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A Performant Insulation System for the Stator Winding of the 6 kV Induction Motors

SONIA DEGERATU, MIHAELA POPESCU, NICU G. BIZDOACA
Faculty of Electromechanical Engineering
University of Craiova
Bd. Decebal, Nr.107, 200440, Craiova
ROMANIA

Abstract: - The paper presents several types of F class insulation systems, designed by the authors of this article, for the stator winding of the 6 kV induction motors, as well as the performances determined by testing these systems. The results of the functional evaluation of the most performing insulation system, identified in the light of the experiments, are also presented in this article. This system improved the performances of the Romanian 6 kV motors, by allowing a power up to 2500 kW, insuring a higher reliability compared to the older ones. One of the essential advantages provided by the selected insulation system consists in space saving in the slots of the stator which gives the possibility to reduce both weight and size up to 15 % compared to the same kind of motors using the ancient insulation system.

Key-Words: - Insulation system, coil, VPI, motorette, thermal endurance tests, thermal endurance graph

1 Introduction

The progress made in the technology of insulating materials affects on a large scale the development of the electric machines. Many new materials made their appearance on the market during these last years. At the same time, new insulation manufacturing processes were created and existing ones were improved. A historical event in this development was the introduction of the thermo hardening resin impregnation without solvents and the process of vacuum pressure impregnation (VPI).

The theoretical and experimental study of the seven types of F class insulation systems, in the way it was conceived by the authors, constitutes a response to the needs of the Romanian Companies Electroputere and Electroturris. Therefore, it was decided to modify the range of the asynchronous 6 kV motors, in order to provide a power up to 2500 kW, one of the objectives being the use of a powerful insulation system for the stator winding.

The tested insulation systems made it possible to reduce the unilateral thickness of the main insulation of the coils from 2 mm down to1,6 mm.

2 Description of the Tested Insulation Systems

Electroputere Company manufactured 21 coils using the seven insulation systems mentioned above, each of them caring a different number punched on its upper part. The coils were made either free or coupled in groups of two same type coils to form the motorettes. In order to manufacture these insulation systems, the following steps were required [1], [2].

2.1 Choosing the conductor

The seven insulation systems use three types of conductors, noted by A, B and C, with rectangular section and rounded angles.

2.2 Aligning the conductors of a coil

This is an important step in the manufacturing process because it provides a uniform thickness of insulation systems in all active points of the coil. The process used for the A and B type was carried out by polymerising the sheet‘s resin. This sheet was applied directly on the conductors, on the right side of the coil, in a single layer. On the other hand, the process used for the C type conductor consists of polymerising the Altron resin of the conductor’s insulation.

2.3 Manufacturing the main insulation system of the coil

Two material combinations were conceived referred to as I and II, by using tapes or sheets based on mica, epoxy resin and also polyester tapes and sheets. Seven insulation systems, noted by A_I, A_{II}, A_{IIGE}, B_I, B_{II}, C_I, C_{II}, were manufactured with these

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three types of conductors (A, B and C). 21 coils were made with these seven systems, where corona protection was made possible using a conductive wrapping on the right part of the coils and a semi-conductive wrapping on the heads of the coils.

2.4 Impregnation

The coils thus carried out, numbered from 1 up to 18, were twice VPI impregnated, in the C57 varnish, with solvent, based on an alchydic resin modified by a phenolic resin. The ones numbered 19, 20 and 21, were VPI impregnated in a thermo-hardening resin, of type GE 74023, without solvent.

2.5 Symbols used for the coils

The naming rule used for the coils is:

nKi (1)

where *n* indicates the number of the coil, *K* the type of the conductor (A, B or C) and *i* the type of the main insulation of the coil (I or II). If the impregnation is made in type *GE* resin, the index *GE* will be added into symbolization (1).

3 Experimental Results

The features of the tested insulation systems were examined during numerous tests on the 21 executed coils. The principal tests [2], [3] carried out are presented hereafter.

3.1 The test at the high - voltage towards the earth of the main insulation

The value of the high voltage was 13 kV, at 50 Hz, during 1 minute. All the coils passed this test.

