TECHNICAL UNIVERSITY – SOFIA
Department Theoretical Electrical Engineering

10TH SUMMER SCHOOL

ADVANCED ASPECTS OF THEORETICAL ELECTRICAL ENGINEERING

Sozopol'14

PROCEEDINGS

Edited by: Valeri Mladenov
Snejana Terzieva

in the framework of

DAYS OF SCIENCE
OF THE TECHNICAL UNIVERSITY OF SOFIA

Sozopol'14, BULGARIA, 19-22.IX.2014

ORGANIZATION

The Summer School is organized by the Department of Theoretical Electrical Engineering at the Technical University of Sofia in the framework of the "Days of Science of the Technical University of Sofia", Sozopol, Bulgaria, September 2014

TECHNICAL UNIVERSITY OF SOFIA, BULGARIA

under the patronage of the INTERNATIONAL SYMPOSIUM ON THEORETICAL ELECTRICAL ENGINEERING (ISTET) and it is a regular ISTET event

INTERNATIONAL SYMPOSIUM ON THEORETICAL ELECTRICAL ENGINEERING (ISTET)

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PREFACE

These Proceedings contains the plenary lectures and the regular papers presented at the *10th* Summer School *Sozopol'14*, which took place in Sozopol, Bulgaria, between *19* and *22 Sept*. 2014 in the framework of the "Days of the Science of the Technical University of Sofia". The Summer School covers the advanced aspects of Theoretical Electrical Engineering and it is a platform for postgraduate training of Ph.D. students and young scientists. During the Summer School well-known experts presented some advanced aspects of circuits and systems theory, electromagnetic field theory and their applications. Apart from the educational part of the Summer School a presentation of original authors' papers took place.

The main topics of the Summer School *Sozopol'14* include Circuits and Systems Theory and Applications, Signal Processing and Identification Aspects, Electromagnetic Fields, Theoretical Concepts, Applications and New Approaches in Educating Theoretical Electrical Engineering. The Summer School *Sozopol'14* has been organized by the Department of Theoretical Electrical Engineering of the Technical University of Sofia with the main sponsorship of the Research and Development Sector of the Technical University of Sofia.

This has been the tenth edition of the event, after the Summer Schools in 1986, 1988, 2001, 2002, 2005, 2007, 2009, 2010 and 2012. The Summer School is under the patronage of the International Symposium on Theoretical Electrical Engineering (ISTET) and it is a regular ISTET event. There were 35 participants at the Summer School this year. There were 6 plenary lectures and 23 regular papers that are published in these Proceedings. Providing the recent advances in Theoretical Electrical Engineering the Proceedings will be of interest to all researchers, educators and Ph.D students in the area of Electrical Engineering.

Special thanks are due to the Research and Development Sector, Faculty of Automation and the Section of Social Services of the Technical University of Sofia about the overall support of the event. We also would like to thank to the IEEE Bulgaria CAS Chapter and the World Scientific and Engineering Academy and Society (WSEAS), which also partially sponsored the event. We hope to meet again in the following edition of the Summer School to continue the good tradition and collaboration in the field of Theoretical Electrical Engineering.

Organizing Committee
Sofia, October 2014

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CAD SYSTEMS IN ELECTROMAGNETICS

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Abstract: *The main purpose of the paper is to review some of the most popular CAD systems in electromagnetics, to explain their most common features and to present solved examples with some of these systems. The common features of the CAD systems are considered and the most important among them are outlined and discussed in details. It is shown, that the optimization module is nearly obligatory in the modern CAD systems for electromagnetics. Several solved examples are presented from the fields of electrical machines, transformers, coupled coils, NDT devices, sensors for ECT, busbar systems and electromagnets, using mostly the MagNet, ElecNet and FEMM CAD systems. Conclusions are drawn about the applicability, the teaching and the future of these systems in the engineering work.*

Keywords: *CAD system, electromagnetics, optimization*

1. INTRODUCTION

The field of computational electromagnetics has undergone a big change in the last 20 years. The use of computers in the analysis, design, optimization, testing and production of electromagnetic systems has become a usual practice. The result is a substantial increase in productivity and efficiency of the engineering work. The great impetus for this is the progress being made in the computer hardware. The modern PCs show impressing power with CPU speeds reaching 3.5 GHz, operating memory of 4-8 GB, hard disk storage of 1÷2 TB, and every year these parameters get an increase of 20-30 %. The second stimulating factor is the advances in computational algorithms for electromagnetics, especially for realistic 3D geometric modeling, analyses and visualization. The contemporary CAD (Computer Aided Design) systems unify all these advances and provide a suitable user interface that helps the engineer to enter his design problem in a graphic way and to perform the electromagnetic analysis without having proficiency in numerical and computational methods. From the state of systems for analysis, shown some 15 years ago, the CAD systems have grown to systems for optimization and design with sophisticated intelligence and database management functionality.

The computer simulation of electromagnetic devices is now predominant in the engineering practice, as well as in the scientific computing. Nowadays, very few electromagnetic devices are built without some kind of design on computers. The expensive physical prototyping of these devices in many cases has been replaced by numerical modeling and optimization by using a suitable CAD system. This saves money, time, expensive work, and as a whole, diminishes the development expenses and results in improved characteristics and more competitive production.

A CAD system is a graphically based information system supporting the engineering work in the design and modeling of real world objects. It gives possibilities for building 2D and 3D graphic models, as well as animations – 4D graphic models, analogous to the real objects. As an additional feature, a CAD system gives opportunity for team work over complex models.

Another popular notion is CAE - abbreviation of "Computer-Aided Engineering". CAE programs analyze the engineering designs, usually by the Finite Element Method (FEM). In electromagnetics, the notion CAD usually embraces the characteristics of CAE systems, as most of the CAD systems here include the finite element method for analysis of electromagnetic field.

The popular CAD systems are usually commercial products. Rarely full-featured CAD systems can be found as freeware, as they require a lot of development efforts and a long history in programming, testing, verifying and improving, that cannot be achieved by a small team of developers.

A typical CAD system for electromagnetics consists of (Fig. 1):

- Geometry definition module – assists the user to create geometric shapes by user specified solid modeling commands;
- Mesh generation module – generates automatically an optimal finite element mesh;
- Finite element analysis module – creates and solves the FEM system of equations;
- Post-processing module – creates field pictures (equipotential lines, color plots of gradients, arrow plots) and computes integral characteristics like energy, inductance, capacitance, force, torque, etc.

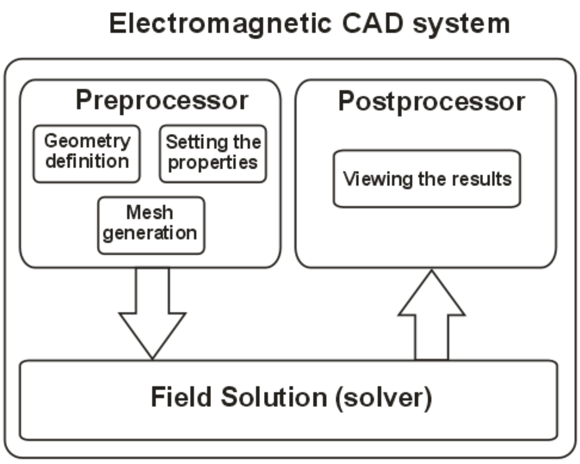

Fig.1. Main structure of a CAD system

The information in the CAD systems must be generated, used and improved for a long time - for the whole life-cycle of the product, and for new generations of software and hardware. Thus, standards are necessary for data exchange among the different CAD systems and their generations in the time. The popular standards for data exchange for CAD systems are DXF, ACIS, SAT, DWF, STEP (ISO 10303), etc.

The main purpose of this paper is to review some of the most popular CAD systems in electromagnetics and to explain their most popular features and possibilities. Next, some critical analysis will be made and the trends and common features in the CAD systems will be emphasized. At the end of the paper some example models will be shown, created by the author.

2. REVIEW OF SOME POPULAR CAD SYSTEMS

2.1. MagNet /ElecNet/ ThermNet/OptiNet (Infolytica Corp.)

Infolytica Corp. [1] has developed a suite of 2D &3D finite element CAD systems for analysis and optimization of magnetic, electric, electromagnetic and thermal fields in electromagnetic devices. The suite consists of:

- MagNet - 2D & 3D Electromagnetic Fields Simulation Software
- ElecNet - 2D & 3D Electric Fields Simulation Software
- ThermNet - 2D & 3D Thermal Simulation Software
- OptiNet – software for continuous and discrete optimization

MagNet can analyze static magnetic fields, time-harmonic electromagnetic fields, and transient fields. The effects of motion for multiple moving components and for arbitrary motion directions can be analyzed also.

ElecNet can analyze static electric fields, static current densities produced by specified DC voltages in conducting material, electric fields produced by specified AC voltages at one frequency in the complex domain, transient electric fields produced by specified voltages that vary arbitrarily in time.

ThermNet can analyze static and transient thermal fields due to conduction, convection & radiation. Both simulation types can be coupled to static or time-harmonic solutions in MagNet.

OptiNet is a tool for optimizing a design based on electromagnetic, electric field and thermal solutions with continuous-valued and discrete-valued variables. OptiNet features evolutionary strategy for finding optimized solutions. Built-in and customizable scripts for the objective functions and constraints are provided. OptiNet works with MagNet, ElecNet, ThermNet & coupled MagNet-ThermNet solutions.

ACIS solid modeler is common for all packages.

Mesh generation can be automatic or user-defined. Automatic mesh adaption tools and higher order elements are available.

All systems have easy importing and exporting of SAT and DXF files; optional modules for CATIA, STEP, IGES, Pro/E and Inventor file Import / export can be obtained.

MagNet also has Circuit modeler for connecting devices to circuit-simulated drives and loads. It is useful for power electronics devices and electric machines.

ElecNet also has modeling of floating conductors, automatic calculation of the resistance and capacitance matrices of electrodes, modeling of thin resistive sheets and surface charges.

Powerful parameterization capabilities are available. Scripting tools (using Visual Basic) help to automate repetitive tasks, customize settings and link all packages.

The Post Processing includes field visualizations - field plots, graphs and animations of time-varying or multi-step problems; data and image exporting. Integral quantities are also computed and exported – inductances, capacitances, impedances, power, power losses, forces and torques.

Drawbacks of the Infolytica packages are: all packages solve low-frequency electromagnetic problems (till several MHz). The packages are not easy to learn, require considerable experience.

2.2. COMSOL

COMSOL [2] is a powerful, interactive environment, developed by COMSOL Corp, for modeling and solving scientific and engineering problems based on partial differential equations.

COMSOL solves a system of partial differential equations (PDE) by the finite element method (FEM) with adaptive meshing and error control. It is possible to set up models as stationary or time-dependent, linear or nonlinear, scalar or multi-component. The package also performs eigenfrequency or eigenmode analyses.

COMSOL has several discipline-specific application modules. These are the Chemical Engineering Module, the Electromagnetics Module, the Structural Mechanics Module, Earth Science, Heat Transfer, and MEMS (Micro ElectroMechanical Systems) Modules.

The Electromagnetics Module covers a broad range of application areas spanning from the static and low-frequency range to very high-frequency phenomena such as optics and photonics.

COMSOL provides powerful CAD tools for creating 1D, 2D, and 3D geometry objects, where Boolean operations (union, subtraction, intersection, etc.) are used for creating composite solid models. Objects created by other modeling software can be imported and used in COMSOL models. The geometry import uses IGES files in 3D and DXF files in 2D.

The triangular- or tetrahedral-shaped unstructured mesh is automatically created by the mesh generator. Adaptive meshing is available.

COMSOL also features a parameterization, which offers a way to examine a parameterized series of models. The varied parameter typically represents a material property or frequency.

COMSOL has equation-based modeling application modes - the PDE Modes. They allow to define own systems of partial differential equations. In the COMSOL GUI, dialogue boxes are provided where equations can be entered in a symbolic way, similar to writing equations by hand. COMSOL can interpret these expressions and arrange the equations so that they can be solved by the FEM.

COMSOL allows to couple physics defined by predefined application modes. The PDE mode can also be used for coupling between systems involving any arbitrary physical description of a phenomenon.

COMSOL is based on MATLAB and allows manipulating model data and the models themselves in the MATLAB environment.

COMSOL features a built-in post-processing tool for direct manipulation and visualization of the results. It provides extensive visualization and post-processing capabilities, including: Interactive plotting of any function of the modeled variables and its derivatives; visualization using slices, isosurfaces, contours, streamlines, vector-field plots, animations, integration along boundaries and sub-domains, cross-sectional plots.

Drawback of COMSOL is the comparatively slow solution of big problems.

2.3. ANSYS Maxwell

ANSYS Maxwell [3] is electromagnetic field simulation software for designing and analyzing 2-D and 3-D electromagnetic and electromechanical devices, including motors, actuators, transformers, sensors and coils. Maxwell uses the finite element method to solve static, frequency-domain, and time-varying electromagnetic and electric fields. Maxwell automatically generates an appropriate and accurate mesh for solving the problem.

A key feature in ANSYS Maxwell is the ability to generate reduced-order models from the finite-element solution for use in ANSYS Simplorer, the multi-domain system simulation software from ANSYS. This capability enables to combine complex circuits with accurate component models from Maxwell to design complete high-performance electromechanical or power electronic systems.

2.4. Flux 2D & Flux 3D / Flux Studio

Flux 2D/3D [4] is a finite element software application used for electromagnetic and thermal physics simulations, both in 2D and 3D.

Flux is featuring a large number of functionalities, including extended multi-parametric analysis, advanced electrical circuit coupling and kinematic coupling. It can analyze:

- Magnetic, electric and thermal fields
- Magnetic/electric/thermal coupling
- Mechanical coupling
- Multi-physics coupling
- Static, harmonic and transient analysis
- Parameterized analysis
- External circuit connections

Flux is suitable for designing, analyzing and optimizing a variety of devices and applications such as rotating machines, linear actuators, transformers, induction heating devices, sensors, HV devices, cables, nondestructive evaluation.

2.5. Integrated Engineering Software (IES)

The software package IES [5] includes AMPERES 3D, COULOMB 3D, FARADAY 3D programmes. It performs analysis of magnetostatic, electrostatic and time-harmonic fields. The main computational method is the Boundary Element Method (BEM). The package has additional possibility for finite element analysis and hybrid BEM-FEM modeling.

2.6. QuickField 5.10

QuickField [6] is a commercial CAD system mainly for 2D FEA. It solves electromagnetic, thermal and mechanical problems. It has simplified interface and is comparatively cheap and suitable for teaching use. Since version 6.0, it supports also 3D electrostatic analysis.

2.7. FEMM 4.2

FEMM 4.2 [7] is a free software package based on finite element method. It performs 2D FEM analysis of magnetostatic, electrostatic, time-harmonic and thermal fields. It has simplified graphical user interface and is very easy to use. It is very easy to learn, very popular in the universities, very suitable for teaching electromagnetics, electrical machines, and electrical apparatus. Its drawbacks are: 1) developed only for 2D FEA; 2) lacks transient analysis.

2.8. CST Studio Suite

CST Studio Suite [8] offers 3D simulations of electromagnetic devices for low-frequency and high-frequency applications. It has intuitive graphical user interface and variety of available solvers. Its strength however is in the high-frequency simulations, where they have long years experience.

The products in the CST STUDIO SUITE® family can carry out electro- and magnetostatic, stationary, low-frequency and high-frequency simulations, as well as calculate the effects of EM fields on magnetic materials, biological tissues and charged particles. Main fields of applications:

- Statics/Low Frequency (CST EM STUDIO)
- Microwave & RF/ Optical (CST MICROWAVE STUDIO)
- EDA/Electronics (CST DESIGN STUDIO)
- Particle Dynamics (CST PARTICLE STUDIO)
- EMS/EMI (CST CABLE STUDIO)

For each field, CST STUDIO SUITE contains tools for designing, simulating and optimizing devices and systems.

The built-in optimizers in all CST STUDIO SUITE modules can be used to optimize any parameter, including the geometry of the model, the properties of the materials and the waveform of the excitation.

CST STUDIO SUITE includes both local and global optimizers. Local optimizers search the parameter space close to the initial values – they offer fast performance for fine tuning a nearly optimal model. Global optimizers on the other hand search the entire parameter space, and are more efficient than local techniques for poorly tuned or complex structures.

2.9. Opera v.16

Opera v. 16 [9] offers 2D and 3D finite element analysis and optimization of electromagnetic devices. It is functionally similar to MagNet/ElecNet, but also has high-frequency module. Opera is a software package for modeling of static and time-varying electromagnetic fields and related multiphysics.

It consists of a powerful 2D/3D modeler for creating design models (or importing from CAD), plus a choice of specialized finite element simulation tools:

- Static electromagnetic fields (‘Tosca’ tool)
- Low-frequency time-varying electromagnetic fields
- High frequency time-varying electromagnetic fields
- Thermal and stress analysis (standalone or coupled)

It is very suitable for:

- Linear and rotating machinery design
- Superconducting magnet quenching
- Particle beams including space charge effects
- Permanent magnet magnetization/demagnetization
- Hysteresis in soft magnetic materials
- Electric field analysis in conducting-dielectric media

After the simulation, a programmable interactive post-processor allows users to view and analyze the simulation results, and performs additional calculations. Model parameters may be changed to rapidly perform ‘what-if?’ investigations. The designs can be automatically improved with the aid of Opera’s Optimizer. Opera is available in 2D or 3D variants.

Main fields of application are:

- Power conversion and electromechanical devices (motors and generators, linear motors, actuators and position sensors, Simulink® co-simulation
- Power systems (losses and interference, insulation and grounding, components)
- Transportation (electromagnetic braking, railways, non-destructive testing)
- Medical physics and science applications (X-ray tubes, electron microscopy/lithography, MRI magnets, superconducting coils)

3. COMMON TRENDS IN THE DEVELOPMENT OF CAD SYSTEMS

The research done about the features of the most popular CAD systems for electromagnetics shows the following trends, which are de-facto standards for the present moment.

3.1. Geometry modeling

Most of the packages use solid modeling for 3D model creation. Parameterization is very common feature, nearly everywhere included. Modeling with geometric primitives and Boolean algebra allows creation of 3D models. Creating 3D models using translation and rotation of 2D cross-sections can be found also. Dimension parameterization is available in most commercial packages.

3.2. Generating the finite element mesh

Mesh generation is automatic, with mostly triangular and tetrahedral finite elements. Adaptively refined meshes, which get more refined in the regions with high gradients are also used in some CAD systems. Higher order elements (till 4-th order) to improve the accuracy, are also used. Bricks, prisms, and other elements, are rarely used. Edge elements are mainly used in 3D. Small number of packages uses BEM.

3.3. Types of analysis

The following types of analysis are mostly used:

- Magnetostatic field analysis
- Time-harmonic field analysis (with sinusoidal quantities)
- Electrostatic field analysis
- Electric fields in conducting media analysis
- Time-dependent (transient) electromagnetic field analysis
- Thermal field analysis – stationary and transient
- Coupled analysis: electromagnetic-thermal or electric-thermal fields.

3.4. Presentation of the results (postprocessing)

The postprocessing is presented usually with separate user interfaces for the different kinds of fields. It includes:

- Plotting of equipotential lines in 2D
- Plotting of color-coded field pictures representing potentials, gradients, errors, etc.
- 2D and 3D graphs of functions (distribution of potentials, magnetic flux density, field intensity, current density)
- Plots of field vectors in 2D and 3D.
- Creation of animation in AVI files

- Computation and output of forces, moments, inductances, capacitances, impedances, induced voltages.

Data output can be in MS Excel, MS Word, text files, etc.

3.5. Links with other CADs

This is done by the use of DXF, DWG, IGES, STEP file standards, for importing drawings, models, and exporting results.

3.6. Boundary conditions

Dirichlet, Neumann and mixed BC are common features; nearly all packages use periodic BC and also infinite elements for open boundary problem, in order to reduce the region analyzed and computational efforts.

3.7. Material libraries

All packages have material libraries containing widespread material data, which can be extended with user defined materials. The material data contain electric, magnetic, thermal, mechanical, etc. properties, including B-H curves. Loss curves of ferromagnetic materials are included also.

3.8. Connecting external circuit connections

Most of the solvers include external circuit coupling feature, together with schematic editor to support arbitrary topology of power-electronic drive circuits and winding connections in electric machines and transformers.

3.9. Solving the system of equations

Mostly iterative PCCG (Preconditioned Conjugate Gradient) solvers are used with sparse matrix storage. Parallel solvers for the FEM systems of equations are already offered for some CADs (ANSYS, CST) which can work on multi-core processors or clusters of computers.

Most of the CAD systems support both 32-bit and 64-bit platforms. The 64-bit versions of the software are used to address bigger memory and obtain higher computation speed.

Using graphic processing units (GPU) is also used to speed-up the computations (e.g., in CST).

3.10. Solving coupled problems

Nearly all electromagnetic CAD systems offer possibilities for solving coupled problems: eddy current+thermal; magnetic+mechanical, etc. - very important feature for solving real-world problems.

3.11. Linear and rotational motion

This feature enables to predict accurately the performance of motors and actuators at different transient conditions, where motion effects are important.

Taking into account of the motion gives better prediction of the characteristics of:

- Linear and rotating electric machines
- Electromagnetic actuators, in which the motion effects in transient analysis are important

3.12. Programming the work of the CAD system

In many CAD systems there exists built-in programming language, which allows a sequence of commands to be created for building and analyzing the model. This feature is useful for:

- Automatic model creation at different input data
- Variant calculations in optimization
- Automatic log of the command sequence at interactive work with the CAD system

Examples of languages used:

MagNet uses Visual Basic Script language;
COMSOL uses MATLAB language;
FEMM uses LUA language;
ANSYS uses APDL, similar to Fortran language.

3.13. Optimization

This capability /Fig. 2/ is included in most of the commercial CAD systems. Very often evolutionary algorithms are used for their ability to find the global optimum and for the lack of derivative computations. The Design of the Experiment (DOE) is also used in some packages /Fig. 3/, to create simplified polynomial models (e.g., in MagNet, in ANSYS). This can decrease considerably the optimization time, especially for 3D models.

The optimization module represents a module included or added in most of the popular CAD systems (e.g., MagNet/ElecNet uses external OptiNet software; COMSOL, ANSYS, OPERA have included optimization module).

3.14. Using parallel computations

The parallel computations can be used effectively in the following cases:

1. Using cluster of computers to solve a problem too big to be solved with one computer.

2. Distributing a large number of independent simulations, that arises in parametric study, to be solved on several computers in parallel.

The independent simulations can come from:

- Optimization problem solved by genetic/evolutionary algorithms
- Computing the variants arising in the DOE application
- Computing the variants for neural network training

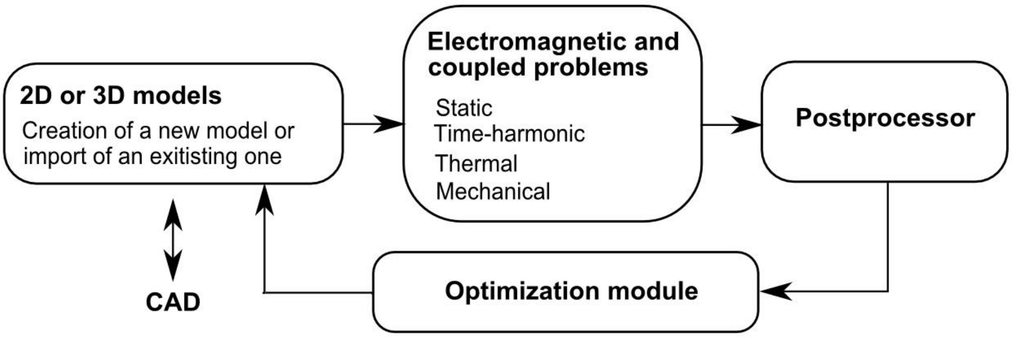

Fig. 2. Flow-chart of CAD system with optimization module

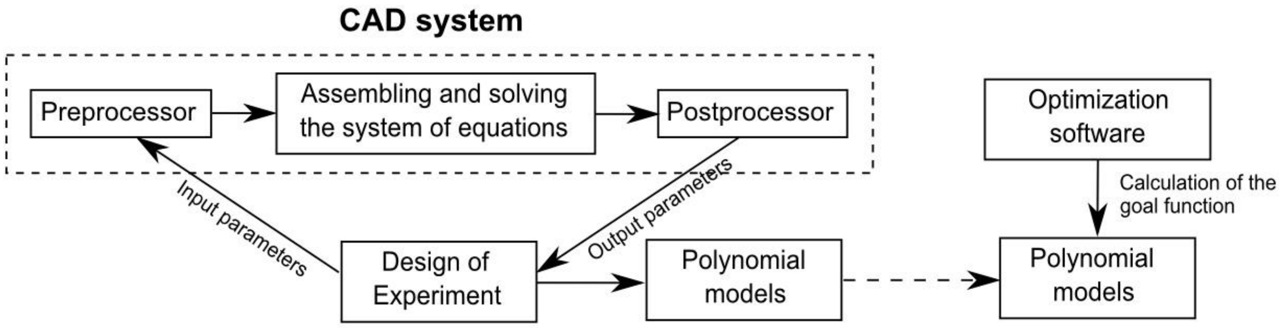

Fig. 3. Flow-chart of DOE in combination with CAD system for optimization

Types of parallel computations used:

- Multithreading - It is used for multi-core processors and multiprocessor systems. It is offered in most of the modern CAD systems...
- Parallel computations using graphic processor units (GPU) – These are used on GPUs like NVIDIA® Tesla, representing additional external modules to the usual workstations. The CST CAD system offers such possibilities.
- Distributed computing - Can be used for independent simulations, which are performed on computer clusters.
- Parallel computations using MPI (Message Passing Interface) - A specialized computer cluster is required, having high computational speed and high-bandwidth connections between the computers. This is the only way to simulate very large models.
- Cloud computing - Offers cluster computing to users that do not own a cluster.

3.15. Availability of simplified free versions

Most of the developers of commercial CAD systems offer also free simplified versions of their software. These are intended mostly for initial acquaintance with the product, mainly intended for 2D magnetostatic and electrostatic simulations.

Some of these simplified free systems have limited number of elements in the created FEM mesh and can be used mainly in the teaching process.

3.16. Price policy and software support

The software prices depend on the desired analysis types, the solvers used, etc.

Usually there is a separate lower price for use in the teaching and in the research at universities. One-month testing period is usually offered for free testing of the full software versions. Usually, there exists one-year free support after the software purchase. Training courses are offered for beginner and advanced users.

Many developers organize dedicated scientific conferences for their users, where they present successful projects with the use of the software.

Availability of Internet site with useful information, examples, help and possibilities to download the software is a common practice.

4. EXAMPLE MODELS

In the following chapter some example models are be presented, developed by the author in the following fields: electric machines; NDT devices; ECT sensors; busbars; dipoles, quadrupoles, etc. The 3D geometrical models, equipotential lines and field vectors of the solution are shown. The MagNet, ElecNet and FEMM CAD systems are used in these examples.

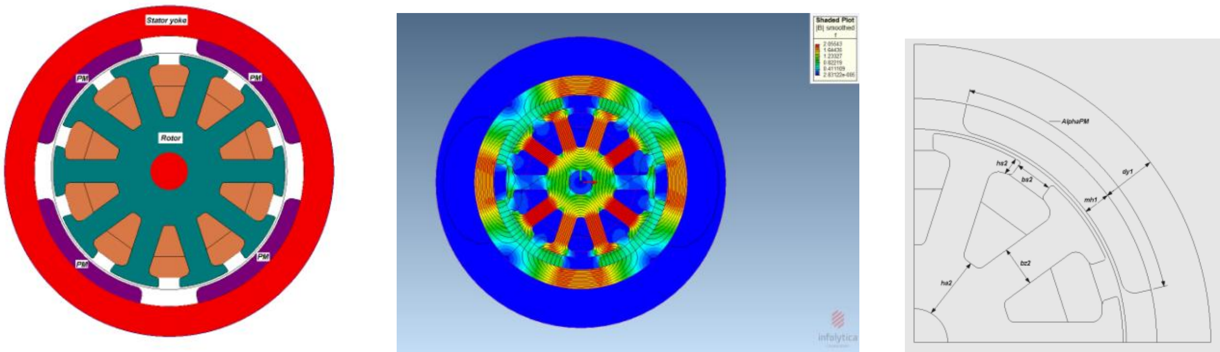

Fig. 4. 4-pole DC machine with permanent magnets

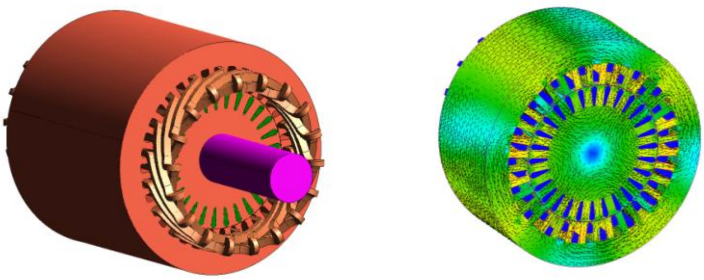

Fig. 5. Induction machine

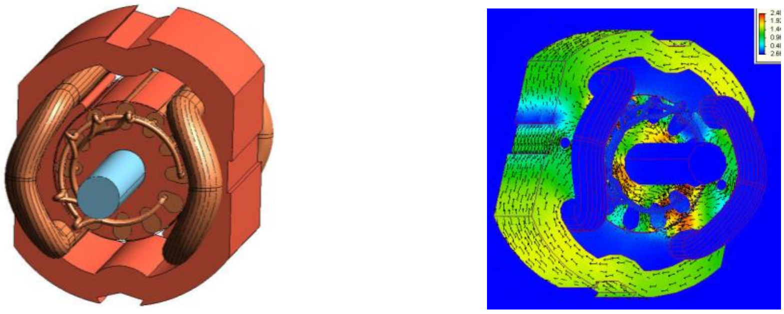

Fig. 6. Universal machine

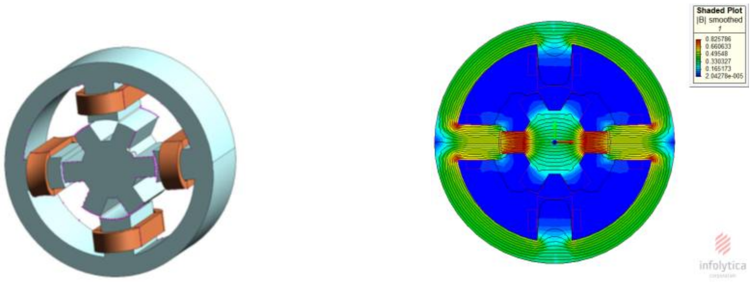

Fig. 7. SRM – Switched Reluctance Machine

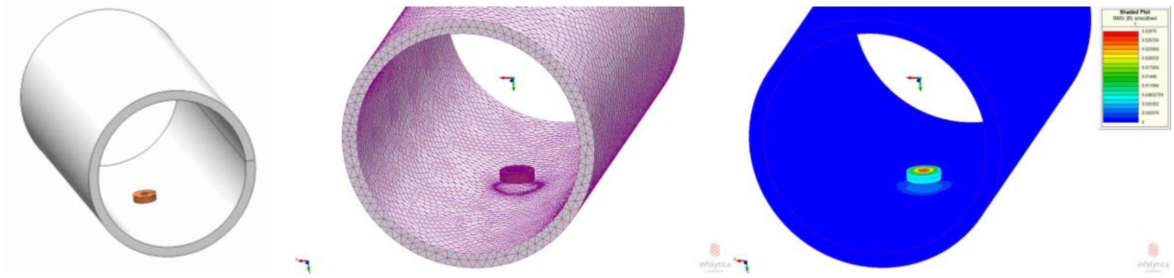

Fig. 8. Pipe and cylindrical NDT sensor

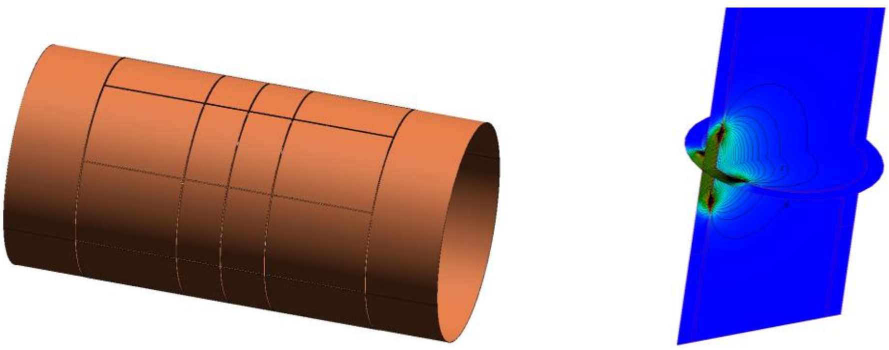

Fig. 9. 32-electrode 4-layer ECT sensor with rectangular electrodes

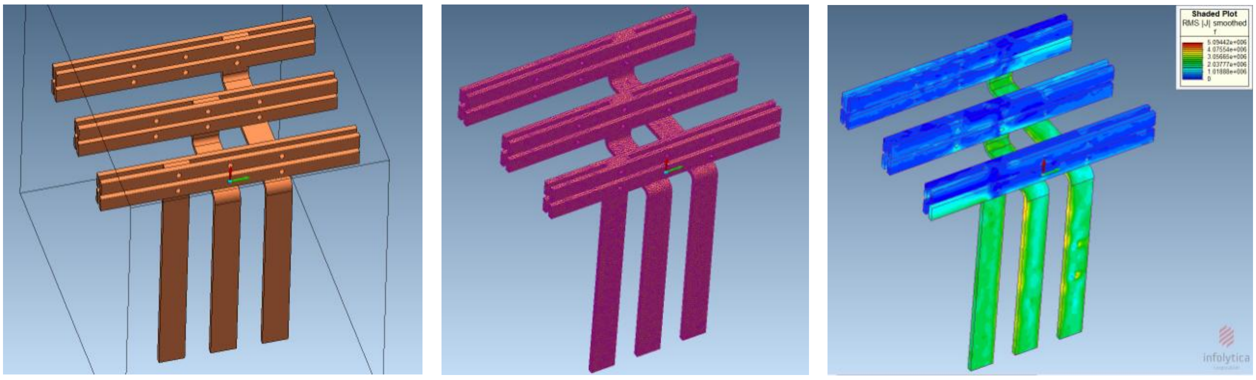

Fig. 10. 3-phase busbar system

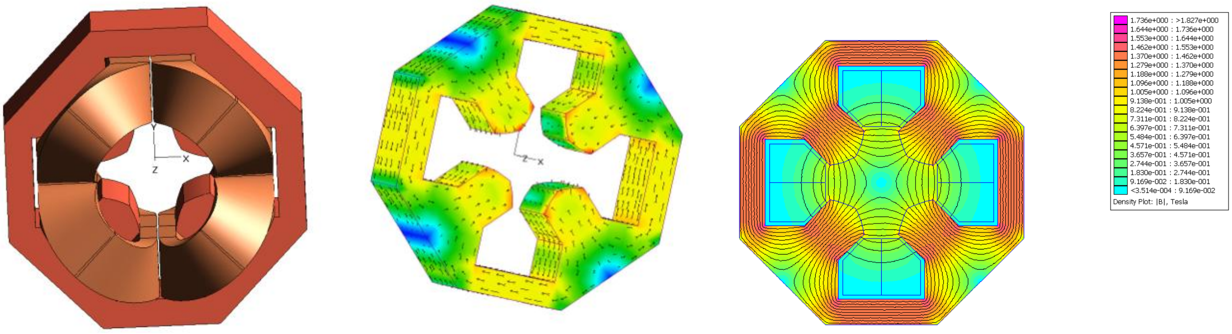

Fig. 11. Quadrupole focusing electromagnet

5. CONCLUSIONS

The CAD systems for electromagnetic calculation are coming in broadly in the engineering work and can be found in every company. So, it is increasingly important for the electrical engineers to get good knowledge of these systems, which makes a necessity their study at the universities. The pedagogical issues of teaching CAD systems in electromagnetics have to be discussed more deeply.

