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Finite Element Modeling and Examination of Axisymmetric Thermal State of the Overvoltage Suppressor

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Abstract

The overvoltage suppressors can be applied to guard the high-voltage electrical networks from lightning and switching surges. One of the factors defining a reliability of an overvoltage suppressor is effective heat sink from varistors at operation. The axisymmetric finite element model of a porcelain overvoltage suppressor with use of ANSYS 5.6 Faculty Research Students was developed. Steady-state and transient temperature fields in overvoltage suppressors originating at the International Electrotechnical Commission test simulations are obtained. The obtained results have allowed us to put forward recommendations for suppressor structure optimization.

Introduction

Overvoltage suppressor (OVS) is a protective device providing the insulation protection of electrical apparatus and overhead transmission lines from lightning and switching overvoltages. The overvoltage suppressor consists of a non-linear resistor combined from highly non-linear zinc oxide varistors connected in series or in parallel, enclosed in a porcelain or polymer housing. The OVS is continuously connected to the electrical network. Therefore, it is constantly under the network voltage. The current flowing through it varies from milliampere range in operating conditions to thousand amperes under lightning or switching overvoltages. The energy liberated in the OVS should be less than the normalized one otherwise its thermostability is violated and it is broken down. Figure 1 (Overvoltage suppressor design) represents the overvoltage suppressor design developed in AutoCAD R14 in the left-hand side with maximum durable admissible operating voltage of 2 kV.

