ANALELE UNIVERSITĂȚII
"EFTIMIE MURGU" REȘIȚA
ANUL XIII, NR. 1, 2006, ISSN 1453 - 7397

Mihaela Răduca

The Modeling and Simulation of Braking-off Voltage at Hydro Generator Stator Winding Insulation

This paper presents the modeling and simulation of braking-of voltage at hydro generator stator winding. The winding stator is supplied at high voltage of 11 kV for high power hydro generator. The braking-of voltage for stator winding is 40 kV.

1. Introduction

Through the electrical insulation to understand the materials (or material ensemble) with electro insulating properties, which separating the metallic pieces, finding out below voltages with different phases (or polarities) and on these from frame connected on ground.

This insulation is very important because of insulation quality depends the good function of hydro generator.

The exploitation experience shows that approximate 40% for defects which appearing at hydro generators in operation appear owning to insulation defects. At any hydro generators the defects can be became at 100%.

For this cause must be a high attention for attempts and checks of insulation, which make in factory and in exploitation.

During the hydro generators operation, the insulation is submitting the thermal, mechanical and electrical solicitations. These solicitations carry at old of insulation.

Through the prophylactic measurements is make with the opportunity current revisions, is can appreciate the degree of ageing respective insulation.
If ageing is advanced, for the welcome out of order appearances in chain, to take the replace measures of the respective insulation, extending in this way the life equipments.

The ageing of insulation understands the degradation (the deterioration) gradually insulating property.

This process of ageing will carry at the insulation degradation, characterize by rhythm of breakdown in time.

The insulation break-off is some cause of insulation ageing.

2. The insulation break-off

The insulation brake-off is a destruction discharge, which carry through the crossing of solid electro insulating material can produces the qualitative irreversible transformations, with decreasing or the cancellation property of insulation.

At these materials, the braking-off can be produce by processes which have at base the electrical phenomena (electrical braking-off) or thermal processes (thermal braking-off) or chemical processes (chemical braking-off).

The braking-off voltage have a linear variation with the dielectrically rigidity. Thus, if at the accelerated ageing probe the braking-off voltage diminishes as in figure 1, therefore life duration, ε, accordingly of ageing temperatures can be determinate from the time interval in which the braking-off voltage was decreased by the prescribed value.

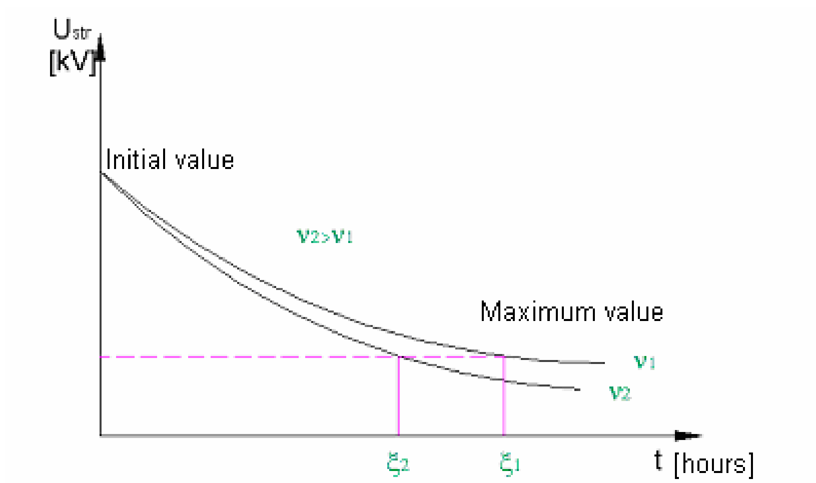

Figure 1. The decrease of insulation braking-off voltage in time owning-to the insulation ageing at different temperatures

3. The mathematical model

The mathematical model is base on the Maxwell equations.