Besides the industrial use, the CAD systems could be used effectively for illustration of topics studied in the courses of Electromagnetics, Electric Machines, Electric apparatus, etc., in most of the universities.

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[5] IES: http://www.integratedsoft.com/
[6] QuickField: http://www.quickfield.com/
[7] FEMM: http://www.femm.info/wiki/HomePage
[8] CST Studio Suite®: https://www.cst.com/
[9] Opera: http://operafea.com/

Reviewer: Prof. DSc R. Stancheva

CREATING QUIZ QUESTIONS TESTS ON THEORY OF ELECTRICAL ENGINEERING WITH QUIZCREATOR

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Abstract: *Test form of examination is a regular way for assessing the acquired knowledge as a result of the teaching process of the students. To some extend it will take part in the final rate but to what exactly degree it depends on the studying subject. For example in Theory of Electrical Engineering the result from a quiz questions test should to join with 60 % in forming the final rate for the students, because the result from the exam have to contain points from others components as control tests during the tutorials, implementing the labs and self-solving course assessments. It determines of the physical nature of the studying discipline. In the paper are described in details the abilities and specifically features of the QuizCreator for creating different types quiz questions. It is suggested an example variants of test for discipline Theory of Electrical Engineering which includes all types of quiz questions defined in the software product.*

Key words: *quiz questions – true/false; multiple choice, multiple response; fill in the blank; matching; sequence; click map; word bank; short essay; blank page, Theory of Electrical Engineering*

1. INTRODUCTION

Nowadays the test form of examination is one of the most popular ways for examination the earning knowledge in the learning process of the students. It is in fact because it has a number of advantages as:

1. The global test can range over a large number of subjects in the studying discipline.
2. The answer of each question gives as a conclusion of detail acquainting with the respective considered problem which sometimes requires applying deductive rules and principles for making final decision.
3. Quiz question testing stimulate the human's thinking and eliminate the possibility of learning by head of the material or cheating from the students during the exam.
4. Test form of examination absolutely eliminates subjective factor (as a human's dialog) during the checking the students' knowledge.

Maybe one of the main disadvantages of the testing is the necessary of making different variant for each examined student and changing the variants every time. This will ensure maximally adequate final rate of the students' knowledge and it will eliminate (or decrease to minimum) the possibility for learning by head the answers of test questions or cheating during the exam.

When it creates the testing form of examination the types of quiz questions depends on the nature of studying discipline. For example usually it uses *short essay* questions if the exam is on the humanities as literature, history, psychology, geography and etc. [1]. If the tests are on math it is sufficient to construct quiz questions on types: *true/false; multiple choice; multiple response; fill in the blank; matching; sequence; click map; word bank* [2]. In case of the testing is on physics [3], chemistry [4], theory of electrical engineering [5] or other similar engineering discipline it is necessary to add *short essay* questions, when to describe the essence of the particular method or algorithm for analysis the specific considered problem. Always as an addition benefit of the test is using the *blank page* questions where on the blind page a student can explain on own the considered problem.

Taking in mind the specific character of the courses on Theory of Electrical Engineering the final rate of the students can be formed in the following way: 60 % of the points from quiz question test; 15 % - from the control tests during the tutorials; 15 % - from the self-solving course assessments during the semester and 10 % - from implementing the labs and generalizing the results in the protocols.

The final rate will be finalized as follows:

- 0 – 50 % - weak (2)
- 51 – 65 % - satisfactory (3)
- 66 – 80 % - good (4)
- 81 – 90 % - very good (5)
- 91 – 100 % - excellent (6)

This evaluation scheme has a high degree for adequacy of the final rate to the earning knowledge on the discipline, because the quiz question test takes parts there with 60 % which is sufficient for passing the exam.

The preset paper is organized as follows. It begins with introduction connected with giving an account of the advantages and disadvantages of test examinations based on quiz questions. In the second section are described specifically features of the software QuizCreator which uses for creating the quiz questions tests. The possible types of questions which can be generated by QuizCreator are written up in details in the next section 3. Next, all possibilities of QuizCreator for creating the quiz questions tests are illustrated on the test of the Theory of Electrical Engineering. The paper finished with conclusion remarks about advantages and disadvantages for generating quiz questions test in the discipline Theory of Electrical Engineering.

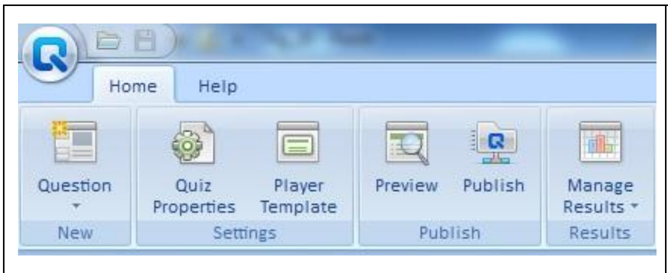
2. SPECIFICAL FEATURES OF QUIZCREATOR

Software QuizCreator 4.5.1 of Wondershare is intended for creating quiz questions tests. It can generate quizzes in Word or Excel as well as to import data from Word and Excel (Fig. 1). The tests can be created either with this product as an .exe files or uploaded in Internet and solved online.

Fig. 1. Initial window of QuizCreator

Main functions of the software for generating the quiz questions are shown on the menu from Fig. 2a. They are following:

- Construct a new question – text + right answer(s).
- Set up the properties of the creating quiz question.
- Choice the desired template for the background of the question.
- Preview either the question or the entire test.
- Publish the ready test in .wqc or .exe file.
- Manage the results from full test – online or by e-mail if the test is upload in Internet.



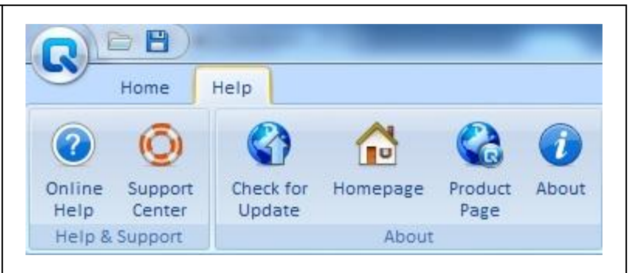


Fig. 2a. Workspace of QuizCreator

Fig. 2b. Help of QuizCreator

Help functions of QuizCreator are shown on the menu of Fig. 2b, where user can get online help of the product; update it to new versions; product page and information about the current version and the company - producer the software.

3. TYPES OF QUESTIONS GENERATING BY QUIZCREATOR

QuizCreator is testing tool for defining the different types of quiz questions (see Fig. 3). Each type gives an opportunity of checking the earned knowledge in different scientific areas. Also it enables to evaluate the same matter from different points of view.

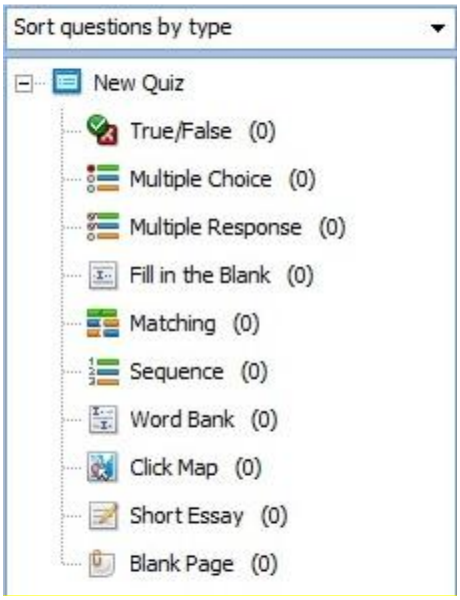


Fig. 3. Workspace od QuizCreator

- *True/False* question – the result is only “True” or “False.
- *Multiple Choice* question – in this situation it have to choose only one right answer from given multiple choices.
- *Multiple Response* question – here it can choice more than one right answer from given multiple choices.
- *Fill in the Blank* question – in this question it has to fill a missing word or phrase in the respective sentence.
- *Matching* question – the user have to match the phrases from the left side with the associated phrases from the right side.
- *Sequence* question – the separately phrases have to order in right sentence.
- *Word Bank* question – previously defined word or phrase have to fill on the right places in the respective sentences so that the latters to get the semantic meaning.
- *Click Map* question – in this situation it has to click the right parts on preliminary defined map.
- *Short essay* question – the answer of this question has to be presented as essay. This type of questions uses when it is necessary to give the definitions of some base quantities – constants or variables.
- *Blank Page* question – it is unrestricted form for presentation of the learning on the respective area, where the user can expose either shorter or longer (of his/her own choice) his earned knowledge.

4. ILLUSTRATIVE EXAMPLE OF QUIZ QUESTIONS TEST ON THEORY OF ELECTRICAL ENGINEERING

Theory of Electrical Engineering is a fundamental discipline from the bachelor's course of the students. The studied matter is the closest to the physics because on one side it has theoretical bases but the other – they confirms of the experiments. Then in this case the theory and the practice go hand-in-hand. When creates test on this discipline it can be applied almost all possible types of questions in QuizCreator - *True/False*, *Multiple Choice*, *Multiple Response*, *Short essay*, *Fill in the Blank*, *Matching*, *Sequence* and *Word Bank*. *Click Map* question is not appropriate in this situation. *Blank Page* can be used as a question (out of the test), where the students will have to describe in details the main steps of some algorithm for analysis of the electric circuit for example. It will be taken with 25 % from the total points forming the final rate (which will be maximum 100 %). An illustrative example of quiz questions test on Theory of Electrical Engineering is following:

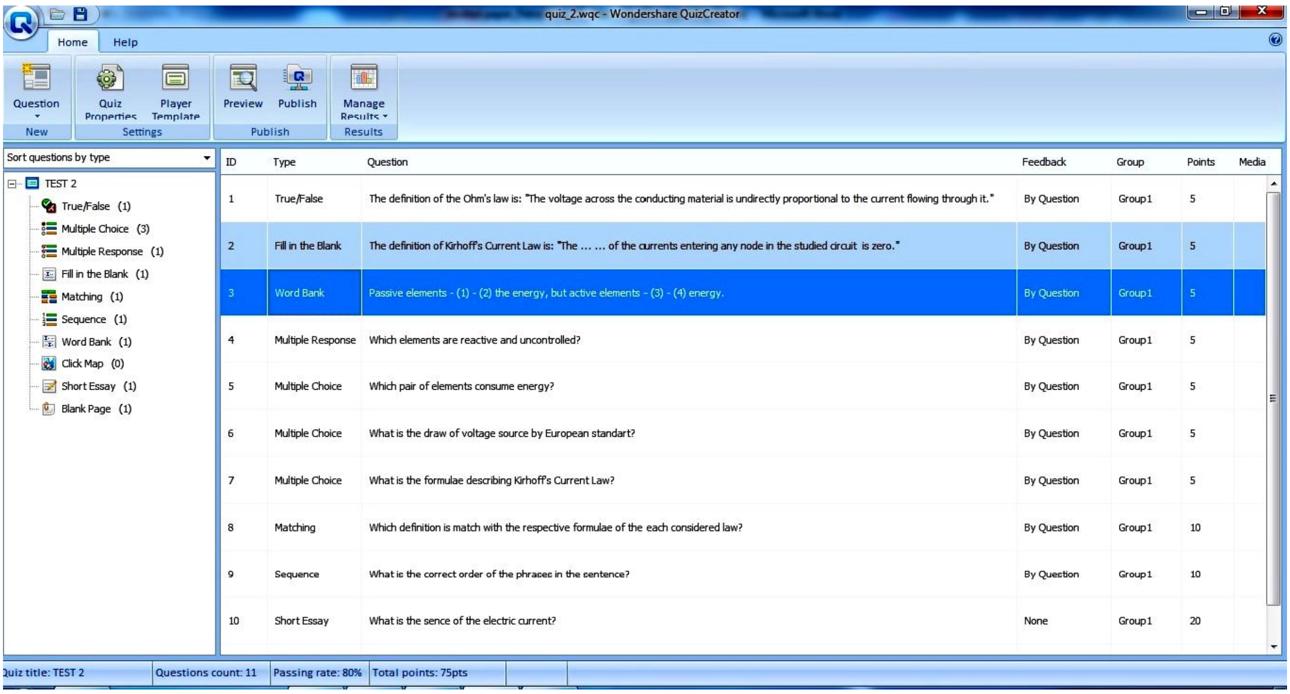


Fig. 4. Quiz questions test on Theory of Electrical Engineering

First seven types of questions are weighted with 5 points because they are easier for solving than the next questions from the test. *Matching* and *Sequence* questions give 10 points because it requires more efforts for answering. Last question is the most difficult because it is defined as an essay where have to reproduce the definition of the one of the base quantity in Physics and Theoretical Electrical Engineering – electric current. Of course this question gives the most points of the test.

5. CONCLUSION

The suggested quiz questions test on Theory of Electrical Engineering illustrates the applicability of this form of examination the students of this discipline. But the results this test is not enough for getting the maximum final rate. Maximum rate from the test will guarantee passing the exam (but unfortunately with minimum rate). The students can get the maximum rate if they have the maximum points on the other components of the exam as control tests during the tutorials (15 %), self-solving course assessments during the semester (15 %) and implementing the labs and generalizing the results in the protocols (10 %). So the excellent presentation on the quiz question test is a sufficient condition for passing the exam but for more ambitious students the final rate is not appropriate and they have to make their control tests on tutorial, self-preparing course assessments and labs very precise according to get higher final rate of the exam.

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Reviewer: Assoc. Prof. PhD S. Guninski

SOFTWARE SYSTEM FOR SYNTHESIS AND ANALYSIS OF COMMUNICATION CIRCUITS AND PROCESSES USING MATLAB

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Abstract: *In this paper a software system for synthesis and analysis of communication circuits and processes is described. It is used in the educational process in the course "Communication Circuits", included as compulsory in the curriculum of the specialty "Telecommunication Systems" for the Bachelor educational degree. The software system is developed by MATLAB and offers the possibility to solve problems for independent work during the practical exercises to the following sections of material: oscillating circuits, electrical filters and modulations.*

Keywords: *MATLAB, communication circuits and processes, oscillating circuits, electrical filters, modulations.*

1. INTRODUCTION

In this paper the operation and architecture of the software system developed for synthesis and analysis of communication devices (oscillating circuits, electrical filters) and processes (modulations) is described. The system will be used in the practical exercises by the students in the course "Communication Circuits" in the specialty "Telecommunication systems" of Bachelor degree at the University of Ruse "Angel Kanchev".

The software system was implemented using MATLAB 7 on Windows, a dialog programming environment for scientific and technical computing and visualization of results [3]. The system allows solving the problems provided for independent work of students during the practical exercises, making the learning process more attractive and more effective for the students and the teacher. The system developed has the following four modules: communication module, training module, calculation module and test module.

2. TEACHING TECHNOLOGY

According to the current syllabus for the course "Communication Circuits" included as mandatory in the curriculum of the specialty "Telecommunication Systems" for the Bachelor educational degree at the University of Ruse "Angel Kanchev", the material is taught weekly in the two-hour seminars. These exercises cover topics from the following three sections: 1) Oscillating (resonant) circuits; 2) Electrical filters; 3) Modulation [2].

Each student receives an individual assignment from the teacher. The student must solve the problems according to the provided methods [1, 2] and present the results to the teacher at the end of the exercise through his/her report. A report will be accepted by the teacher, if it contains up to 4 wrong answers for the exercise. It was established by the practice in order to eliminate "the tricks" by students for recording numerical calculations values "by eye". If the student has not submitted reports for individual exercises, he/she does not receive certification by the teacher for the practical exercises. Heavy labor-consumption of the process of verifying the work of the students by the teacher required the development of the software system described in the paper. The system aims to facilitate the activity of the teacher in assessing students' knowledge partially.

The training technology in the course was introduced in the academic 2010/2011 year. Since there are always students who fail to submit their reports by the end of the current academic year, it requires storing the information for each academic year and continuous "monitoring" the status of the students to "clear" all "indebted" students.

A flow-diagram illustrating the process of creating and using the developed MATLAB-based application is given in Fig. 1. Participants in this process are the teacher conducting the practical exercises, and students studying the course "Communication Circuits".

Before the creation of the software system (Fig. 1, Block 1) materials which will be used by the application are prepared (by the teacher). For this purpose widespread and accessible products as MS Word, MS Excel, MS PowerPoint and Paint are used. A "database" with multiple graphical images stored in a format *.png* is created. The images are used by the training module of the application developed. Then the actual development of the application by MATLAB (Fig. 1, Block 2) follows.

Surrounded by a dotted line Block 1 and Block 2 (Fig. 1) are namely the application contribution of the system developed.

The next blocks in Fig. 1 (Block 3 … Block 6) illustrate the use of MATLAB-based application, the students work in parallel with the four modules of the system: communication module, training module, calculation module and test module. The system will be put into practice in the academic 2014 – 2015 year (due to replacement of the course "Communication Circuits" from the fourth term into the fifth term according to the the new curriculum of the specialty "Telecommunication Systems").

The test module of the system enables the teacher to form the final assessment of a problem, of an exercise or for the term (Fig. 1, Block 7) for each student. The marks will be published online in the platform for e-learning [2] in the course "Communication Circuits" at the University of Ruse.

The four modules of the system are connected with each other and operate in parallel in time. So, the presentation of the connectivity of blocks 3 to 6 with one-way arrows is formal. Practically continuous transition from working with a module of the system to working with its other module is carried out. For example, the test module requires the student to enter a numerical value of a calculated quantity, which means the student communicates with the system, i.e. one of the activities of the communication module.

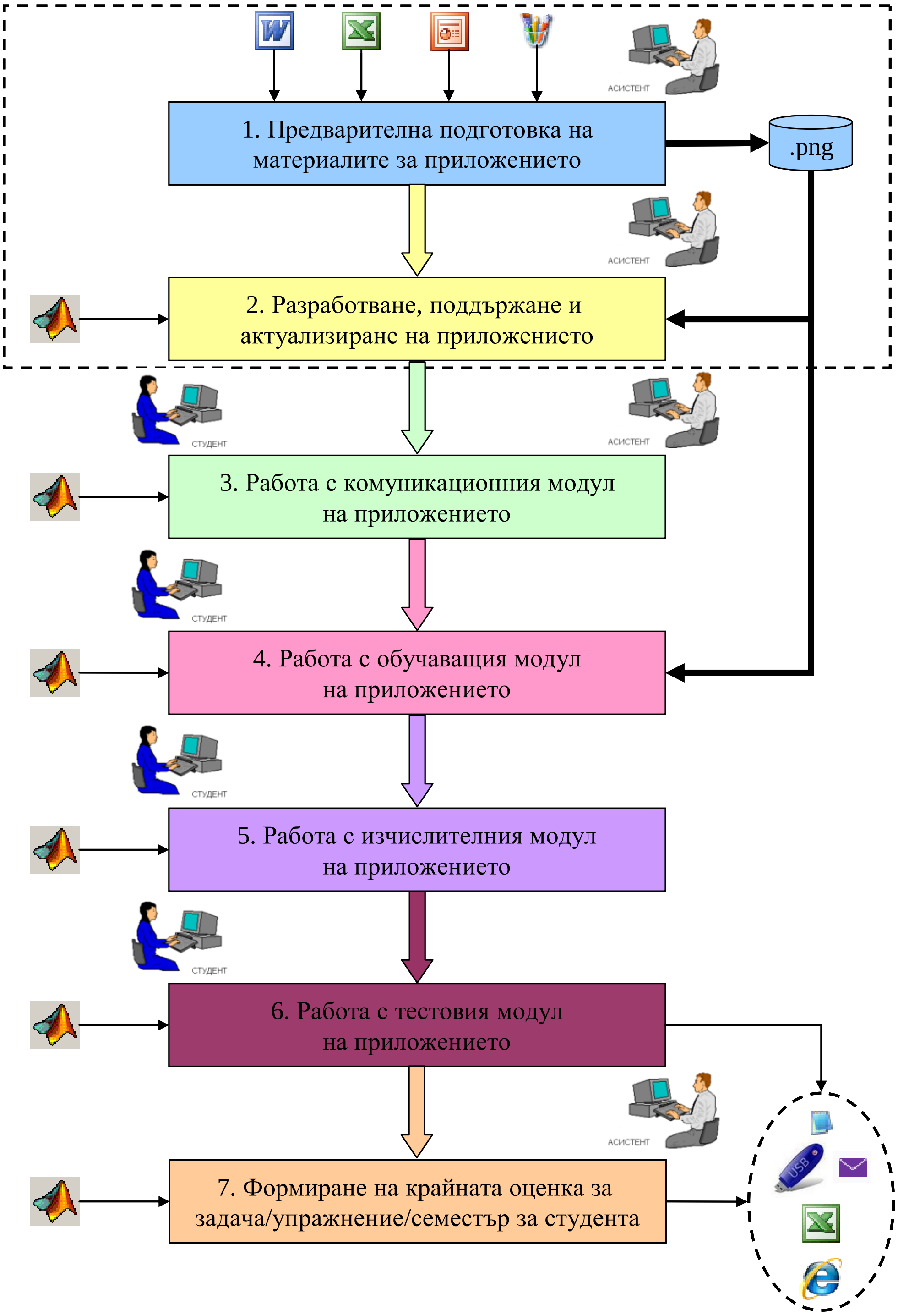
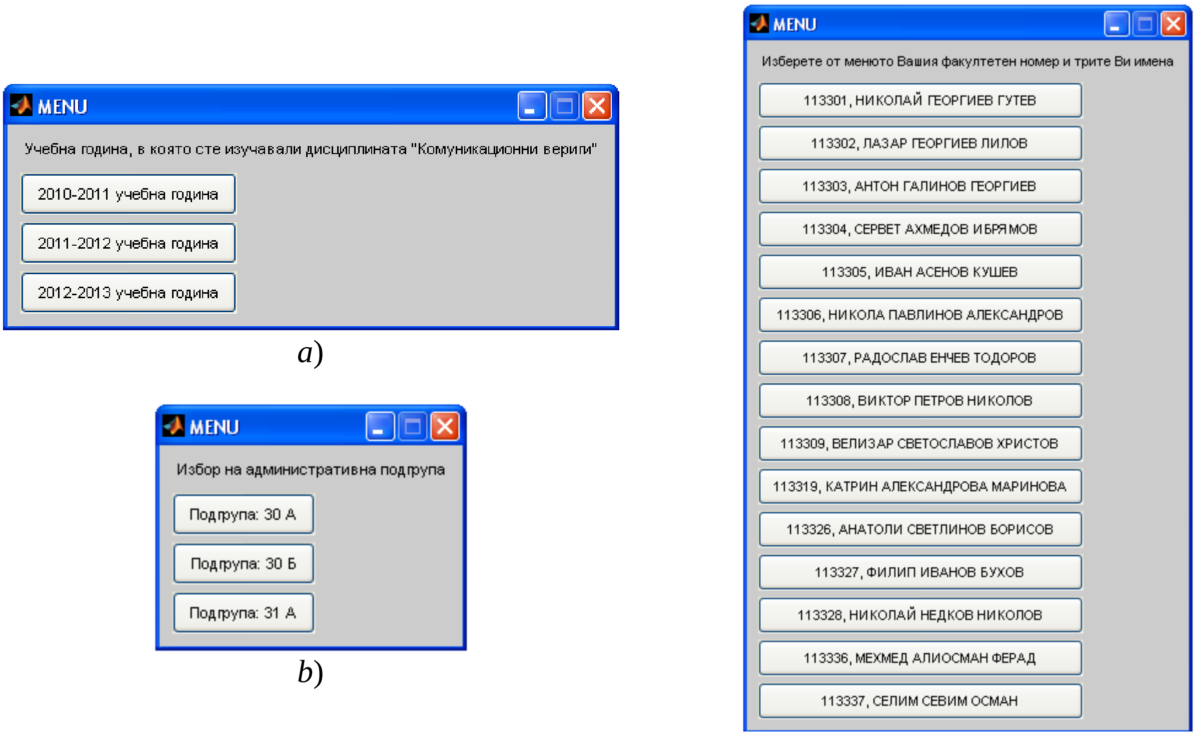


Fig. 1. Flow-diagram illustrating the process of creating and using the MATLAB-based application developed

The communication module of the system realizes the communication with the student, including: **1)** the student's registration in the system; **2)** entering the input data needed to solve the problem; **3)** entering numerical values for calculated quantities through the key-board; in fact it is testing of the student and also communicating of the student with the system.

When starting the application by typing in the command window of MATLAB its name *ILM_CCs* a menu for choosing the academic year in which the student studies (or has studied) the course “Communication Circuits” appears (Fig. 2 *a*). It is necessary because of the students who have not submitted their reports by the end of the current academic year in which they have studied the discipline, and for the collection and further processing the statistical data on training.



c)

Fig. 2. Registration of students in the system

After selecting the academic year, a menu for choosing the administrative subgroup which the student is assigned to (according to the division of the Dean's Office) appears. Students in the specialty “Telecommunication Systems” form the administrative groups 30 and 31, and the group 30 has two subgroups (Fig. 2 *b*). After selecting the subgroup a menu with a list of the students in the subgroup for the academic year selected is displayed (Fig. 2 *c*). The menu contains buttons with the data of each student (faculty number and full name), of which the student must select and press “his/her button”. In Fig. 2 *c* a list of second-year students in the subgroup 31 *A* studying the course “Telecommunication Systems” during the academic 2012-2013 year is given. In such a way the student is registered in the system. The system stored in a file information about the academic year, the subgroup, the faculty number and full name of the student and the student's work with the system during the practical exercise. Using the generated file the teacher can monitor the actions of the student after completing the exercise in his/her convenience, and the generation of the file allows the teacher to store information about the actions of students during the practical exercises. The generated text file can be opened using widely-spread product Notepad, be carried through flash drive or possibly be sent by email to e-mail address of the teacher (Fig. 1, block 7). At the moment sending the generated file by e-mail in MATLAB is not realized due to difficulties in the use of the built-in MATLAB function *sendmail* for sending e-mails to servers that require authentication and a solution to fix the problem is looking for. The content of the generated file is described in [9]. Currently, registration of students in the system is relatively low. This requires improving it, for example, through the usage of passwords. For the moment, the system only provides a synthesis and analysis of the relevant communication devices and processes, not the processes of authentication or authorization of the student.

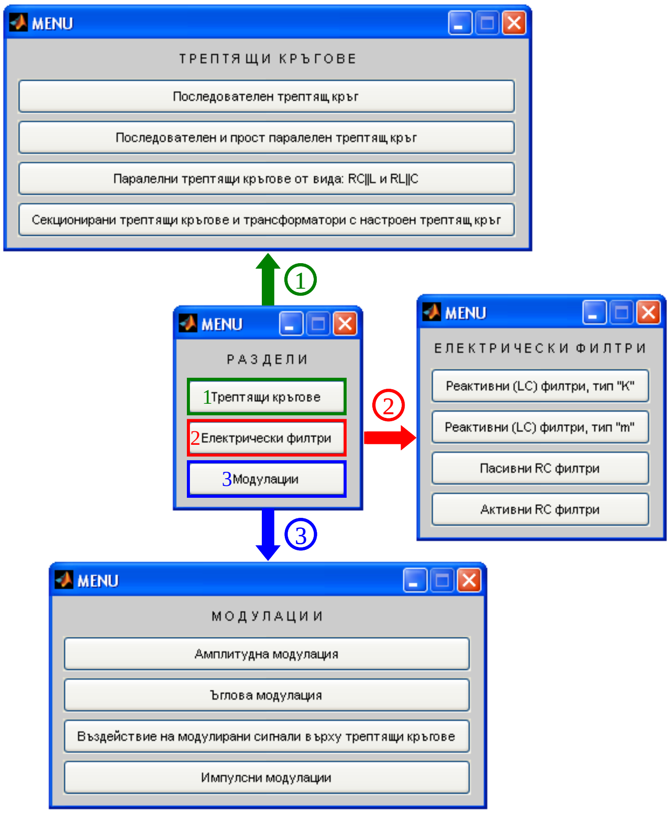


Fig. 3. Series of menus for selecting the section and the topic

After registration of the student, through a series of menus the choice of the section and the topic is done (Fig. 3), and a problem in the topic to be solved, the numbering of pages and problems is according to [1] (for the section “Resonant circuits”: Fig. 4 *a*, for the section “Electrical filters”: Fig. 4 *b*, and for the section “Modulations”: Fig. 4 *c*). According to the curriculum each section is planned to be studied within four weeks, so the themes to each section are four (Fig. 4).

The calculation module of the system allows computing the desired values for each of the problems on the basis of previously entered input data from the students via the communication module. In the implementation of the calculation module the methods presented in [1, 2] for solving the problems for independent work during the practical exercises are used.

The most attractive module is **the test module** of the system, which aims to assess the knowledge and skills of the student, allowing the teacher to form the final assessment of a problem, for an exercise or for the term (for each student).

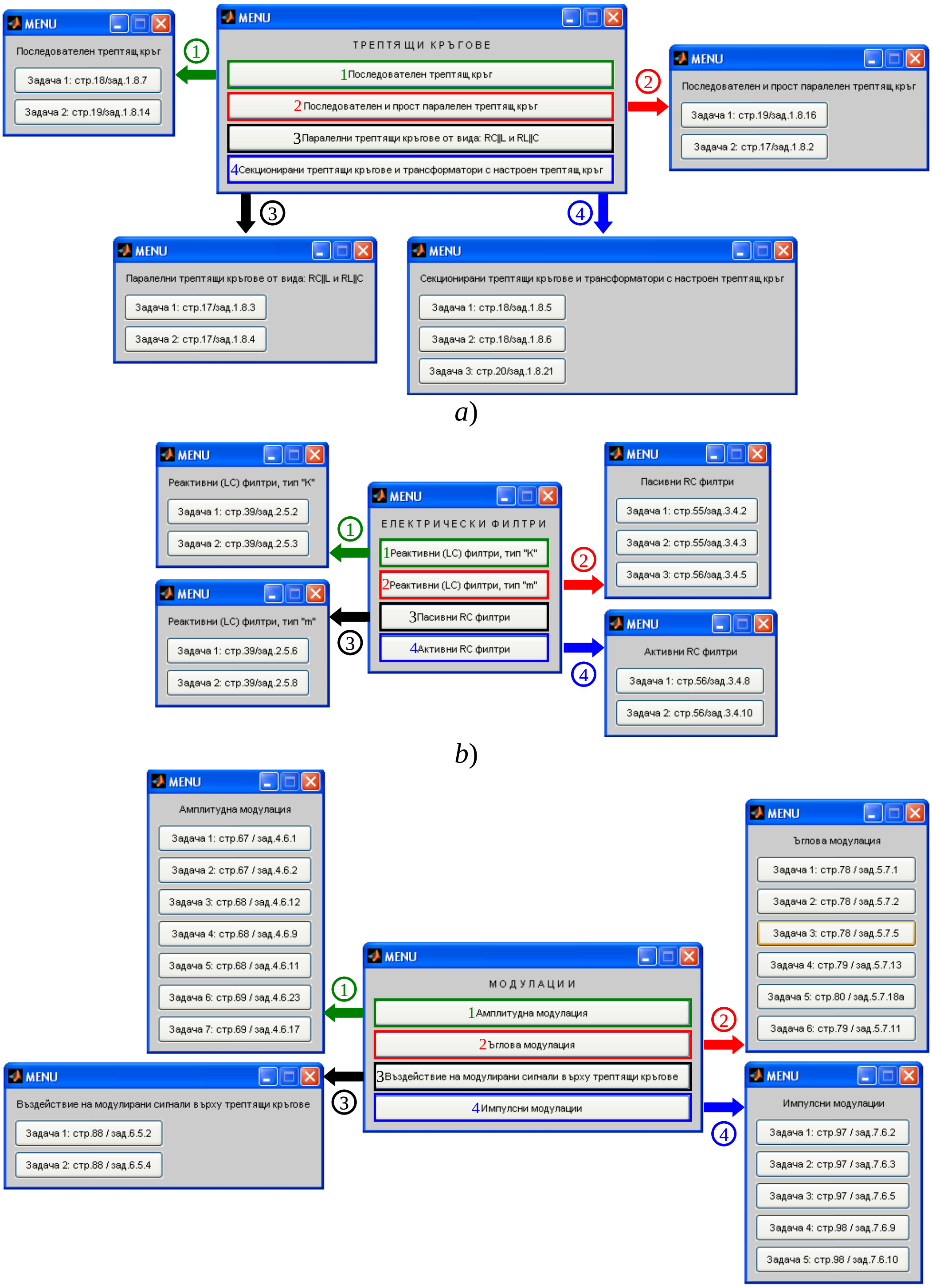


Fig. 4. Choice of a problem to be solved through a series of menus:
a) for the section “Resonant circuits”; *b*) for the section “Electrical Filters”,
c) for the section “Modulation” (via the communication module)

3. ARCHITECTURE OF THE SOFTWARE SYSTEM

The architecture of the software system developed for synthesis and analysis of communication devices (resonant circuits, electrical filters) and processes (modulations) is given in Fig. 5.