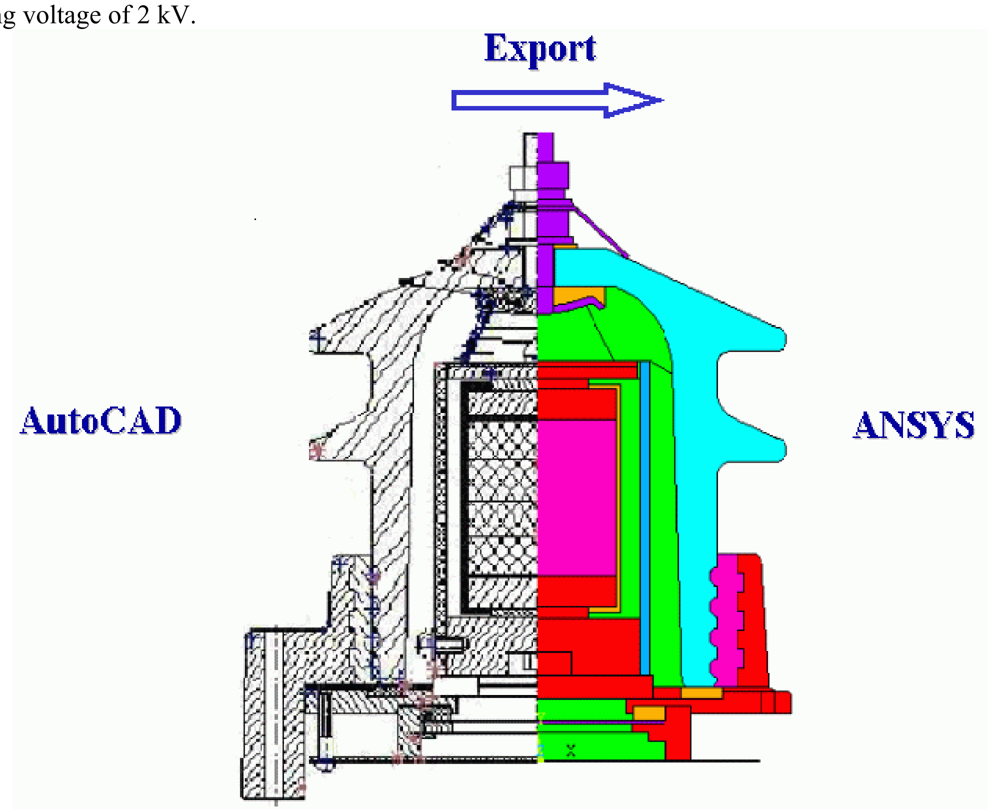

Figure 1 - Overvoltage Suppressor Design

OVS Operating Conditions

Two operation modes of the OVS were examined. The first one is the OVS switching in when the leakage current (i=0.001A) flows through the varistor column. The leakage current was taken into account as volume heat liberation in the varistor column. The conditions of convective heat exchange with the environment having temperature of 20^0C were assumed at the OVS's surface; the convective heat exchange factor of h=6 W/(m^2*K) was accepted.

The direct finite element (FE) modeling of testing by a sequence of rectangular 2 kV pulses 2 µs long, which corresponds to one of the IEC (The International Electrotechnical Commission) tests (Figure 7 - IEC test). The time interval between the pulses was 50 s. The volume heat liberation in the varistor volume was determined on the basis of the real volt-ampere characteristic of zinc oxide varistors of standard form:

$$U = 0.86 U_{100} I^{\alpha},$$

where U - voltage, U_{100} - level of the safe voltage, I - intensity of current, a - coefficient of nonlinearity (Reference 1).

Model

The geometry produced in AutoCAD R14 was transferred into the system of FE analysis ANSYS 5.6. Figure 1 (Overvoltage suppressor design) shows the drawing of the design in AutoCAD R-14 in the left-hand side. The right-hand side shows the plane model developed in ANSYS 5.6. The axisymmetric FE model (Figure 2 - FE model) has the following characteristics: 3393 quadratic finite elements (PLANE77) and 10153 nodes. The Preconditioned Conjugate Gradient (PCG) solver was used to solve the system of linear algebraic equations (Reference 2). The linear thermophysical properties (Figure 3 - Materials, Figure 4 - Material properties, Reference 3) of eight components were taken into account in solving the problem: 1) porcelain, 2) 35X steel, 3) aluminum, 4) glass fiber, 5) zinc oxide, 6) air, 7) polyethylene, 8) cement. Inside the construction there was no flow of air and air thermal properties were accounted for with use of the coefficient of thermal conduction. The contact resistance between the materials was ignored. Fourier criterion (Reference 4) was used for the choosing of an initial integration time step and then the routine of the automatic time stepping was applied.

