GRIDCON 2025
Paper ID 1180
PS1

Significance of DGA for evaluation of Multiple Chopped Impulse Test on Instrument Transformer

[1,2]Manjusha. S. NAMBIAR
[1]Electrical Research and Development Association (ERDA), Vadodara, INDIA.
manjusha.nambiar@erda.org

[1]Nitin SHINGNE
[1]Electrical Research and Development Association (ERDA), Vadodara.
nitin.shingne@erda.org

[1]Anil. S. KHOPKAR
[1]Electrical Research and Development Association (ERDA), Vadodara.
anil.khopkar@erda.org

[2]C. N. MURTHY
[2]The Maharaja Sayajirao University of Baroda (MSU), Vadodara.
chivukula_mn@yahoo.com

Summary:

Instrument transformers are connected in power system for measurement of electrical quantities and protection of system. Hence, instrument transformers are one of the key elements of power system reliability. During the operation of an instrument transformer, lightning strikes or switching surge can cause over voltages across its terminals. Such over voltages damage the insulation of instrument transformer which results to its failure. Hence, to avoid such failures insulation provided to instrument transformer must be capable to withstand over voltages at least up to the designed system insulation level, which has been derived from insulation coordination. Type tests and special tests are performed to ascertain quality of insulation system and reliable operation of instrument transformer. Multiple Chopped Impulse (MCI) test is one of the special test carried out on instrument transformer to ascertain its capability to withstand high-frequency transients. This test is entirely different than lightning Impulse voltage withstand test as the test parameters, procedure, acceptance criteria and conditions are largely different. MCI test is carried out at ERDA on various ratings of instrument transformers up to 400 kV since more than two decades. This paper describes ERDA's experience related to importance of Dissolved Gas Analysis (DGA) of insulating oil for analysis of MCI test on Instrument transformers. Various case studies related to MCI test where DGA results have been proven as an important tool for analyzing the test results of liquid filled instrument transformers have been discussed in this paper.

Keywords:

Instrument transformer, Dissolved gas analysis, multiple chopped impulse test

1. Introduction

Reliable operation of electrical power system is very important for uninterrupted power supply. Instrument transformers are used in electrical power system for protection as well as precise measurement of high voltages or high currents. To avoid catastrophic failure, it is important to identify faults at early stage in their development. For reliable operation of power system, instrument transformers connected in the system must operate within its accuracy limit and shall be capable to withstand transients generated in the system during abnormal system operation. Hence, adequate qualitative operations of instrument transformers are very important which is directly depends on the quality of its insulation system. To verify the insulation quality, various dielectric tests like dry & wet power frequency voltage, lightning impulse voltage, switching impulse voltage, chopped lightning impulse test and MCI test etc. are required to be carried out as per national or international standards. Each dielectric test has its own significance and create different stresses on insulation system. MCI test is entirely different than the other applicable dielectric tests, due to application of very fast rising and decaying voltage. This test proves withstand capability of instrument transformer against very fast rising transients which can generate in the system due to frequent flashover across string insulators. During such phenomenon solid & liquid insulation of instrument transformer experiences very high stresses. When insulating oil and cellulosic materials in oil insulated equipments are subjected to higher than normal electrical or thermal stresses, they decompose to produce some combustible gases referred to as fault gases which can be analyzed by using DGA. It is one of the most widely used diagnostic tools for transformer condition assessment [1].

The highest voltage for the equipment (Um) i.e., the highest r.m.s. value of phase-to-phase voltage for which the equipment is designed in respect of its insulation and other characteristics as per relevant equipment standards. The primary terminals of oil-immersed instrument transformers having Um ≥ 300 kV, where the oil shall comply as per IEC 60296, shall withstand multiple chopped impulses. MCI test simulate over voltage conditions, particularly those caused by switching operations or lightning strikes, where voltages are suddenly interrupted or chopped. Hence this test is crucial for evaluating the insulation strength to determine the equipment's ability to withstand transient over voltages ensuring reliability and operational safety. Gas evaluation using DGA, during a MCI test in instrument transformer is a crucial diagnostic technique that provides insight into the dielectric strength and health of insulation. If the insulation has defects or voids, the rapid voltage changes can lead to partial discharges or even complete breakdowns, because of which gases are getting generated due to localized overheating or chemical reactions in the insulating materials. Hence, by analyzing the gases produced during MCI test, it can validate the quality of insulating materials and its design robustness under transient conditions.