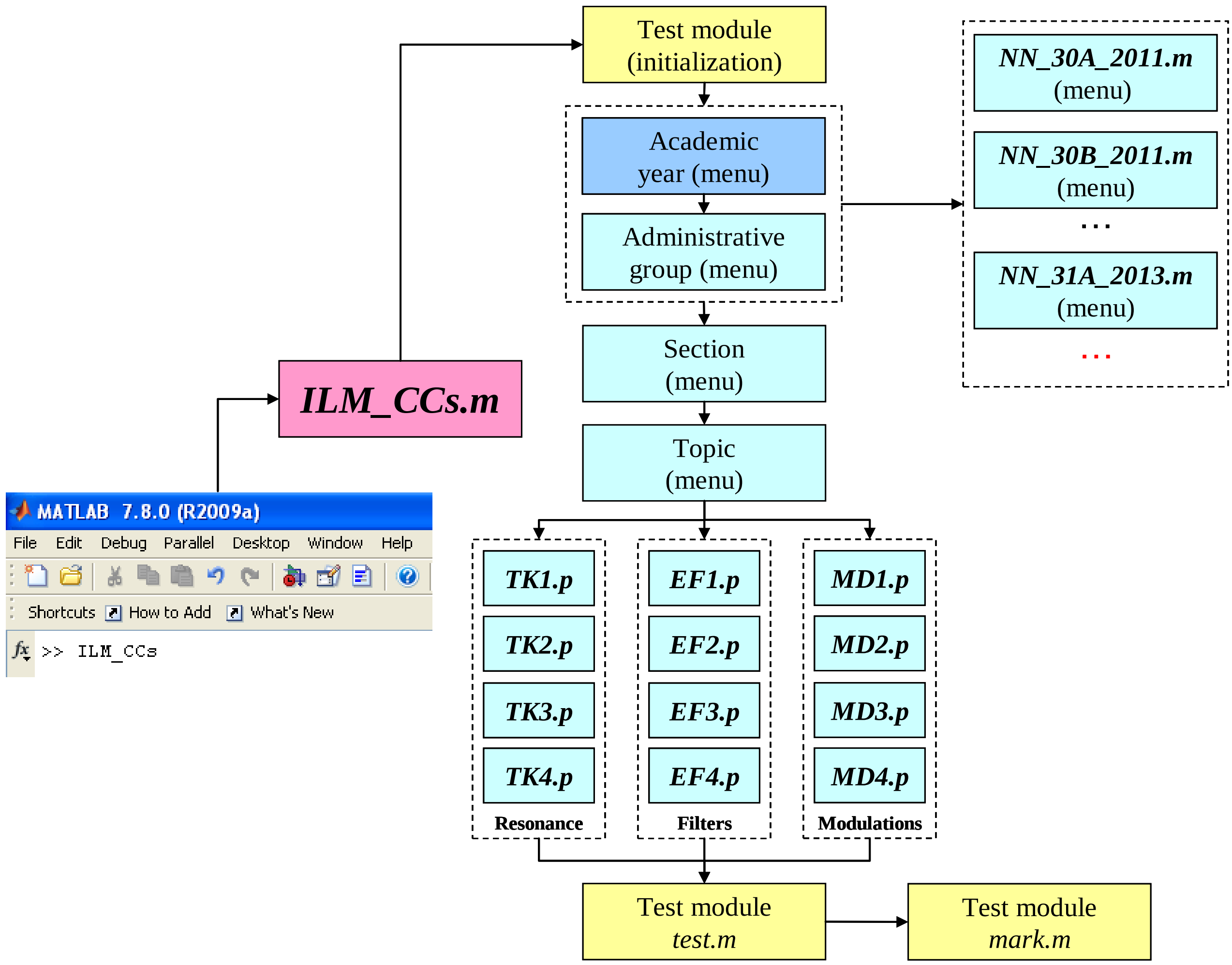


Fig. 5. Architecture of the software system developed for synthesis and analysis of communication devices and processes

The software system includes a main script file, *ILM_CCs.m*, by which the application is started when typing the name *ILM_CCs* (*Interactive Learning Module*, *Communication Circuits*) in the command window of MATLAB. This script file performs initialization of the test module by resetting the initial number of points $s = 0$ and displays consistently several menus for choosing the academic year (every year this menu must be completed by the current academic year), the administrative group, the section and the topic respectively. Depending on the choice made for the academic year and the administrative group, the script addresses to another *m*-file, one of *NN*_30*A*_2011.*m*, *NN*_30*B*_2011.*m*, ..., *NN*_31*A*_2013.*m*. These files show menu with a list of students (faculty numbers and full names) in the group for the academic year selected. Their number is increasing every year because it requires the creation of new data files of students for the next academic year.

Then the choice of the section, the topic and solving problems for the current practical exercise is done. The script addresses to the corresponding *p*-file: *TK*1.*p*, *TK*2.*p*, *TK*3.*p* and *TK*4.*p* (when choosing one of the four topics of the section "Resonant circuits") or *EF*1.*p*, *EF*2.*p*, *EF*3.*p* and *EF*4.*p* (when choosing one of the four topics of the section "Electrical filters") or *MD*1.*p*, *MD*2.*p*, *MD*3.*p* and *MD*4.*p* (when choosing one of the four topics of the section "Modulations"). In the performance of *p*-files in each problem the test module updates the value of the variable *s* by calling the function *test.m*, and finally, the final number of points *s* is transformed into a mark by the function *mark.m* [9].

P-files (files with the extension .*p*), generated by the command *pcode*, have the following features [3]:

1. *p*-codes are executed faster than the corresponding *m*-files.

2. If *m*-files and their *p*-codes are located in the same directory, when typing the name of a file (without extension) in a command, then the system executes the corresponding *p*-code.

3. If *m*-file and the corresponding *p*-code are in different directories, the system executes one of them, which is in the current directory or in a directory that precedes the other one in the list of available directories.

4. The usage of *p*-code allows hiding the original (source) code of programs by others.

The last feature is one of the advantages of the system, because the code for calculating the corresponding values in the problems remain hidden from students. This requires either independent programming in MATLAB or manually resolving the problem using a calculator by the student.

The algorithm (Fig. 6), embedded in the system, contains the following steps:

1. Registration of the student – by choice through a series of menus for the academic year, the administrative group, the names and the faculty number of the student (Fig. 2).

2. A menu for choosing one of the three sections, one of the four topics of the relevant section (Fig. 3) appears. After selecting the topic, again a menu for choosing the problem appears; the numbering of pages and problems are according to the reference [1], used during the practical exercises (Fig. 4).

3. To be used in the learning process the application developedt is extended by the following options – the following information is shown in separate graphical windows: 1) the condition of the problem; 2) the scheme of the communication circuit (if any); 3) formulas for the calculation of the demand values (Fig. 6, called "initialization phase"; it is designed for training students, i.e. training module).

4. Entering the input data necessary for the problem as hints and any restrictions on the choice of the value entered appear. A check for the correctness of the numerical values of the quantities is done and if necessary a message to re-enter input data displays.

5. The output data is calculated (an activity of the calculation module).

6. In the case of testing the student through the software system, the student enters the input data through keyboard and next the next value is calculated.

7. The output data is displayed on the screen and graphical dependencies (such as spectral charts, time-diagrams of the input and output signals) if required when solving the problem are visualized.

8. The willingness of students to solve a new problem is checked. If the student has finished with all the problems of the current practical exercise, his/her work with the system ends. If he/she wants to solve more problems, then a second choice of the problem through menu is performed (Fig. 4).

The functioning of the individual modules of the software system for synthesis and analysis of communication devices and processes is described in the previous publications of the authors [4, 5, 6, 7, 8, 9].

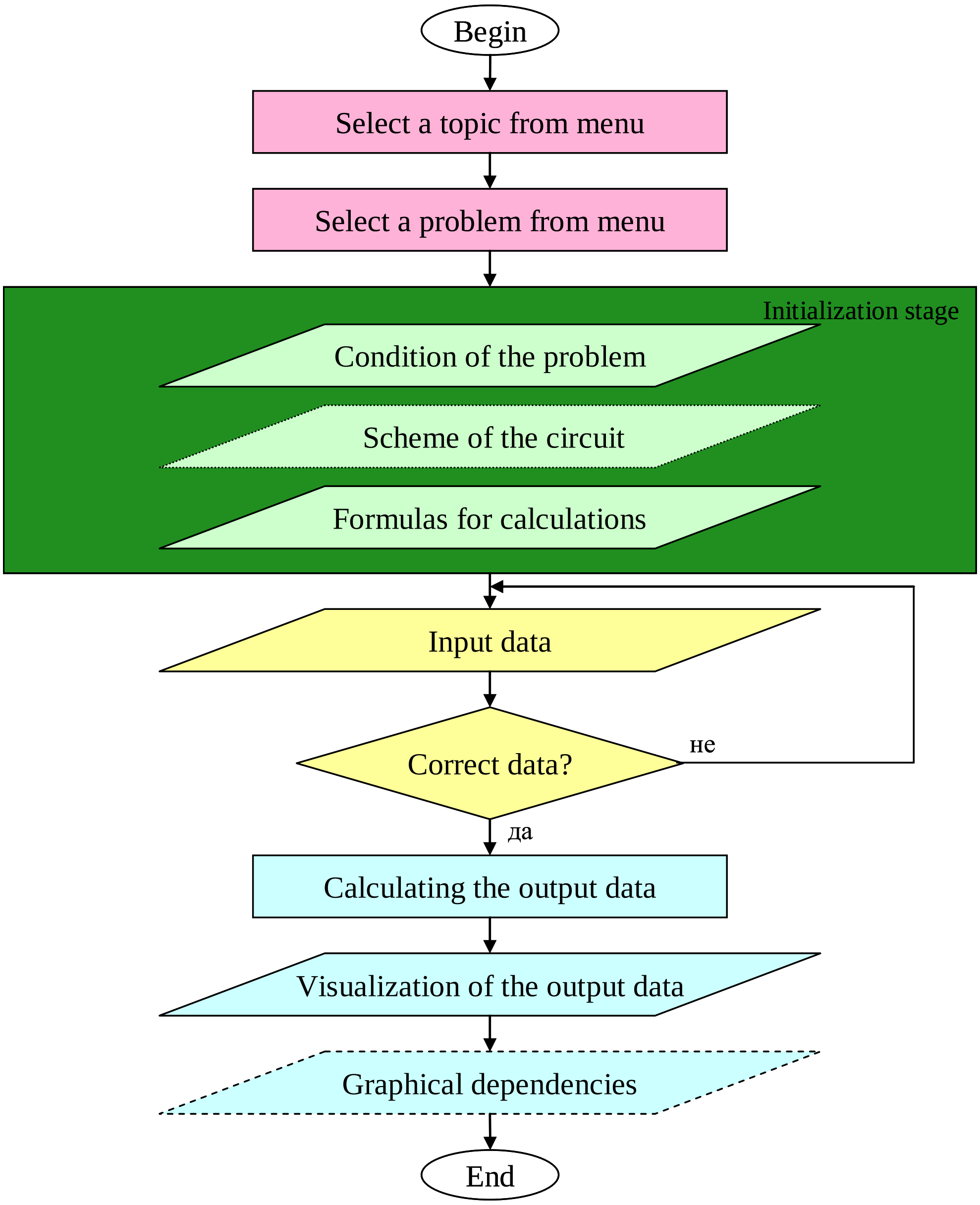


Fig. 6. Algorithm in the software system developed

4. CONCLUSIONS

The architecture and functioning of the software system developed for synthesis and analysis of some communication circuits and processes are considered in the paper. The system allows a faster process of synthesis and analysis by the students and an easier, more efficient, and at any time monitoring by the teacher when used in the course “Communication Circuits” included as mandatory in the curriculum of the specialty “Telecommunication systems” for Bachelor degree at the University of Ruse.

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Reviewer: Prof. PhD K. Brandisky

MODELLING AND INVERSE PROBLEMS IN ELECTROMAGNETIC SYSTEMS

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Abstract: *The development of high technology, energy-efficient and reliable electromagnetic devices, requires high level of knowledge not only for the electromagnetic processes in the devices, but also for interrelated with electromagnetic field thermal, mechanical physicochemical conditions. Such kind of profound studies gives possibility for determination and control of the parameters and characteristics of the systems even in inaccessible for experimental investigation areas.*

In spite of the differences in the type and the purpose of the devices, modeling of the processes is based on the precise numerical analysis of the electromagnetic and coupled with them fields and subsequent optimization of the constructions and working parameters of the studied systems. This determines the necessity for correct formulation and solving two basic tasks: forward problem – problem for numerical analysis of the field and inverse problem – optimization, identification and synthesis of field structures. Several examples of modeling and optimization of processes in electromagnetic system have been presented in the paper, using 2D and 3D FEM analysis.

Keywords: *electromagnetic processes, coupled field problems, finite element method, modeling and inverse problems*

1. INTRODUCTION

Development of electronic and electromagnetic systems is crucial to the operation of modern society. Nowadays the most important task of the design engineers is to produce a high-quality, market competitive products, which ensure effective work with respect to given requirements and limitations. Obtaining of the final technical product is complicated synthesis process of detailed investigations, optimisations, expert consultations and ranking [1]. The bibliographic survey shows that in over the last two decades, the focus in research related to electromagnetic devices has moving from analysis of the device performance towards the automatic optimisation of a particular device to meet the needs and requirements specified by an user [2].

The creation of high technology, energy-efficient and reliable electromagnetic devices that do not harm the environment is of significant importance. The development and improvement of such systems requires high level of knowledge not only for the electromagnetic processes taking place in the devices, but also of complex interrelated with electromagnetic field thermal and mechanical processes and physico-chemical conditions [4, 5, 6, 7 and 8]. The profound study and numerical modelling and optimisation gives possibility for determination and control of the parameters and characteristics of the system even in inaccessible for experimental investigation areas.

2. MAIN STEPS AND SPECIFIC FEATURES IN MODELING AND OPTIMISATION OF ELECTROMAGNETIC SYSTEMS

2.1. Main steps in modeling and optimization of the processes

In spite of the differences in the type and the purpose of the studied objects, achieving the aims of modeling and optimization is obtained on the basis of precise numerical analysis of the electromagnetic and coupled with them thermal, mechanical and physicochemical processes and subsequent optimization of the constructions and working parameters of the studied systems. This determines the necessity for correct formulation and solving two basic tasks:

- *Forward problem* – problem for numerical analysis of the field (electromagnetic, thermal and mechanical) of the studied device. This problem is connected with precise diagnostics of the state of existing devices and obtaining significant for the studied process characteristics and parameters. Different numerical methods are used for the determination of the field quantities and characteristics –finite difference method, finite element method, boundary element method, some hybrid methods and so on. The most often used for the field analysis is finite element method (FEM) It has been successfully applied for solving the analysis in 2D and 3D linear and non-linear coupled problem.

- *Inverse problem* – optimization, identification and synthesis of field structures. The problem is connected with the necessity of control of processes in existing devices or with the design of new ones with preliminary set desired parameters and characteristics. The solving of the problem is based on optimization procedure. The choice of optimization method to a great extent depends on the specifics and complexity of the forward problem to be solved at each step of the optimization procedure. requirements: The analysis and compassion of different approaches and techniques for solving inverse problems in electrical engineering, concerning their robustness, speed and convergence shows that there is no universal optimisation strategy which can guarantee ”the best of the best solutions” and the solution of the optimisation problem usually depends on the researcher’s experience and available programme tools. But developments in numerical field analysis methods, as well as powerful computers offer the opportunity to attack realistic problems of technical importance.

2.2. Efforts and investigations for improving the models

The main goal of computer modeling is to help the design engineers to develop high-quality, market competitive products, which ensure effective work with respect to given requirements and limitations. Therefore, the efforts and investigations are focused on the following main directions:

1. Précising the solution of the forward problem. It automatically improves formulation and solution of the inverse problem. It can be realized by:

- Applying for the analysis of the processes in the investigated systems precise numerical methods, taking into account real geometry (2D or 3D) and material properties (linear, nonlinear or presence of hysteresis);
- Solving the problem as a coupled electromagnetic-thermal-mechanical, taking into account mutual dependencies taking place in coupled field modeling.

2. Precising the solution of inverse problem. It can be achieved by:

- Proper formulation of the inverse problem as problem of:
  - optimisation
  - parameter extraction
  - identification
  - synthesis
- Using (according to the specific futures of the investigated device) modern, powerful optmisation methods such as:
  - Simulated annealing
  - Evolution strategies
  - Genetic algorithms
  - Neural networks
  - Response surface supply methodology

3. Experimental investigations and adjustments of the numerical models, obtained during the solution of forward problem. The analysis of the processes and experimental verifications of the mathematical model are carried out for different combinations of the designed parameters, according the Design of experiment theory (DOE).

2.3. Specific features of modeling and inverse problem solutions

The analysis and compassion of different approaches and techniques for solving inverse problems in electrical engineering, concerning their robustness, speed and convergence shows that there is no universal optimisation strategy which can guarantee ”the best of the best solutions” and the solution of the optimisation problem usually depends on the researcher's experience and available programme tools. But developments in numerical field analysis methods, as well as powerful computers offer the opportunity to attack realistic problems of technical importance.

A numerical optimisation combined with modern field computation methods numerical methods is found to be an important and powerful engineering tool for the design of electronic and electromagnetic systems. During the past decade important researcher's efforts have been devoted to the development of efficient optimisation techniques, which could amplify the power, brought by modern numerical analysis tools such FEM. Many publications have been reported about successful solutions applying new modern stochastic optimisation technique, combined with FEM and with circuit simulation programs.

In order to select and develop effective approach for solving inverse problems in the region of electrical engineering it is very important to point out the properties of typical optimisation problem and then to estimate the application possibilities.

The main common features of the inverse problems in the region of electrical engineering are:

- Complexity, which means a high number of design parameters.
- Constrained – there are constraints concerning device behaviour, as well as constraints concerning device geometry. Any of them can be determined as equality or inequality constraints.
- The objective function is non-linear.
- Design variables are real.
- There is no derivative information available (interdependencies between design variables and quality function are unknown).
- Type of the optimisation problem is parameter or static optimisation. Nowadays optimisations are performed mainly as static problems. Optimisation of dynamic system behaviour, combined with detailed numerical field and processes analysis will be too time consuming.
- The quality function is disturbed by stochastic errors caused by the truncation errors of numerical field computation.

Generally, thousands of different optimisation methods exist, but unfortunately many of them can be successfully applied only for certain types of problems. Despite their huge number, optimisation methods have many common features and even they can be considered as improved versions of each other. Using these common features many different classifications are possible. The most popular classifications of the optimisation algorithms are:

- Deterministic or Stochastic methods
- Direct or Indirect methods

The main features of the methods and approaches for solving inverse problems have to be analysed regarding the mentioned specific problems, taking into account their:

- Reliability
- Robustness
- Insensibility to stochastic disturbances
- Application range
- Stable solutions
- Performance

The literature observation on this topic shows the following situation: The deterministic methods such as Conjugate Gradient (CG), Newton, Quasi Newton and etc. are classical optimisation methods.

- They are basically local optimisation methods and often are convening to a local minimum

- They are often based on the construction of the derivatives or approximations of the derivative of the objective function. But when using FEM for electromagnetic field analysis it is often difficult to obtain derivatives. It requires human interaction in the optimisation procedure.
- They are very sensitive to stochastic disturbances, especially contained in the derivative information they are based on.
- These gradient based methods are very popular and very effective and converge to the local minimum in a small number of steps when analytical objective function exists.

Stochastic optimisation methods, such as Simulated annealing (SA), evolution strategy (ES) and genetic algorithms (GA) are modern methods, based on statistical analysis.

- These methods utilise random processes to scan the whole parameter space. That is way they can reach the global optima with high probability.
- They accept deterioration in the objective function during the solving process and this enables them to escape local minimum and find the region of the global optimum no matter where the strategy is started from.
- They do not require derivative information
- They are rather simple to implement.
- They are stable in convergence.

The main drawback of these methods is the fact that they need a very high number of function evaluations during the solving process. It means that when applying FEM for electromagnetic field analysis the process becomes too time consuming for the complex realistic problems. There are also reports for combined optimisation strategy. It begins with stochastic method and after localisation of the global optimum region searching process continues with deterministic method. The problem is how to choose the switching point between the two methods.

3. EXAMPELS

3.1. 2D modeling of coupled electromagnetic-thermal field in induction heating device

The motivation for carrying out the presented work is necessity of development, analyzing and estimation of the efficiency of real induction heating system used for heating of flat details, usually of regular shape – discs of ferromagnetic and nonferrromagnetic materials [9]. After heating and plastic deformation, hardened discs are used for producing instruments. For this reason it is necessary to develop system, creating such electromagnetic field, which ensures thermal field with specified distribution. To design such a system it is necessary to analyse electromagnetic and thermal field for number of different possible variants and then choose the proper system parameters. Thus the main goal of the work is precise investigation of the coupled electromagnetic and temperature field distributions for a number of parameters defining different design of the system. Investigations are based on the finite element method (FEM).

The principal geometry of the system is shown in Fig. 1. It consists of disc-type inductor and heated detail. The inductor is multi-sectioned and consists of four sections – first three with three and the last one with two turns. Each turn consists of two square cross section (15mm x 15mm) hollow conductors and 1mm insulation between turns. The inner inductor radius is 35mm. The distance between the inductor and the detail is 7÷15 mm. The frequency is 8 kHz and applied voltage varies from 100 to 700V. The heated detail is ferromagnetic disc with diameter 550÷700mm and height 4÷8mm. The final heating temperature must be 950^0C.

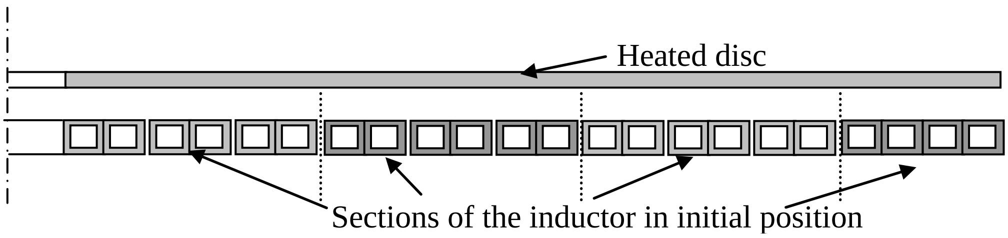

Fig. 1. Principal geometry of the induction system

There is a possibility to change the position of the different sections in z- direction. These changes depend on distances h1, h2, h3 and h4. This design variant is shown in Fig. 2. Thus changing the section positions we can change the field distribution.

Another possibility for obtaining different field distribution is that we can supply different section combinations - for example first, third and forth sections, or any other possible combination. In this way it is again possible to obtain rather different distribution from the initial temperature field.

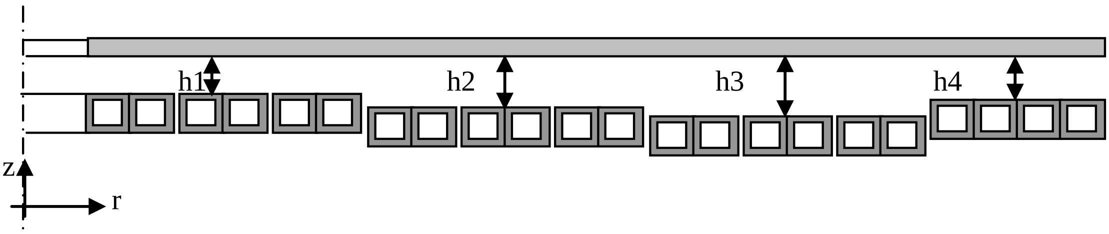

Fig. 2. Variant of possible geometry of the induction system

Coupled Field Model – Theoretical Basis

The temperature field determination in the considered induction heating systems can be obtained by solving the coupled – quasistatic electromagnetic and transient thermal field problem. Due to the geometry the problem is considered as axisymmetrical one. Numerical simulation of the heating process consists of analysis of time harmonic electromagnetic problem coupled with transient thermal problem, taking into consideration change of physical properties during the heating.

The investigated region is shown in Fig.2. Both the electromagnetic and transient thermal problems are solved in a domain consisting of the whole system and a wide buffer zone around it. It includes domains: Ω1- heated disc, Ω2- inductor, Ω3- buffer zone with air. The time harmonic electromagnetic field is modelled by equation:

$$\nabla\text{x}(\mu^{-1}\nabla\vec{A}) = \vec{J} - \sigma\frac{\partial\vec{A}}{\partial t} \quad (1)$$

$\vec{A}$ is magnetic vector potential, σ is electric conductivity, μ is magnetic permeability , $\vec{J}_e$ is current density. Taking into account that $\vec{A} = A_\varphi(r,z)\vec{1}_\varphi$ and $\vec{J}_e = J_\varphi(r,z)\vec{1}_\varphi$ the Eq. 1 can be written as:

$$\nabla\text{x}(\mu^{-1}\nabla A_\varphi) = J_\varphi - j\omega\sigma A_\varphi, \quad (2)$$

where ω is angular current frequency. The boundary conditions are $A_\varphi = 0$ for the axis of symmetry b1, as well for the buffer zone boundaries b2, b3 and b4.

The time varying electromagnetic field produces eddy currents $\vec{J} = j\omega\sigma\vec{A}$ and corresponding Joule losses – source of the heating in the region:

$$Q = \frac{[\sigma]^{-1}\vec{J}\vec{J}^*}{2} \quad (3)$$

The transient thermal field is modeled by equation:

$$\rho C\frac{\partial T}{\partial t} + \nabla(-k\nabla T) = Q \quad (4)$$

where k is thermal conductivity , ρ is density, and C is heat capacity.

The boundary conditions are imposed: $\frac{\partial T}{\partial n} = 0$ along the symmetry line b1; Dirichlet boundary conditions T = 20^0C along the buffer zone boundary b2, b3 and b4. The water cooling of the inductor along boundaries b5 was taking into account using convection boundary condition:

$$-k\frac{\partial T}{\partial n} = h(T_{\text{inf}} - T)\ , \quad (5)$$

– *h* is heat transfer coefficient, T_{inf} is the external temperature. The initial temperature is $T_0=20^0$C.

FEM Analysis

Numerical investigations of coupled field distribution have been made using FEM and COMSOL 3.3 software package [11]. The change of physical properties during the heating process is possible by using Materials/Coefficients library in the software.

Study was carried out when varying different design parameters, like distances between inductor sections and heated detail, supply voltage and supply inductor sections. Analysis of the results gives possibilities to make reasonable choice of design parameters. Some results for the field distribution during the heating process for the system with initial design (h1=h2=h3=h4), are given in Fig. 3, Fig. 4 and Fig. 5. Temperature distribution after 200 seconds heating is shown in Fig. 3. In Fig. 4 temperature increase during the heating process is observed in case of supply of all four sections. The temperature in radial direction is nonuniform, has one maximum and varies from 600 to 1080ºC.

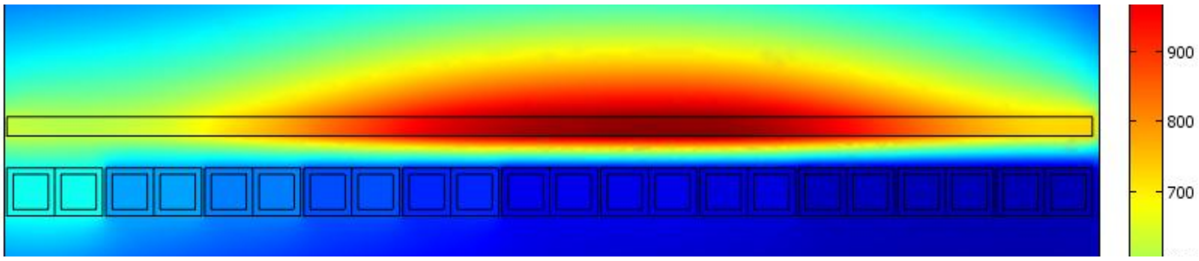

Fig. 3. Temperature distribution for the initial (h1=h2=h3=h4) geometry of the system, t = 200 sec.

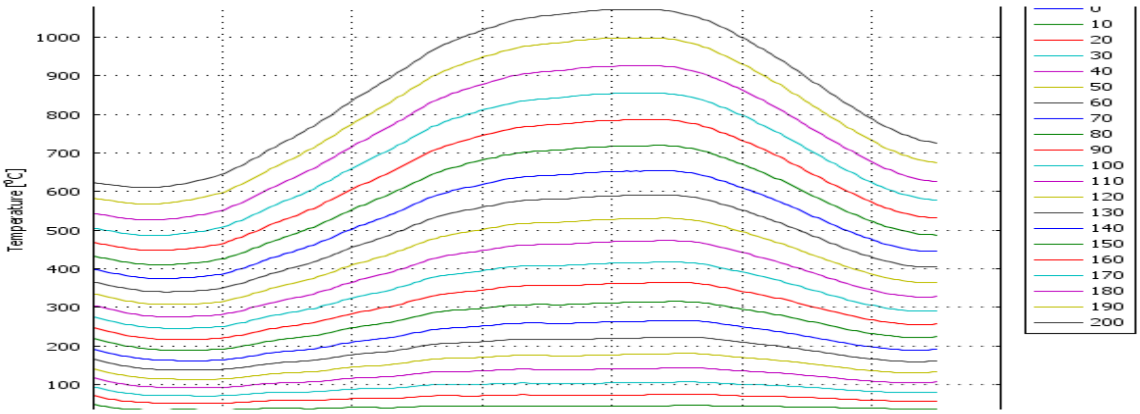

Fig. 4. Temperature increase during 200 seconds heating process (t=10,20,30,…200s)

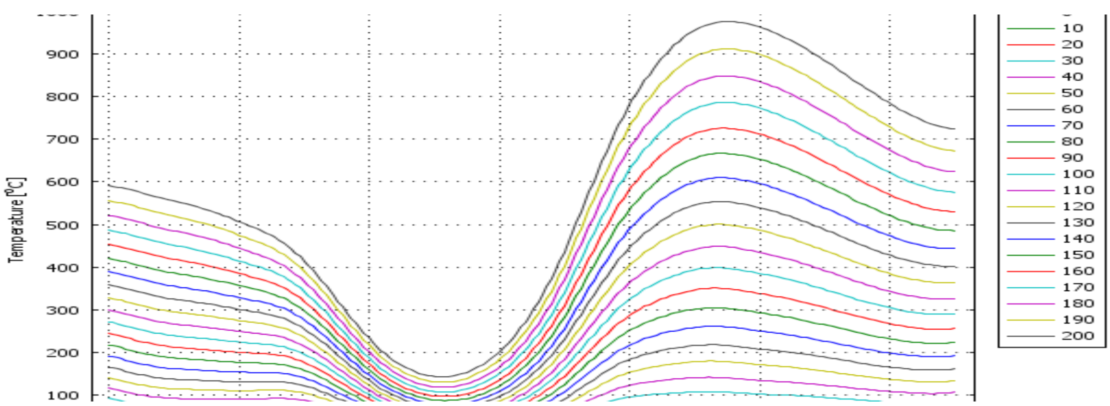

Fig. 5. Temperature increase during 200 seconds heating process (t=10,20,30,…200s). Second section of the inductor is not supplied.

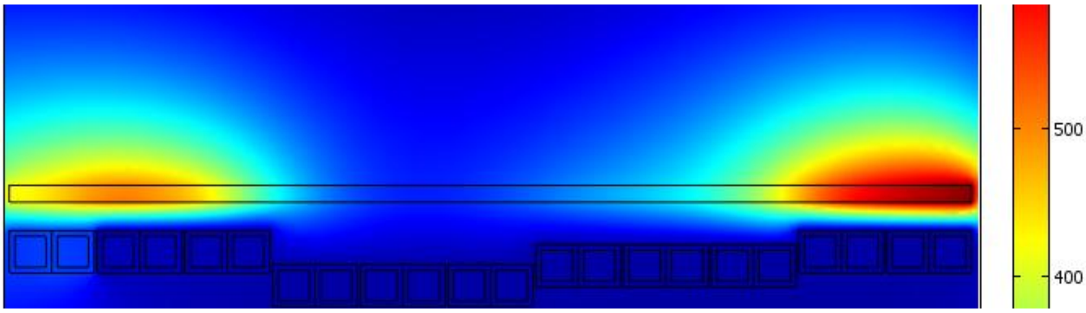

Fig. 6. Temperature distribution at moment t=200s. The inductor sections are in different positions (h1≠h2 ≠h3≠h4)

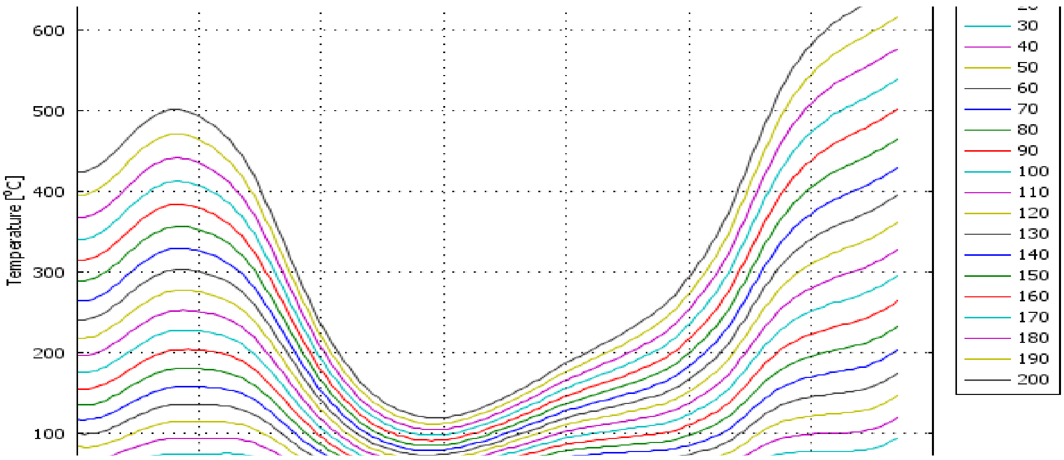

Fig. 7. Temperature increase at different moments during 200 seconds heating process when inductor sections are in different positions (h1≠h2 ≠h3≠h4)

In Fig. 6 the process of heating is shown, when inductor sections are again in the initial position, but second section of the inductor is not supplied. Temperature distribution for moment t=200 second in case of different distances between inductor sections and heated detail (h1≠h2 ≠h3≠h4) is shown in Fig.6. In Fig.7 process of disc heating for different moments t=0÷200 seconds can be observed. It is evidently that heating process and its result at moment t=200 seconds is quite different for this different design.

3.2. 3D modeling of coupled electromagnetic-thermal field in induction heating system for high frequency welding

The aim of the research is investigation of induction heating system used for high frequency longitudinal pipe welding [10]. The main task is to determine optimal factors and parameters influencing on quality of the welding process and required energy: frequency, welding speed, ‘vee’ angle, ferrite impeder presence (inner and outer).

The principal geometry of the investigated system is shown in Fig. 8. It consists of high frequency spiral inductor, which induced a voltage across the edges of the open steel pipe. The induced voltage causes high frequency currents, concentrated on the surface layer due to the skin and proximity effects. The currents flow along the edges to the point where they meet, causing rapid heating of the metal. The weld squeeze rolls are used to apply pressure, which forces the heated metal into contact and forms welding bond. Inner ferrite impeder is also used, which concentrates magnetic flux and improves the welding efficiency.

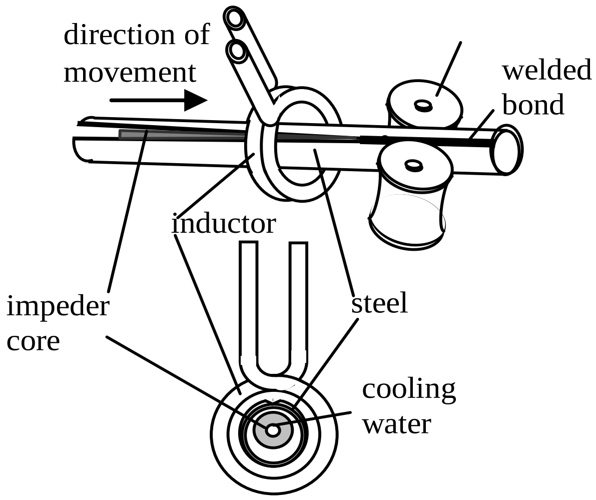

Fig. 8. Geometry of the investigated induction system

The parameters of investigation are: applied current -1000A; voltage - 500V; cosφ = 0,1 and f = 200 kHz ÷ 500 kHz. The end heating temperature must be about 1300 ÷ 1450^0C. The cooling water flowing inside the conductors is with temperature 40^0C.

