Considerations regarding the impulse ignition test for level of protection “eb” and ignition test for protection levels “eb” and “ec” stator insulation systems of Ex-proof electric motors

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Abstract. According to the provisions of the 5th edition of the standard IEC 60079 – 7, equipment protection by increased safety “e”, for Level of protection “eb” and “ec” electrical machines, if the rated voltage exceeds 1 kV, type tests in explosive mixtures have to be carried out, in order to certify such an electrical machine. The purpose of this paper is to provide some considerations regarding the impulse ignition test for level of protection “eb” and ignition test for levels of protection “eb” and “ec” stator insulation systems of explosion proof electric motors and also to present a case study regarding such tests conducted in the specialized laboratory of INSEMEX Petrosani, on a stator insulation winding system of a 6 kV electric motor type of protection Ex eb IIC Gb, case study which will assist manufacturers in designing appropriate stator winding insulation systems for increased safety type of protection electric motors.

1. Introduction

Electric motors are a vital component in numerous industrial applications, and ensuring their reliable operation is of utmost importance. Particularly in hazardous environments, where the presence of flammable gases or vapors poses a significant risk, the need for increased safety measures becomes paramount [1, 2, 3]. In such scenarios, electric motors complying with Ex eb (respectively Ex ec), standards SR EN IEC 60079 – 0, SR EN 60079 – 7 [4, 5] play a crucial role. One important aspect of their design is the impulse ignition test for stator insulation systems (in case of Ex eb electric motors), which help to mitigate potential ignition hazards [5]. This article delves into the significance of the impulse ignition test and its role in ensuring the safety and reliabilty of electric motors in hazardous environments.

2. General considerations

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Understanding the impulse ignition test and the over voltage test

The impulse ignition test, as well as the over voltage test are an essential assessement procedure carried out on stator insulation systems of electric motors intended for use in hazardous areas classified as Ex eb motors, or Ex ec motors (in this case only the over voltage test applies) [4, 5]. These tests aim to verify the ability of the motor's insulation system to withstand and prevent the occurrence of sparks or arcs that could ignite a potentially explosive atmosphere.

Key elements of the Impulse Ignition Test:

1. High Voltage Impulses. During the impulse ignition test, the stator winding is subjectetd to high voltage impulses, simulating potential transient voltage surges that may occur in the motor's operation. These high voltage impulses aim to evaluate the insulation system's ability to withstand transient electrical stresses without experiencing any internal discharges or insulation breakdown [1, 3, 5].
2. Test Conditions. The test conditions are designed to simulate the worst-case scenarios that the motor may encounter during its operation in a hazardous environment [4, 5]. This includes considering factors such as maximum ambient temperature, the presence of flammable gases or vapors and the electrical loading conditions specific to te motor.
3. Ignition Prevention. The primary objective of the impulse ignition test is to ensure that no internal discharges or sparks occur within the stator insulation system during or after the application of high voltage impulses. The insulation system should effectively prevent any ignition source that could ignite the surrounding potentially explosive atmosphere [1], 2, 3].

Significance of the Impulse Ignition Test and Over voltage Test

The impulse ignition test and the over voltage test serve multiple purposes in enhancing the safety of electric motors operating in hazardous environments [1, 2, 3]:

1. Hazard Mitigation. By subjecting the stator insulation system to rigorous testing, the impulse ignition test, as well as the over voltage test help identify potential weaknesses or vulnerabilities. This allows manufacturers to make necessary design improvments to ensure that the motor's insulation system can effectively prevent sparks or arcs that could ignite flammable gases or vapors [5].
2. Compliance with standards. The impulse ignition test and the over voltage test are essential for electric motors seeking compliance with Ex eb standard, which focus on increased safety in hazardous areas [4, 5]. Meeting the requirements of this standard ensure that the motors are specifically designed and tested to mitigate explosion risks, providing confidence to end-users and regulatory authorities [1, 3].
3. Reliability and Longevity. Both the impulse ignition test and the over voltage test not only ensure safety but also contribute to the overall reliability and longevity of electric motors. By verifying the insulation system's abillity to withstand high voltage impulses and over voltages without experiencing internal discharges or breakdowns, the tests help identify potential insulation weaknesses that could compromise the motor's performance and life span [1].