Manufacturers and utilities can ensure whether the transformer will perform reliably in the field under similar transient conditions, avoiding unexpected failures and maintaining grid stability. In this paper the significance of DGA for confirmation of the MCI test has been discussed. Various case studies have been discussed in this paper where the DGA of key gases have been proven as deciding factor to verify the insulation withstand capability during MCI test.

2. Significance of DGA during MCI test

Mineral insulating oils are composed of a mixture of different hydrocarbon molecules containing -CH_3, -CH_2 and -CH chemical groups linked together by carbon-carbon chemical bonds. Scission of some of the C-H and C-C bonds can occur as a result of electrical and thermal faults, with the formation of small unstable fragments, in radical or ionic form. These unstable fragments recombine rapidly, through complex reactions, into gas molecules such as Hydrogen (H - H), Methane (CH_3 - H), Ethane (CH_3 - CH_3), Ethylene (CH_2 = CH_2) or Acetylene (CH ≡ CH). The gases formed dissolve in the oil and can be analyzed by DGA [2]. For incipient fault conditions, the gases generated and dissolved into the oil .The particular combination of gases that is generated in oil depends on the nature of the fault and is related to the energy level and temperature at the fault location. Thus, by analyzing an oil sample for dissolved gas content, it is possible to assess the condition of the equipment, detecting faults at an early stage. Low-energy faults, such as partial discharges of the cold plasma type (corona discharges), favor the scission of the weakest C-H bonds and the accumulation of hydrogen as the main recombination gas. More and more energy and/or higher temperatures are necessary for the scission of the C-C bonds and their recombination into gases.

Table (I): Key gases generated due to different fault types in transformers

Notation for fault	Fault Description	Key gases generated
PD	Partial discharges	Hydrogen & Methane (H_2 & CH_4)
D1	Discharges of Low energy	
D2	Discharges of High energy	Hydrogen & Acetylene (H_2 & C_2H_2)
T1	Thermal fault T< 300 °C	Ethylene (C_2H_4)
T2	Thermal fault 300°C<T< 700°C	
T3	Thermal fault T>700 °C	

Gas analysis by DGA during MCI test provides valuable data for predictive maintenance. Gas evaluation during such tests play complementary roles in ensuring the robustness, safety and longevity of high-voltage equipment there by ensuring the manufacturing and operational reliability. The different fault categories in oil filled electrical equipments and the key gases generated according to each fault type is mentioned in table (I) [1], [3]. During the chopped test the rapid voltage changes can lead to partial discharges or discharges of high/low energies within the equipment. Hence by analyzing the key gases such as Hydrogen (H_2), Methane (CH_4) and Acetylene (C_2H_2) can provide early indication of insulation deterioration during MCI test.

3. Methodology of Gas evaluation during MCI Test

MCI test is performed by applying multiple impulses of negative polarity with chopped close to the crest. The test voltage is applied between the primary terminals and earth for current transformers and between the primary high voltage terminals and the primary earth terminals for voltage transformers. The frame, case, core and all the terminals of the secondary windings shall be connected to earth. The peak value of the test voltage should be 70% of the rated lightning impulse withstand voltage. Hence, if instrument transformer having rated voltage of 400 kV the test voltage for MCI test would be 998 kVp, considering basic impulse withstand voltage of 1425 kVp. To conduct MCI test, 600 consecutive impulses shall be applied at a rate of 1 impulse/minute approximately. The wave shape shall be recorded at the beginning and at the end of the test, as well as after a minimum of every 100 impulses.

The criteria for evaluating the test results is based on:

a) Impulse voltage recorded at the beginning and after each 100 impulses should not give evidence of any modification which could be attributed to internal discharges.
b) Partial discharges measured should not exceed the standard permissible limit values as per test voltage and instrument type (10 pC max. at U_m).
c) The capacitance and dielectric dissipation factor measured before and after 24 hours of test should be the same.
d) The increase of the dissolved gases in the oil measured 72 hours after the test shall not exceed the values as per table (II).

Table (II): Maximum gas-in-oil level in instrument transformers

Gas	Concentration, µl/l (ppm)		
	Before test	**Maximum acceptable increase after test**	**Minimum detectable Level**
Hydrogen	30	15	3
Methane	5	5	0.1
Acetylene	Not detectable	1	0.1

An oil sample shall be taken before the MCI test and a second sample shall be taken 72 hours after the test, to assure the diffusion of the small quantities of gas generated during the test, The primary terminals of liquid-insulated instrument transformers with Um ≥ 300kV shall withstand multiple chopped impulses in accordance with IEC: 61869-1 [4]. Before and after MCI test the dissolved gases for mineral oil shall comply with requirements given in table (II). For DGA, receiving a qualitative and a representative sample is crucial for obtaining a reliable assessment of the electrical equipment. Hence proper oil sampling is very important for gas analysis and it is critical to strictly follow the sampling procedures by well trained and experienced personnel [5].