The field problem is considered as coupled - electromagnetic and thermal. The electromagnetic field is analysed as time harmonic and eddy current losses in conductive parts of the system are considered as heat sources in analysis of transient thermal field problem. Both the electromagnetic and transient thermal problems are solved in a domain consisting of the whole system and a wide buffer zone around it. The investigated region is shown in Fig.9. It includes domains: Ω1- inductor; Ω2- impeder; Ω3- welded pipe; Ω4- cooling water; Ω5- buffer zone with air.

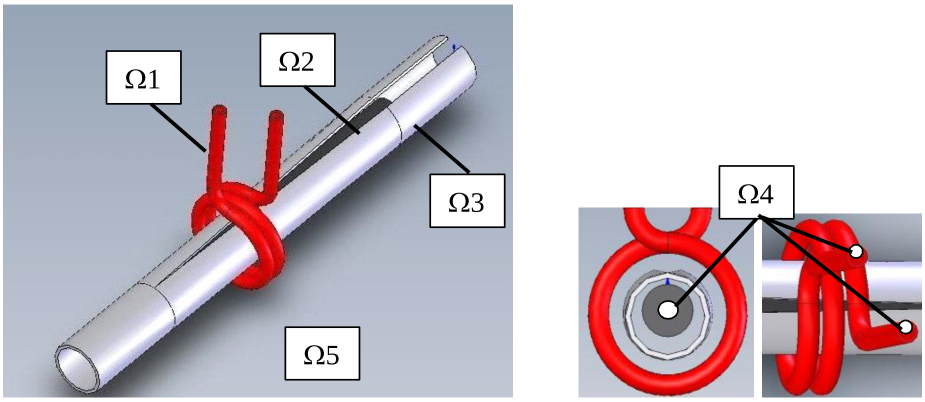

Fig. 9. Investigated region

FEM Analysis

3D-coupled electromagnetic and temperature field problem and has been solved using finite element method and COMSOL 4.2 software package [11].

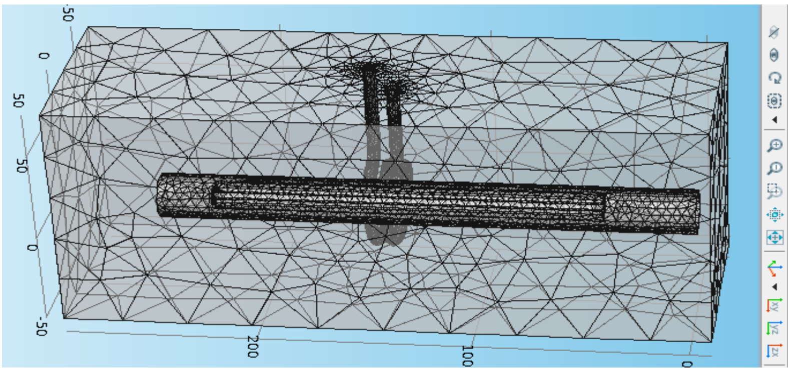

Fig. 10. 3D FE mesh in the investigated region

The finite element mesh used in investigation is shown in Fig. 10 and current density distribution in two specific for the problem cross sections in Fig. 11. The obtained temperature value around the “point of closure” (Fig. 12) is about 1400 0C.

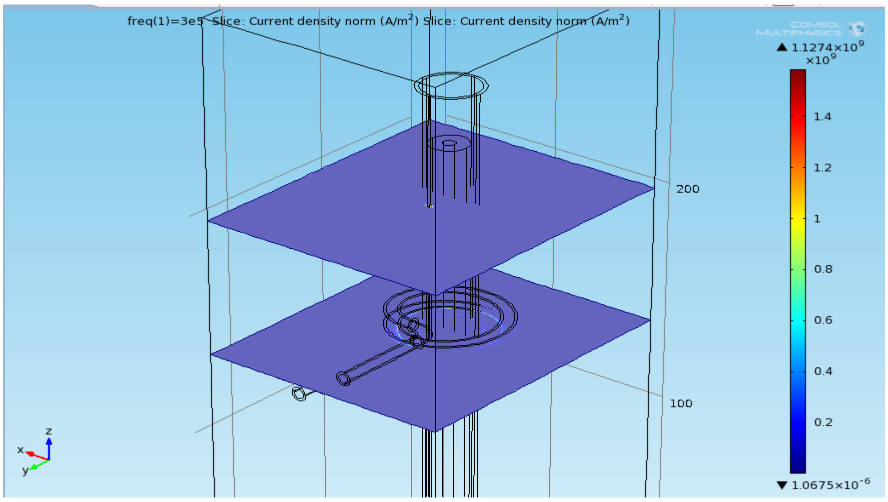

Fig. 11. Current density in two cross sections: around “point of closure” and spiral inductor.

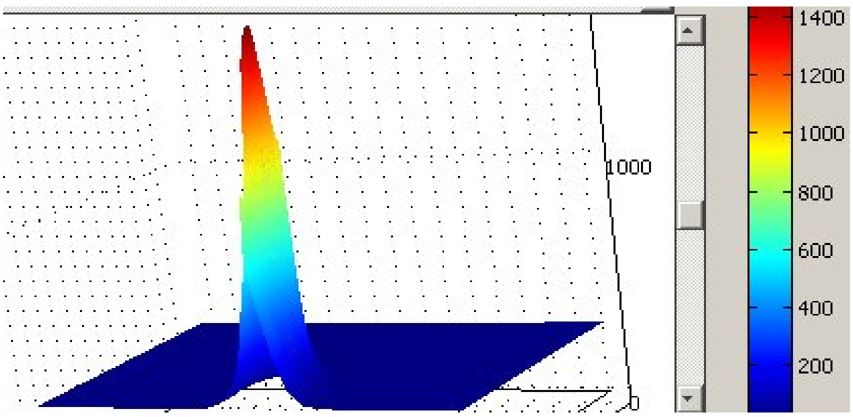

Fig. 12. Temperature increase around the “point of closure”

4. CONCLUSION

The paper presents the main steps, problems and possibilities in numerical modelling and optimisation of the high technology, energy-efficient and reliable electromagnetic devices that do not harm the environment. The development and improvement of such systems is based on profound, complex field study and subsequent optimisation. Such modelling gives possibility for determination and control of the parameters and characteristics of the systems even in inaccessible for experimental investigation areas.

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Reviewer: Prof. DSc R. Stancheva

TEST MODULE OF A SOFTWARE SYSTEM FOR SYNTHESIS AND ANALYSIS OF COMMUNICATION CIRCUITS AND PROCESSES

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Abstract: *In this paper a test module of a software system for synthesis and analysis of communication circuits and processes is described. It is used in the educational process in the course "Communication Circuits", included as compulsory in the curriculum of the specialty "Telecommunication Systems" for the Bachelor educational degree. The test module of the software system, developed by MATLAB, offers the opportunity to test the students in the following sections of material: oscillating circuits, electrical filters and modulations.*

Keywords: *test module, communication circuits and processes, oscillating circuits, electrical filters, modulations.*

1. INTRODUCTION

According to the current syllabus for the course "Communication Circuits" included as mandatory in the curriculum of the specialty "Telecommunication Systems" for the Bachelor educational degree at the University of Ruse "Angel Kanchev", during the practical exercises students solve individual problems in accordance with certain methods [1, 2]. The problems solved should be submitted to the teacher at the end of the exercise.

A test module of a software system developed for synthesis and analysis of communication circuits and processes is considered in the paper.

2. TEST MODULE – IMPLEMENTATION

The test module of the system is designed to assess the knowledge and skills of students allowing the teacher to form the final marks for a problem, for an exercise or for the term (for each student).

The test module is based on the use of both functions developed: *test* and *mark*, whose flow-charts are shown in Fig. 1 and Fig. 2.

Testing students is realized using the function *test*. The calculation module of the system enables the calculation of various parameters and the test module generates 5 possible values for the quantity requested (this number can be increased, which will reduce the chance of guessing the correct answer). The student chooses one of these five options the closest one to the value calculated by him/her. When the correct answer for the quantity calculated the function *test* adds a fixed number of points. When the answer is wrong, the function *test* takes off a fixed number of points. By the withdrawal of points when wrong answers the willingness of students to "blindly guessing the correct answer" is reduced.

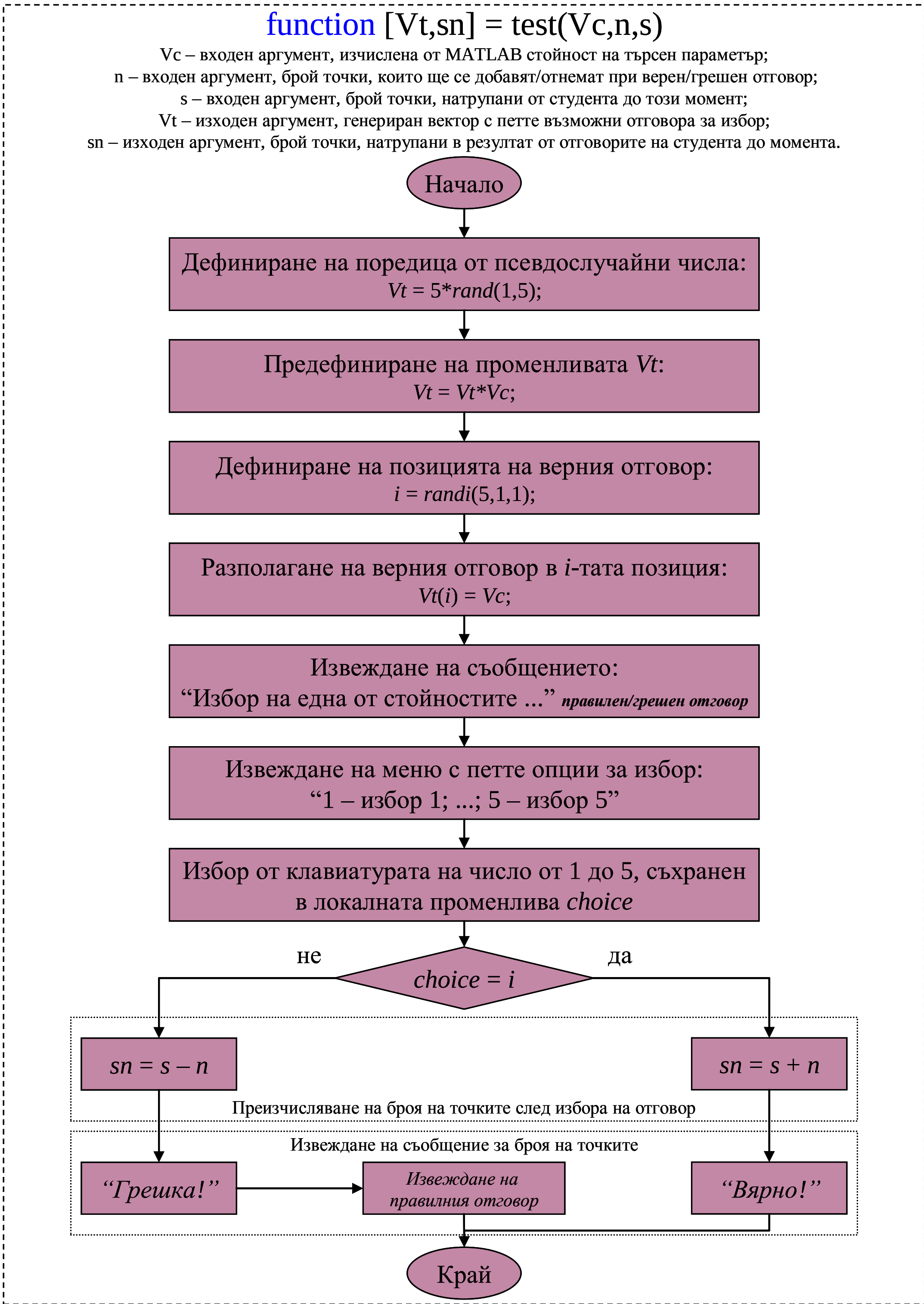


Fig. 1. Block diagram of the algorithm of the function *test* for generating five different options for selecting the correct answer

The test module is tested at calculated "exact" value 100.0000. 20 trials are done and the results of testing are presented in Table 1.

Using the built-in MATLAB functions *tic* and *toc* the time required for generating the five possible values for answers, for generating the position the correct answer will be located at and for the settlement can be determined. The simulation time (in seconds) is indicated in the last column of Table 1 – it is of the order of 4 – 8 *ms*, i.e. too little.

Table 1. Simulation results of the testing the function *test*

№	*i*	Select "1 of 5" for a value of *R*					Time, *sec*
1	**2**	289.8523	**100.0000**	72.4774	426.5156	311.0276	0.005331
2	**1**	**100.0000**	200.9040	37.9833	119.9581	61.6595	0.004993
3	**3**	119.9763	208.6335	**100.0000**	451.3581	472.3936	0.005270
4	**4**	244.6263	168.8597	450.0269	**100.0000**	55.6014	0.005276
5	**5**	194.8694	120.8456	201.9561	48.2273	**100.0000**	0.005551
6	**5**	478.0673	287.6043	29.8898	117.3900	**100.0000**	0.005859
7	**4**	7.7017	21.5119	84.4950	**100.0000**	365.8612	0.005694
8	**4**	225.4619	273.5044	148.1604	**100.0000**	94.4775	0.005591
9	**5**	91.7556	184.2423	312.8093	390.1137	**100.0000**	0.005026
10	**3**	387.8563	243.3958	**100.0000**	223.3919	153.1747	0.006029
11	**4**	335.9041	347.5702	33.9964	**100.0000**	112.0200	0.005270
12	**4**	422.1961	172.2312	390.2598	**100.0000**	3.3577	0.005574
13	**3**	193.3856	457.9956	**100.0000**	231.2246	212.1745	0.006480
14	**1**	**100.0000**	161.2359	392.3696	235.6786	17.8814	0.008226
15	**1**	**100.0000**	236.7430	76.3606	170.5623	303.6946	0.004760
16	**1**	**100.0000**	121.4248	458.7122	134.5308	382.7500	0.006068
17	**3**	143.7491	45.5567	**100.0000**	341.6816	273.2966	0.005620
18	**2**	322.2214	**100.0000**	339.5084	317.8934	472.5871	0.006695
19	**3**	354.6409	118.1153	**100.0000**	303.6520	225.0688	0.005756
20	**5**	330.9724	385.1428	175.1090	331.0048	**100.0000**	0.006781

Using the function *mark* (*function M* = *mark* (*A*, *B*, *C*, *D*, *E*, *Maxpoint*, *Sn*)) the points obtained (the score for a problem, topic or term) is converted into the six-point system of marks. The function has 7 input arguments: the first five arguments (*A*, *B*, *C*, *D* and *E*) are the lower limits of the marks: "Excellent 6", "Excellent", "Very Good", "Good" and "Satisfactory". These values are intended to be coordinated with the scale of the State matriculation examinations for the previous school year. For the school 2012 – 2013 year, they are as follows: $A = 95$; $B = 77$; $C = 59$; $D = 41$; $E = 23$ (Table 2). The sixth input argument in the function *mark* is *Maxpoint*, indicating the maximum number of points per problem / topic / term (as the maximum number of points is not fixed at 100, as in the State matriculation examinations) [3]. The seventh input argument is *Sn*, indicating the number of points accumulated by the student for a problem / topic / term, which will be transformed into a mark. The function has one output argument *M*, which is a string indicating the mark of the student.

In the function *mark* the interval which the points converted fall in is checked up. If the number of points received by the student at the moment *Sn* is greater than or equal to $A * Maxpoint / 100$, then the function takes the value 'Excellent 6'. If *Sn* is greater than or equal to *B* * *Maxpoint* / 100, then *M* = 'Excellent'. If *Sn* is greater than or equal to *C* * *Maxpoint* / 100, then *M* = 'Very Good'. If *Sn* is greater than or equal to *D* * *Maxpoint* / 100, then *M* = 'Good'. If *Sn* is greater than or equal to *E* * *Maxpoint* / 100, then *M* = 'Satisfactory', otherwise the mark is defined as *M* = 'Poor'.

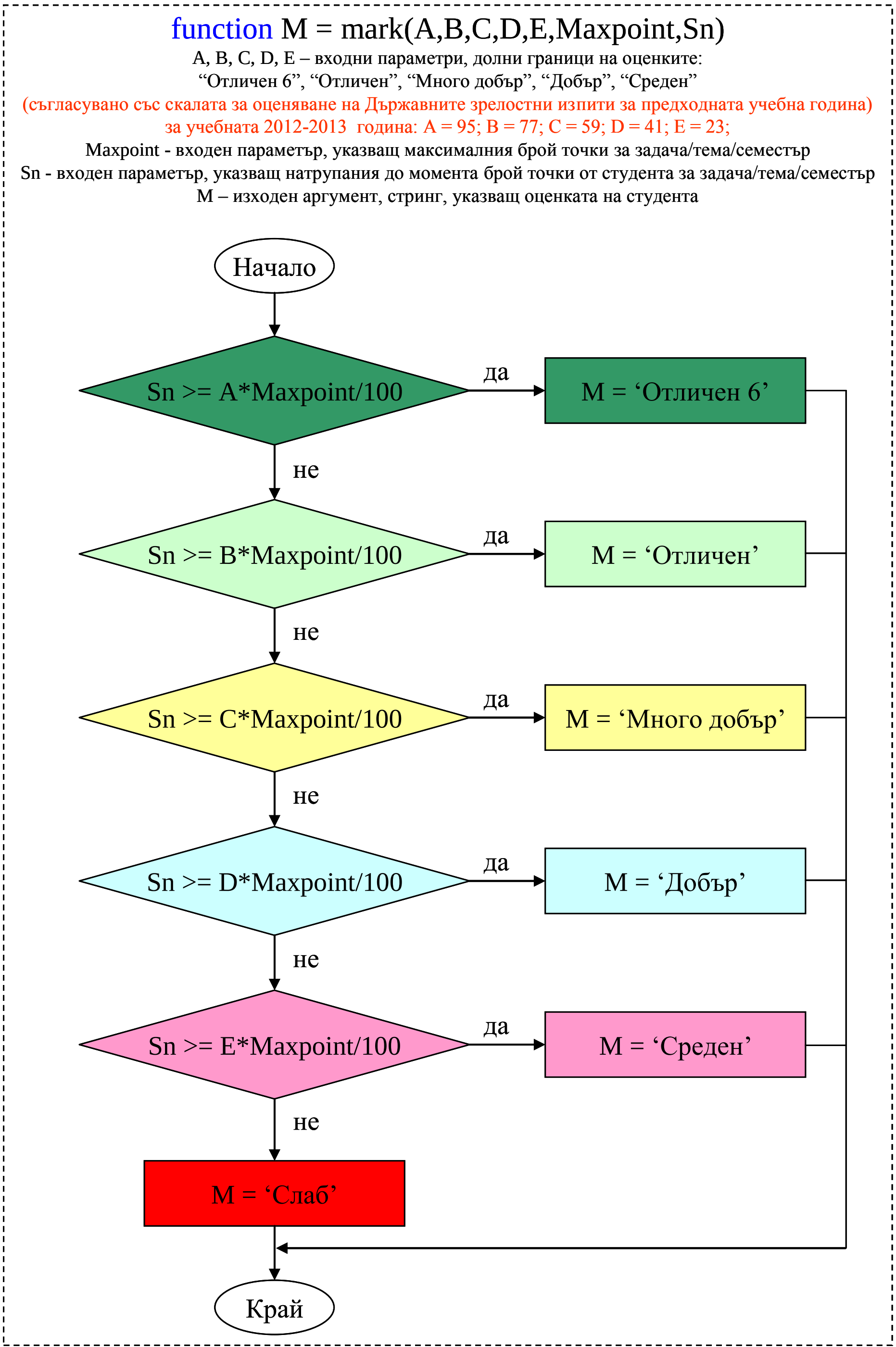


Fig. 2. Block diagram of the algorithm of the function *mark* for converting the number of points into marks

At the moment in the function *mark* realized the mark formed by the test module is not specified to the nearest hundredth, but improvement of the function is expected.

3. TEST MODULE – SIMULATION RESULTS

The test module created shows the value for each quantity a number of possible values and the student must choose one of them. When the answer is right or wrong the student receives or loses the point / points. Then the test module forms the mark of the student for a problem / topic / term according to pre-set scale. The number of points is set by the teacher for each calculation, depending on its complexity.

Table 2. Scale for transforming the number of points in marks in the State matriculation examinations for the academic 2012-2013 year

State Matriculation Examinations - assessment scale

Scale for conversion of points in marks	
MARK	**POINTS**
Poor 2	up to 22,5 points incl.
Satisfactory (3,00 - 3,49)	from **23 to** 40,5 points incl.
Good (3,50 - 4,49)	from 41 to 58,5 points incl.
Very Good (4,50 - 5,49)	from 59 to 76,5 points incl.
Excellent (5,50 - 5,99)	from 77 to 94,5 points incl.
Excellent 6	from **95 to** 100 points

A further expansion of the test module to increase the types of problems to be solved during the practical exercises in the course "Communication Circuits" is expected.

In Fig. 3 the principle of operation of the test module in solving a problem in the topic "Amplitude modulation" (Problem 4.6.23, [1]) is demonstrated. The operation of the test module is given for two computed values (the index and the percentage of amplitude modulation) with the aim of visualizing the result on a single screen.

In block 1 of Fig. 3 the input data to solve the problem is entered: the power of the carrier ($P_c = 5\,W$) and the total power ($P_t = 5{,}625\,W$, when the second input numerical value is entered) as the correctness of the input data is checked. An improper input value of the total power ($P_t = 3\,W$) is indicated with an arrow because the value entered is less than the power of the carrier.

In block 2 and block 3 of Fig. 3 the principle of operation of the test module is illustrated: the script *MD*1.*m* calculates the values of the index and the percentage of amplitude modulation, then calls the function *test*, for generating five possible options for answers. The student must choose one of them – the value closest to the calculated one by him/her (if properly calculated).

For calculating the index of amplitude modulation in the formula $m_a = \sqrt{2(P_t / P_c - 1)}$ yielding the value $m_a = 0{,}5$, the teacher defines as weight of 3 points, i.e. receiving 3 points for a correct answer or taking off 3 points for a wrong answer. The function *test* displays a warning message. The percentage of amplitude modulation is obtained $m_a = 50\,\%$ and because of ease of calculation (by multiplying by a factor of 100), the teacher defines as weight of 1 point, i.e. receiving 1 point for the correct answer or taking off 1 point for the wrong answer, the function *test* displays a warning message also.

In block 2 of Fig. 3 it can be seen that the correct answer (0.5) is located at position 3. When selecting the third position by the student, i.e. the correct answer, the function *test* shows the message "You answered correctly! The number of your points has just increased and now they are 3.".

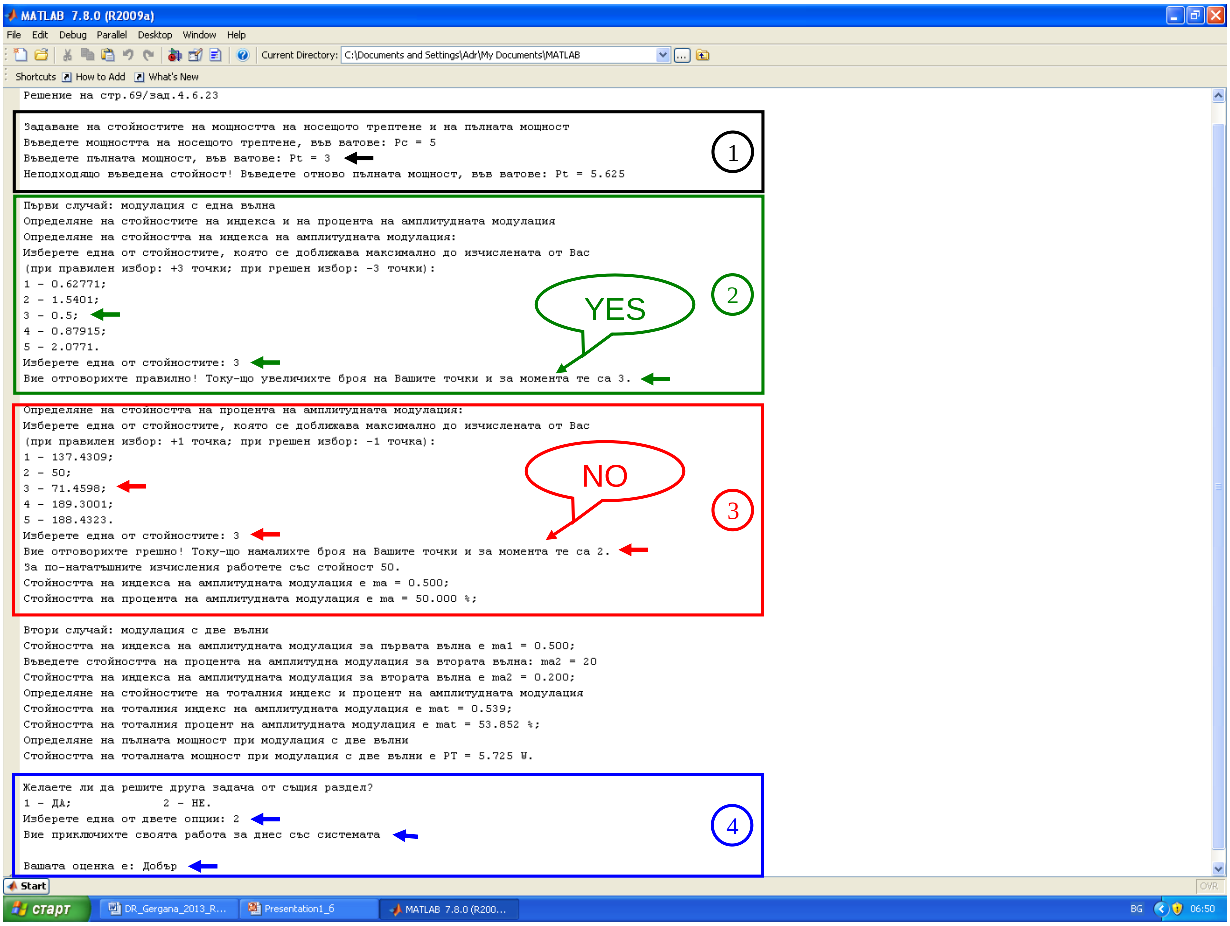


Fig. 3. Principle of operation of the test module in solving a problem
for amplitude modulation (Problem 4.6.23)

In block 3 of Fig. 3 it can be seen that the correct answer (50) is located at position 2 now. When selecting the third position by the student, i.e. one of the wrong answers, the function *test* shows the message "You answered wrong! The number of your points has just reduced and now they are 2.". The correct value is displayed by the message: "For further calculations use the value 50". It is done with the aim not to accumulate more errors in the process of further problem solving. Of course, the student has already been "punished" by taking off points for the wrong answer. Position of the correct answer is random (number from 1 to 5).

After the end of solving each problem (Fig. 3, block 4) a message: "Would you like to solve another problem in the same section?" with two possible answers: "Yes" (by pressing the button "1" on the keyboard) and "No" (by pushing the button "2" on the keyboard). If the student wishes to solve another problem in the same section a menu for choosing a topic / problem appears. If the student does not want to solve another problem, the system shows the message: “You finished your work for the day with the system”. Then the final mark of the student is formed. This is realized by the function *mark*. The student can see that he has been assessed for both the answers with a mark “Good”. It means that the student must be careful when entering values, respectively when calculating the desired quantities.

4. SPECIAL FEATURES OF THE SOFTWARE IMPLEMENTATION USING MATLAB

In the architecture of the software system developed the scripts for solving the problems in the individual topics (*TK*1.*m*, *TK*2.*m*, *TK*3.*m*, *TK*4.*m*, *EF*1.*m*, *EF*2.*m*, *EF*3.*m*, *EF*4.*m*, *MD*1.*m*, *MD*2.*m*, *MD*3.*m* and *MD*4.*m*) [4], respectively, were transformed into pseudo-code using the command *pcode* and are stored in files with the extension *.p* (*TK*1.*p*, *TK*2.*p*, *TK*3.*p*, *TK*4.*p*, *EF*1.*p*, *EF*2.*p*, *EF*3.*p*, *EF*4.*p*, *MD*1.*p*, *MD*2.*p*, *MD*3.*p* and *MD*4.*p*). When trying to open such a file (in this case *MD*1.*p*) a message that Windows can not open this file and the user must choose the kind of software to open it is obtained (Fig. 4). In Windows Explorer, both files are shown as files on MATLAB (MATLAB *m*-file and MATLAB *p*-code), but *p*-code can not be opened with MATLAB Editor (unlike file *MD*1.*m*, which will automatically be opened).

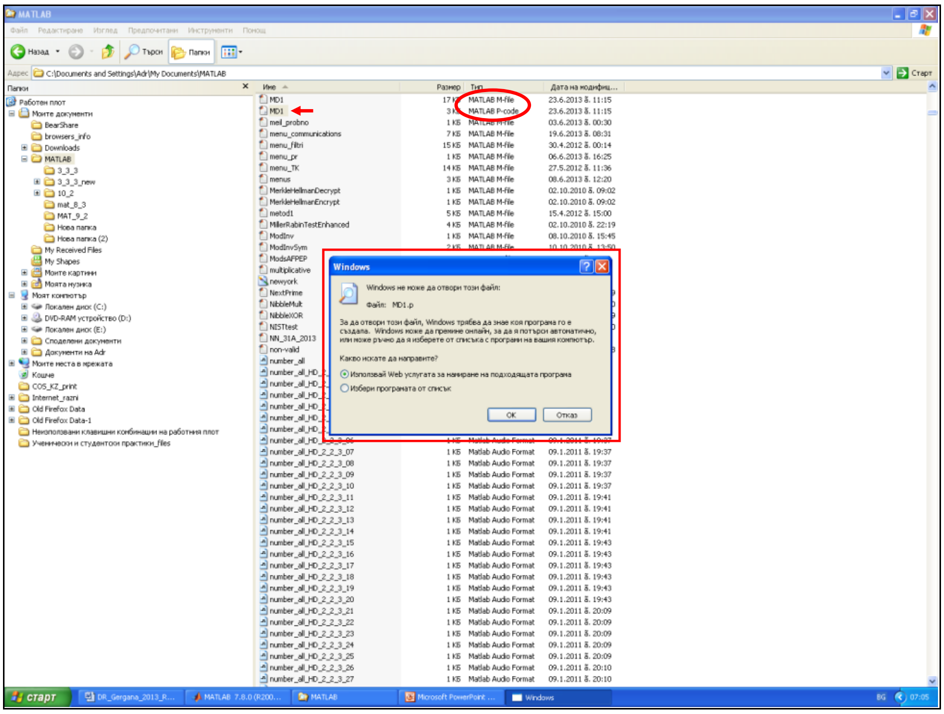


Fig. 4. Illustrating the impossibility of recognizing the file *MD*1.*p* (with extension *.p*), containing the pseudo-code of the script *MD*1.*m*

When choosing a widespread product Notepad, this file can be opened (Fig. 5), but the code of the program in it is hidden from the user (in this case students) – the file looks like an encrypted file.

The software system developed stores the student's work during the practical exercise in a text file. The way of forming the name of the text file is inspired by the method for creating e-mails to students at the University of Ruse, namely *sXXXXXX.txt*, where *XXXXXX* are the six digits of the faculty number of the student. It could also include a number indicating for example, the number of the exercise.

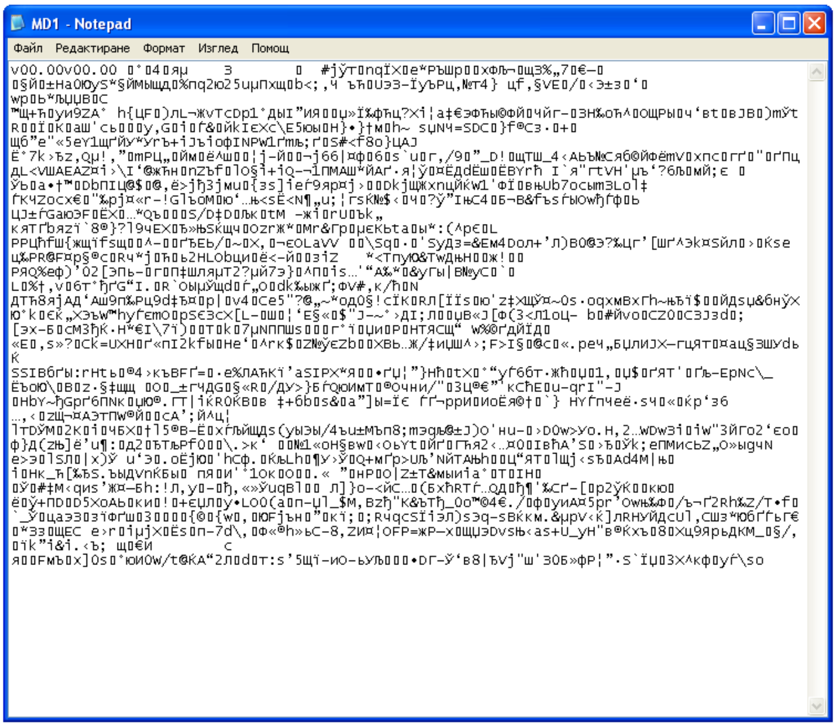


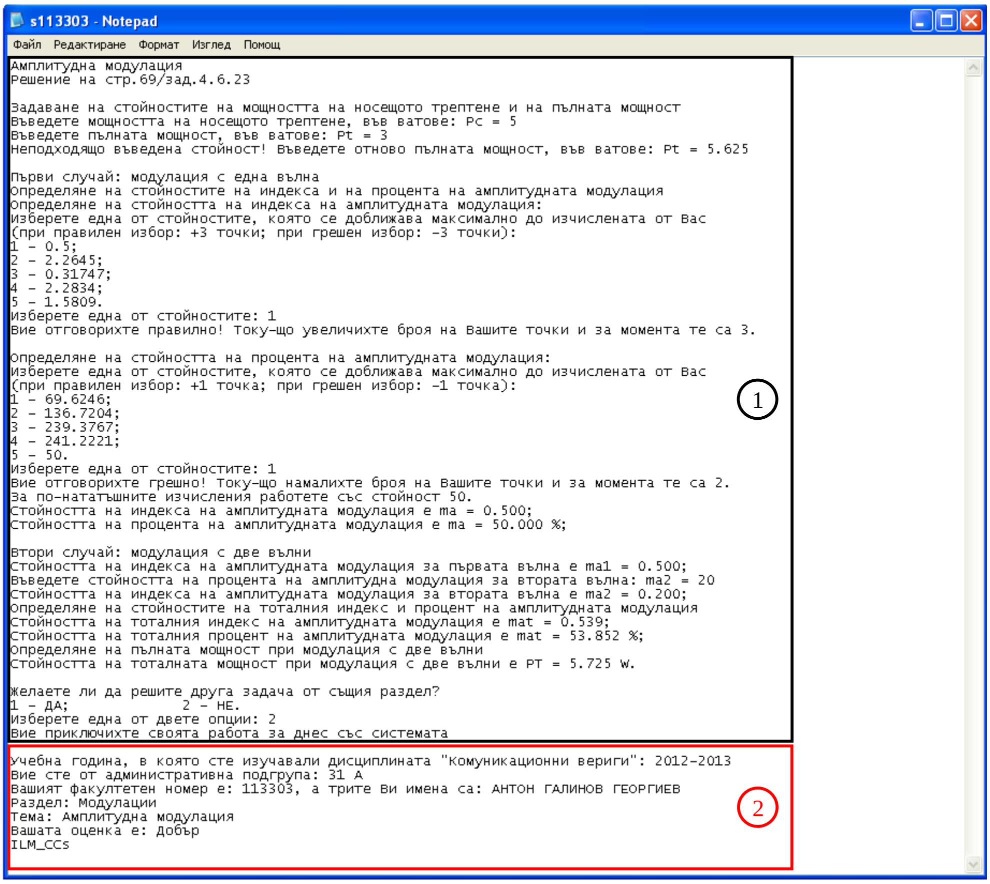
Fig. 5. Visualizing the file *MD*1.*p* (with extension .*p*),
containing the pseudo-code of the script *MD*1.*m*

Using the command *diary sXXXXXX.txt* recording MATLAB-session in the text file *sXXXXXX.txt* is done, i.e. all subsequent MATLAB commands and results of their implementation (no graphics) are stored in the file with the given name. The command *diary* with another file name switch entries in the new file. Contents of the file *s*113303.*txt* (with extension .*txt*) with the data from the current MATLAB-session of the student with faculty number 113303 is visualized through Notepad (Fig. 6).