3. Regulatory principles

The EN 60079-7 standard establishes the specific requirements for stator winding insulation systems for both Ex eb and Ex ec electric motors. [5].

For all motor stators with a rated voltage above 1 kV, the electrical machine shall be fitted with anticondensation heaters [5].

In addition, for Level of Protection “eb” machines, if the rated voltage exceeds 1 kV, type tests in explosive mixtures, for the stator insulation system, have to be carried out. Type tests in explosive mixtures, that have to be conducted in this case, are the following [5]:

- Impulse ignition test;
- Steady state ignition test (over voltage test).

For Level of Protection “ec” machines, if the rated voltage exceeds those shown in Table 1 for the applicable equipment groups, type tests corresponding to the steady state ignition test for the stator winding insulation system have to be carried out [5].

Table 1. Stator insulation systems tests of Level of Protection “ec” machines

Rated voltage	Equipment Group
>1 kV	IIB or IIC
>1 kV with random wound stator	IIA
>6.6 kV with form-wound stator	IIA

It is recommended that partial discharges be minimized for all high voltage windings. For windings with a rated voltage of 6.6 kV, or greater, the use of partial discharge suppressant materials is recommended [5].

3.1 Impulse ignition test for Level of Protection “eb” stator insulation systems

Insulation systems and connecting cables have to tested in an explosive test mixture as shown in Table 2. They have to be subjected to 10 voltage impulses of not less than three times peak phase to earth voltage and with a voltage rise time between 0.2 μs and 0.5 μs. and with a time to half value which is at least 20 μs. The impulse voltage has to be applied between one phase and earth with the other phases earthed and repeated for each phase [5].

This is a non-standard waveform but it is believed that it is necessary to use a rise time as can practically be achieved to initiate discharge with a sufficient length to contain enough energy for ignition. This is based on the results of experiments conducted by Physicalisch Technische Bundesanstalt (PTB) in Germany [5].

This test is representative of wye (star) connected machines with the supply midpoint earthed or delta connected machines with the virtual midpoint near system earth. Other supply connections have to be subject of discussions between the manufacturer and the user to determine suitable insulation system tests. No ignition of the explosive test mixture has to occur, in order for the test sample to successfully pas these tests [5].

3.2 Steady state ignition test for Levels of Protection ‘eb” and “ec” stator insulation systems

Insulation systems and connection cables have to be tested in an explosive test mixture, as shown in Table 2 with a sinusoidal voltage of at least 1.5 times the rated r.m.s line voltage for at least 3 min. The maximum rate of voltage rise has to be 0.5 kV/s. The voltage has to be applied between one phase and earth with the other phases earthed, and repeated for each phase. In this case also, no ignition of the test mixture has to occur [5].

Table 2. Explosion test mixtures

Equipment Group	Test mixture in air V/V
IIC	(21 +/- 5) % hydrogen
IIB	(7.8 +/- 1) % ethylene
IIA	(5.25 +/- 0.5) % propane

4. Case study

4.1. Testing programme presentation

Testing programme for winding test sample for 6 kV rated voltage.

Tests for the certification of the stator winding insulation system, according to EN 60079 – 7, for Ex eb IIC motors, with a rated voltage Un = 6 kV.

The test sample object is the winding test sample.

The winding test sample was submitted to the following tests:

1. Impulse ignition test for the stator insulation systems, Level of Protection "eb", according to art. 6.2.3.1.2 from EN 60079-7 (10 voltage impulses of 14.7 kV).

Description: The insulation systems and the connection cables were tested in an explosive test mixture, according to the Table 2 (IIC - (21 ± 5) % hydrogen). They were subjected to 10 voltage impulses of not less than three times peak phase to earth voltage (14.7 kV) and with a voltage rise time between 0.2 µs and 0.5 µs and with a time to half value which is at least 20 µs. The impulse voltage has to be applied between one phase and earth with the other phases earthed and repeated for each phase.

Equipment used: Baker Station type DS30R and PP – impulse generator.