3.2 The test of the insulation system between the wires of the coil

The value of the high - voltage is 1.3 U_N (where U_N represent the nominal voltage of the motor), thus resulting the value 7800 V (for the voltage of 6 kV), applied during 5 minutes.

If the number of the wires is *N*, it results that between wires a voltage $U_{sp\ voltage}$ = 7800/N appears, in volts. All the coils passed the test.

3.3 The test to determine the polarization index and absorption coefficient

If the polarization index, K_p, is small (between 1 and 2) the conduction is relatively high, generally due to humidity or to a great amount of conductive pollution in the insulation materials. On the other hand if the index is large (greater than 2) then the insulation is considered to be dry and in good state [2], [3], [4].

Figure 1, gives us the values of K_P index for all the tested coils.

Coils having values for the absorption coefficient K_{abs}, greater than 1.3 have a good insulation. The same evaluation rules, as for K_p index, can be applied for the K_{abs} coefficient [2], [3], [4].

Figure 2, gives us the values of K_{abs} index for all the tested coils.

The polarization index K_P and the absorption coefficient K_{abs} don't give us issues about a particular malfunctioning of the isolation but an overview of the general state of the insulation system. They don't allow a prediction of breakdown risks.

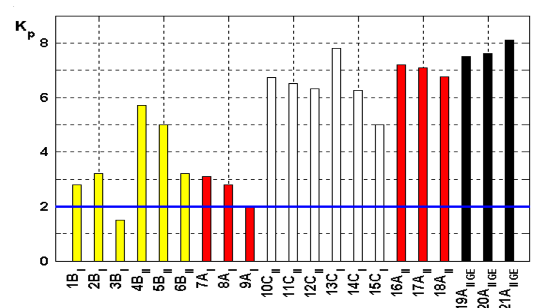

Fig.1 K_p values for the tested coils

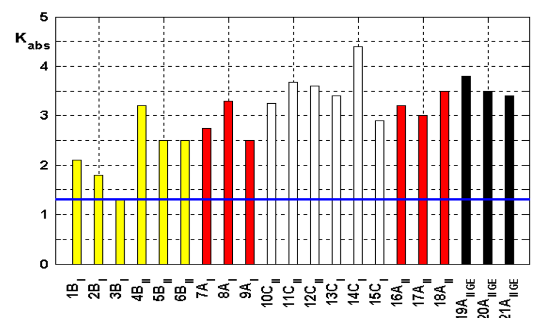

Fig.2 K_{abs} values for the tested coils

By analysing the two figures it is noted that high and grouped values of K_p and K_{abs} were obtained for the A_{IIGE}, A_{II} and C_{II} types of coils.

3.4 The test of variation dielectric loss factor to the relative values of applied voltage U/U_N

This is one of the most efficient tests in order to establish the quality of an insulation system.

A good insulation system should have a tanδ - U/U_N curve as linear as possible. Its ionization threshold should be greater than its service voltage in order to avoid a premature wear.

At the same time the asymptotes to both of the curve branches should make a small angle related to the ionization threshold. A great angle means that a great number of air pockets are present in the insulation.

Figure 3 gives the average values of tanδ, noted by X, for all similar type of coils which correspond to the relative applied voltage $U/U_N = 0.2$. A good insulation system corresponds to values lower than 0.04, limit given by international standards [5].

Figures 4 and 5 indicate the values of Y and Z for all tested insulated systems. Y and Z have the following significance [2], [5]:

$$Y = \frac{1}{2}\left(tg\delta_{0,6} - tg\delta_{0,2}\right) \le 2{,}5 \cdot 10^{-3} \quad (2)$$

$$Z = \left(tg\delta_{0,8} - tg\delta_{0,6}\right) \le 5 \cdot 10^{-3} \quad (3)$$