In block 1 of Fig. 6 all MATLAB commands and results of their execution in the current session of the student are displayed. In block 2 the data of the student, such as the academic year, the administrative group, the names and faculty number of the student, the section, the topic and the mark of the student, formed by the activity of the test module of the system is displayed.

5. CONCLUSIONS

The test module of a software system developed for synthesis and analysis of communication circuits and processes is presented in the paper. The test module is designed to objectively assess the knowledge and skills of students allowing the teacher to form the final mark for a problem / exercise / term (for each student). It will be used in the course “Communication Circuits” included as mandatory in the curriculum of the specialty “Telecommunication Systems” for the Bachelor degree at the University of Ruse.



```
s113303 - Notepad
Файл  Редактиране  Формат  Изглед  Помощ
Амплитудна модулация
Решение на стр.69/зад.4.6.23

Задаване на стойностите на мощността на носещото трептене и на пълната мощност
Въведете мощността на носещото трептене, във ватове: Pc = 5
Въведете пълната мощност, във ватове: Pt = 3
Неподходящо въведена стойност! Въведете отново пълната мощност, във ватове: Pt = 5.625

Първи случай: модулация с една вълна
Определяне на стойностите на индекса и на процента на амплитудната модулация
Определяне на стойността на индекса на амплитудната модулация:
Изберете една от стойностите, която се доближава максимално до изчислената от Вас
(при правилен избор: +3 точки; при грешен избор: -3 точки):
1 - 0.5;
2 - 2.2645;
3 - 0.31747;
4 - 2.2834;
5 - 1.5809.
Изберете една от стойностите: 1
Вие отговорихте правилно! Току-що увеличихте броя на Вашите точки и за момента те са 3.

Определяне на стойността на процента на амплитудната модулация:
Изберете една от стойностите, която се доближава максимално до изчислената от Вас
(при правилен избор: +1 точка; при грешен избор: -1 точка):                   (1)
1 - 69.6246;
2 - 136.7204;
3 - 239.3767;
4 - 241.2221;
5 - 50.
Изберете една от стойностите: 1
Вие отговорихте грешно! Току-що намалихте броя на Вашите точки и за момента те са 2.
За по-нататъшните изчисления работете със стойност 50.
Стойността на индекса на амплитудната модулация е ma = 0.500;
Стойността на процента на амплитудната модулация е ma = 50.000 %;

Втори случай: модулация с две вълни
Стойността на индекса на амплитудната модулация за първата вълна е ma1 = 0.500;
Въведете стойността на процента на амплитудна модулация за втората вълна: ma2 = 20
Стойността на индекса на амплитудната модулация за втората вълна е ma2 = 0.200;
Определяне на стойностите на тоталния индекс и процент на амплитудната модулация
Стойността на тоталния индекс на амплитудната модулация е mat = 0.539;
Стойността на тоталния процент на амплитудната модулация е mat = 53.852 %;
Определяне на пълната мощност при модулация с две вълни
Стойността на тоталната мощност при модулация с две вълни е PT = 5.725 W.

Желаете ли да решите друга задача от същия раздел?
1 - ДА;              2 - НЕ.
Изберете една от двете опции: 2
Вие приключихте своята работа за днес със системата

Учебна година, в която сте изучавали дисциплината "Комуникационни вериги": 2012-2013
Вие сте от административна подгрупа: 31 А
Вашият факултетен номер е: 113303, а трите Ви имена са: АНТОН ГАЛИНОВ ГЕОРГИЕВ
Раздел: Модулации                                                              (2)
Тема: Амплитудна модулация
Вашата оценка е: Добър
ILM_CCs
```

Fig. 6. Visualizing the contents of the file *s*113303.*txt* (with extension .*txt*), containing the data from the current session of the student with faculty number 113303 using Notepad

References

[1] Manukova, A., A. Borodzhieva. Communication circuits – a handbook for exercises. Ruse, University of Ruse, 2002 (in Bulgarian).

[2] http://ecet.ecs.uni-ruse.bg/else

[3] http://mon.bg/opencms/export/sites/mon/top_menu/general/dzi/dzi2008/08-06-13_dzi_skala_ocenjavane.pdf

[4] Borodzhieva, A., T. Stoyanova. Software System for Synthesis and Analysis of Communications Circuits and Processes Using MATLAB. 10th Summer School, Advanced Aspects of Theoretical Electrical Engineering, Sozopol '2014, 19.09. –22.09.2014, Sozopol, Bulgaria, (in the press).

Reviewer: Prof. PhD K. Brandisky

POWER SOURCE TYPE IMPACT ON THE OUTPUT SIGNAL OF PULSE ECT

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Abstract. *In the paper are investigated the differences between the output signal of pulse eddy-current transducer when it is supplied with ideal voltage source and ideal current source in two types of periodical pulses. It is considered parametric transducer when the controlled parameter is specific electrical conductivity of the conductive ferromagnetic controlled object. It is shown the difference in the form of output signal and based on these results are increased the number of its information parameters in different type of supplying and in different form of input pulses.*

Keywords: *pulsed ECT, voltage driven, current driven*

1. INTRODUCTION

The output signal of the eddy current transducers (ECT) depends mainly on the shape, dimensions and electrophysical parameters of the controlled object (CO). The signal depends equally on the shape, dimensions and electrophysical parameters (especially in the presence of magnetic circuit) of the ECT and mostly on the parameters of the field current generated by it. The output signal also depends on the relative location of the ECT and the CO.

In the classic theory of electromagnetic control most often the excitation winding of the ECT is supplied from *ideal* ***current*** *source.* The change of the output signal type is insufficiently studied when the supply is from *ideal* ***voltage*** *source*. The occasional studies [1] consider the case of stationary *sinusoidal mode*. The recent intensive development of the pulse methods for non-destructive control bring up the issue of the difference in the type of the output signal of the transducer in case of pulse supply from *ideal voltage source* and *ideal current source*. The subject of this study is a *parametric ECT* (i. e. only one-coil) supplied with the two types of ideal sources (Fig. 1 – of voltage and Fig. 2 – of current), characterised with EMF (electromotive force) and EMC (electromotive current) that change periodically and are single-pole with triangle (Fig. 3) and rectangular (trapezoidal) (Fig. 4) shape. In the studied example in both cases the frequency is f = 2.5 kHz, and the mark-to-space is 0.5. The fronts of the rectangular (trapezoidal) pulse are 1 μs, i. e. 0.5 % of its duration. The controlled object is non-ferromagnetic, the ECT is without ferromagnetic core, which enables the latter to be modelled in the equivalent circuit with linear resistor R_{ECT} and linear inductance L_{ECT} (Fig. 1 and Fig. 2).

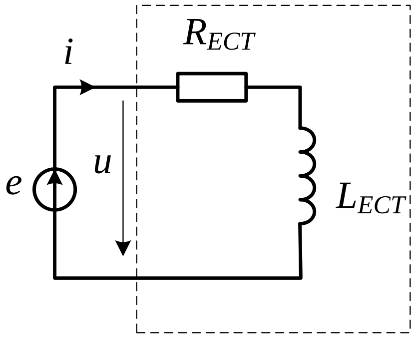

Fig. 1

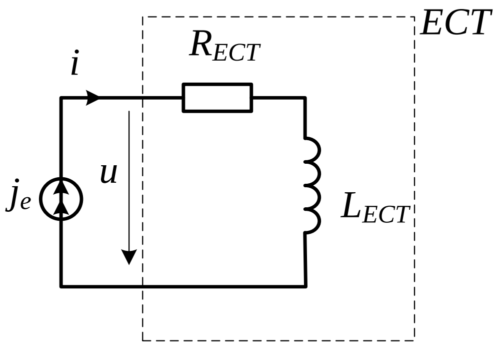

Fig. 2

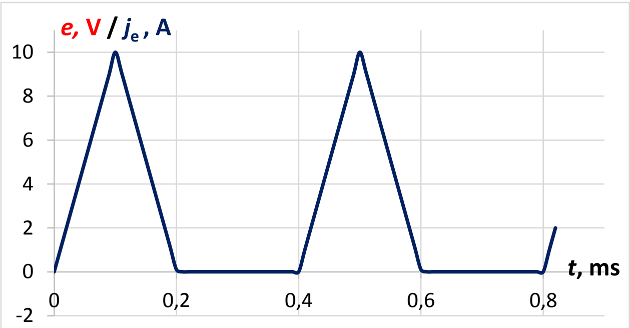

Fig. 3

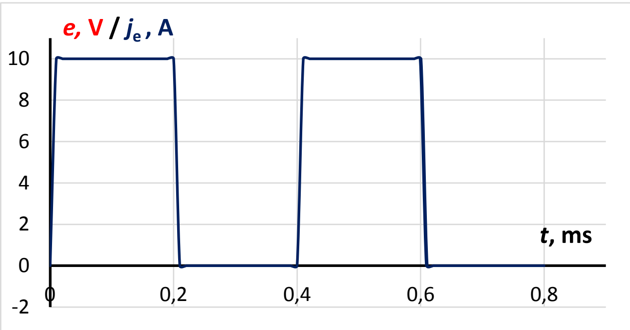

Fig. 4

2. SETUP OF THE PROBLEM

A. *Output signal*

The classic theory of the non-destructive control [2] considers the complex *imported* impedance Z_{BH} of the coil, as output signal of the parametric ECT, because the generally considered modes are sinusoidal, the supply is from ideal current source:

$$Z_{ECT} = Z_0 + Z_{im}, \quad (1)$$

$$Z_0 = R_0 + j\omega L_0, \quad (2a)$$

$$Z_{im} = R_{im} - j\omega L_{im}. \quad (2b)$$

Of course the imported complex conductance may be introduced in case of supply from ideal voltage source.

$$Y_{im} = G_{im} - jB_{im}. \quad (3)$$

The main information parameters of the output signal in sinusoidal mode are the real and imaginary part of the complex representations or their module and phase. Their frequency is less used.

Fig. 5 shows the *normalized plan diagram* of **the relative imported complex impedance** $Z_{im}^* = Z_{im}/\omega L_0$ in case of supply from ideal current source and change of the specific electricity conductance of the CO from 0 to 1.10^6 MS/m, which is a fundamental relation in the theory of NDT. Fig. 6 presents the equivalent *normalized plan diagram* of the **relative imported complex admittance.**

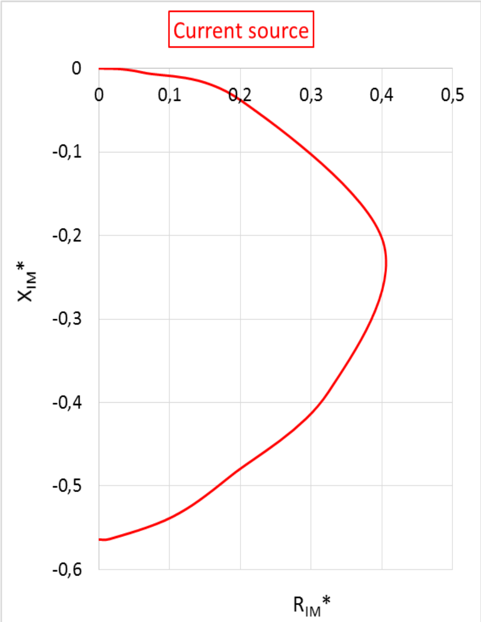

Fig. 5

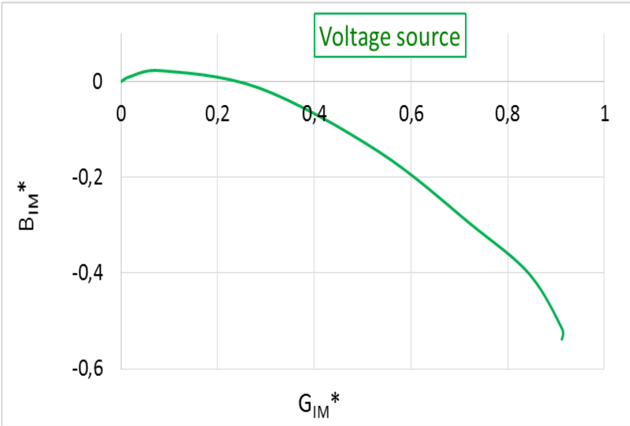

Fig. 6

Obviously in case of pulse modes this is not possible, therefore here the current through the transducer in case of supply from voltage source (Fig. 1) and the voltage at the terminals of the ECT in case of supply from current source (Fig. 2) will be considered as output signal. It shall be noted that these output signals by their nature coincide with the complex impedance (admittance) in case of the sinusoidal supply, but unlike them offer much more information parameters. They depend on the shape of the currents and voltages and most often are with extreme values, average or RMS values and phase ratios.

B. *Calculation model*

The controlled object is a homogenous upright circular cylinder. It is non-ferromagnetic and conducting with specific electric conductance γ, considered as the controlled (measured) value. ECT is a real three-dimensional cylinder coil, coaxial with the CO and is made of standard copper winding wire (Fig. 7).

The problem in case of supply from ideal current source is purely a “field” one, while in case of ideal voltage source the problem is mixed – Maxwell’s equations and the equations following Kirchoff’s laws shall be solved together. Both cases do not offer useful for direct application outcomes of analytic solutions – it is always necessary to apply, even partially, numerical methods. That is why it is very useful to apply modern software products that use numerical models (most often FEM) to solve the electrodynamic problem, enabling the inclusion of coils in electric circuits. In this case the product MagNet 7.4 [3, 4] is used, which involves creation of 3D models, performs analysis under non-stationary modes and enables inclusion of the elements of the model in various electric circuits.

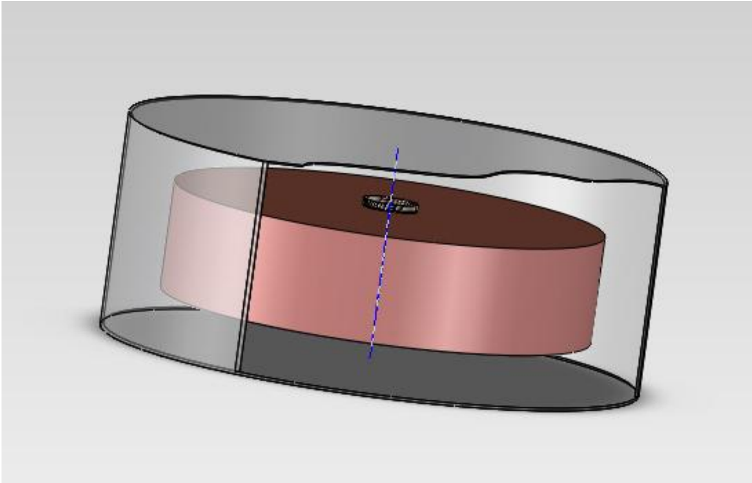

Fig. 7

3. RESULTS OF THE NUMERICAL EXERIMENTS

A series of numerical experiments are carried out with different type of the supplying source –current driven (Fig. 2) and of voltage driven (Fig. 1) and with two shapes of the supplying pulses – triangular (Fig. 3) and rectangular (Fig. 4) with eight values of the specific electric conductance: problem P1 – γ = 0.01 MS/m, P2 – γ = 0.2 MS/m, P3 – γ = 1 MS/m, P4 – γ = 8 MS/m, P5 – γ = 50 MS/m, P6 – γ = 300 MS/m, P7 – γ = 1500 MS/m, P8 – γ = 20000 MS/m.

- Supply from ideal current source in case of pulses with:
  – Triangular shape

Fig. 8 and Fig. 9 show the grafs of the output voltage.

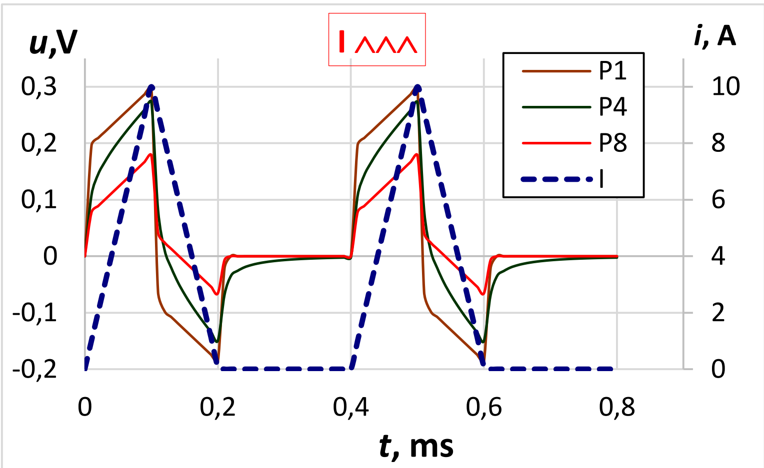

Fig. 8

Fig. 10 shows the dependence of the extrema of the output voltage (in absolute terms) on the specific electric conductance.

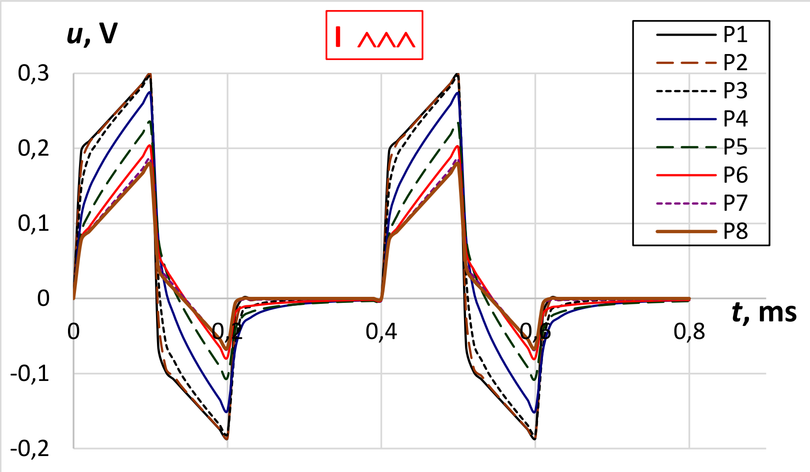

Fig. 9

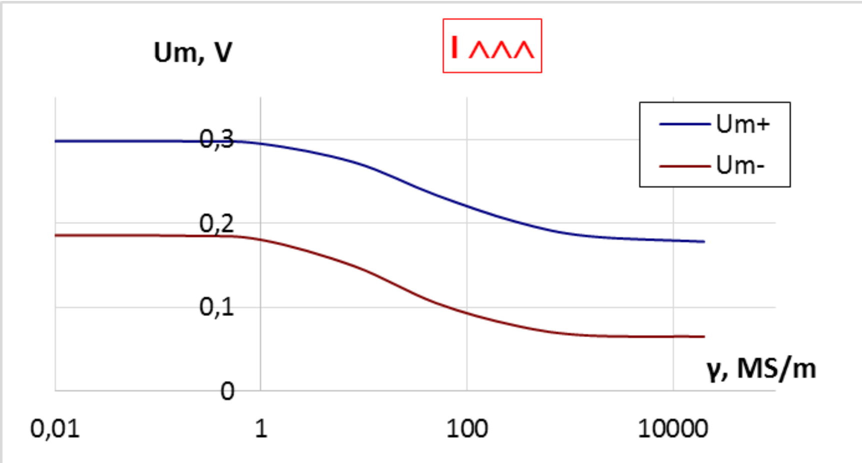

Fig. 10

– Rectangular shape

Fig. 11 and fig. 12 show the grafs of the output voltage.

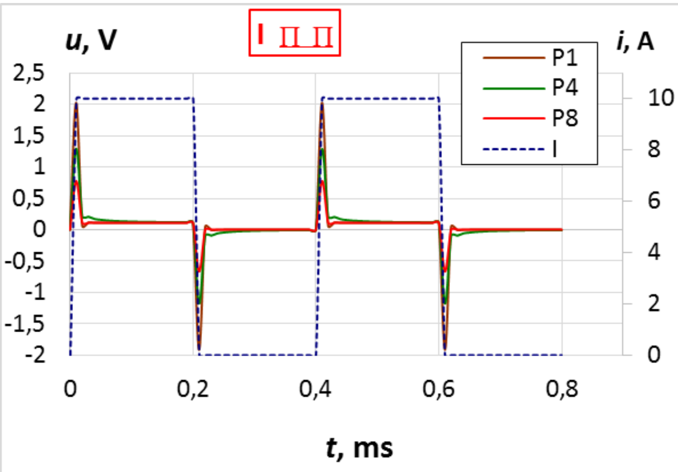

Fig. 11

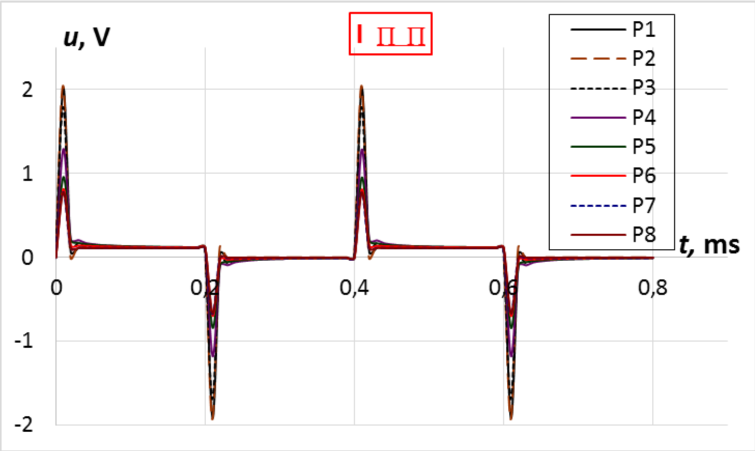

Fig. 12

Fig. 13 shows the dependence of the extrema of the output voltage (in absolute terms) on the specific electric conductance.

- Supply from ideal source of voltage in case of pulses with:
  - Triangular shape

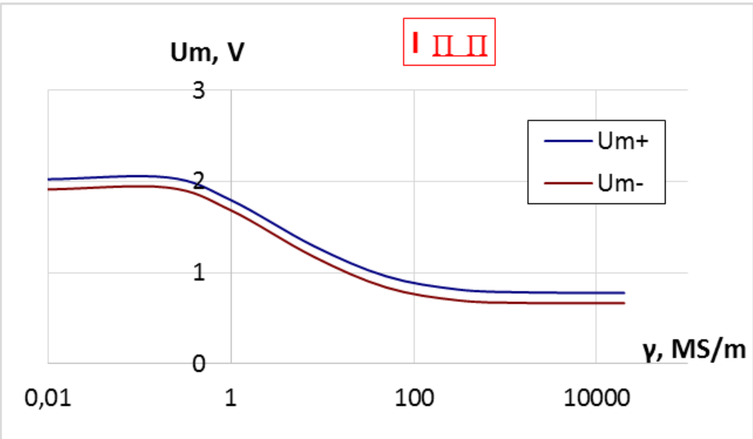

Fig. 13

Fig. 14 and Fig. 15 show the grafs of the output current.

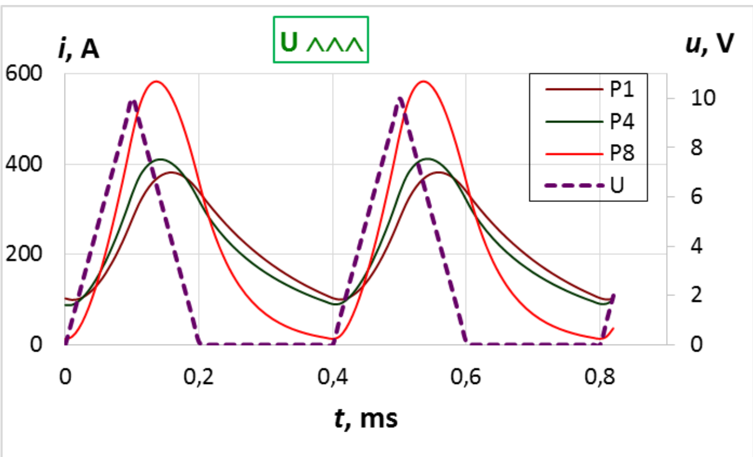

Fig. 14

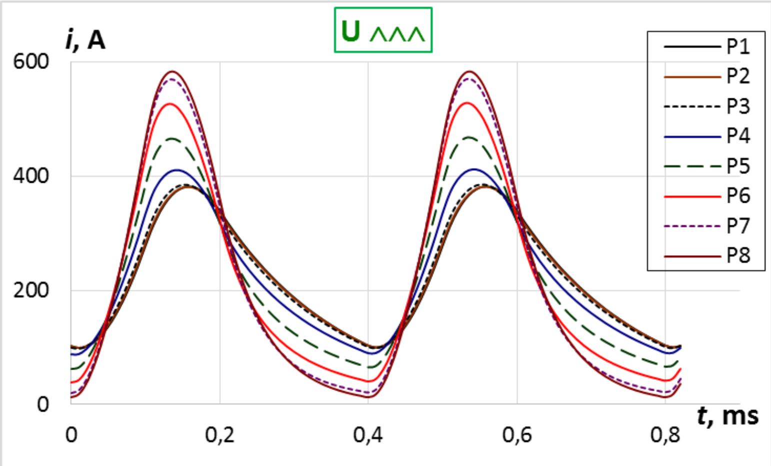

Fig. 15

Fig. 16 shows the dependence of the extrema of the output current on the specific electric conductance.

– Rectangular shape

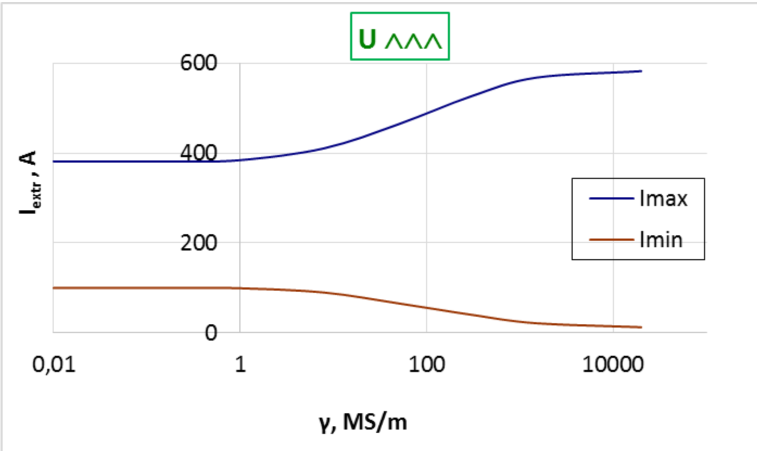

Fig. 16

Fig. 17 and fig. 18 show the grafs of the output current.

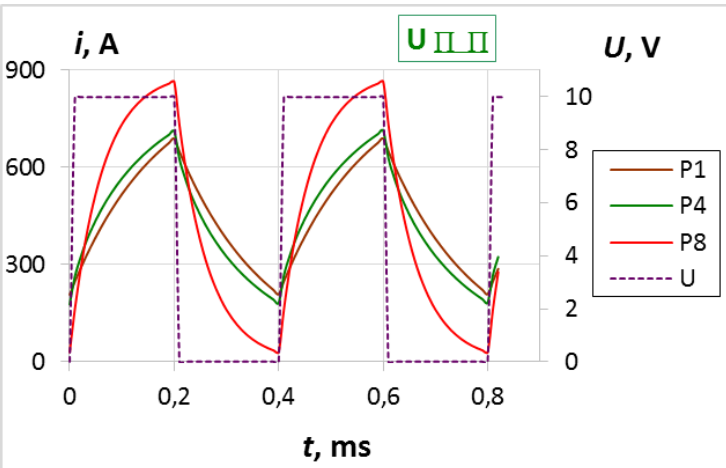

Fig. 17

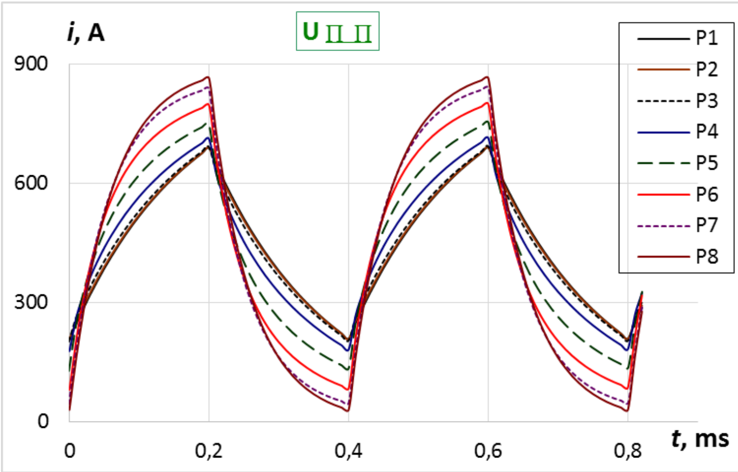

Fig. 18

Fig. 19 shows the dependence of the extrema of the output current on the specific electric conductance.

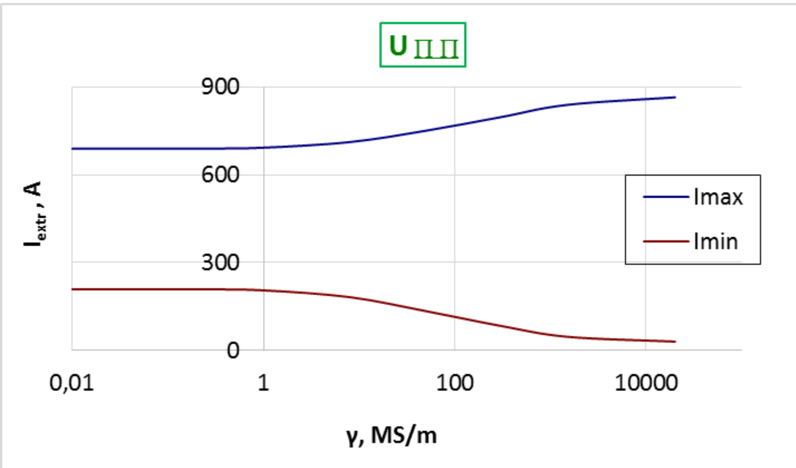

Fig. 19

4. CONCLUSIONS

- The shape of the output pulses with the two types of ideal sources differs substantially:
  - In case of current source with triangular pulses the output voltage is with the shape of *bipolar trapezoidal pulses* (Fig. 9) and with the increase of the specific electric conductance the negative part becomes *triangular*. In case of voltage source with triangular pulses, the output current is with the shape of *single-pole bell-shaped pulses* that do not reach zero (Fig. 14).
  - In case of current source with rectangular pulses, the output voltage is with the shape of *bipolar narrow peaked pulses* during the fronts of the field current (Fig. 11). In case of voltage source with rectangular pul-

ses, the output current is with the shape of *single-pole triangular pulses, which sides are exponents* that do not reach zero (Fig. 17).

- In case of supply from ideal voltage source with both output pulse shape, the average value of the output pulses is an appropriate information parameter, while in case of supply from ideal current source, the average (RMS) value of the output current is useful only for triangular pulses.
- **In all cases the extrema of the output pulses are an appropriate information parameter!** The character of their dependence on the specific electric conductance γ is similar in cases of different shapes of the output pulses.

The table presents the ranges, in which the sensitivity of the output signal towards the specific electric conductance is greater for the different cases.

Source	Pulse shape	Max sensibility to γ, MS/m	
		from, MS/m	to, MS/m
Current driven	triangular	1	100
	rectangular	0.5	120
Voltage driven	triangular	3	200
	rectangular	3	200

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Reviewer: Prof. PhD K. Brandisky

DIAGNOSIS OF CHAOTIC PROCESSES IN NONLINEAR DYNAMICAL SYSTEMS

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Abstract. *The paper presents an algorithm proposed for diagnosis of chaotic process in a nonlinear dynamic system. The algorithm is illustrated by examination of a classical Lorenz system.*

Keywords: *nonlinear dynamical systems, chaotic processes, phase portrait, chaotic attractor*

1. INTRODUCTION

To study the irregular processes in nonlinear dynamical systems (NDS) different methods are used: physical experiments, numerical and analytical methods, computer modeling and simulation. Some of them are related to visual diagnosis of the process [1,2] and are applicable only at initial diagnosis and prediction of chaotic behavior.

More accurate evaluation of the process is given by analytical and numerical methods [3], the result is objective and convenient also for creating algorithms for synthesis of chaotic systems.

Undoubtedly, the diagnosis methods and the choice of diagnostic criteria depend on the particular system and tasks assigned for solving. It is typical for all of them that they are built based on the main properties of chaotic fluctuations [5,6].

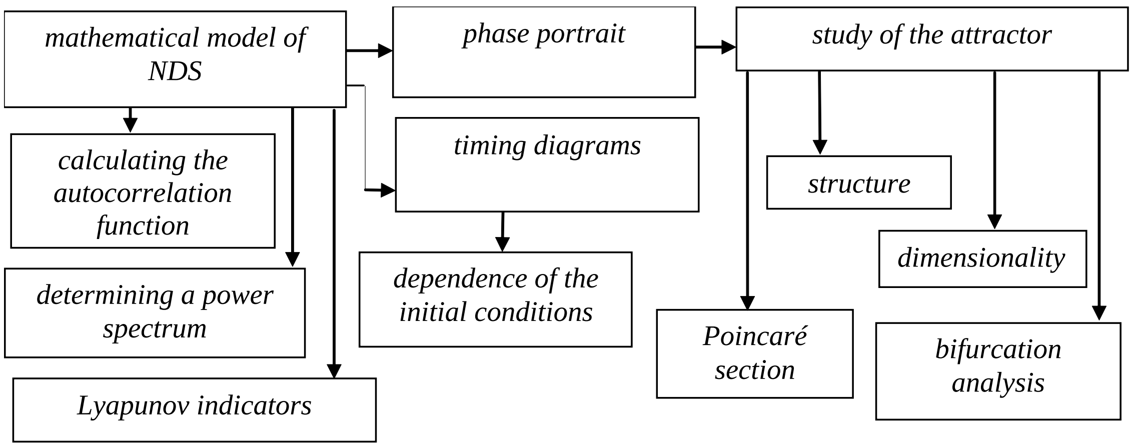

Fig. 1

Considering these properties, the research methods of the NDS, given in Fig. 1, are systemized and the paper presents an algorithm proposed for the diagnosis of chaotic processes in NDS. The algorithm is illustrated on the basis of the Lorenz system [4], which is a classical example of the existence of chaotic fluctuations.