4. Case Studies – Gas analysis Before and After MCI test

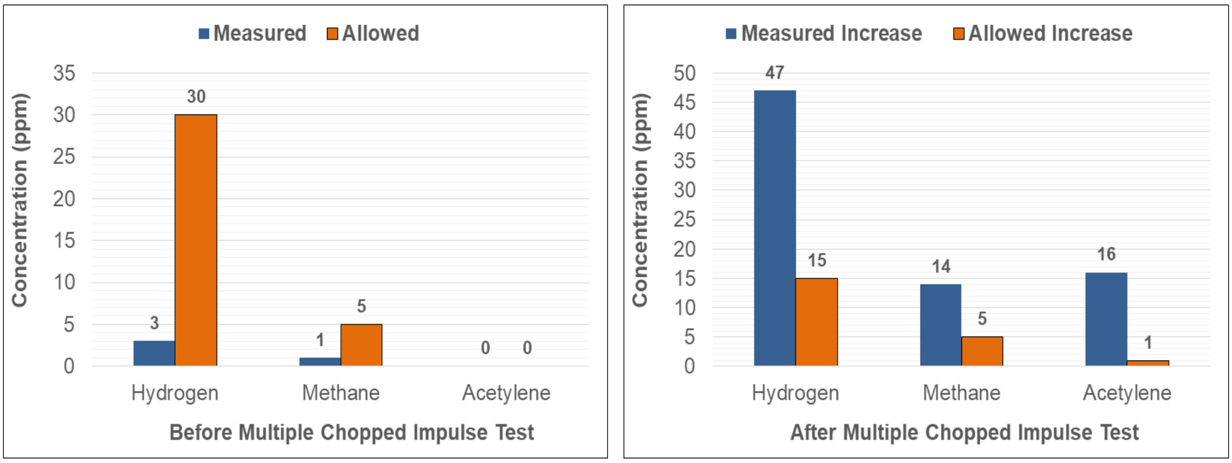
Four cases of MCI test on various ratings of instrument transformers and oil DGA before and after MCI test are discussed here. First oil sample is taken before MCI test and a second sample is taken 72 hours after MCI test to assure the diffusion of the small quantities of gas generated during the test. The cases have been selected for discussion based on the diagnosed pass/fail conditions of the instrument transformers with different ratings as mentioned in table III. The oil samples were tested according to IEC: 60567 using 'Head Space method'. The interpretation of DGA results has been done using acceptance criteria provided in IEC 61869-1 as mentioned in table II.

Table (III): Summary of diagnosed conditions of different cases

Case Study	Transformer Type	DGA Results	Result of MCI Test
1	245 kV Current transformer	Significant increase in value of key gases	Fail
2	420 kV Current transformer	Key gases within specified limit	Pass
3	220 kV Current transformer	Significant increase in value of key gases	Fail
4	220 kV Current transformer	Obtained high value of key gases	Fail

4.1. Case Study - 1

This case is of a 245 kV Current transformer where the DGA data for before and after MCI test is as shown in Figure 2.



(a) (b)

Figure 2. (a) Gas-in-oil before MCI test and (b) increased gas-in-oil after MCI test for Case-1

In this case, all the three gases, Hydrogen (H_2), Methane (CH_4) and Acetylene (C_2H_2) generated after 72 hours of multiple chopped impulse test crosses the maximum acceptable increase. Hence this Current transformer failed in the test. The increase in the key gases, Hydrogen & Acetylene is an indication of electrical stress which caused the generation of these abnormal gases within the insulating oil. In a MCI test, the voltage is rapidly interrupted (chopped), creating high frequency transients. These transients stress the insulation system, including the oil and paper insulation causing generation of these gases.

4.2. Case Study - 2

This case is of a 420 kV Current transformer where the DGA data for before and after MCI test is as shown in Figure 3. In this case, all the three gases, Hydrogen (H_2), Methane (CH_4) and Acetylene (C_2H_2) dissolved in the oil before test and generated after 72 hours of the test are within the maximum acceptable increase. Hence this Current transformer passed the test which shows that even after 600 shots of multiple chopped impulses, the windings and insulation could withstand the stresses which is required for its proper functioning.

