecting Add-on hardware module to CB

The prototype module was tested on 220 kV Single break circuit breaker. The breaker was first tested with traditional method, with earthing from both sides disconnected and then it was tested with add-on module with both sides earthed. The closing time, bounces, opening time and C-O time were comparable. The difference in readings was generally less than 1.5 mS. The graphs are shown in following Figures:

6.1 DCRM Test:

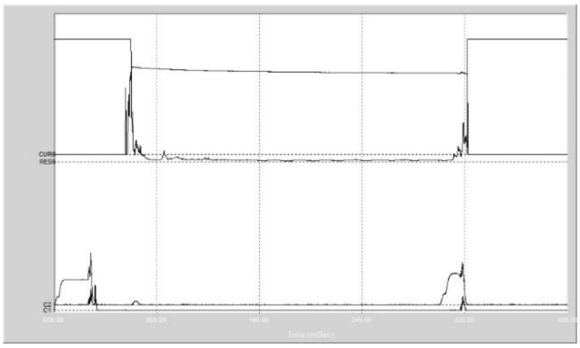

Fig 7A: DCRM without both sides earthed

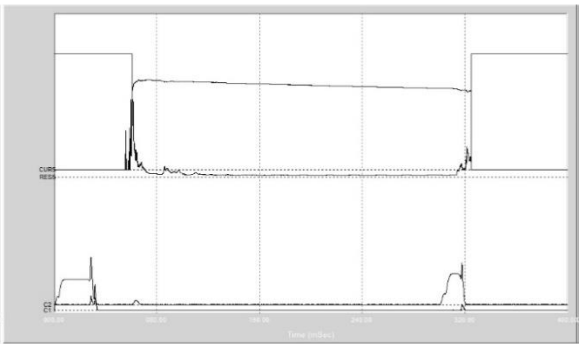

Fig 7B: DCRM with both sides earthed

6.2 Close Time:

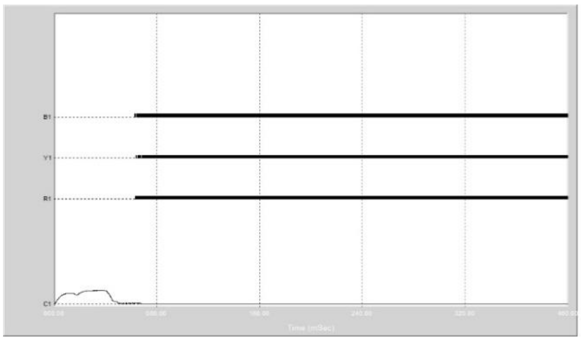

Fig 8A: Close Time without both sides earthed

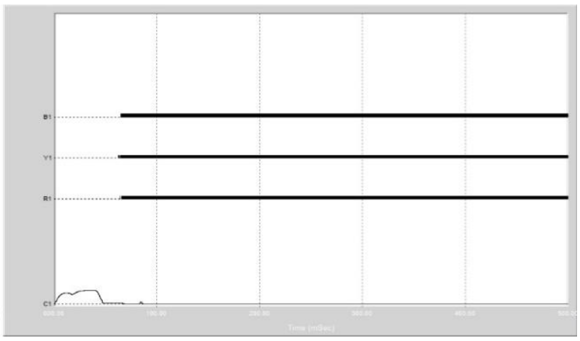

Fig 8B: Close Time with both sides earthed

Table 1A for Fig 8A

	Without Earthing		
	R	**Y**	**B**
Close Time (mS)	63.20	63.80	62.80
Total Bounce (mS)	2.60	4.80	2.00
No of Bounces	3	3	3