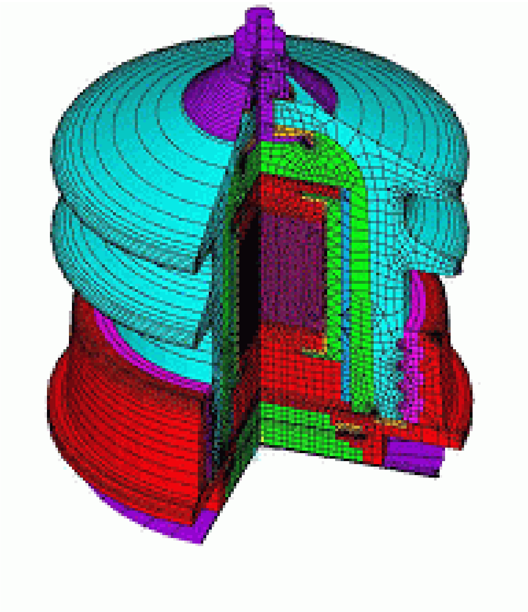

Figure 2 - FE Model

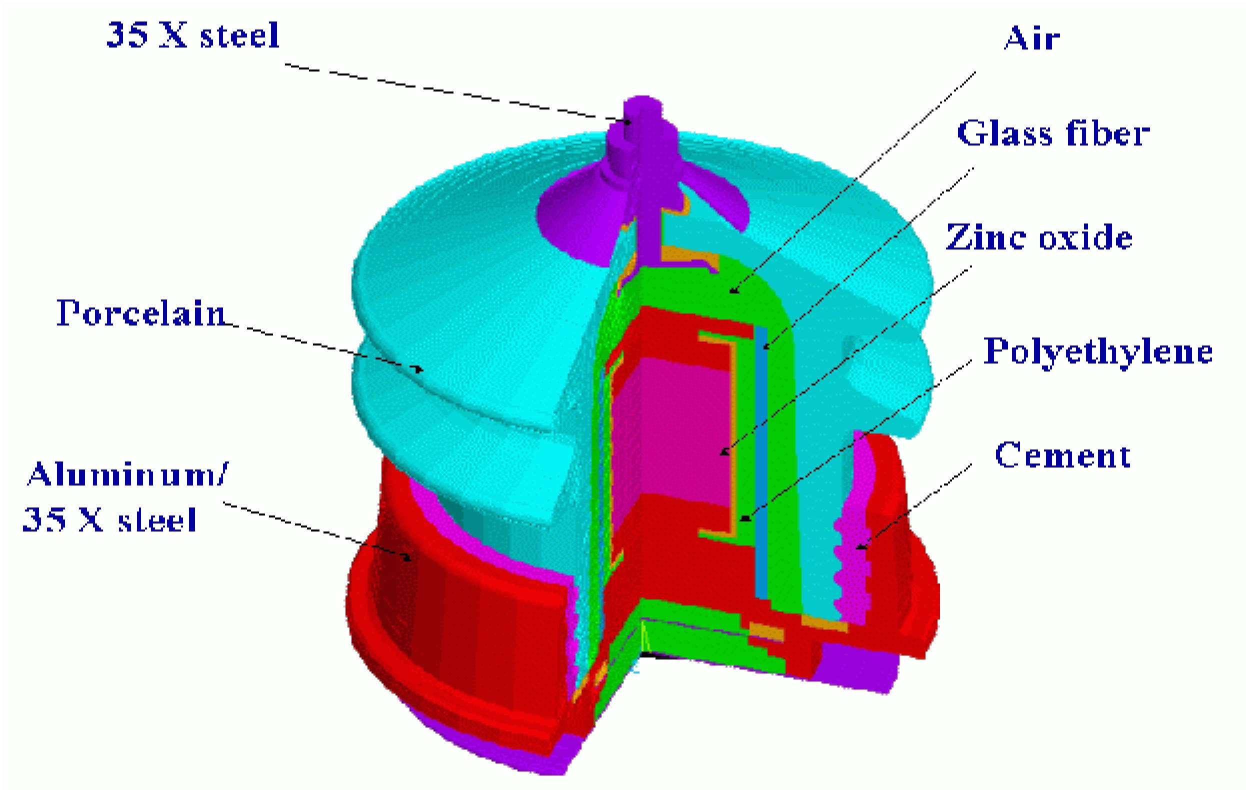

Figure 3 – Materials

	Material	P kg/m³	Heat exchange factor W/(m*K)	Spec. heat J/(kg*K)
1	Porcelain	2.4E3	2.6E0	9.0E2
2	35 X steel	7.3E3	4.8E0	4.6E2
3	Aluminum	2.7E3	3.4E2	9.3E2
4	Glass fiber	2.7E3	1.0E3	3.9E2
5	Zinc oxide	5.7E3	1.2E2	2.9E2
6	Air	1	2.4E-2	4.5E2
7	Polyethylene	9.3E3	1.0E0	6.2E2
8	Cement	1.8E3	1.2E0	8.4E2

Figure 4 - Material Properties

Results

The FE examination of transient temperature fields corresponding to reaching the OVS stationary thermal conditions has shown lower rate of heat extraction from the upper part of the apparatus and therefore achievement of higher temperatures under the current around the upper contact of the varistor column. The stationary temperature field is presented in Figure 4 (Material properties). It was established that the system reaches stationary conditions in 1.5-2 hours (Figure 5 - Steady-state conditions). The time along the x-axis is shown in hundreds of seconds.