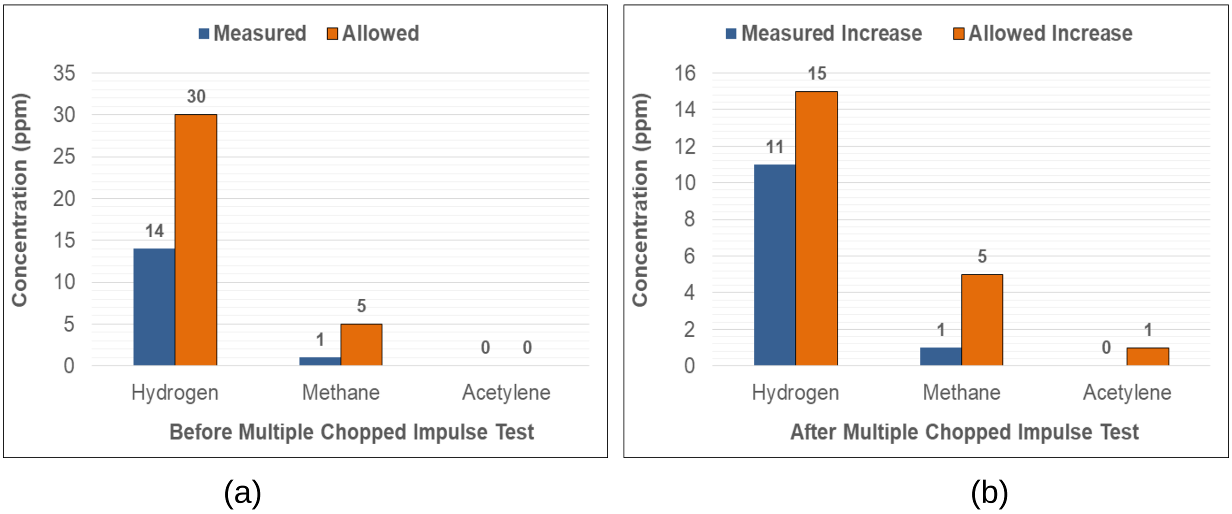
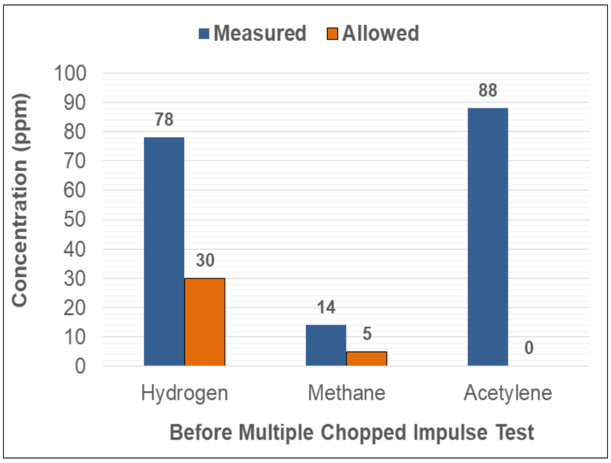


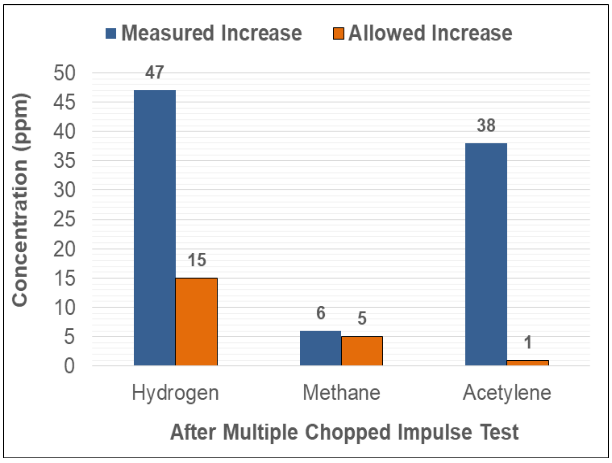
Figure 3. (a) Gas-in-oil before MCI test and (b) increased gas-in-oil after MCI test for Case-2

4.3. Case Study - 3

This is another case of a 220 kV Current transformer where the DGA data for before and after MCI test is provided in Figure 4. In this case, even before MCI test all the three gases, Hydrogen (H_2), Methane (CH_4) and Acetylene (C_2H_2) were detected which increased after 72 hours of multiple chopped impulse test. Hence this Current transformer failed in electrical stress withstanding criteria. The probable reason for gas generation even before the test may be poor insulation or winding quality because of which gases might have generated and dissolved during different type tests or routine tests. Any reactions of internal paints or some catalytic reactions of steel with oil can also cause generation of gases under temperature rise conditions.