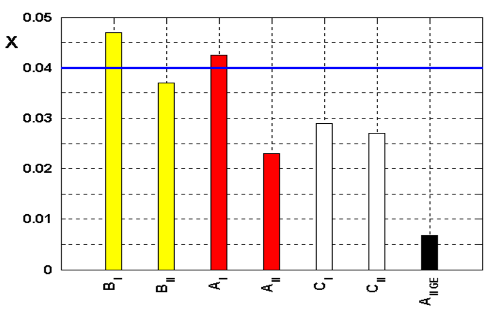

Fig.3 X values for all tested insulated systems

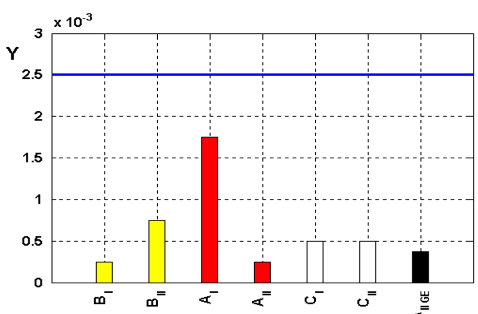

Fig.4 Y values for all tested insulated systems

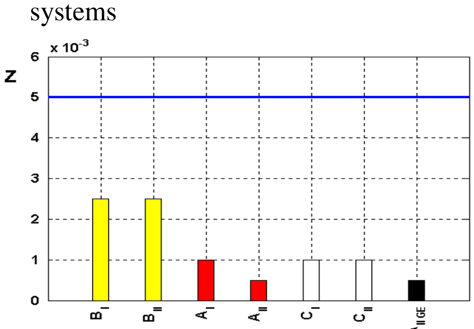

Fig.5 Z values for all tested insulated systems

where: $\tan\delta_{0.2}$; $\tan\delta_{0.6}$; $\tan\delta_{0.8}$ represent the average values of tanδ for all similar type of coils and for both parts of the coil with a relative tension applied (U/U_N) of 0.2; 0.6 and respectively 0.8.

By analysing the figures 3, 4 and 5 we observe very low values, either for X, or for Y and Z, in the case of A_{IIGE} and A_{II} systems.

Figures 6 and 7 indicate the variation tanδ - U/U_N for all the tested coils (for the small and respectively big part of the coil).

Figure 8 indicates the average values of tanδ for the both parts of the coil related to U/U_N, for the best three systems (A_{IIGE}, A_{II} and C_{II}).

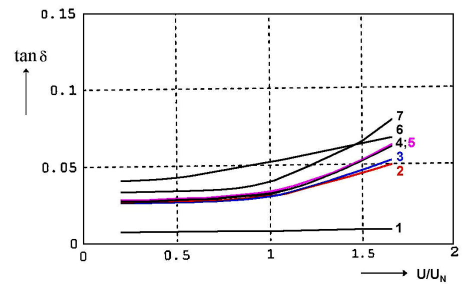

Fig.6 Curves tanδ-U/U_N for the following types of coils (small part of coils): 1-$A_{II\,GE}$; 2-C_{II}; 3-A_{II}; 4-C_I; 5-B_{II}; 6-B_I; 7-A_I

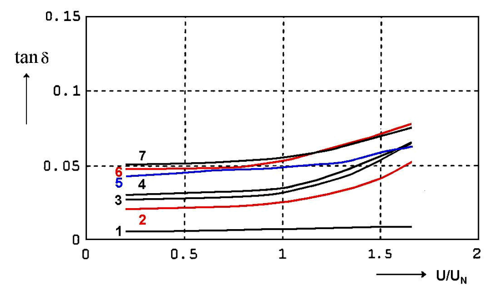

Fig.7 Curves tanδ-U/U_N for the following types of coils (big part of coils): 1-$A_{II\,GE}$; 2- A_{II}; 3- C_{II}; 4-C_I; 5- A_I; 6- B_{II}; 7- B_I

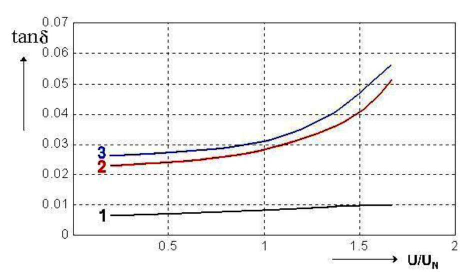

Fig.8 Curves tanδ-U/U_N for the following types of coils: 1-A_{IIGE}; 2- A_{II}; 3- C_{II}

Figure 8 shows that A_{IIGE} system has a dielectric loss factor, tanδ, lower with 71% than A_{II} system, at nominal voltage. The only difference between the two types of systems is the type of resin impregnation.