Table 1B for Fig 8B

With Earthing		
R	**Y**	**B**
64.25	62.30	64.55
2.00	4.35	1.85
2	3	2

6.3 Open Time:

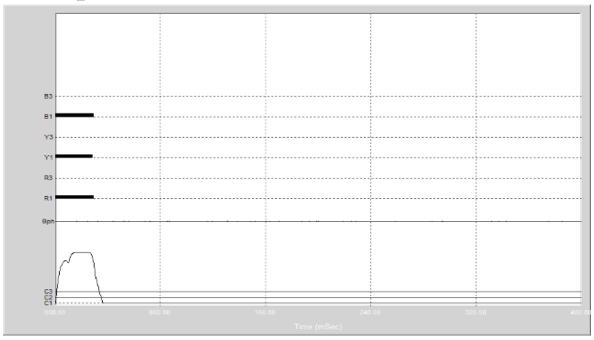

Fig 9A: Open Time without both sides earthed

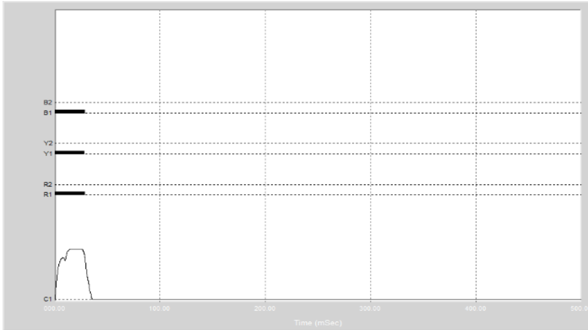

Fig 9B: Open Time with both sides earthed

Table 2A for Fig 9A

	Without Earthing		
	R	**Y**	**B**
Open Time (mS)	29.40	28.60	29.40

Table 2B for Fig 9B

With Earthing		
R	**Y**	**B**
29.05	28.30	29.15

In the DCRM operation also the signatures taken with both the methods were matching. Measurement of arcing tip length and contact resistance was possible with both side earthed method.

7.0 Final Implementation

The instrument with this technology was developed indigenously and extensive field trials were conducted on different breakers of 220 kV/ 400 kV/ 765 kV having single break and multiple breaks per pole. The instrument is developed with latest technology using small size super capacitor based current source and having arrangement of hanging the instrument near the CB interrupter. This significantly reduced the length and weight of test cables needed.

Some of the actual graphs and results for multi-break CBs are presented hereunder:

7.1 DCRM Test:

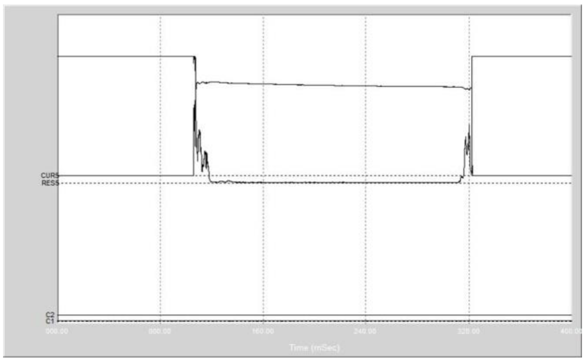

Fig 10A: DCRM test without both sides earthed
Contact resistance – 53 micro-ohms

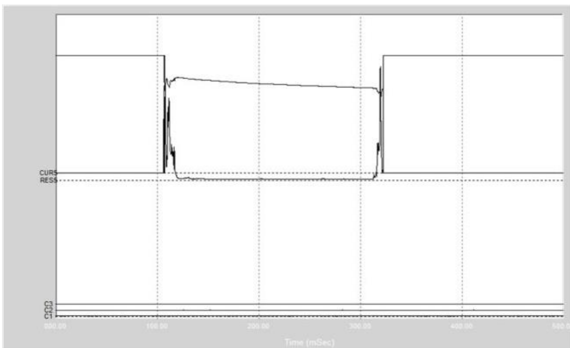

Fig 10B: DCRM test with both sides earthed
Contact resistance - 56 micro-ohms

7.2 Close Time:

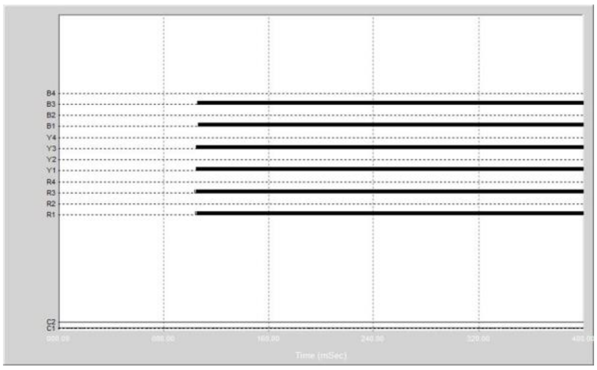

Fig 11A: Close Time without both sides earthed

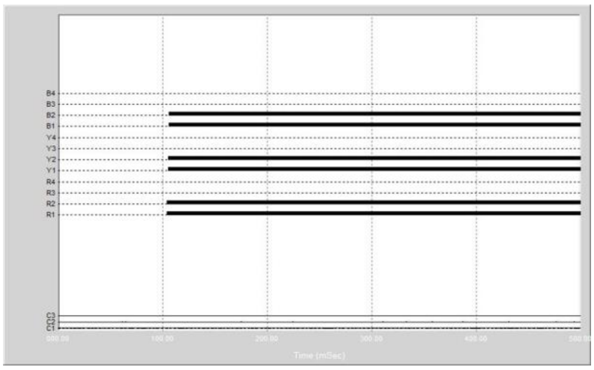

Fig 11B: Close Time with both sides earthed

Table IIIA for Fig 11A (without earthing)

	R1	R2	Y1	Y2	B1	B2
Closing Time (mS)	104.4	104.0	104.8	105.0	105.8	106.0
Total Bounce (mS)	1.0	1.1	0.8	0.9	0.9	0.8
No Of Bounce	2	3	1	1	3	2