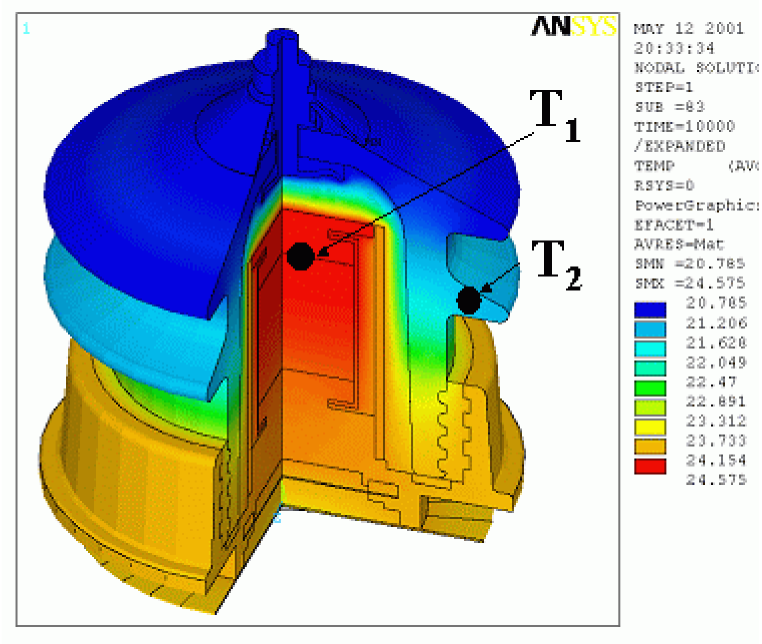

Figure 5 - Steady-state Conditions

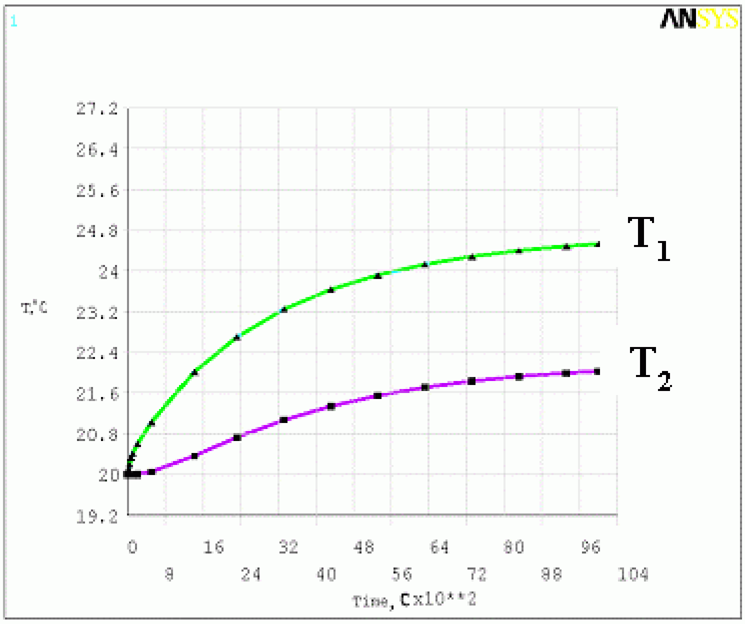

Figure 6 - Reached Stationary Conditions In The Two Points

As a result of the FE examination of testing conditions provided by the IEC the transient temperature distribution in the construction was determined when it was under rectangular 2 kV pulses (Figure 7 - IEC test). Figure 8, 9 (Transient field at time instant 113 s after first impulse, Transient field in the four points) shows the temperature variations at the characteristic points of the varistor column vs time. The examined time interval was 250 s. The T_1, T_2, T_3, T_4 dependencies represent the temperatures at the bottom, middle, top points of the OVS and at the OVS's surface, correspondingly.