The system $A_{II}P_{GE}$ presents losses comparable with those of certain insulation systems manufactured by international companies, for example Ansaldo (of Italy) or Elin (of Austria).To confirm the assertion above, in figure 9 one represented the curves tan δ-U/U_N for the insulation systems marked on the figure [2], [3], [6].

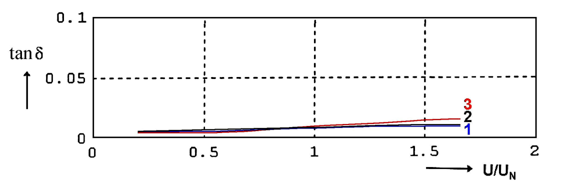

Fig. 9 The curves tan δ - U/U_N for the following insulation systems: 1-Ansaldo; 2-$A_{II}P_{GE}$; 3-Elin

3.5 The test to determinate the insulation time factor

The insulation time factor, denoted by T_{10}, is not dependent on the motor's size.

Values of T_{10} greater than 25000 seconds correspond to a good insulation system resistance [2], [6].

By analysing the figure 10 one notices that high and grouped T_{10} values were obtained for the A_{IIGE}, A_{II}, B_{II}, C_I and C_{II} type of coils.

3.6 The test of the voltage impulse related to the normal lighting impulse

The tests were carried out on the coils grouped in motorettes: $1B_I$ with $2B_I$, $4B_{II}$ with $5B_{II}$, $7A_I$ with $8A_I$, $10C_{II}$ with $12C_{II}$, $13C_I$ with $14C_I$, $17A_{II}$ with $18A_{II}$, $20A_{IIGE}$ with $21A_{IIGE}$.

This test concerns the lightning over-voltage with a front value of 1.2 μs and an average value of 50 μs. The value of applied voltage is [2]:

$$U_P = 4U_N+5 \tag{4}$$

where:

U_P = the nominal lightning voltage impulse, given in [kV];

U_N = the nominal voltage, given in [kV].

For the type of testing motors the value was: U_P = 29 kV.

This step includes the test at voltage impulse of the insulation between the wires and the main insulation. The following types of coils correspond to this test: A_{IIGE}, A_{II}, B_{II} and C_{II}.

3.7 The test to determinate the breakdown voltage of the main insulation

The test includes the following steps [2]:

- the selection of the tested coils: we chose all the coils that have not been tested during section 3.6, and those which passed section 3.6 test;
- their thermal ageing: exposure to a temperature of 170^0 C for 28 days;
- their mechanical stress: endurance of an oscillation movement of 50 Hz with an amplitude of 0.3 mm;
- their moisture stress: exposure to a 95% humid environment during 48 hours at a temperature of 25^0C;
- the determination of the breakdown voltage of the main insulation.

The results obtained are presented in the figure 11.

The values of the breakdown voltage for the coils also tested with the voltage impulse are presented with black bars and for the other coils with white bars.

The analysis of figure 11 shows that the impulse voltage test did not affect in a significant way the values of the breakdown voltage for the II type insulation system and that the higher values for breakdown voltage were achieved by A_{IIGE} and AII insulation systems.

