Abstract of the Ph.D. thesis of Ioannis F. Gonos

"Transient behaviour of grounding systems"

The aim of this Ph.D. thesis is the study and the investigation of the transient behaviour of grounding systems. The Ph.D. thesis includes the review of the relative bibliography of grounding systems, the description and the elaboration of the experiments and the analysis of the experimental results, the circuital and field approach of grounding systems and conclusions or assumptions about the influence of different parameters (layout of the grounding system, quality of the soil, waveform and peak value of the injected current) on the transient behaviour of grounding systems.

The first chapter of the Ph.D. thesis includes the review of the up-to-date scientific research bibliography, associated with the transient behaviour of grounding systems. The papers are grouped in this review, according to their content, as follows: a) the steady state b) the transient state, c) the resistivity and multi-layer structure of the ground, d) the ionisation of the soil and e) the methodologies of simulation of grounding systems.

The experimental arrangements and the methods of tests and measurements, which have been used in the present thesis, are in detail described in its second chapter. These arrangements are used for the experimental study of a) the transient behaviour of grounding systems, b) the soil ionisation and c) the soil resistivity and the grounding resistance.

The third chapter includes the presentation and the investigation of the experimental results and the arisen conclusions. The used experimental approaches (experiments in scale model, experiments in real grounding systems and experiments studying the soil ionisation) have essentially contributed in the elaboration, the inference and the verification of the suppositions of the present study. This verification is also proved through the convergence between experimental and computed (using the circuital and field approach) results of this Ph.D. thesis.

The fourth chapter presents several simulation methods (circuital and field approach) of the transient behaviour of grounding systems and comparisons between the experimental and simulation results of this work, with relevant results of other researchers. The chapter also presents a proposed methodology, which uses a developed genetic algorithm (GA) for the calculation of the parameters of the multi-layer structure of the ground. In the end, a method of Monte-Carlo simulation is applied, which evaluates the grounding resistance of towers of a transmission line.

The conclusions are summarized in the fifth chapter, showing clearly the contribution of the present study in the research of the transient behaviour of grounding systems.

- When a grounding system has to be installed, the knowledge of the ground structure in the given location is compulsory. The parameters of the ground structure are the necessary data for the circuital or the field simulations of the grounding systems. The measurements of the soil resistivity, which have been carried out, have shown that the ground has to be simulated as a (at least) two-layer structure. It is, also, clear that the value of the soil resistivity is changing during the year reaching its maximum value in the summer months. The calculation of the parameters of the multi-layer structure of the ground is transformed to a problem of minimization; a methodology is proposed in this Ph.D. thesis, based on a GA, which calculates the parameters of the multi-layer structure of the ground, using the measurements of the soil resistivity. The effectiveness of the GA, which is developed in this Ph.D. thesis, is proved by

comparing the results of the GA to the results of other researchers. The conclusion of this comparison is that the application of the GA for the computation of the parameters of the ground structure gives more accurate results than other published methods. Hence, using the suggested methodology, it is possible to calculate accurately the parameters of the multi-layer ground, which will compose the essential input data for the simulation of the behaviour of the grounding system that will be installed in this ground.

- A methodology is proposed for the calculation of the parameters of the π-nominal circuit, to make possible the circuital simulation of every grounding system. This methodology has been applied for the calculation of the transient ground potential rise and of the transient impedance of different grounding systems. The influence of the problem parameters has been studied using different waveforms of the injected current and varying the ground resistivity; the merit and the convenience of this methodology for the calculation of the parameters of the π-nominal circuits has been proved. The effectiveness of the approach has been verified, by comparing the results of the circuital simulation, using the program EMTDC, with: a) the own experimental results presented in this Ph.D. thesis and b) the experimental and simulation results of other researchers.
- The field simulation has been carried out using the PC Opera package. The developed methodology allows, in case of a known ground structure, the efficient simulation of the system and the accurate calculation of the potential on the surface of the ground. The advantage of this program is that it can be used in every grounding system, while the use of the equations of multi-layer analysis is limited only to point or vertical electrodes. The advantage of the simulation can be estimated by comparing the results of the field analysis, using the PC Opera package, with the results of other methodologies. From this comparison, it is concluded that the PC Opera can be a useful tool in the simulation of grounding systems and in the accurate calculation of the potential on the surface of the ground, where the grounding system is installed.
- The variation of the rate of the critical ionisation gradients versus the rate of the resistivities (wet/dry soil) has been studied in the experiments, which have been carried out to study the soil ionisation for different kinds of soil and for different resistivies. It has to be noticed that the decrease rate of the ratio of the critical ionisation gradients is substantial, as it is expected, but less than the decrease rate of the ratio of the soil resistivities. A comparison has been, also, carried out with relevant experimental results of other researchers for different kinds of soils. The results of this comparison were quite satisfactory. It was ascertained that the critical ionisation gradient for wet soil decreases to the 35% of the corresponding value for dry soil. The majority of the values of critical ionisation gradient for different kinds of soil are in the interval between 600kV/m and 1000kV/m. This range of values has been also used by other researchers, with the estimation that in the wet soil the critical ionisation gradient seems to be half of the corresponding value in the dry soil; it results to an estimation of a critical ionisation gradient in the range of 300kV/m. The ascertainment, which has been made in this thesis (decrease to 35%), is a useful knowledge for the accurate estimation of the critical ionisation gradient that can decrease to values of 200kV/m.

The references used and the indispensable appendixes are presented in the end of this thesis.

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