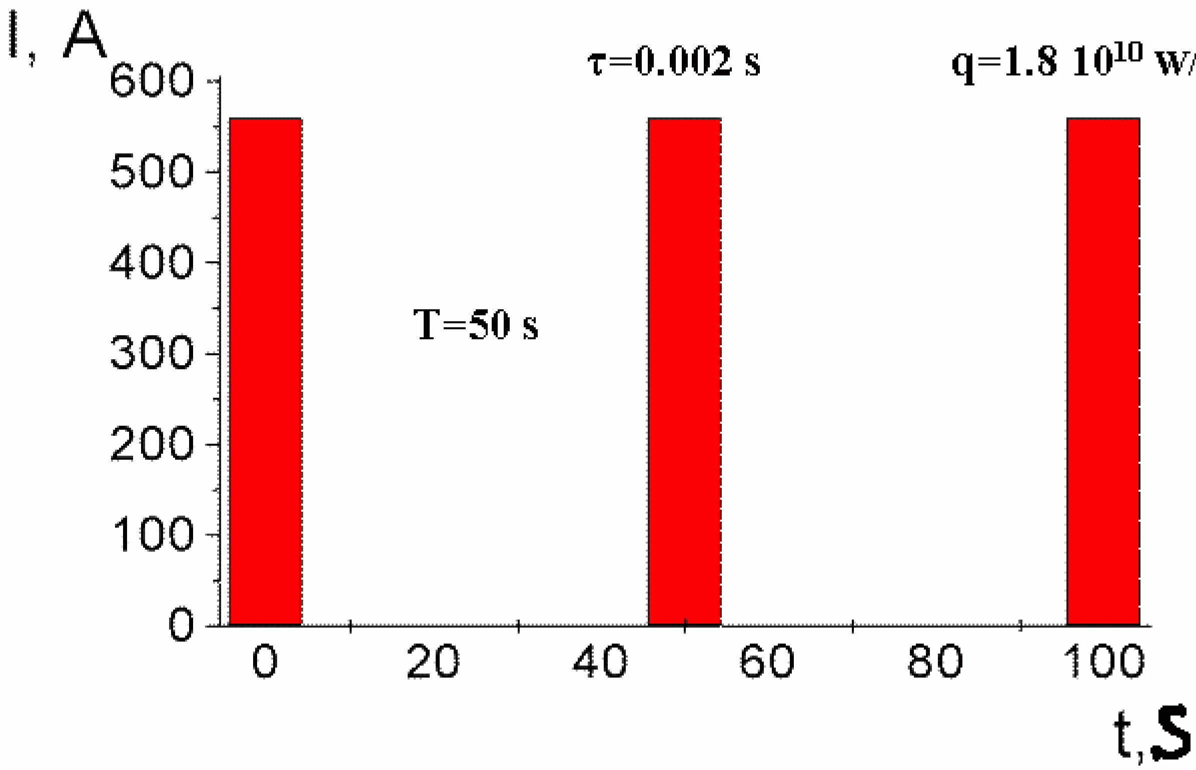

Figure 7 - IEC Test

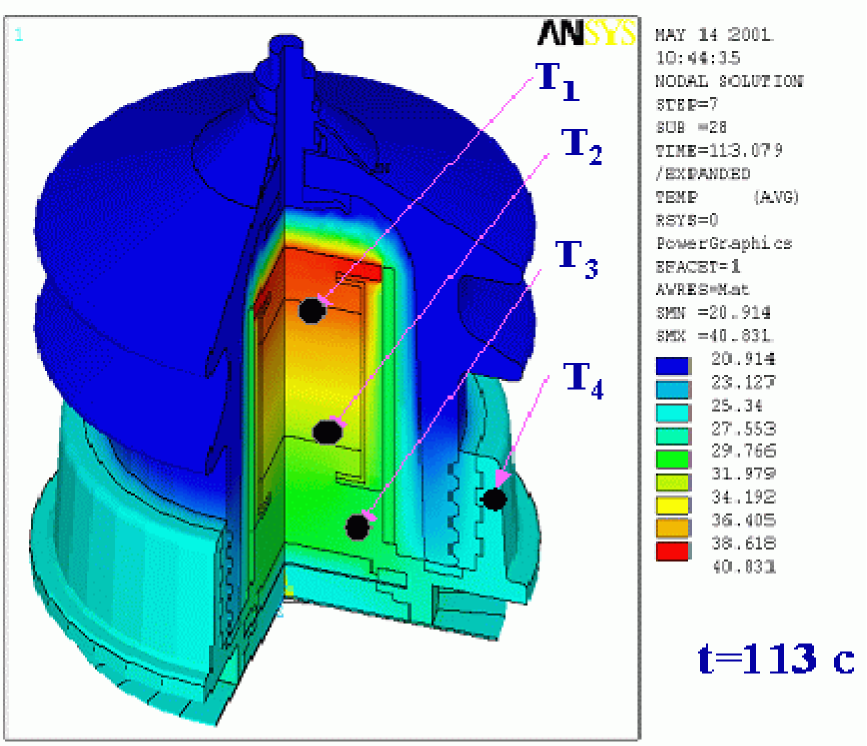

Figure 8 - Transient Field At Time Instant 113 S After First Impulse

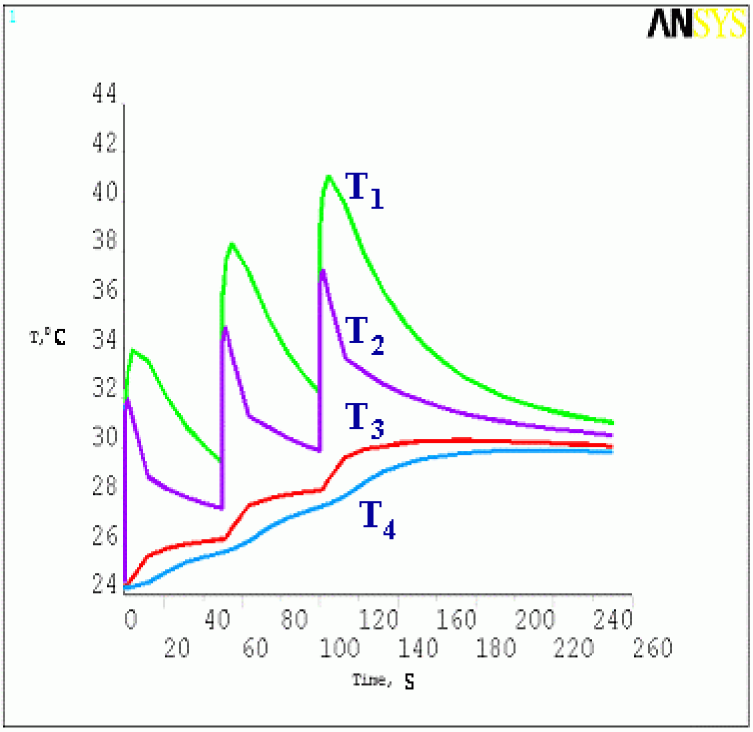

Figure 9 - Transient Field in the Four Points

Conclusion

Geometric and thermophysical OVS parameters affect substantially the stationary and non-stationary temperature distribution both in time and in space. Quasi-optimum choice of materials and design features was conducted with the aid of direct FE modeling of stationary and non-stationary temperature fields. The use of the ANSYS system allowed us to analyze thermal conditions of complex multicomponent systems such as up-to-date overvoltage suppressors. This provides the basis for the optimization of their construction at the design stage. The results of FE modeling yielded the recommendations for the improvement of the heat exchange at the upper part of the apparatus. For example for meliorating heat exchange some aerial fields of the construction were completed by sand. The examined transient temperature fields were used as external actions in the problem of the thermal stresses of the construction.

References

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