2. ALGORITHM FOR DIAGNOSIS OF CHAOTIC PROCESSES IN NDS

The examination on the nature of the processes in NDS starts with construction of a phase portrait as shown in Fig. 2.

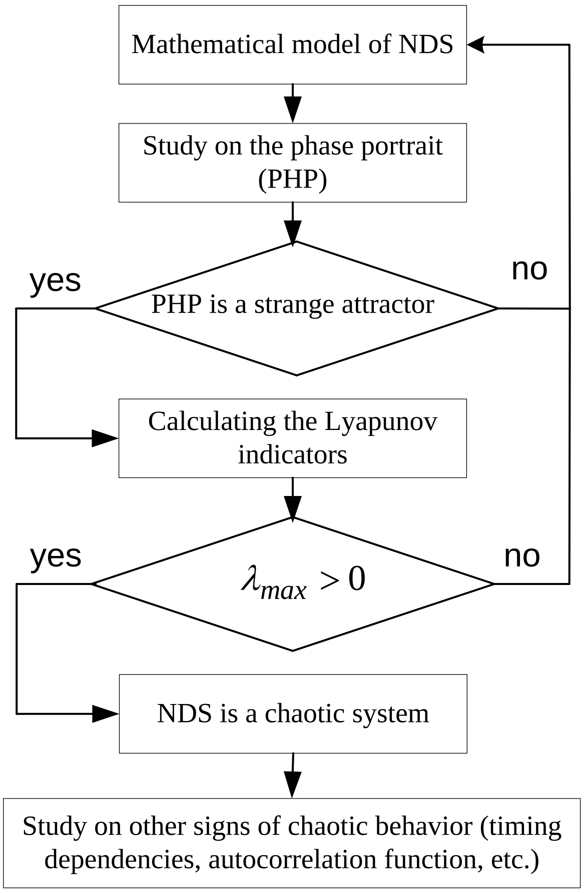

Fig. 2

The analysis of the phase portrait allows to judge about the topological structure of the chaotic process. Here it is useful to examine also the qualitative transformations of the phase portrait in altering parameters of the examined system, i.e. the bifurcation diagram. In regard to the attractor characteristics, it is appropriate to determine also its dimensionality, as the fractal dimensionality [6] indicates for existence of a fractal structure, i.e. "Strange" attractor.

Undoubtedly, however, the most important feature of the attractor is the presence of Lyapunov indicators and their spectrum [5]. They determine the stability of the attractor orbit. The presence in the spectrum of minimum one positive Lyapunov indicator means instability of the examined phase trajectory. The largest Lyapunov indicator being positive is a necessary and sufficient condition for chaotic of the system [5].

After examining NDS by these basic criteria and detecting the signs of chaotic behavior, the other properties of irregular processes are tracked as well: the nature of time dependencies, sensitivity to initial conditions and changes of the autocorrelation function.

3. ILLUSTRATIVE EXAMPLE

The proposed algorithm for diagnosis of chaotic regime is discussed on the basis of the Lorenz system with classical parameters $\sigma = 10$, $\rho = 28$ и β =8/3 [4]:

$$\begin{aligned} \dot{x} &= \sigma(y - x) \\ \dot{y} &= \rho x - y - xz \\ \dot{z} &= xy - \beta z \end{aligned} \tag{1}$$

For the purpose of research, a simulation model is developed in Matlab/Simulink environment (Fig. 3) to obtain the phase portrait (Fig. 4) and timing diagrams (Fig. 6).

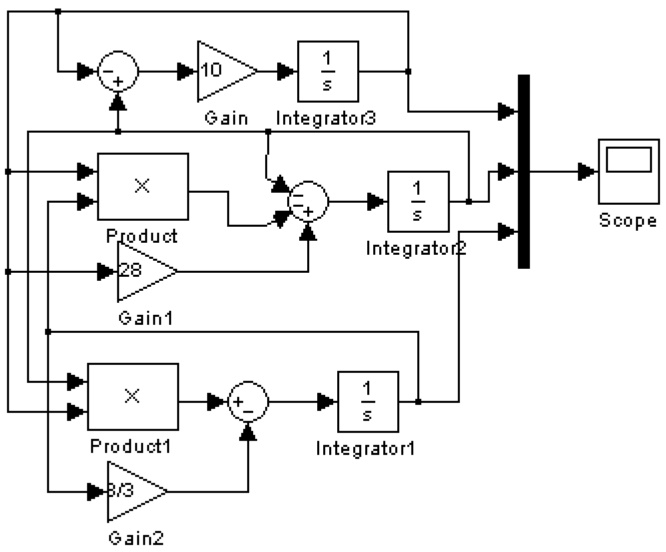

Fig. 3

The spectrum of Lyapunov indicators is calculated using Matlab and shown in Fig. 5. The chaotic of the system is confirmed with the existence in the spectrum of maximum positive indicator $\lambda_{max} > 0$.

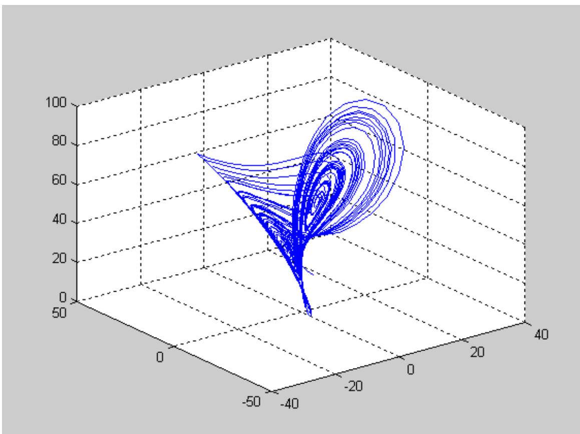

Fig. 4

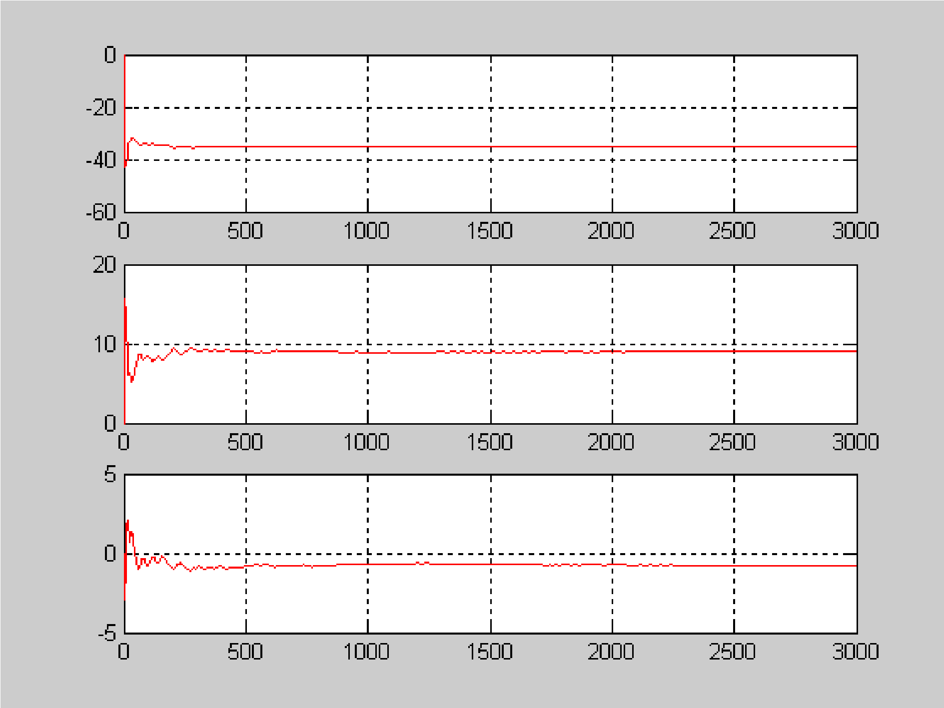

Fig. 5

Fig. 6 shows the timing diagrams illustrating the complete lack of periodicity in the amplitude of phase variables *x, y, z*.

One of the most significant features of the chaotic process, sensitivity to initial conditions, is evident by the dependencies shown in Fig. 7 where the solution with two different initial values is given: $x_1(0)=10$, $x'_1(0)=9$.

Through numerical study in Matlab, the amendment of the autocorrelation function (Fig. 8) for the variable *x* of system is built (1). It can be seen that the autocorrelation function strongly decreases, which is another evidence for chaotic of the process.

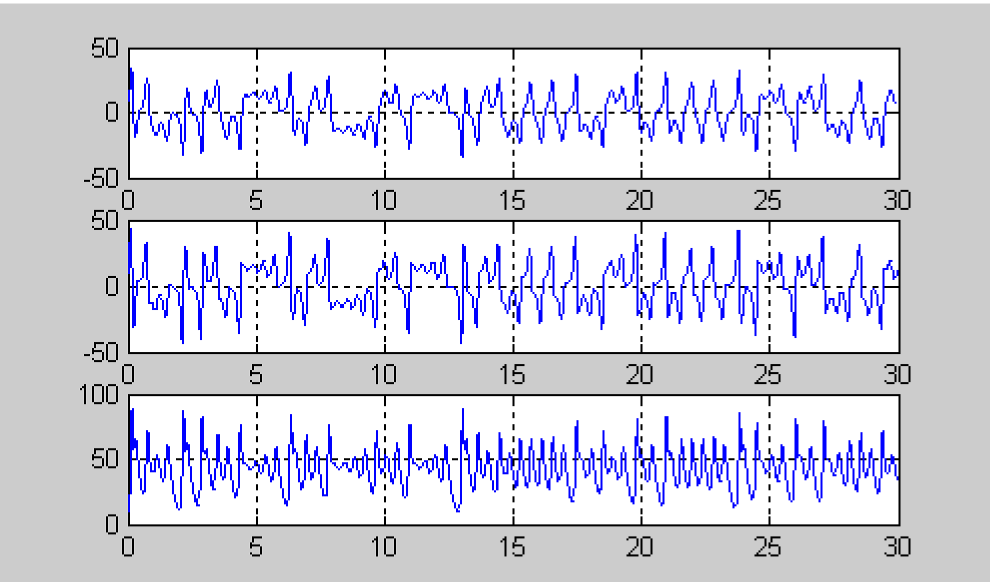

Fig. 6

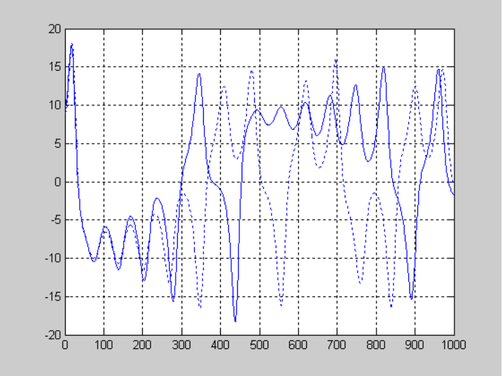

Fig. 7

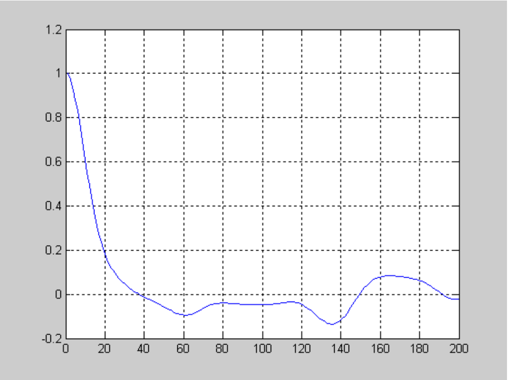

Fig. 8

4. CONCLUSION

While studying the chaotic in NDS, it is not necessary to check all criteria and features of the irregular processes, since many of them are interchangeable. The complex of diagnostic methods for a chaotic process is sufficient to include examination on the phase space and calculation of the spectrum of Lyapunov indicators as illustrated by the algorithm proposed in this paper.

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Reviewer: Assoc. Prof. PhD S. Petrakieva

MODELING OF THE ELECTRICAL DISCHARGE OF LIGHTING ON OVERHEAD POWER LINE

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Abstract. *The electrical discharge of lightning, which strikes down the wires of overhead power line for high voltage – 110 kV is investigated. Electrostatic discharge model of lightning is created. Simulations of emergency mode of the power line in the case of direct hit of lightning are made. The harmonic composition of the current of lightning discharge is investigated. The electrical discharge of the lightning creates a high voltage level of the power line. These surges and the availability of harmonic currents violate electromagnetic compatibility. They create disturbing effects of the overhead power line for high voltage and other electrical equipment in the vicinity.*

Keywords: *electrostatic discharge, overhead line, high-voltage, modelling, SPICE simulation, electromagnetic compatibility*

1. INTRODUCTION

The lightning is an eternal source of charge of Earth electric field. Source of lightning are electric charges of the storm clouds. At any time, at different points of the Earth's lightning flashes over 2,000 thunderstorms. In every second of about 50 lightning strikes the surface of the earth, and on average, each square kilometre of its lightning strikes six times per year. More Benjamin Franklin showed that lightning hitting on the ground from the storm clouds - are electrical discharges that carry a negative charge on it.

Formation of storm clouds according to the modern theory of thunderstorms is done in the following way. In an atmosphere of saturated steam under the influence of a strong air flow occurs spray of water droplets. The received as a result of spray water mist is loaded with negative charges, and the remaining drops with positive charges.

Lightning - greetings from the space, and X-ray source. However cloud unable itself so electrify itself to cause a discharge between its lower part and ground. The electric field in the thundercloud never exceeds 400 kV/m, and the electric breakdown in air occurs when the tension more 2500 kV/m. Therefore for the occurrence of lightning need something else other than the electric field. In 1992 Russian scientist Alexander Gurevich of Physics Institute Lebedev (LPI RAS) has suggested that a kind of lightning-ignition may be cosmic rays- high energy particles raining down on Earth from space at nearly the light speed [7].

2. LIGHTNING ELECTROMAGNETIC PULSE

The current of the lightning has the shape of a pulse shown in Fig. 1 [8] and is characterized by three parameters:

- I_m is amplitude of the lightning current;
- $\tau_в$ is wavelength;
- $\tau_ф$ is length of the front
- $\alpha = \dfrac{I_m}{\tau_ф}$ is average steepness of the current.

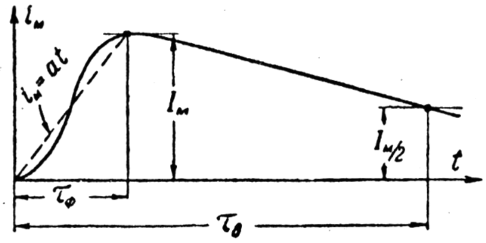

Fig. 1. Electromagnetic wave form of lightning current

The amplitude value of the current is 20kA up to 200 kA. The steepness of the wave front of the current is about 300 kA / μs. The electric field intensity in the cloud is about $E_0 \approx 10^4 V/m$. At certain points the electric field intensity can reach 1 MV/m ÷ 3 MV/m.

3. MODELING OF THE LIGHTNING CURRENT

Circuit model of the lightning current is created. The software package PSpice (ORCAD) [9] is used. The lightning current is represented by a piece-wise linear current source.

The shape of the lightning current has the form shown in Figure 2.

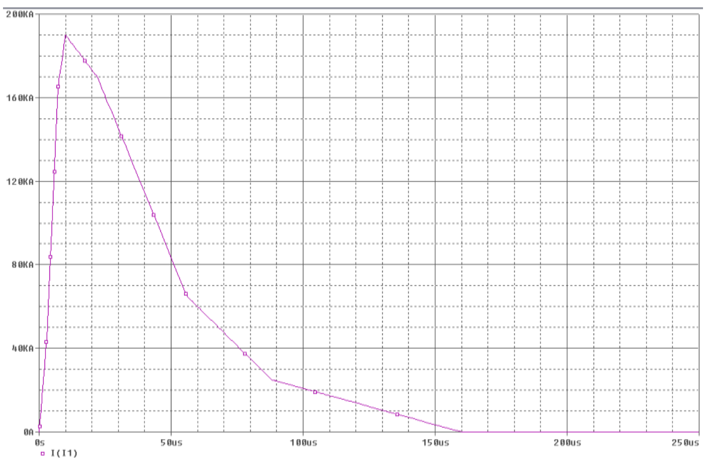

Fig. 2. The shape of the lightning current model

4. MODEL OF THE ELECTRIC DISCHARGE OF LIGHTNING ON THE POWER LINE

A lightning strike on the final stretch of overhead high voltage power line 110 kV is considered. The electrical discharge of lightning strike on the power line wires is investigated.

Circuit model of overhead power line 110 kV, presented with concentrated parameters is used [10].

A model of electrostatic discharge lightning is created.

The SPICE model of the lightning discharge on overhead power line110 kV is shown in Fig. 3.

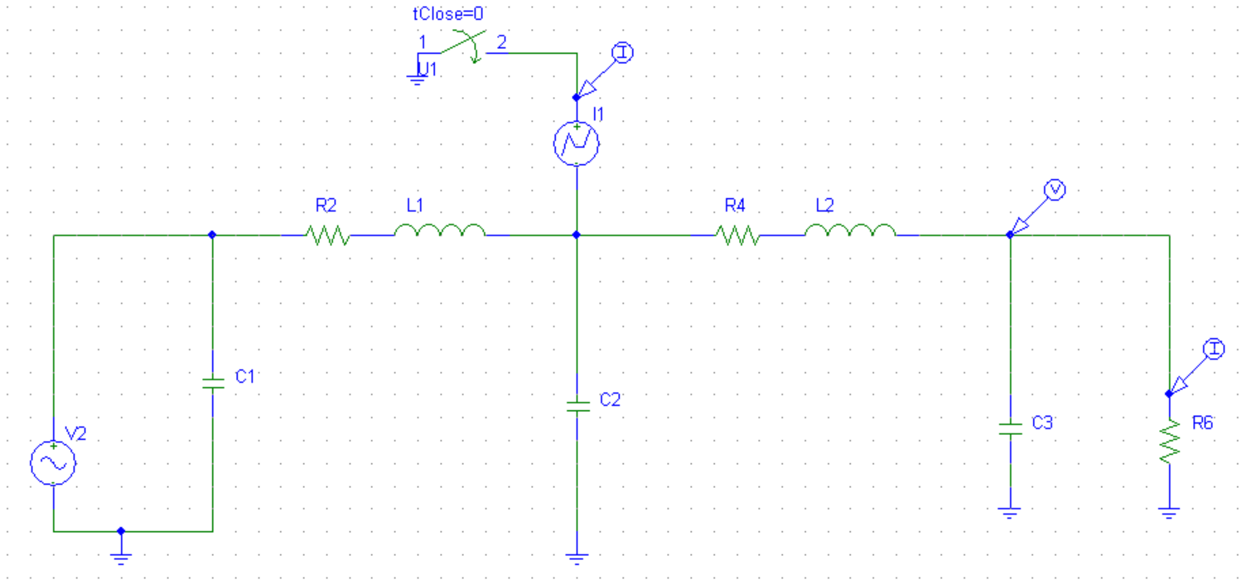

Fig. 3. Model of the lightning discharge in power line for HV

5. SIMULATIONS REZULTS

Simulations are carried on the work of the power in emergency mode at discharge in the power of lightning. The power line is supplied from a voltage source 110 kV from the nearest substation is loaded with load lowering substation 110/20 kV.

When lightning strikes occurs emergency mode in which the voltages and the currents in the power line significantly exceed the nominal values.

The results of the simulations of discharge through the power line of the bolt shown in Fig. 4 and Fig. 5.

The voltage on the 110 kV power line even for a very short time reaches too high values of the order of several MB. These surges can disrupt the normal operation of the power line, due to the appearance short-earth compounds. As a result will be reduced the operation resource of the insulation.

In terms of electromagnetic compatibility for other electrical equipment located in vicinity, the power line can creates surges, which can create dangerous levels of electric intensity and disrupt their normal operation. As a consequence, the radio-electronic equipment will create harmful interference, which will briefly interrupt its work.

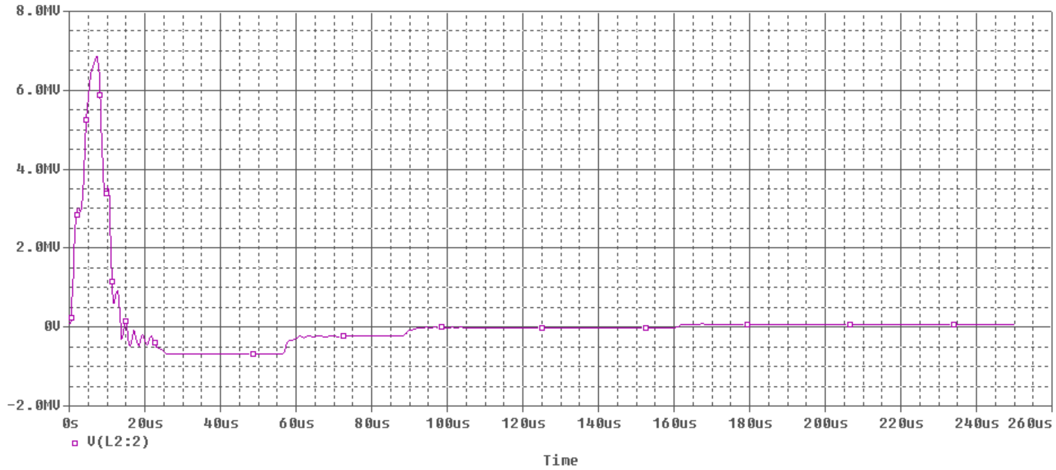

Fig. 4. Surge of lightning discharges on the 110 kV power line

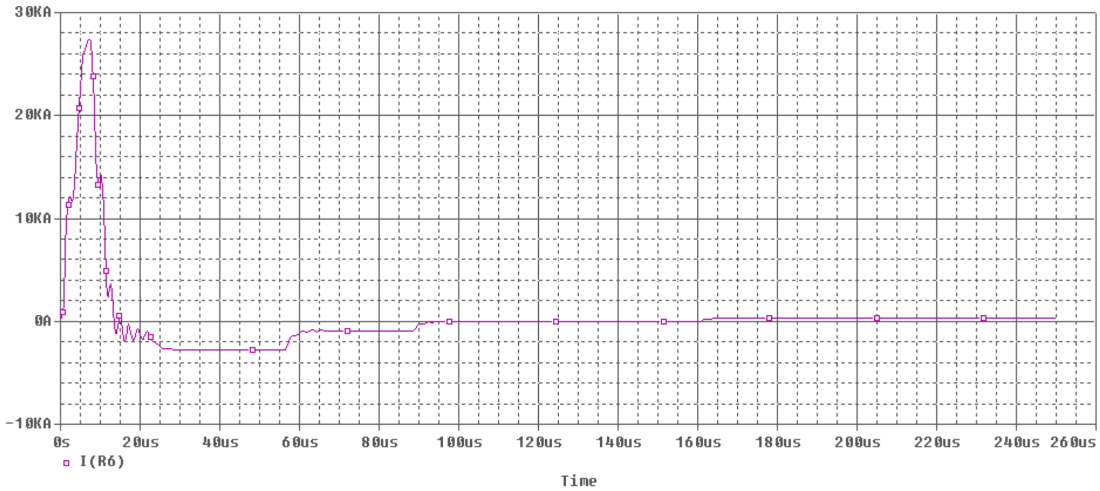

Fig. 5. Electricity lightning current in 110 kV power line

The induced overcurrents from the lightning of range of several kA can disrupt the normal operation of the power line. They can increase the power losses and voltage in the power line wires 110kV Albeit for a short time they will be given a large amount of energy. This affects the performance of power line.

These large currents, even for a short time will create strong magnetic fields around 110 kV power line. This will also lead to distortions of normal operation of other electrical equipment around the power lines.

6. CONCLUSION

The electrical discharge of lightning striking on overhead power high voltage 110 kV is investigated.

A model of current electrostatic discharge of lightning is created.

Circuit model of the power line of high voltage in a lightning strike is composed.

Simulations are carried on the work of the power line in emergency mode in the case of discharge of lightning in the power line.

Electrical discharge of lightning creates a high voltage in the power line. These surges and the presence of harmonic currents violate the electromagnetic compatibility of high voltage power lines and other electrical equipment located in the vicinity of lightning strikes on power lines.

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Reviewer: Prof. PhD Zh. Georgiev

DETERMINING OF FUNCTIONAL PARAMETERS IN ELECTRICAL DRIVES ACCORDING MOUNTING ARRANGEMENTS

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Abstract. *The electric motors are part of any electric drive. Depending on the way of connecting the electric motor and executive mechanism, the electric motor must be have specified mounting arrangements. The mounting arrangements of the electric motors are regulated by BDS EN 60034-7:2007. Rotating electrical machines – Part 7: Classification of types of construction, mounting arrangements and terminal box position (IM Code). On the mounting arrangements of the electric motors determine its functional parameters. They are quality indicators of each assembled unit. Functional dimensioning of the electric motors connected to the correct operation of the system "electric drive". This paper recommends this approach be offered to Students – Bachelor in teaching them discipline Fundamentals of Engineering Design.*

Keywords: *electric drive, electric motor, functional dimensioning*

1. INTRODUCTION

Electric drive is system which consists of a power supply, an electric motor and reducer. This system is designed as to move actuator by electricity. Electric drives are used primarily in industry, electric transport, households. In Fig. 1 shows the scheme of electric drive.

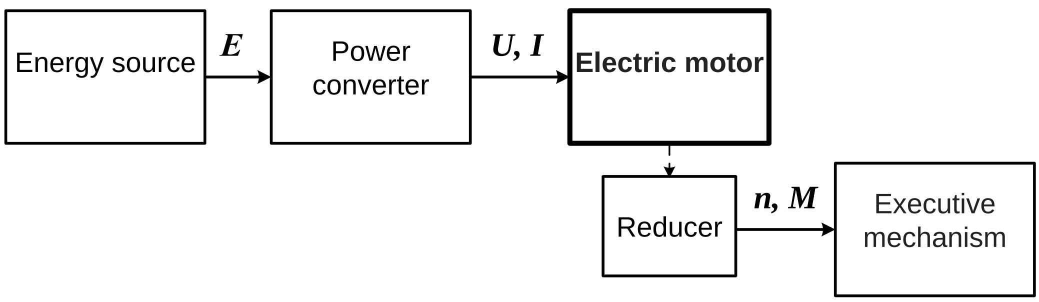


Fig. 1

The source of the energy lodged single phase or three-phase sinusoidal voltage with fixed frequency and amplitude. Power converter converts electrical energy ***E*** in the proper format (frequency, voltage ***U*** and current ***I***) with values that are optimal for the operation of the electric motor. The electric motor is an electromechanical device that converts electrical energy to mechanical energy that drives the working machine. The electric motor consists of a stator – a stationary component and a rotor –

rolling component. In the stator creates a rotating magnetic field which is necessary to drive the rotor. The rotor rotates on a shaft that is connected to the housing through bearings. The working machine to be operated is connected to the shaft.

The working position of the actuator depends on how it will be connected to the electric motor. Of this relationship depends on what will be the operating state of the electric motor. Mounting arrangements electric motors are regulated by BDS EN 60034-7 [1].

Proper functioning of a system largely depends on the performance of precision requirements for its components [2, 3]. Determining the installation parameters representing these precision requirements called functional dimensioning of the assembled units. The functional dimensioning of the electric motor is related to its working position and then to its mounting arrangements.

2. CLASSIFICATION OF MOUNTING ARRANGEMENTS OF ELECTRIC MOTORS

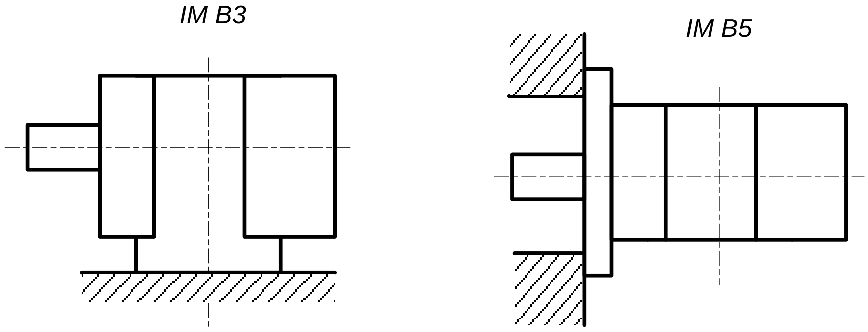
The mounting arrangements of electric motors are regulated by BS EN 60034-7: 2007 Rotating electrical machines. Part 7: Classification of types of construction, mounting arrangements and terminal box position (IM code). The standard gives two classification systems:

- an alpha – numeric designation applicable to machines with end shield bearings and only one shaft extension (code I);
- an all numerical designation applicable to a wider range of types of machines (code II), including types covered by code I.

2.1. Code I – alpha–numeric designation

- *Designation machines with horizontal shaft*

In the *Code I* machine with a horizontal shaft is designated by alpha code **IM** (international mounting), followed by a space, letter **B** and one or two digits – **IM Bxx** (Fig. 2).



a b

Fig. 2

Digits in the designation indicate the type of electrical machine design – bearings shields presence of foot, flange presence, presence of additional details. Designation

IM B3 (Fig. 2 a) is an electric machine with a horizontal shaft (letter **B**), two bearings shields, with feet (feet down) (the digit **3**). Designation **IM B5** (Fig. 2 b) electrical machine with a horizontal shaft (letter **B**), two bearings shields, no feet, flange, additional detail – flange shield D – end (drive end of the machine) with rear access, mounted on the flange side of the D – end (the digit **5**).

- *Designation machines with vertical shaft*

In the *Code I* machine vertical shaft is indicated by alpha code **IM** (international mounting), followed by a space, letter **V** and one or two digits - **IM Vxx** (Fig. 3).

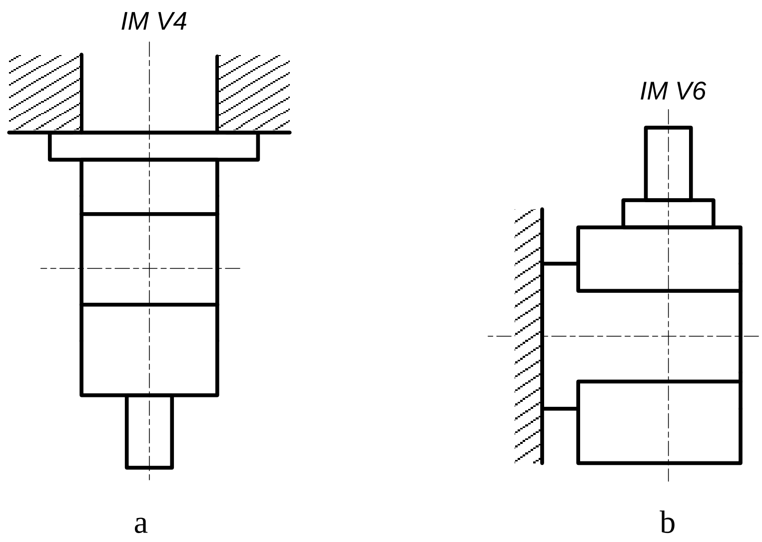


Fig. 3

2.2. Code II - numerical designation

In *Code II* a machine is indicated by a letter code **IM** (international mounting), followed by a space and four digits – **IM xxxx**. The first, second and third digits indicate the embodiment of the machine. The first digit defines the installation of the machine (the presence of foot, bearing shields, flanges, additional bearing supports). The significance of the second and third digits is determined by the first digit to which they are connected. Fourth digit indicates the type of shaft end (cylindrical – 1, 2, cone – 3, 4, flange – 5, 6, 7; not determined – 8, other ways – 9). If after four numbers used point, it should mean the location of the terminal box.

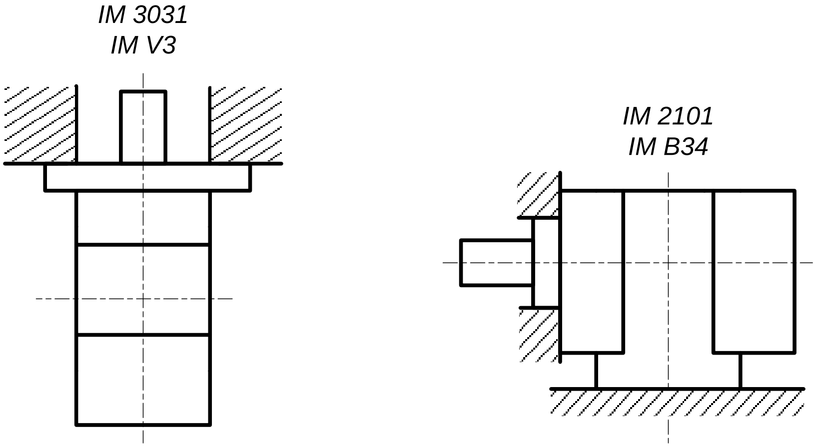
2.3. Relationship between Code I and Code II

Since the designation *Code II* has a wider range including machines covered by the *Code I*, there is a connection between the *Code I* and *Code II* (Table 1).

In Fig. 4a shows an example of the relationship between the code I and the code II. The electric machine is according *Code I* designation **IM V3**, and according to *Code II* designation **IM 3031** (Fig. 4a). In Fig. 4b electric machine *code I* have under designation **IM B34**, and according to *Code II* designation **IM 2101**.

Table 1

machines with horizontal shaft		machines with vertical shaft	
Code I	***Code II***	***Code I***	***Code II***
IM B3	IM 1001	IM V1	IM 3011
IM B5	IM 3001	IM V2	IM 3231
IM B6	IM 1051	IM V3	IM 3031
IM B7	IM 1061	IM V4	IM 3231
IM B8	IM 1071	IM V5	IM 1011
IM B9	IM 9101	IM V6	IM 1031
IM B10	IM 4001	IM V8	IM 9111
IM B14	IM 3601	IM V9	IM 9131
IM B15	IM 1201	IM V10	IM 4011
IM B20	IM 1101	IM V14	IM 4031
IM B25	IM 2401	IM V15	IM 2011
IM B30	IM 9201	IM V16	IM 4131
IM B34	IM 2101	IM V17	IM 2111
IM B35	IM 2001	IM V18	IM 3611
		IM V19	IM 3631
		IM V30	IM 9211
		IM V31	IM 9231
		IM V35	IM 2031
		IM V37	IM 2131



a b

Fig. 4

3. FUNCTIONALLY DIMENSIONING OF ELECTRICAL MOTOR

Mounting parameters $\boldsymbol{P_i}$ one assembled unit is directly related to how its installation. They are indicators of the quality of the assembled unit. They obtained after assembly of the device – through the implementation of combined teams dimensional chains. Determining the mounting parameters $\boldsymbol{P_i}$ and solving their dimensional chains is an important stage in the design documentation of the items is called size – precision analysis. The purpose of this assay is to achieve a reasoned dimensioning of the functional devices.