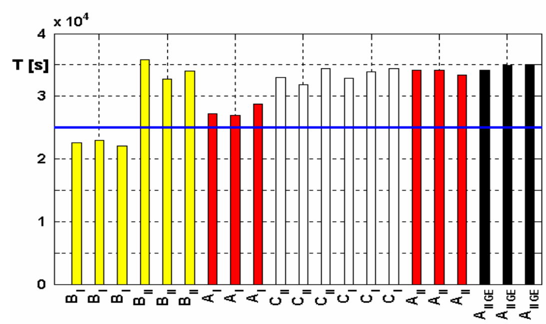

Fig.10 T_{10} values for all tested coils

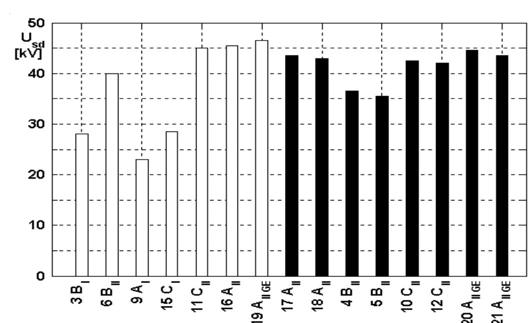

Fig.11 Breakdown voltage values for all the selected coils

By analyzing the results of the tests, we can say that the best tested insulation system is A_{IIGE}.

3.8 Evaluation of the thermal endurance

This test was carried out only for the A_{IIGE} system. We have used a part of a real motor's stator called formette. Each formette contained 10 coils. Three formettes were manufactured each one corresponding to a different exposure-temperature. The thermal endurance graph for the A_{IIGE} tested insulation system is presented in figure 12. This thermal endurance graph was acquired by means of statistical computing of the results [2], [7], [8], using a home developed Visual C++ 6.0 program.

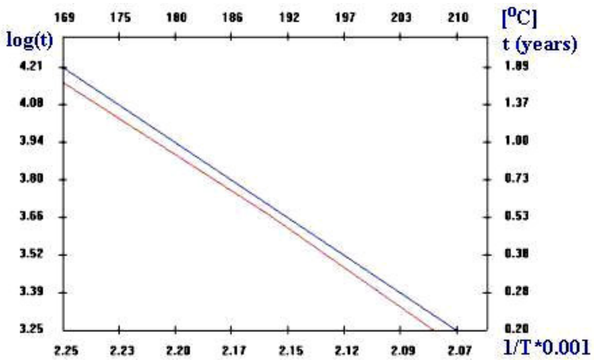

Fig.12 Thermal endurance graph for the system A_{IIGE}

We can observe a long life (around 30 years) at the optimal motor's temperature, a thermal index of 167^{0}C, and an active energy E = 1.025 eV.

Figure 13 indicates the life-curve of the Ansaldo insulation system [9], with a thermal index 166^{0}C.

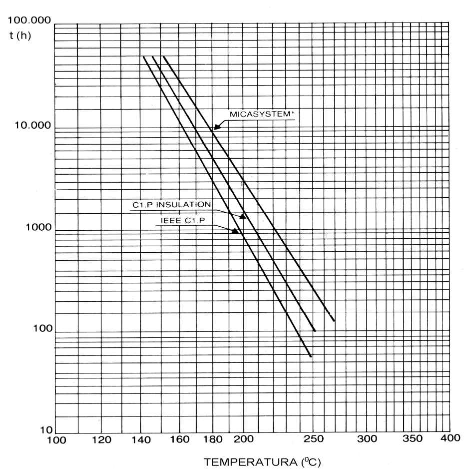

Fig.13 The life-curve of the Ansaldo insulation system

If we choose an ageing temperature of 180^{0}C, the average life time for the systems $A_{IIGE,}$ and ANSALDO are 9146 h and respectively 9890 h.

After this test the A_{IIGE} insulation system was approved in the F-class temperature.

4 Conclusions

The tests achieved in our laboratories on the seven insulated systems showed that the best one is $A_{IIGE.}$

The A_{IIGE} insulation system was approved in the F-class temperature.

Due to the fact that the temperature index of F-class type is 155^{0}C, and for our insulation system we have obtained 167^{0}C, there is still room for thermal resistivity, and the practical service factor therefore becomes 1.1.

Its performances are comparable with the ones obtained by other famous firms such as Ansaldo [3], [9], and Elin [3], [4], [6].

At the beginning the new insulation system A_{IIGE} was used only on one motor produced by Electroturris Company solving his heating problems which he was having before with the old insulation system. Now, this system is applied at all windings of high voltage induction motor made by Electroputere Company. One of the essential advantages provided by the selected insulation system consists in space saving in the slots of the stator which gives the possibility to reduce both weight and size up to 15 % compared to the same kind of motors using the ancient insulation system.

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