$$\nabla x\{H\}=\{J\}+\left\{\frac{\partial D}{\partial t}\right\}=\{J_s\}+\{J_e\}+\{J_v\}+\left\{\frac{\partial D}{\partial t}\right\}, \qquad (1)$$

$$\nabla x\{E\} = -\left\{\frac{\partial B}{\partial t}\right\}, \tag{2}$$

$$\nabla \cdot \{B\} = 0, \tag{3}$$

$$\nabla \cdot \{D\} = \rho, \tag{4}$$

where:

∇x - operator

$\nabla \cdot$ - divergence operator

{H} – vectorul intensităţii câmpului magnetic

{J} – vectorul densităţii totale de curent

$\{J_s\}$ – vectorul densităţii curentului sursei aplicate

$\{J_e\}$ – vectorul densităţii curentului indus

$\{J_{vs}\}$ – vectorul densităţii curentului

{D} – vectorul densităţii fluxului electric

t – timpul

{E} – vectorul intensităţii câmpului electric

{B} – vectorul densităţii fluxului magnetic

ρ - densitatea sarcinii electrice

For electrical field and the braking-off voltage the Maxwell equations became:

$$\{J\} = [\sigma][\{E\} + \{v\}x\{B\}], \tag{1}$$

$$\{D\} = [\varepsilon]\{E\}, \tag{2}$$

where:

$$[\sigma] = \begin{bmatrix} \sigma_{xx} & 0 & 0 \\ 0 & \sigma_{yy} & 0 \\ 0 & 0 & \sigma_{zz} \end{bmatrix}, \tag{3}$$

$$[\varepsilon] = \begin{bmatrix} \varepsilon_{xx} & 0 & 0 \\ 0 & \varepsilon_{yy} & 0 \\ 0 & 0 & \varepsilon_{zz} \end{bmatrix}, \tag{4}$$

$$\{v\} = \begin{Bmatrix} v_x \\ v_y \\ v_z \end{Bmatrix}, \tag{5}$$

[σ] – electrical conductivity matrix;

[ε] – permittivity matrix;

{v} – speed vector;

σ_{xx} – conductivity in x direction;

ε_{xx} – permittivity in x direction.

The matrix equation for electrostatic analysis is:

$$\left[K^{vs}\right]\left\{V_e\right\}=\left\{Q_e\right\}, \tag{6}$$

$$\left[K^{vs}\right]=\int_{vol}(\nabla\{N\}^T)^T[\varepsilon](\nabla\{N\}^T)d(vol), \tag{7}$$

$$\left\{Q_e\right\}=\left\{Q_e^n\right\}+\left\{Q_e^c\right\}+\left\{Q_e^{sc}\right\}, \tag{8}$$

$$\left[Q_e^c\right]=\int_{vol}\{\rho\}\{N\}^T d(vol), \tag{9}$$

$$\left[Q_e^{sc}\right]=\int_{s}\{\rho_s\}\{N\}^T ds, \tag{10}$$

where:
$[K^{vs}]$ – matrix of dielectric permittivity coefficients
$\{\rho\}$ – vector of load density
$\{\rho_s\}$ – vector of load density on the surface
The electric potential, the braking-off voltage is:

$$V=\{N\}^T\{V_e\}, \tag{11}$$

where:
$\{N\}$ – the model functions
$\{V_e\}$ – electrical potential, braking-off voltage in element nodes

3. The geometrical model

The geometrical model is making by:
- insulation
- coil.

The coil and insulation are from the high power hydro generator.
The high power hydro generator has the following characteristics:
- apparent power S_n = 14710 kVA;
- nominal voltage U_n = 11 kV;
- power factor cos φ = 0,85;
- nominal speed of hydro generator n = 250 rpm;
- supply frequency f = 50 Hz.

The stator winding is supplied at voltage of 11 kV and the design data, the stator winding is make by coils, with elementary conductors of copper by 7,1 mm x 2,24 mm (width x high elementary conductor).

The insulation of coil is making by Calmicaglass 2005. This insulation has very good proprieties of insulated.

This geometrical dimension of stator winding coil is shows in figure 2.

This coil is practically realized and was tested on the stand in SC UCM Reşiţa SA, the "Electrical machines" department.