Table IIIB for Fig 11B (with earthing)

R1	R2	Y1	Y2	B1	B2
104.2	104.3	105.3	105.3	106.4	106.4
1.2	1.4	1.0	1.3	1.4	1.3
2	3	1	2	2	2

7.3 Open Time:

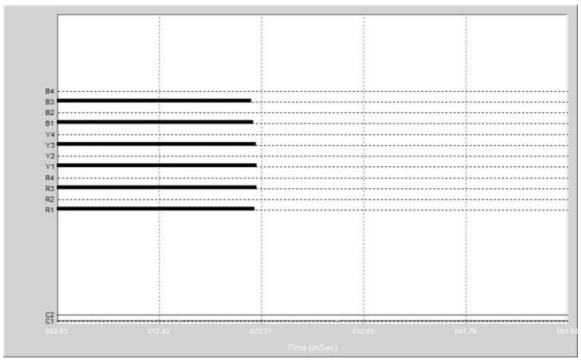

Fig 12A: Open Time without both sides earthed

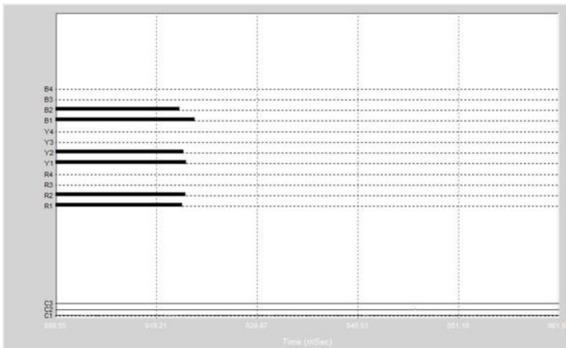

Fig 12B: Open Time with both sides earthed

Table IVA for Fig 12A (without earthing)

	R1	R2	Y1	Y2	B1	B2
Open Time (mS)	21.6	21.8	21.8	21.8	21.4	21.2

Table IVB for Fig 12B (with earthing)

R1	R2	Y1	Y2	B1	B2
22.0	22.2	22.2	22.0	23.0	21.7

From the different field trials, it has been proven that it is possible to test the circuit breaker with both side earth switches connected. The difference in timing results was generally found to be within 1 to 1.5 mS.
The repetitive results are within 0.5 mS, when timing measurement is done without earthing both sides of breaker. As this is digital measurement and no closed loop is formed across breaker contacts, it is possible to achieve this accuracy. In case of timing measurement with both sides earthed, the measurement employed is analog and 50Hz / 60Hz noise is present in earthing loop. This noise is eliminated through digital filter as well as special algorithms. Moreover the noise conditions are different at different substations. Still with this method, it is possible to keep the difference below 1.5 mS.

During the field trial of the instrument the emphasis was on to test different breakers at different substations under different site conditions, to understand the differences in the results of timings and nature of DCRM graph by testing breakers with & without both sides earthed. More work is required to be done to further reduce on the time difference below 1.5 mS, and to carry out repetitive tests on a specific breaker with both the methods to find out scatter of the operating times.

Measurement of closing bounces with bounce duration is possible and we get the exact nature of DCRM signature. With new test method user need not have to operate earth switch frequently, thereby avoiding possible chances of human error leading to severe accidents. User can do the complete testing safely while keeping earth switches on both sides closed.

The new method has reduced the length & weight of test cables significantly, as new unit is lighter and can be hanged near CB interrupter, instead of being operated from ground. With reducing manpower at EPUs, this is big relief, as for testing EHV CBs like 765 kV, up-to 35 meter long test cables (rated for 100A) were needed. New unit hardly needs 3 to 5 meter lengths. Use of Super capacitors have not only made new unit lighter, but has also eliminated usage of environmentally hazardous lead acid batteries for generating 100A.

8.0 Conclusions:

- Testing Circuit Breaker with both sides earthed is must as it meets the crucial need of safety during testing. The new technique provides this facility for both Contact Timings and Dynamic Contact Resistance measurement, with both sides earthed.
- It's possible to test all breaks of CB in one operation. This reduces no. of CB operations and time to test the breaker, saving downtime of CB.
- The reduction in size, usage of lesser & environment friendly materials makes new solution sustainable, compact, easy for handling & transportation.
- The test results in digital form can be interfaced with remote Asset Management Systems providing for effective asset health assessment & helping Utilities with lifecycle management of assets.
- All above contributes in decarbonisation by reducing carbon footprint of the activity of diagnostic testing of CBs.
- This domestic availability of 'Both Side Earthed' measurement is not only expected to make CB testing safer & faster, but may just prove to be a tipping point in transformation of overall approach towards safety by EPUs in India.
- Above mentioned benefits make a strong case for EPUs / Asset (CB) owners to adapt to new technology developed. Overall, it is expected to make testing safer, faster, leaner & environment friendly.

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