In Fig. 5 shows the induction motor with an indication of the mounting arrangements **IM B3**, feet (feet down), and identified and labeled two installation parameters P_{1f} and P_2. Parameter P_{1f} is functional mounting parameter related to the functioning of the electrical machine and depending on how its mounting arrangements. Its determination is necessary to have information about the installation the motor and how the motor will be connected to the machine which he will drive.

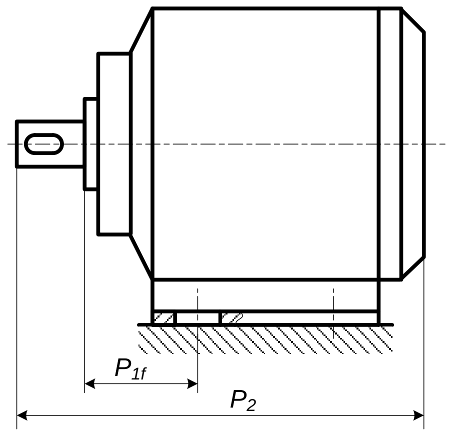


Fig. 5

4. CONCLUSION

Of analysis performed it is clear that the correct approach to the functional design of the electric motor is necessary to consider its working position and mode of mounting. In their studies students in field "Electrical Engineering and Automatics" developed by task assignment "Functional dimensioning in Electro technical assembled unit". The authors believe that it is appropriate first students to acquaint themselves with the working position and mounting arrangements of the electric motor. Then determine the mounting parameters of the assembled unit and perform functional dimensioning the electric motor. So developing of the assignment will follow the natural course of the construction activity.

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Reviewer: Assoc. Prof. PhD S. Guninski

DEFINING THE PARAMETERS OF EQUIVALENT ELECTRIC - FILTER REPLACEMENT SCHEME

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Abstract. *In the present study the parameters of an equivalent replacement scheme of a tube type test specimen electric filter has been defined and it's capacitance and resistance have been determined. The study shows that this resistance has clearly defined nonlinear character. The results could be used either for designing and sizing of high voltage sources and power electric-filters, or to study the work of these electricity-filters in different modes.*

Keywords: *electric filter, parameters, active resistance, nonlinearity.*

1. INTRODUCTION

The electric filters are high-tech equipment and are a common solution for filtration of air and gas emissions from solid and liquid particles. Their advantages compared to the other dust collectors are undisputed – high efficiency, low consumption, universality, fast and easy cleaning [3]. Their investigation and optimization for different modes could become much easier if a corresponding equivalent replacement scheme is used. The effect of collecting dust is a consequence of the corona discharge between the two electrodes of these devices, but for gas environments the U-I characteristic has a strong nonlinear character [4]. The resistance of an electric filter for its working section also is non-linear. This requires the usage of methods for analysis of nonlinear circuits to be used during investigation and optimization.

The goal of this study is to define and investigate the parameters of an equivalent replacement circuit of an electric filter: active resistance, capacitance for its working section of voltage variation of the corona discharge.

2. STATE-OF-THE-ART

Electric filter: it's structure is based on a classical electric filter scheme of a tube type, shown on fig. 1 [2].

On top of the corona electrode (4), connected with the positive high voltage end (2), are installed circular copper plates (5) with diameter 5 mm, determining the fixed discharge points. The fan (3) provides air flow through the electric filter, who's length and diameter of the sedimentation electrode are 720 mm and 110 mm respectively. Using the autotransformer (6) parametrically is altered the rotating frequency of the fan (3). This construction allows to begin a corona discharge with minimal voltage U_{cr} = 10 kV. This defines the main requirement towards the high voltage source: to provide DC voltage U > 10 kV for the different working modes of the electric filter. It is also presented with an equivalent replacement scheme (fig. 2). The capacitor reflects the capacity $C_{E\Phi}$ between the two electrodes and the resistor $R_{E\Phi}$ – the active resistance between them during a corona discharge.

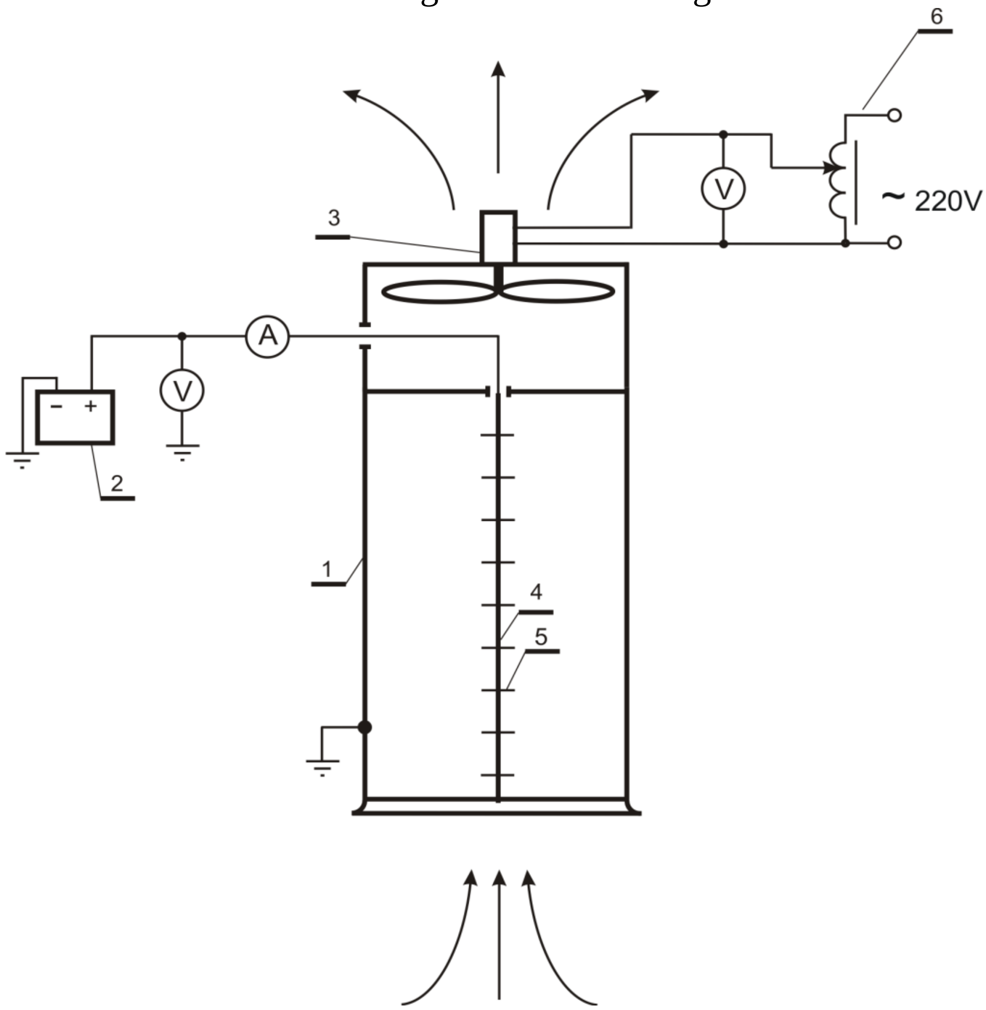

Fig. 1. Schematics of the test specimen electric filter: 1 – sedimentation electrode; 2 – high voltage source; 3 – fan; 4 – corona electrode; 5 – fixed points for discharge (pressed circular copper plates); 6 – autotransformer; 7 – isolator.

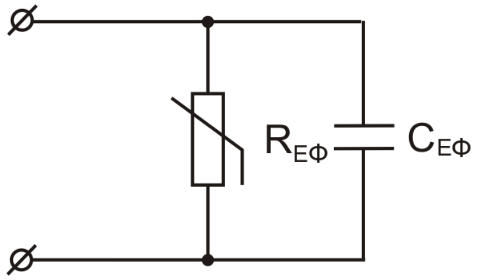

Fig. 2. Equivalent replacement scheme of the electric filter

3. RESULTS

The capacitance of the electric filter ($C_{EФ}$) is directly measured to be $C_{EФ}$ = 15 pF. The experimental values of the current (I) and the active resistance ($R_{EФ}$) of the electric filter, according to the corona discharge voltage (U) in the diapason U= (10÷16), kV, are presented in table 1. The work of the electric filter has been investigated for the same voltage diapason [1]. The dependencies I (U) and $R_{EФ}$ = f (U) are presented on fig. 3 and fig. 4. They show that the increase of U leads to an increase of I and a decrease of $R_{EФ}$. Both dependency have strong nonlinear character. This is caused by the intensive impact ionization, which occur on the surface of the corona electrode of the electric filter during voltage increase.

Table 1. Experimental results of the current I, the resistance $R_{EФ}$ of the test specimen electric filter, ass a function of the voltage U

U, kV	10	12	14	16
I, μA	30	120	250	420
$R_{EФ}$, MΩ	330	100	56	38

After a statistical processing of the experimental data with one quantity controllable factor, for the U-I characteristic of the electric filter from fig. 3 has been obtained a mathematical model – a second order polynomial (1), with a significance level α = 0,05 confidence level P = 0,95.

The analytical curve of the polynomial, is presented on fig. 5. It has been obtained using the statistical software STATISTIKA10.

$$U = 9{,}3507 + 23{,}3612 \,.\, I - 18{,}0756 \,.\, I^{2}, \text{кV}. \qquad (1)$$

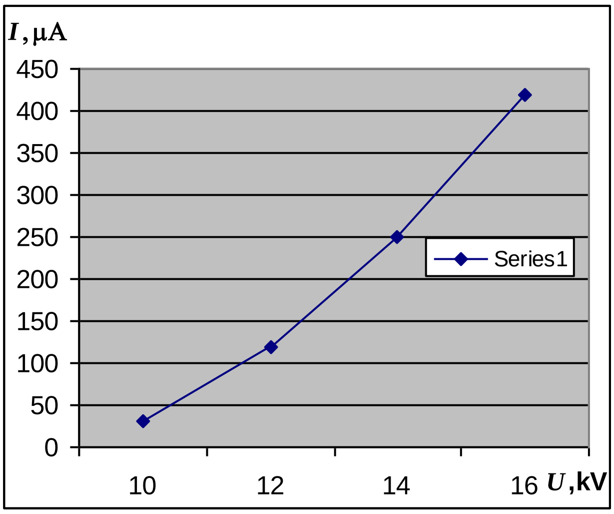

Fig. 3. The current I through the electrical filter as a function of the corona discharge voltage U

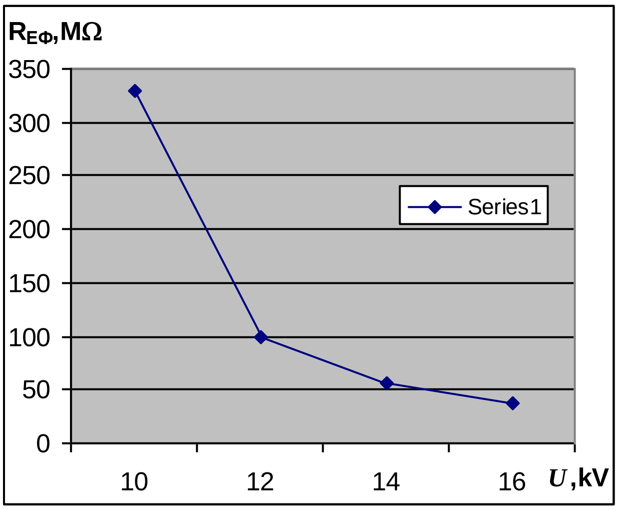

Fig. 4. The active resistance $R_{EФ}$ of the electric filter as a function of the corona discharge voltage U

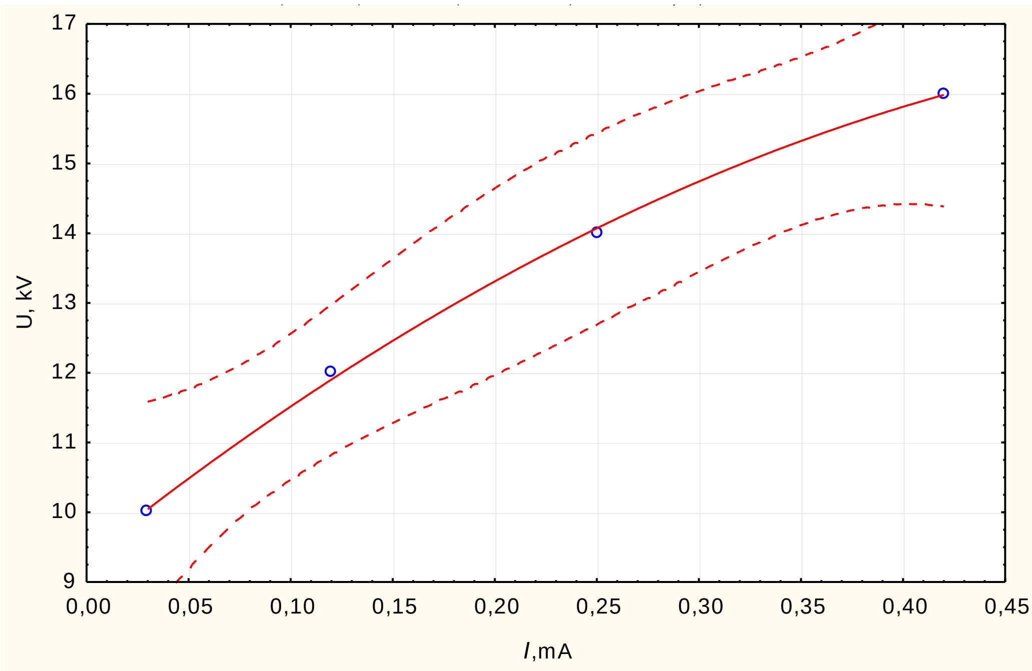

Fig. 5. Analytical curve of the determined polynomial

4. CONCLUSIONS

The experimental data shows that the active resistance of the used electric filter test specimen of tube type is strongly nonlinear for the working section of the corona discharge voltage. This requires the usage of nonlinear methods for circuit analysis to be used.

A mathematical model has been determined, describing the U-I dependency. The obtained results can be used for design and sizing of high voltage sources for electric filters, as well as for study of the working modes of such equipment.

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Reviewer: Assoc. Prof. PhD Sn. Terzieva

STRENGTH MEASURING SENSORS MADE OF ELECTRICALLY CONDUCTIVE ELASTOMERS OPERATING AT RESONANT MODE

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Abstract. *This paper explores the opportunity to work with and investigates the qualities of strength measuring sensors of electrically conductive elastomers at alternative current supply and more narrowly – their work under resonant mode. Surveys have been conducted by means of different methods. Static characteristics U = f(F) and I = f(F) are taken from samples, constructed with different types of electrically conductive elastomers. Analysis of the characteristics and the sensitivity of the sensor has been made depending on the operating frequency, as well as on the magnitude of the applied static force and the type of the used elastomer.*

Keywords: *elastomers, strength measuring sensors, tactile sensors, resonance, sensitivity*

1. INTRODUCTION

The sensors of electrically conductive elastomers (SECE) are a special kind of tactile strength and pressure measuring transformers with a major characteristic – compactness.

Another characteristic is their capability to transform the mechanic interaction of the sensor with the object into an electric signal. The strength measuring sensors react to applying a compressive force to their axis, and a relay, digital or analogue signal is obtained as a result [3].

SECE are applicable in measuring both static and dynamic forces. In the event of elastic deformation caused by external forces, the SECE change their volume and contact resistance

Traditionally, the SECE measuring static forces work in DC mode which reveals their major disadvantages: low sensitivity, non-linear characteristics and hysteresis of residual deformation [5].

Studies of the SECE at an AC power supply in various schemes of connection have been carried out in order to improve their characteristics.

In this paper the opportunity to include SECE in circuits with additional reactive elements is explored. These reactive elements provide a resonant mode which applies maximum voltage prior to the application of external force.

2. THEORETICAL JUSTIFICATION

Rubber is amorphous polymer - highly molecular compound, obtained by polymerization, the molecules of which have greater flexibility. It is used predominantly in highly elastic state as a composite material, which, after vulcanization, turns into rubber [4].

Electrically conductive elastomers are mixtures built on high quality rubber and electrically conductive impurities - carbon (soot, graphite) or metal (gold, silver) particles.

The different number, size and shape of the deposited metal particles alter the characteristics (mechanical and electrical) of the composite materials.

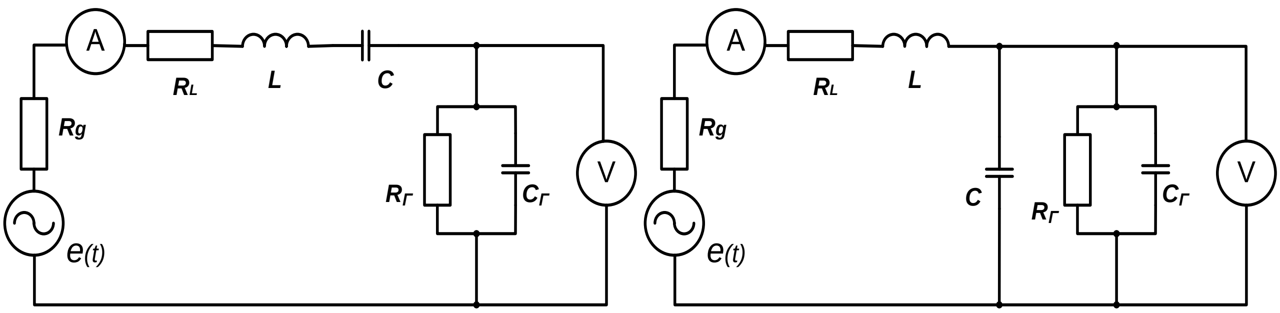
In this study five electrically conductive rubbers with different content of metal particles have been used.

An experiment of using SECE in circuits, working under a resonant mode is conducted, based on the formulation that the voltages on the reactive elements increase several times at a coherent resonance [1].

3. DESCRIPTION OF THE EXPERIMENT

Fig. 1 is a schematic diagram of the electrical circuits where SECE are connected and R_L indicates the active resistance of the coil, while R_g is the equivalent output resistance of the sine wave generator.

The electrical parameters of the SECE are presented with the help of the resistor $R_Г$ and the capacitor $C_Г$, connected in parallel. The volume and the contact resistance of the sensor is presented by the resistor, and by $C_Г$- the capacitor, obtained from the sensors constituent structure (metal-elastomer–metal), is denoted.



a) Scheme1 б) Scheme 2

Fig. 1. Equivalent electrical circuits

The studied sensors have the following dimensions - 40/10/1 mm (length, width, thickness). The influence of these dimensions has been examined in previous studies [2].

The experiment for both circuits is conducted in the following sequence:

- the resonant frequency is determined for each sample of SECE without externally applied compressive force;
- the transformative functions $U = f(F)$ are taken for every SECE when static force F from 0 to 10 N is applied for three frequencies – the resonant one and other two around it (one lower and one higher).

4. RESULTS

By combining different values of the reactive elements, resonance is realized in the circuit of the SECE. Values, leading to a well-defined resonance are selected. The resulting amplitude - frequency characteristics are shown in fig. 2 and fig. 3

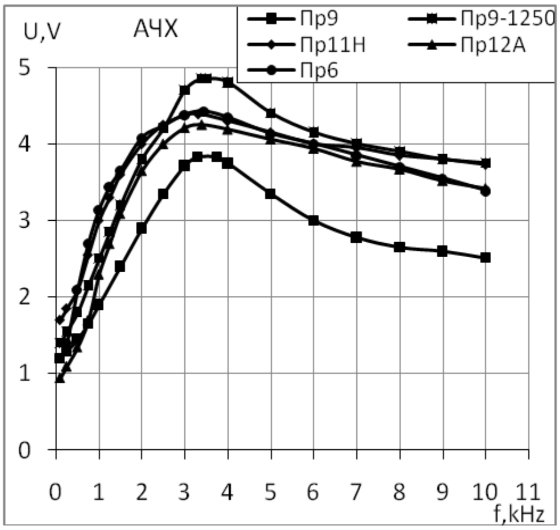


Fig. 2. AFC of SECE for Scheme 1

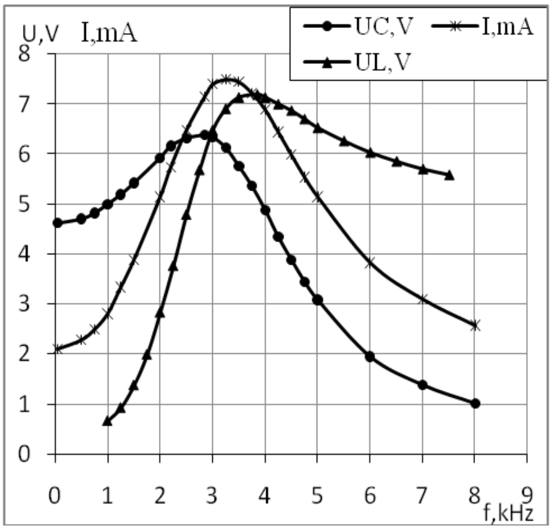
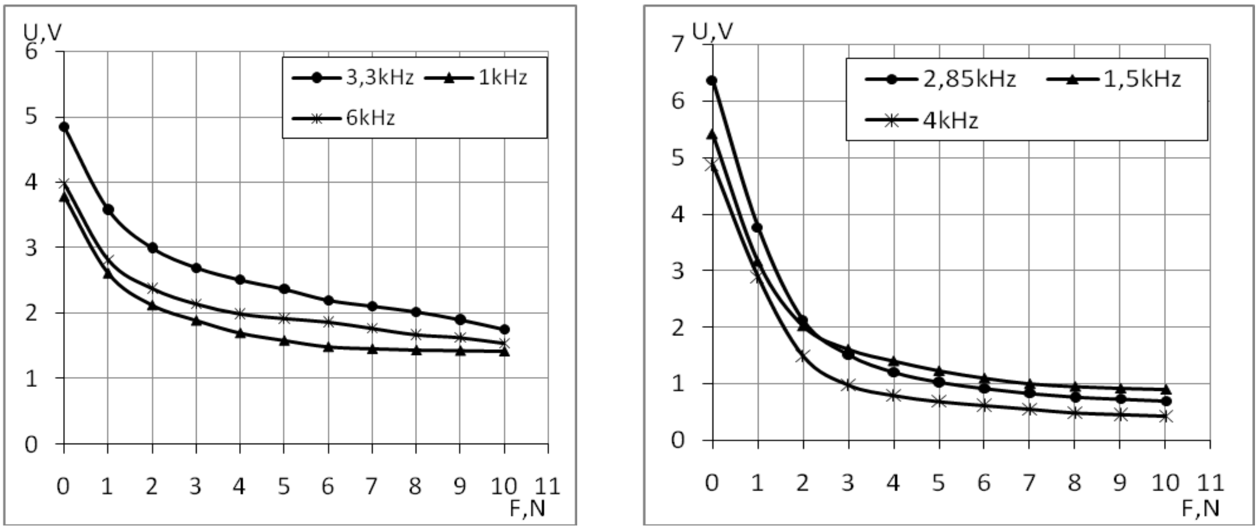


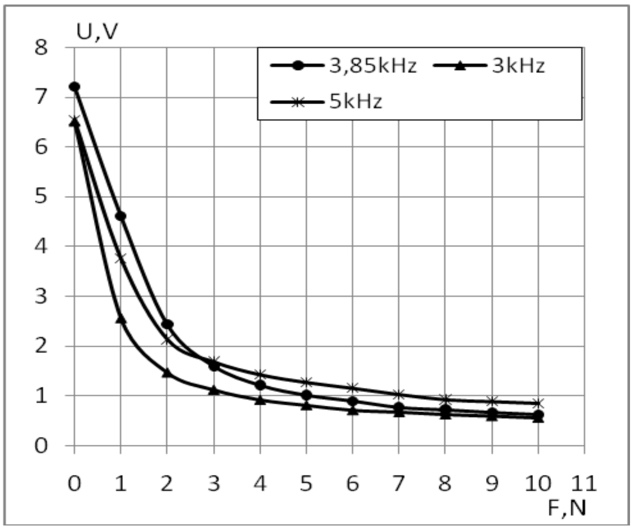
Fig. 3. AFC of SECE for Scheme 2

Frequency responses are taken before the application of the force *F* and the resonant frequencies for the different schemes of connection are recorded. In case of a circuit with reactive elements connected in series $f_0 = 3.3\ kHz$. The experiment is conducted in two different versions for the circuit from fig. 1.b:

- The capacitor *C* is connected in parallel to the SECE $(C // C_Г)$ - $f_0 = 2.85\ kHz$;
- The coil *L* is connected in parallel to the SECE $(L // C_Г)$ - $f_0 = 3.85\ kHz$.



a) b)



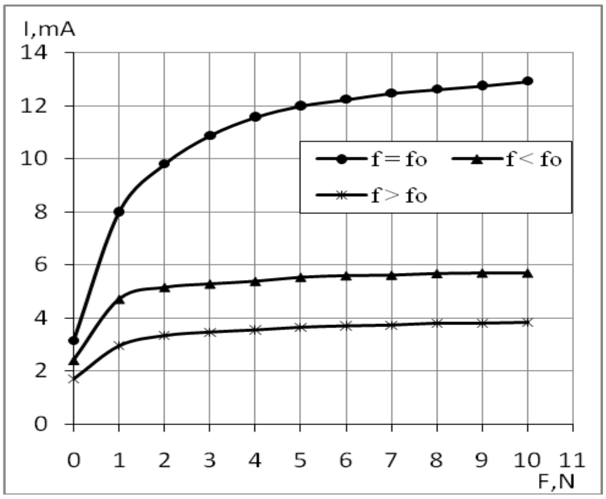
c)

a) Characteristics in case of connecting the reactive elements of SECE in series;
b) Performance in case of connecting the capacitor *C* in parallel to SECE;
c) Performance when connecting the coil *L* in parallel to SECE

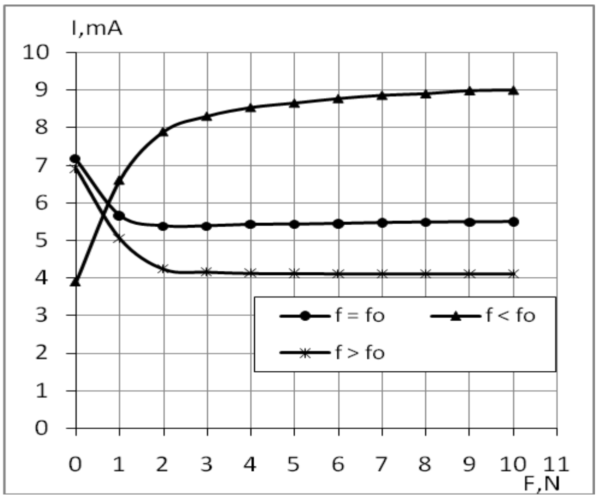
Fig. 4. Conversion function *U = f(F)*

Fig. 4 shows the graphs of the conversion functions *U = f (F)* during the operation of an external force *F* from *0* to *10 N*. The characteristics are nonlinear, with a greater slope at the beginning of the range (up to *F = 4 N*). After this zone the characteristics are linearized and the change of the output voltage decreases. Similar is the degree of sensitivity of the CEE. It has the highest sensitivity, *S > 2 V / N*, during the initial force impact when the volume of its resistance changes the most.

Fig. 5 shows the changes in the ongoing currents during the elastic deformations.



a) for Scheme 1



b) for Scheme 2

Fig. 5. Conversion function *I = f(F)*

The sensitivity of the sensor is calculated from the recorded experimental values of the applied voltage on SECE before and after the application of force.

Fig. 6 shows the graph of the sensitivity S of the sensors for the three operating frequencies and the different variants of circuit connection. The results confirm the idea of SECE working under a resonant mode. For all three schemes the highest sensitivity is recorded when SECE work with the resonant frequency.

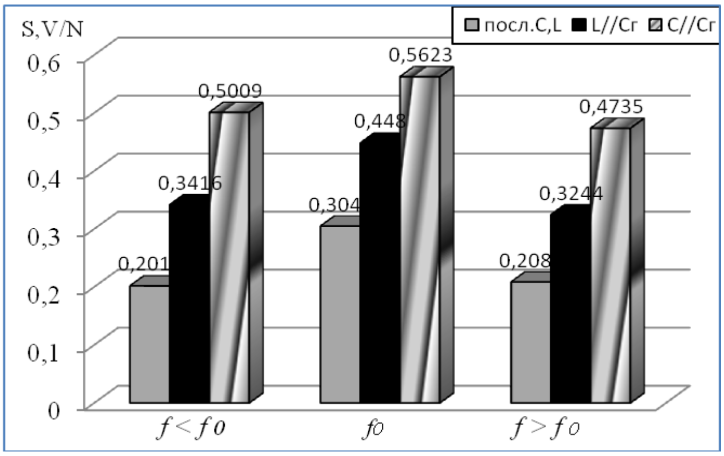


Fig. 6. Sensitivity S for the different frequencies

After analyzing the results of the experiments the conclusion is that the best performance of the sensors has been recorded for Scheme 2 with the coil L connected in parallel with SECE (fig. 1.b, $L//C_g$) *S=0.562 V/N.* This scheme is used for further experiments with sensors built with different types of electrically conductive rubber – Pr9, Pr9-1250, Pr 11N, Pr 12A, Pr6. Fig. 7 shows that the sample Pr9-1250 has the highest sensitivity - *S=0.657 V/N*.

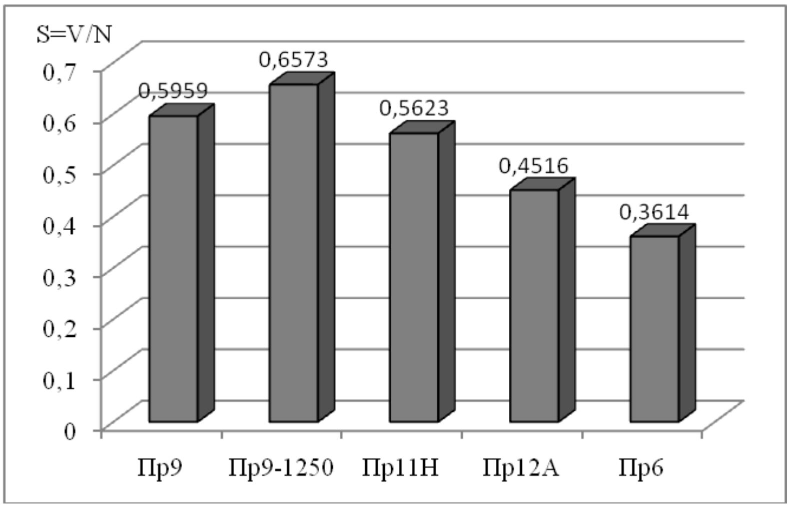


Fig. 7. Sensitivity S for the different samples

5. CONCLUSIONS

The choice of a particular type of sensor according to the specific conditions of application depends on its parameters such as sensitivity, response threshold and static characteristics.

In order to improve the performance of SECE the opportunity to include them in circuits operating under a resonance mode is seized. Various schemes for realization of a resonance mode are implemented. In Scheme 2 the voltage and the current have the characteristics of standard variables at a coherent resonance. This is not so well expressed in Scheme 1 and can be defined as fuzzy resonance.

The analysis of the experimentally obtained values shows improved performance compared to the performance at an AC mode with a frequency, other than the resonant.

Both the type of the electrically conductive rubber and the specific scheme for SECE connection, for which the highest sensitivity is reached, has been defined and this is SECE with electrically conductive rubber Pr9-1250 in a circuit with the coil L connected in parallel(fig.1.b, L // C_Γ).

The greatest change in the output voltage obtained from SECE is observed with the original force impact. This determines their main application as threshold or signaling devices, as well as for measurement of small forces.

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Reviewer: Assoc. Prof. PhD A. Chervenkov

MODELING OF SENSORS OF ELECTRICALLY CONDUCTIVE ELASTOMERS

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Abstract. *This article clarifies the key issues in the development of models of sensors of electrically conductive elastomers (SECE).Mathematical models of SECE are composed operating at direct and alternating current mode. Based on them two simulation models are realized in Matlab environment. These models allow study of the properties of the sensors and the impact of input influences prior to their practical realization. This article offers an analysis of the results obtained in the simulations and experimentally. The article aims to support the construction works of sensors to which are applied ever – increasing requirements for improvement of their metrological characteristics.*

Keywords: *elastomers, strength measuring sensors, mathematical models, simulations*

1. INTRODUCTION

With the development of electronic technology and the increasing desire to replace manual labor with automated production activities, the design and implementation of specialized industrial robots is required. To properly perform their tasks the robots need a large amount of different types of sensors.

A number of requirements are placed on the sensors: small size and weight, high reliability, sensitivity, repeatability of statements, minimum equipment costs, immunity from interference and aggressive and moist environments, thermal stability, etc [5].

The tactile sensors are a special class of sensors detecting force and pressure that are characterized by their compactness and low cost.

The most commonly used construction of tactile sensors with electrically conductive rubbers (elastomers) is the "sandwich" type (fig. 1). In it the elastomeric material is placed between two metal electrodes. This structure is embedded as the base used in test samples and their models. The pressure is applied statically, perpendicular to the sensor, by means of a suitable mechanical system and weights, and the volume resistance of the material changes in result. We are rarely interested in surface resistance. It is measured and constitutes one of the criteria for quality in production of elastomeric blends [1].

The purpose of this work is the mathematical modeling of sensors of electrically conductive elastomers (SECE) and the creation of simulation models.

Matlab Simulink programming environment allows the description and study of the selected object. The model, thus constructed, allows investigation of the sensor prior to its practical implementation, which shortens the design time [3].

2. THEORETICAL JUSTIFICATION

The used electrically conductive elastomers are polymers, for which glass transition temperature is below the ambient (room) temperature, their melting point is above the ambient temperature and they are in a highly elastic condition. They have properties similar to those of natural rubber and are known as "rubbers".

All real objects under the influence of external forces change their shape and volume. The aspiration of the objects to recover their volume and shape is called elasticity [2].

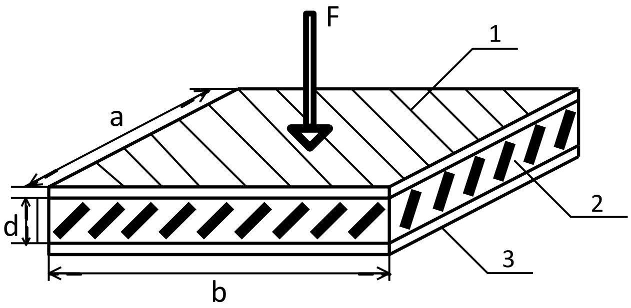


Fig. 1. Structural Scheme of SECE

Fig. 1 shows the structure of the SECE. The external impact -the slowly changing static force F- is applied perpendicular to the metal plates. With increasing the force F the active internal resistance of the sensor $R_Г$ reduces, which is due to the reduction in the volume resistance and to the increase of the contact area between the electrodes 1 and 3, and the elastomer 2. The dependence $R_Г = f$ (F) is nonlinear. For its analytical display the theory of the elastic properties of bodies is used [6].