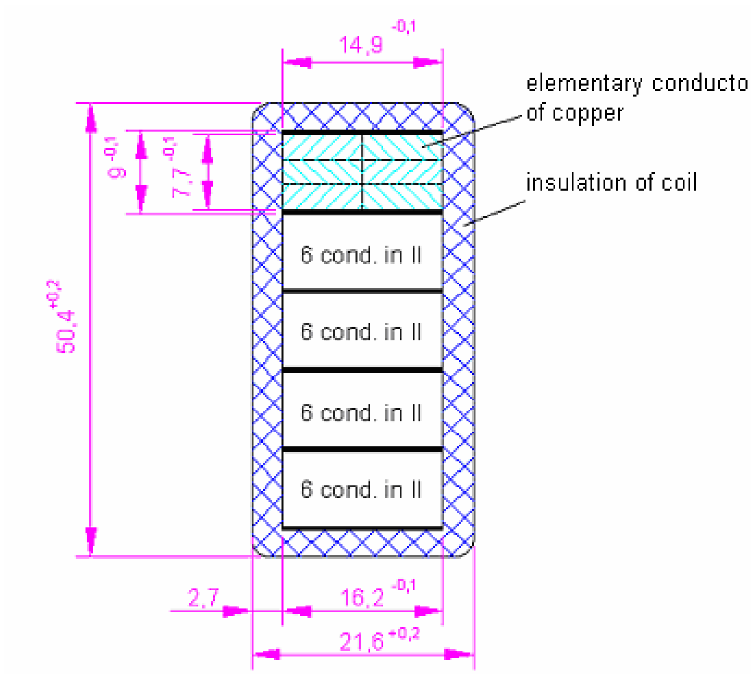

Figure 2. The geometrical dimensions of stator winding coil

These coils are tested in U.C.M. Resita factory at 40 kV of braking-off voltage.

4. The prototype model

The prototype is identically with stator winding. This prototype is modeling through by three areas:

- copper area (of elementary conductors) – area 1
- insulation area – area 2
- air areas – area 3

This prototype is discreditation in finite elements for obtained a very precise calculus of behavior insulation.

This discreditation of prototype is shows in figure 3.

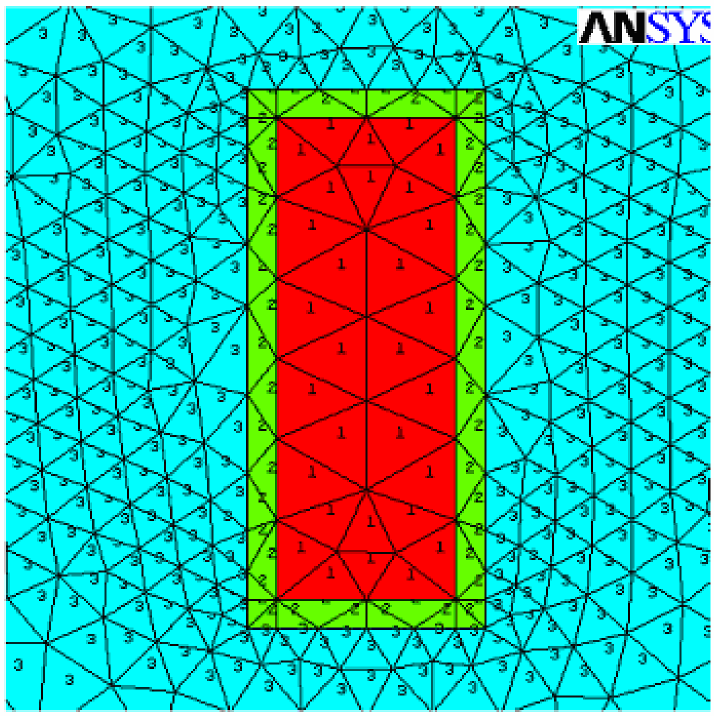

Figure 3. The discreditation of prototype in finite elements

These areas have been the following characteristics:

- the finite element type
- the real constant is coil characteristic (area 1) because this is make by many copper conductors supplied by voltage of 11 kV
- the material properties for areas are:
    - o area 1 – copper
    - o area 2 – calmicaglass 2005 for insulation
    - o area 3 – air
- the discreditation net for these areas

After the characteristics attribution was resolved thus:

- the load application by 40 kV of braking-off voltage
- the solution of this problem
- the visualization and the interpretation results through comparison with result obtained from practice

4. The prototype model

After the modeling and simulations obtained the following results:
- distribution of braking-off voltage in insulation
- the graph of this distribution.