Parameters of the impulses for line voltage Un = 6 kV:

- voltage value: 14.7 kV
- frequency: 50 Hz
- testing period: 10 sec - 50 impulses
- voltage rise time: 0.1- 0.2 µs
- connection of the winding test sample terminals was made according to Figure 1.

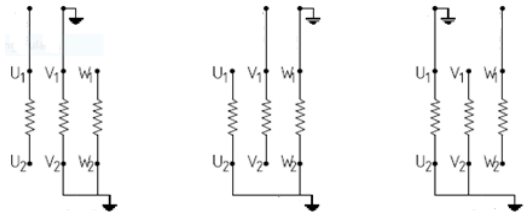

Fig. 1. Impulse ignition test

The impulse ignition test was carried out at the voltage value of $3 \cdot \left(\frac{Un}{\sqrt{3}}\right) \cdot \sqrt{2}$ = 14.7 kV, where Un is the rated voltage of the motor and U1-U2, V1-V2, W1-W2 are the three phase windings of the motor.

2. Ignition test in balanced conditions for the stator winding insulation systems, Level of Protection „eb" and „ec" according to art. 6.2.3.1.3 from EN 60079-7.

Description: Insulation systems and connection cables were tested in an explosive test mixture, as shown in Table 2 (IIC - (21 ± 5) % hydrogen), with a sinusoidal voltage of at least 1.5 times the rated r.m.s. line voltage for at least 3 min. The maximum rate of voltage rise was 0.5 kV/s. The voltage was applied between one phase and earth with the other phases earthed, and repeated for each phase.

Tests carried out:
Tests in explosive mixtures for the stator winding insulation system (Group IIC). High voltage testing at 1.5 x Un = 1.5 x 6 = 9 kV in explosive mixture (21 ± 5) % hydrogen).
The voltage (9 kV) was applied for a time period of 3 min between the U phase winding and earth (the windings of the phases W and V were shortcircuited and earthed together with the stator core).
The voltage (9 kV) was applied for a time period of 3 min between the V phase winding and earth (the windings of the phases W and U were shortcircuited and earthed together with the stator core).
The voltage (9 kV) was applied for a time period of 3 min between the W phase winding and earth (the windings of the phases U and V were shortcircuited and earthed together with the stator core).
- connection of the winding test sample terminals was made according to Figure 2.

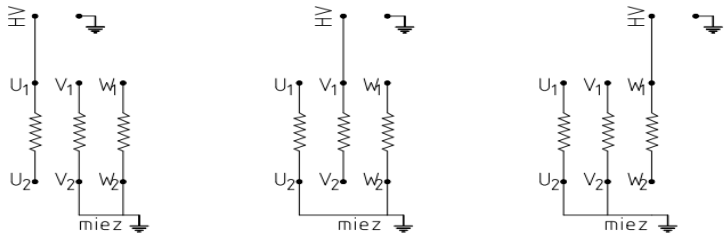

Fig. 2. Over voltage test

The over voltage test was carried out at: $1{,}5 \cdot Un$ = 9 kV, where Un is the rated voltage of the motor, HV stands for High Voltage and "miez" is the stator core of the motor.

4.2. Results obtained

Table 3. Results for the impulse test and the over voltage test

No.	Ignition place	Test mixture pressure [bar]	Gas	Percentage of gas in air	Humidity [%]	Temperature [°C]	P1 [bar]	P2 [bar]	P3 [bar]	Transmission
1	3	0.97	Hydrogen	21.70	24.60	22.88	0.00	0.00	0.00	no
2	3	0.96	Hydrogen	21.56	22.48	22.97	0.00	0.00	0.00	no
3	3	0.95	Hydrogen	21.12	20.01	23.17	0.00	0.00	0.00	no
4	3	0.95	Hydrogen	21.46	18.64	23.46	0.00	0.00	0.00	yes
5	2	0.94	Propane	5.38	21.70	24.09	0.00	0.00	0.00	no
6	2	0.94	Propane	5.34	26.17	24.03	0.00	0.00	0.00	no