(a)



(b)

Figure 4. (a) Gas-in-oil before MCI test and (b) increased gas-in-oil after MCI test for Case-3

4.4. Case Study - 4

This is another case of a 220 kV, 400-800/1A Current transformer and the DGA data is as given in Figure 5. This transformer failed in the initial criteria of DGA values itself and hence not performed the MCI test and proceeded for the required winding/insulation rectification process. Apart from chemical reactions of paint or steel, even stray gassing behaviour of insulating oil can also cause gas generation under elevated temperatures. There is also possibility of poor sealing due to which moisture penetration during transportation. Hence to identify the exact reason and rectifications of the same is also important for proper transformer functioning.

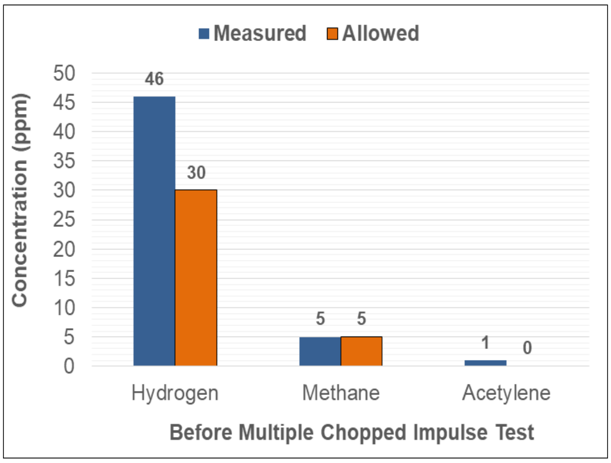


Figure 5. Gas-in-oil before MCI test for Case-4

4.5 Possible Causes of Failure

Following a thorough analysis of each of these failure examples, the potential reasons for failures generally can be summed up as follows:

a) Localized Arcing: The front chopped impulse may have caused high energy arcing within the windings due to very fast rising & very fast decay at terminals or in the oil.

b) Weak insulation: The required oil compatibility and dielectric strength of the oil or paper insulation may be insufficient to withstand the transient over voltages.

c) Gas formation at Hotspots: Impulse stresses can create hotspots in the windings or insulation causing oil decomposition and gas generation.
d) Mechanical deformation: The high-stress surges may mechanically deform the windings or insulation, creating points of partial discharges or arcing.

Gas bubbles and moisture in the oil reduce its dielectric properties increasing the risk of further breakdown. As a consequence of continued operation of faulty transformers can lead to insulation flashover or catastrophic failure. To avoid this, rectification or replace of the specific damaged parts like windings or bushings and confirmation regarding the reliability of the equipment is necessary. By diagnosing and addressing the root cause of failure, further damage can be prevented and transformer lifespan can be extended.

5. Conclusion

DGA of insulating oil is very important for confirmation of MCI test, though other pre & post electrical tests are applicable. In this paper, ERDA's experience related to importance of DGA of insulating oil for confirmation of tests results of MCI test on Instrument transformers is described. Four case studies where DGA has been proven for analyzing the test results of multiple chopped impulses of liquid insulated instrument transformers have been discussed in this paper. MCI test and DGA provides a significant contribution for improved insulation design and system reliability. MCI test assess the equipment's transient withstand capability and DGA identifies the insulation failures during MCI test thereby preventing the in-service failures of instrument transformers. Hence utilities are required to adopt MCI test with DGA in testing protocols. Further research directions include development of advanced DGA interpretation models for transient tests and integration of artificial intelligence and machine learning for real-time gas analysis and fault prediction.

BIBLIOGRAPHY

[1] "IEEE Guide for the Interpretation of Gases Generated in Mineral Oil-Immersed Transformers," in IEEE Std C57.104-2019, doi: 10.1109/IEEESTD.2019.8890040.

[2] "Mineral oil filled electrical equipment in service – Guidance on the interpretation of dissolved and free gases analysis", IEC 60599-2022.

[3] Duval, M., "Ongoing Activities at IEEE, IEC and CIGRE on DGA", Proceedings of the Transformer & Switchyard Users Group (TSUG) Meeting, St-Louis, Aug 5, 2013.

[4] "Instrument transformers – Part 1: General requirements", IEC 61869-1-2023.

[5] "Method of sampling insulating liquids" IEC 60475-2022.