The distribution and the graph are shows in figure 4 and figure 5.

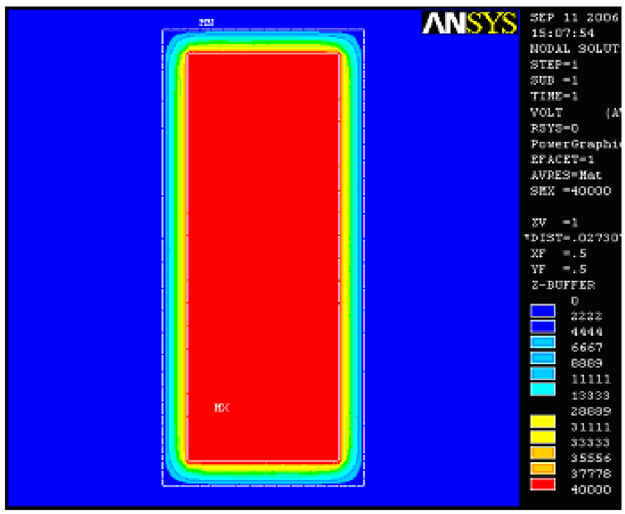

Figure 4. The distribution of braking-off voltage in insulation

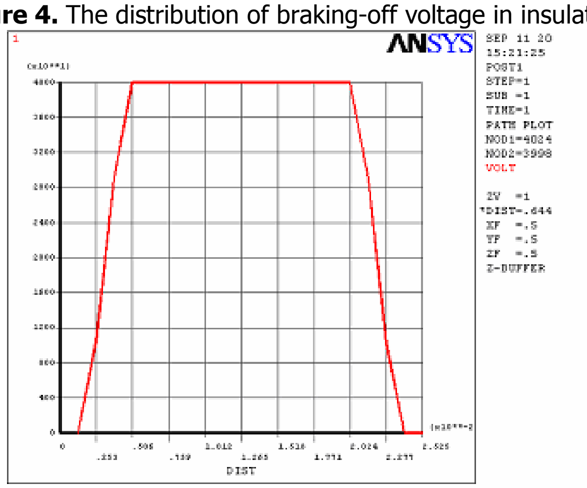

Figure 5. The graph of braking-off voltage distribution in insulation

5. Conclusion

After the testing in stand was determinate that minimum braking-off voltage of coil insulation was U_{str}=40,5 kV.

Through modelling and simulation was determinate that the braking-off voltage of coil insulation U_{str}=40 kV.

To find that through simulation was obtained a correctly value of braking-off voltage of insulation coil, having a appropriate value front the real value.

The modelling and simulation can be replacing, in future, a part of practical tests.

References

[1] Fu W. N., Zhou P., Lin D., Stanton S., Cendes Z. J. *Modeling of Solid Conductors in Two-Dimensional Transient Finite-Element Analysis and Its Application to Electric Machines* IEEE Transactions on Magnetics, VOL. 40, NO. 2, MARCH 2004, pp.426-434

[2] Zhou P., Fu W. N., Lin D., Stanton S., Cendes Z. J., Xu L. *Numerical modeling of electrical machines and its application* IEEE Industry Applications Soc. 37th Annu. Meeting, Pittsburgh, PA, Oct. 13–18, 2002

[3] ***** *Recommended practice for insulation testing of large AC rotating machinery with high direct voltage*. International Standard IEEE 95.

Address:

- Lect. ing. Mihaela Răduca, "Eftimie Murgu" University of Romania, Piaţa "Traian Vuia", nr. 1-4, Reşiţa, raducamiha@yahoo.com