7	2	0.94	Propane	5.34	25.53	23.97	0.00	0.00	0.00	no
8	1	0.94	Propane	5.29	25.39	24.01	0.00	0.00	0.00	no
9	2	0.94	Propane	5.34	26.04	23.99	0.00	0.00	0.00	no
10	2	0.94	Propane	5.34	26.05	23.92	0.00	0.00	0.00	no

Table 4. Description of each test carried out

No. of test	Comment
1	Impulse test acc. to SR EN 60079-7 pct.6.2.3.1.2. Voltage of 14700 V applied on winding U1-U2, with the other windings earthed.
2	Impulse test acc. to SR EN 60079-7 pct.6.2.3.1.2. Voltage of 14700 V applied on winding W1-W2, with the other windings earthed.
3	Impulse test acc. to SR EN 60079-7 pct.6.2.3.1.2. Voltage of 14700 V applied on winding V1-V2, with the other windings earthed.
4	Over voltage test of 9 kV applied for 3 min on winding V1-V2, the other windings connected to the stator and earthed, acc. to SR EN 60079-7 pct.6.2.3.1.3.
5	For Group IIA Over voltage test of 9 kV applied for 3 min on winding V1-V2, the other windings connected to the stator and earthed, acc. to SR EN 60079-7 pct.6.2.3.1.3.
6	For Group IIA Over voltage test of 9 kV applied for 3 min on winding W1-W2, the other windings connected to the stator and earthed, acc. to SR EN 60079-7 pct.6.2.3.1.3.
7	For Group IIA. Over voltage test of 9 kV applied for 3 min on winding U1-U2, the other windings connected to the stator and earthed, acc. to SR EN 60079-7 pct.6.2.3.1.3.
8	For Group IIA Over voltage test of 9.9 kV applied for 3 min on winding V1-V2, the other windings connected to the stator and earthed, acc. to SR EN 60079-7 pct.6.2.3.1.3.
9	For Group IIA Over voltage test of 9.9 kV applied for 3 min on winding W1-W2, the other windings connected to the stator and earthed, acc. to SR EN 60079-7 pct.6.2.3.1.3.
10	For Group IIA. Over voltage test of 9.9 kV applied for 3 min on winding V1-V2, the other windings connected to the stator and earthed, acc. to SR EN 60079-7 pct.6.2.3.1.3.

4.3. Discussions

a) The impulse ignition test carried out according to subchapter 4.1 (point 1) was successfully passed by the winding insulation test sample. No explosion of the test mixture occurred.

b) The over voltage of 9 kV applied for 3 min on winding V1-V2, the other windings connected to the stator and earthed, acc. to SR EN 60079-7 pct.6.2.3.1.3. (see subchapter 4.1, point 2), led to the explosion of the testing mixture corresponding to Group IIC (21 ± 5) % hydrogen). The decision then, was taken to continue with the over voltage testing of the winding test sample, but for Group IIA (5.25 ± 0.5) % propane, instead of hydrogen, in this case, the test mixture (propane-air) having a higher minimum ignition energy. Three sets of tests were carried out successfully in this case, between each winding and earth, with the other windings connected to the stator and earthed. Then the over voltage was raised to 9.

kV (corresponding to a rated volage Un = 6.6 kV) and a new set of tests corresponding to Group IIA were carried out successfully again.

c) After concluding all the tests required by the standard SR EN 60079 – 7, the stator winding insulation system qualified for certification for Group IIA application of gases and vapors.

5. Conclusions

In hazardous environments where the presence of flammable gases or vapors poses significant risks, electric motors complying with Ex eb (or Ex ec) standards provide increased safety measures. The impulse ignition test and the over voltage test for stator insulation systems play a crucial role in the assessment and enhancing the safety and reliability of these motors. By subjecting the insulation system to high voltage impulses and over voltages and ensuring that it can withstand potential transient electrical stresses without causing sparks or arcs, the impulse ignition tests, as well as the over voltage tests mitigate ignition hazards and contribute to the safe operation of electric motors in hazardous environments.
Manufacturers and users alike should recognize the importance of these tests and their role in promoting the safe and reliable operation of electric motors with type of protection increased safety Ex eb and / or Ex ec.

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