For an evenly deformed object from perpendicular directed force F, the elastic forces are evenly distributed and directed perpendicular to the entire cross-section S. Then $\sigma = \frac{F}{S}$ is called normal elastic stress.

The dimensionless parameter $\varepsilon = \frac{\Delta d}{d}$ is called relative deformation. When the external forces shrink the object, the relative deformation is negative *(ΔL <0)* and the elastic stresses are called pressure stresses.

For relatively small deformations the elastic pressure stresses are directly proportional to the relative deformation ε - Hooke's law

$$\sigma = k\varepsilon . \qquad (1)$$

The proportionality factor k is a constant which does not depend on the dimensions of the object, it is characterized only by the elastic properties of its building material. It is called modulus of elasticity. During stretching or shrinking the elastic modulus is called Young's modulus and is marked with E. For this type of deformation the Hooke’s law has the form

$$\sigma = E\varepsilon . \qquad (2)$$

Then, the equation for the operating force is:

$$F = \sigma S = E_Г \varepsilon S = E_Г S \frac{\Delta d}{d} \quad . \qquad (3)$$

The following expression is derived for the relative deformation:

$$\varepsilon = \frac{\Delta d}{d} = \frac{1}{E_\Gamma S} F \,. \tag{4}$$

2.1. SECE working at direct current mode

For the purposes of modeling it is assumed that all the elements that make up the scheme of the sensor are ideal.

The electrical circuit for studying the SECE is shown in fig. 2.

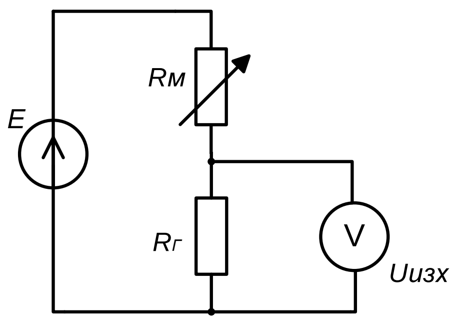


Fig. 2. Scheme for connecting SECE with a direct-current source

With the resistors R_Γ the volume and contact resistance of the sensor are defined. The load resistance is denoted by R_M, which allows for realization of different conditions for sensor operation. The output value from the work of the sensor is the voltage on R_Γ.

The equation for the output voltage is

$$U_V = \frac{R_\Gamma}{R_\Gamma + R_M} E = \frac{E}{1 + \dfrac{R_M}{R_\Gamma}} \,. \tag{5}$$

Considering the relative deformation ε (2) and a correction factor β for the function of voltage variation, the following expression is obtained:

$$U_V = \frac{E}{1 + \dfrac{R_M}{R_{\Gamma_0} e^{-\frac{\beta}{E_\Gamma S} F}}} \,. \tag{6}$$

The expression (6) is used to create a simulation model in Matlab environment, as shown in fig. 3.

As a controlling example the experimental results (fig. 1.b) are compared graphically with those from the simulation in Matlab (fig. 1.a). A very good match is observed. This is confirmed by the comparison of the baseline values determined in both ways. The relative error is within the boundaries of $\delta_U = \pm 5\%$.

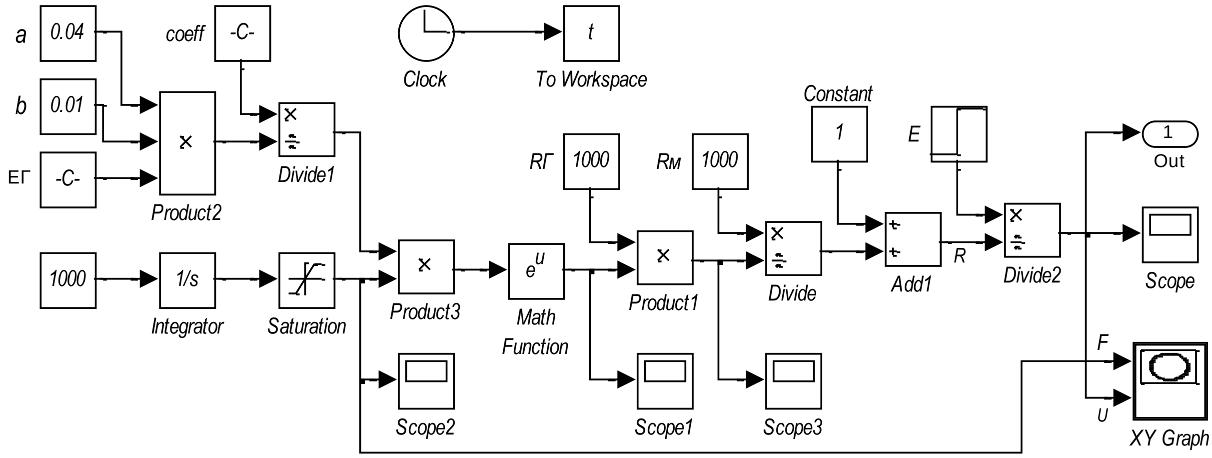
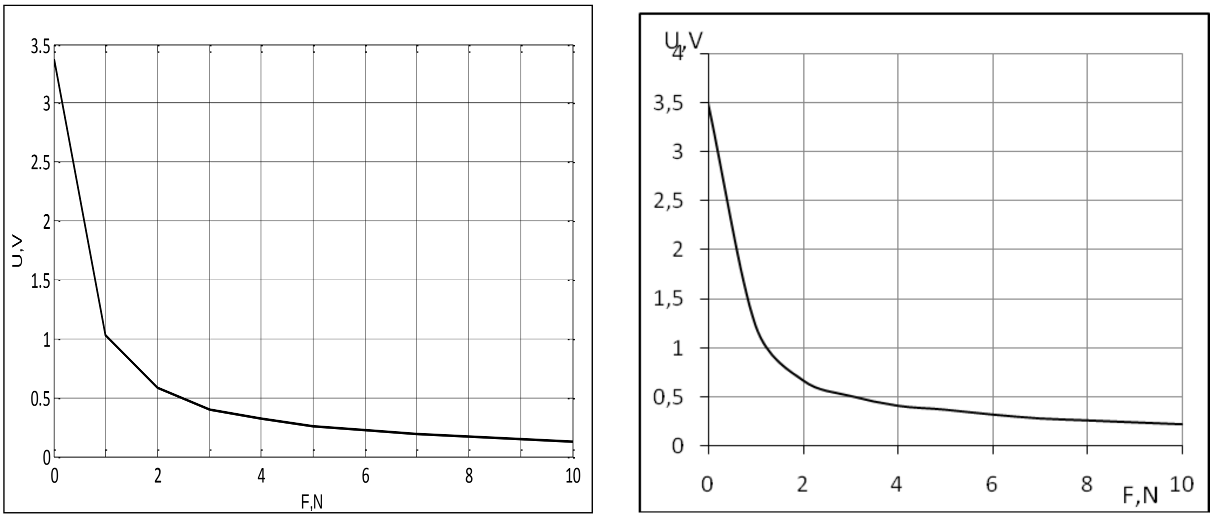


Fig. 3. Simulation scheme in Matlab environment



a) b)

Fig. 4. Change in the output voltage as a function of the force measured

2.2. SECE operating at an alternating current mode

Fig. 5 shows the electrical scheme for examination of SECE with and AC-current source.

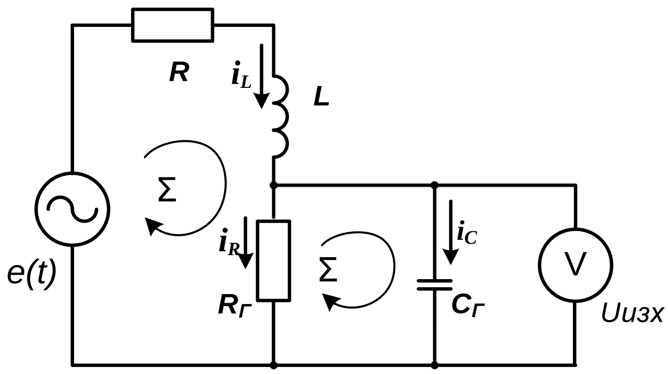


Fig. 5. Scheme for connecting SECE with an AC-current source

The electrical parameters of SECE are presented with the help of a resistor R_Γ.and capacitor C_Γ, connected in parallel. With the resistor again the volume and contact resistance of the sensor is expressed, and by C_Γ the capacitor, which is obtained from the presented constituent structure of the sensor (metal - electrically conductive elastomer – metal) is denoted. SECE is connected in series with the coil with inductance L.

For the electric circuit (fig. 5) the following system of equations under the laws of Kirchhoff in a snapshot is composed:

$$\left|\begin{array}{l} i_L(t) = i_R(t) + i_C(t) \\ i_R(t) = \dfrac{1}{R_\Gamma}\left[e(t) - Ri_L(t) - L\dfrac{di_L(t)}{dt} \right] \\ i_C = C_\Gamma R_\Gamma \dfrac{di_R(t)}{dt} \\ u_C(t) = \dfrac{1}{C_\Gamma}\int i_C(t)dt \end{array}\right. . \tag{7}$$

The variation of the resistance and the sensor capacity as a result of external, deforming, force impact is determined by the following expressions:

$$R_\Gamma = R_{\Gamma_0} e^{-\frac{\beta}{E_\Gamma S}F} \quad \text{and} \quad C_\Gamma = \varepsilon_0 \varepsilon_\Gamma \frac{S}{de^{-\frac{\beta}{E_\Gamma S}F}} . \tag{8}$$

The system (7) and the equations (8) are used for the creation of a simulation model in Matlab environment, shown in fig.6.

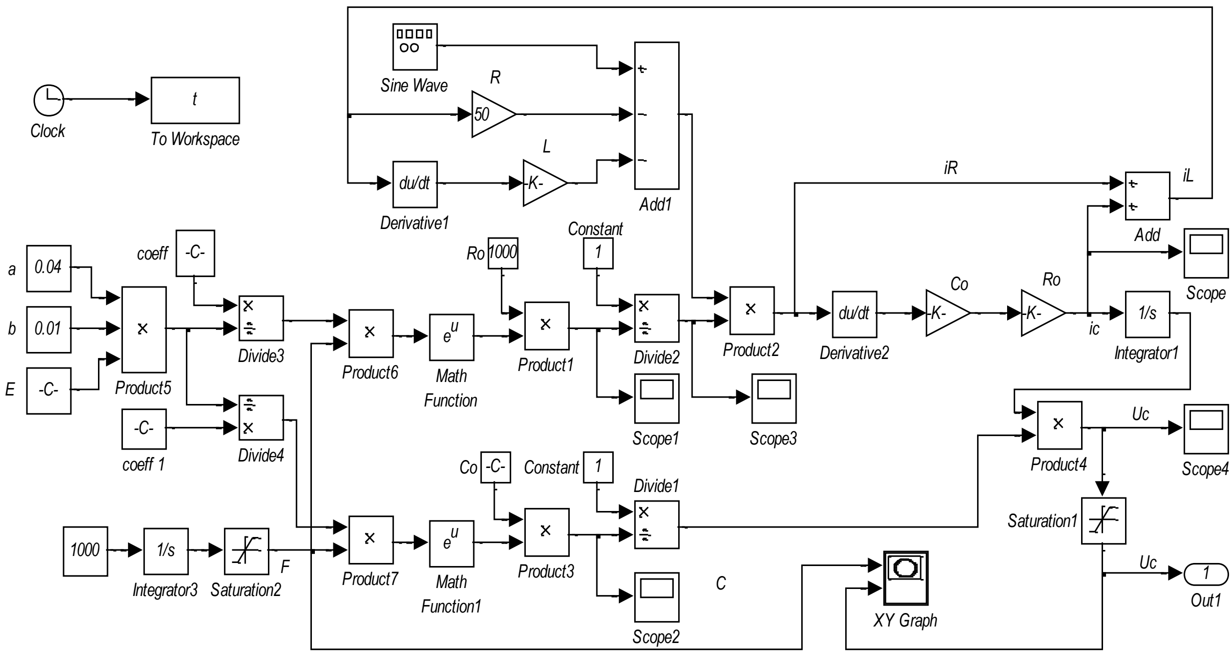


Fig. 6. Simulation scheme in Matlab environment

The graphs with variations in the output voltage as a function of the force *F* are given in fig. 7 (a - simulation, b - experimental data).

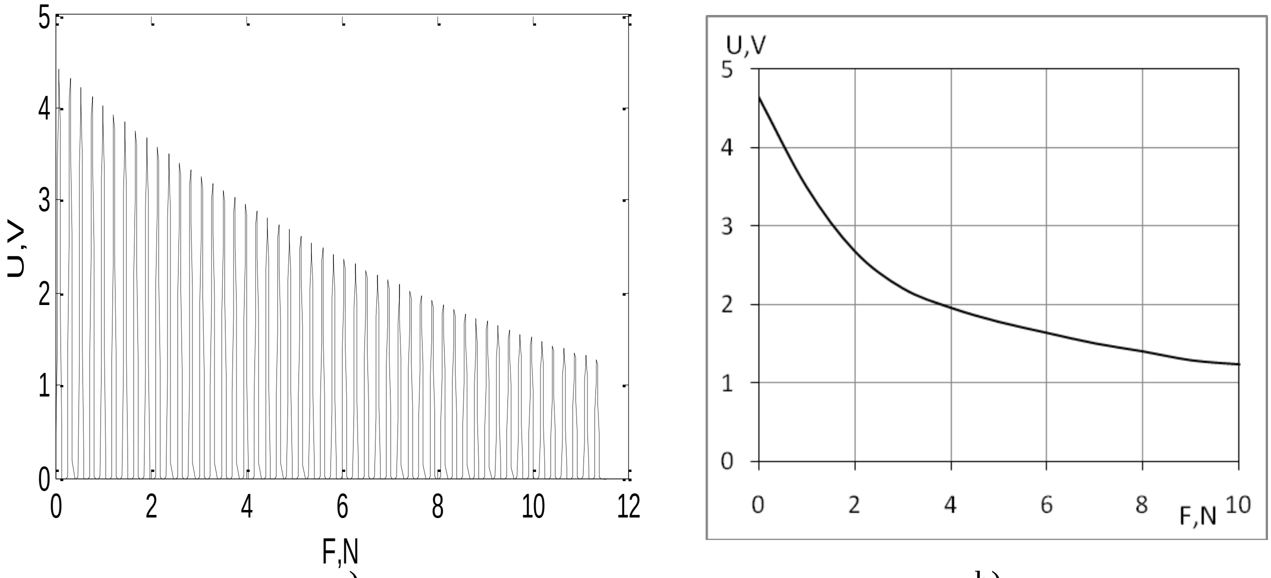


Fig. 7. Change in the output voltage as a function of the force measured

5. CONCLUSIONS

Analytical expressions are obtained for the effect of SECE in two modes of operation: direct and alternating current. The parameters of the models are defined. Simulations in Matlab environment are created. The simulation results overlap with the experimental ones with a maximum relative error $\delta_U = \pm 5\%$.

The results can be used to derive dependencies related to the other parameters of the sensor by means of which the overall design could be afterwards executed.

The presented modeling approach can be applied to other types of sensors with different size, different elastomers with different resistivity, for determining the type, possessing the best metrological characteristics according to the specific pre-set requirements.

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Reviewer: Assoc. Prof. PhD A. Chervenkov

PSPICE MODEL OF A SLIDING MODE CONTROLLED DC/DC BUCK CONVERTER

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Abstract: *The control in high performance DC/DC converters requires not only to ensure system stability but also to achieve a rapid response to sudden changes of the load, to achieve good regulation. There are basically two ways to control the switched DC/DC converters - linear and nonlinear control. Nonlinear control often produces better results but sometimes increases the complexity of the practical implementation of the scheme. Switch-mode power supplies represent a particular class of variable structure systems. Thus, they can take advantage of nonlinear control techniques developed for this class of systems. PSpice model of DC/DC buck converter controller is designed, based on the classical sliding mode control (SMC) which is a nonlinear control method.*

Keywords: *buck converter, sliding mode control (SMC), convergence factor*

1. INTRODUCTION

Switched Mode DC/DC converters are essential for efficient conversion of the battery voltage to various supply voltages, needed to perform every function with minimum power drain. With a DC/DC converter a variable battery supply voltage can be converted to an optimal supply voltage for an application.

It is known that the switching DC/DC converters are highly nonlinear plants with uncertain parameters and inevitable and significant perturbations during operation. The control in high performance DC/DC converters requires not only to ensure system stability but also to achieve a rapid response to sudden changes of the load, to achieve good regulation.

In this contribution a DC/DC buck converter controller based on conventional sliding mode control (SMC) is considered [1] – [3].

The paper is organized as follows. The analytical model of buck DC/DC converter is considered in the next section. The basics of the sliding mode control for buck DC/DC converter is considered in section 3. PSpice model of buck DC/DC converter controller based on the classical SMC is presented in section 4.

2. ANALYTICAL MODEL OF THE BUCK CONVERTER

Figure 1 shows a sliding mode controlled buck DC/DC converter [7].

The output voltage v_0 is sensed and multiplied by appropriate coefficient $\beta = R_2/(R_1 + R_2)$ that is subtracted from the reference voltage V_{ref} forms the first state variable x_1 (voltage error).

$$x_1 = V_{ref} - \beta v_0 \tag{1}$$

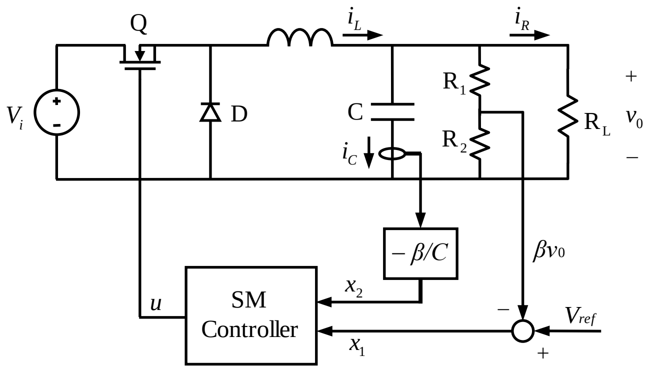

Fig. 1. Sliding Mode Controlled Buck DC/DC Converter

The rate of change of the voltage error x_2 is the second state variable:

$$x_2 = \dot{x}_1 = -\beta \frac{dv_0}{dt} = -\beta \frac{i_C}{C} \tag{2}$$

The differentiation of equation (2) with respect to time gives

$$\dot{x}_2 = -\frac{\beta}{C}\frac{di_L}{dt} + \frac{\beta}{R_L C}\frac{dv_0}{dt} \tag{3}$$

Based on the state space averaging method [4], [5] and [6] it can be written $v_L = uV_i - v_0$. Taking into account $v_L = L(di_L/dt)$, then

$$\frac{di_L}{dt} = \frac{v_L}{L} = \frac{uV_i - v_0}{L} \tag{4}$$

where u is the control input that can be 1 (switch Q is 'ON') or 0 (switch Q is 'OFF').

The substitution of equation (4) in (3) gives

$$\dot{x}_2 = -\frac{\beta}{LC}(uV_i) - \frac{1}{LC}x_1 - \frac{1}{R_L C}x_2 + \frac{V_{ref}}{LC} \tag{5}$$

3. SLIDING MODE CONTROL FOR BUCK DC/DC CONVERTER

In sliding mode control the controller employs a sliding surface or line to decide its control input states u (Figure 2), which corresponds the turning on and off the power converter's switch, to the system

$$S = \alpha x_1 + x_2 \tag{6}$$

where α is a positive quantity in some literature called a convergence factor and is taken to be

$$\alpha = \frac{1}{R_L C} \tag{7}$$

Graphically the sliding line is a straight line on the state plane with gradient α that determines the dynamic response of the system in sliding mode with a first order time constant $\tau = 1/\alpha$.

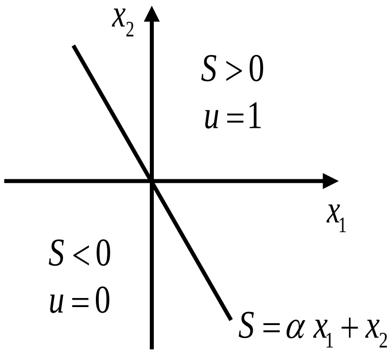

Fig. 2. A diagram of sliding mode control

To ensure that a system follows its sliding surface, a control law must be imposed

$$u = \begin{cases} 1 = 'ON' & when\ S > 0 \\ 0 = 'OFF' & when\ S < 0 \end{cases} \quad (8)$$

The existing condition for sliding mode [2], [6] is

$$\dot{S} = \begin{cases} \dot{S} < 0 & for\ S > 0 \\ \dot{S} > 0 & for\ S < 0 \end{cases} \quad (9)$$

Based on the above the expression for $\dot{S}$ is

$$\dot{S} = \alpha\dot{x}_1 + \dot{x}_2 = \alpha x_2 + \dot{x}_2 = \alpha x_2 - \frac{\beta}{LC}(uV_i) - \frac{1}{LC}x_1 - \frac{1}{R_L C}x_2 + \frac{V_{ref}}{LC} \quad (10)$$

Depending on S and u the state space is divided into two regions

region 1: $S > 0$ and $u = 1$

$$\dot{S}_1 = \left(\alpha - \frac{1}{R_L C}\right)x_2 - \frac{\beta}{LC}(uV_i) - \frac{1}{LC}x_1 + \frac{V_{ref}}{LC} < 0 \quad (11)$$

region 2: $S < 0$ and $u = 0$

$$\dot{S}_2 = \left(\alpha - \frac{1}{R_L C}\right)x_2 - \frac{1}{LC}x_1 + \frac{V_{ref}}{LC} > 0 \quad (12)$$

Sliding mode will only exist on the portion of the sliding line that covers both of the region 1 ($\dot{S}_1 < 0$) and region 2 ($\dot{S}_2 > 0$) [6].

From one side the speed of the system increases with increasing of α, but from other side the existing region of the sliding mode decreases that can cause an over-shoot in the voltage response ($\alpha >> 1/R_L C$) [6].

4. PSPICE MODEL OF A SLIDING MODE CONTROLLED BUCK DC/DC CONVERTER

Based on the classical sliding mode control, on the above calculations and on the Simulink model of a buck DC/DC converter controller shown in Figure 3 [7], a PSpice model of the converter controller is designed and presented in Figure 4. The parameters of the converter are: V_i = 3.7V; L = 10μH; C = 50μF; R_L = 10Ω.

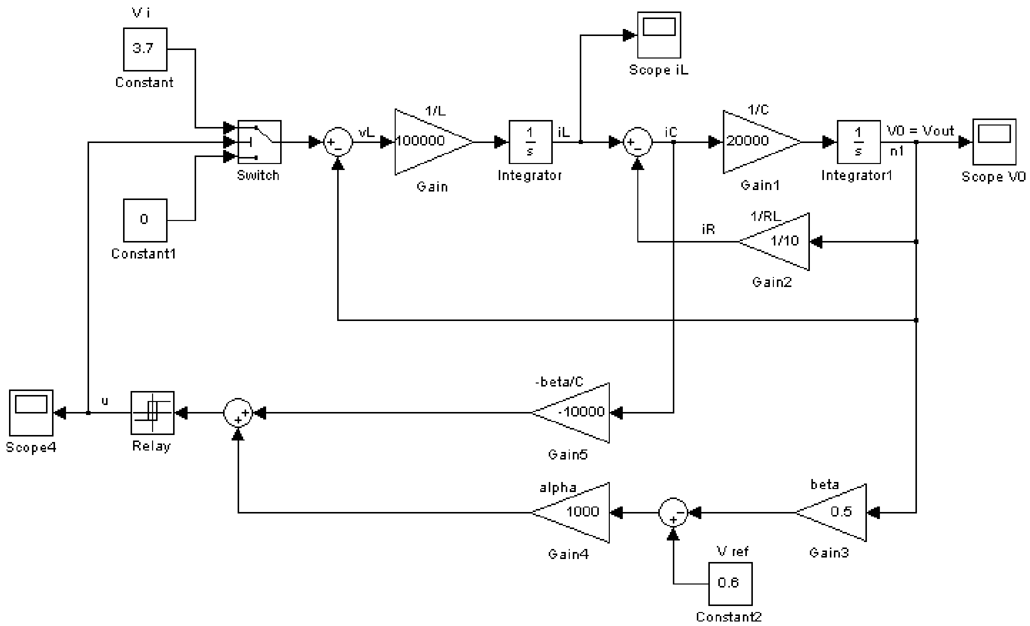

Fig.3. Simulink model of a buck DC/DC converter controller

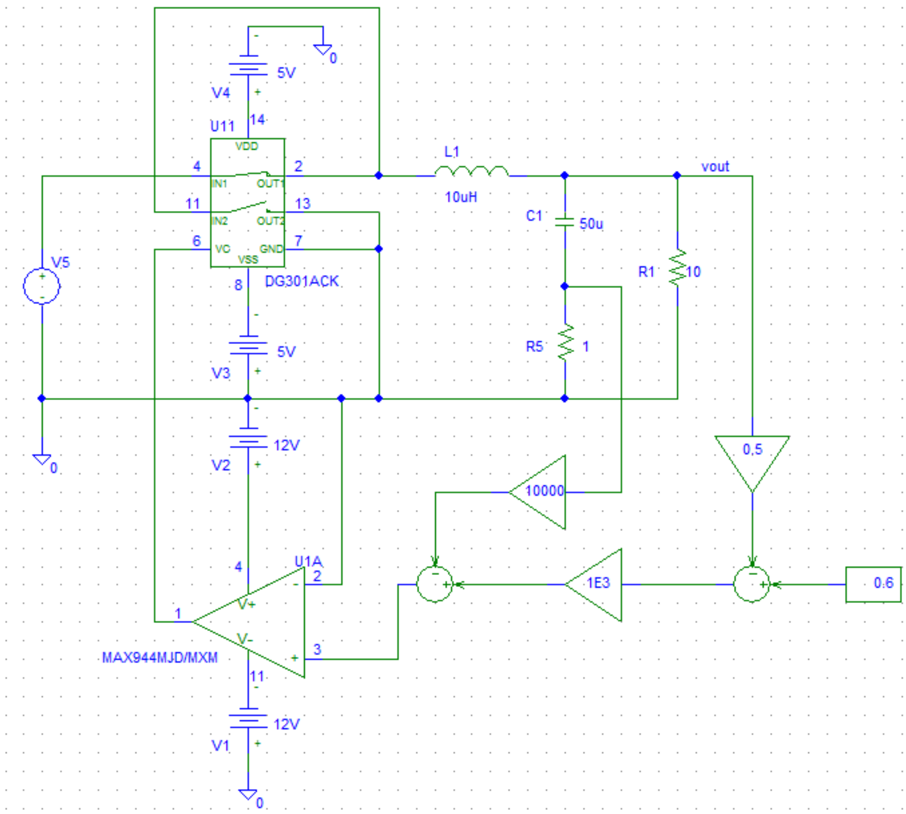

Fig. 4. PSpice model of the converter controller

5. SIMULATION RESULTS

The Simulink simulations are made for two different cases: when α=6000 and α=1000. The other parameters of the controller are: V_{ref} = 0.6V, β=0.5.

The output voltage response in the case when α=6000 is shown on Figure 5.

The simulation starts with a nominal load of 10Ω, than apply a step load change to 2Ω at time *t* = 3 ms and step load change to 20Ω at time *t* = 5 ms.

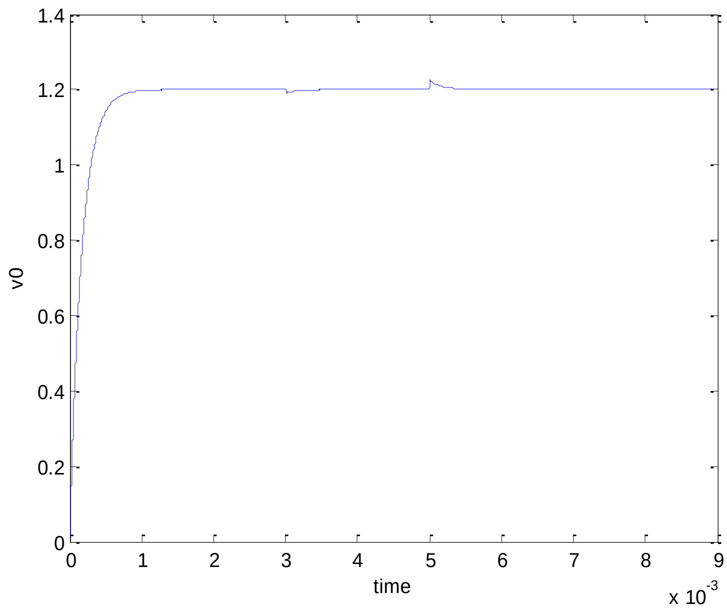

Fig. 5. Output voltage response in the case when α = 6000

The output voltage response in the case when α=1000 is shown on Figure 6. The simulation starts with a nominal load of 10Ω, than apply a step load change to 2Ω (over-loaded condition) at time *t*=2 ms and step load change to 20Ω (under-loaded condition) at time *t*=4 ms.

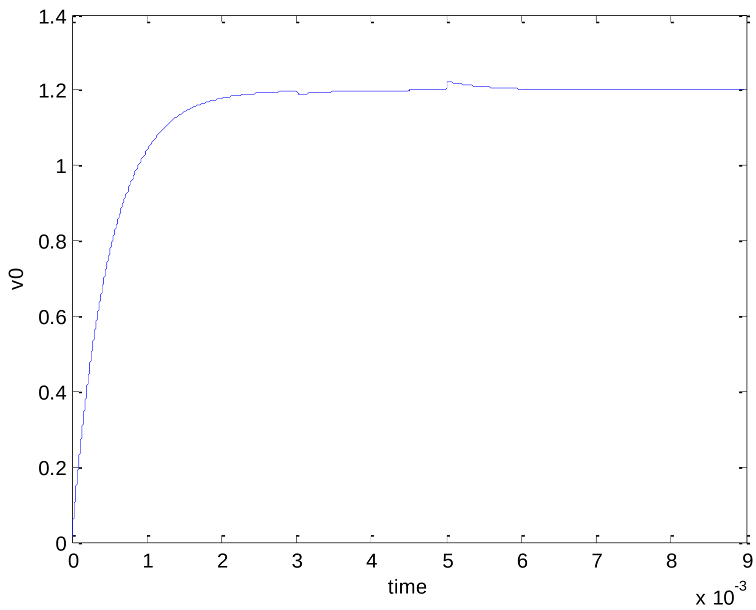

Fig. 6. Output voltage response in the case when α=1000

6. CONCLUSIONS

Simulation results show that the controller with higher α has faster dynamic response at over-loaded and at under-loaded conditions. The results in Simulink and PSpice are similar.

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Reviewer: Assoc. Prof. PhD S. Petrakieva

APPLICATION OF ARTIFICIAL NEUTRAL NETWORKS FORTIME SERIES DALY ELECTRIC LOAD FORECAST PREDICTION IN MATLAB

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Abstract. *Daily electric load prediction is an important task for the companies that are involved with energy distribution. In this paper are presented results for energy load daily forecasting, when presenting the consumer power load as time series dataset. As predictor the Feedforward Error Backpropagation Neural Networks from the MATLAB Neural Networks Toolbox are used, when changing the resulting Neural Networks structure for best prediction accuracy. Also an comparison with forecasts based on mean average value of the power load data from the previous week with the prediction results when using Neural Networks is also presented.*

Keywords: *time series, electric load, neural networks, function approximation*

1. INTRODUCTION

The prediction of the consumed electric power in the electric power distribution systems is an important task. An essential element of electric utility resource planning is the successful short or long term forecast of the electrical consumption. It is so, because in order the delivery of electric energy to be efficient the operators from the distribution companies will need to know for instance, which are the nodes with higher expected instantaneous load, in which hours of the day are the peak network distribution loads, what is the quality of the supplied electrical energy, what are the effects from power savings and etc.

A definite prerequisite for development of an accurate forecast model is the understanding of the characteristics of the consumers that are going to be analysed. The knowledge about the load behavior can be learned from experience with usage of consumer data and statistical analysis of electrical consumption from the past. Usually electricity consumers are operating in a similar economic and climate environment, and usually we have similar consumer behavior and consumption forecast models developed for a consumer can usually be easily adapted for use with another consumer. Load that is supplied by a power distribution system has a dynamic development and reflects directly the activities and conditions in the environment.

In this paper is presented an approach for adequate forecast of electricity consumption. The forecast is done by usage of artificial neural networks (ANN) based on historical data for several transmission nodes in Bulgaria. It involves the development of several ANN designs and selection of the best network that can produce the best results in terms of its accuracy. Also, a comparison is presented between prediction using mean average of several preceding days and ANN method.

2. INTRODUCTION IN THE NEURAL NETWORK THEORY

The neural networks are parallel processing systems with the capability of storing experimental knowledge. Basically every neural network consists of simple information processing elements named neurons. Every neuron is interconnected with the others and the weights of these connections determine their strength. Every neuron input data is the weighted sum of the signals of the other neurons connected to it, while the neuron output is determined by a transfer function based on the weighted input sum value. The information in one neural network is accumulated in a training process, where the strength of the connections between the various nodes is modeled with weights on the according connections, which are used for information storage.

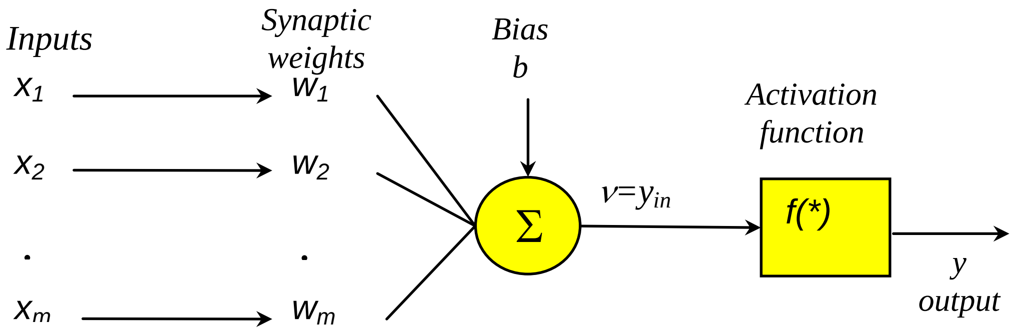


Fig. 1. Single neuron abstract mathematical model

Every neuron have many inputs and one output. Inputs *x1, x2,…,xm* are the signals coming to the neuron and can be external signals or other neuron outputs. Every input is connected with weight w_j, j=1,2,…,m, that models the strength of the transduced signal. The aggregated input signals are modeled with sum unit:

$$v = y_{in} = \sum_{j=1}^{m} w_j x_j + b \tag{1}$$

For convenience, constant signals are modeled with bias b. In most of the cases the activation function is nonlinear and the single neuron output is:

$$y = f(y_{in}) = f\left(\sum_{j=1}^{m} w_j x_j + b\right) \tag{2}$$

Neural networks can be realized in different structures, but the classical structure is with two layers of neurons Feedforward error backpropagation as shown on Fig. 2.

Neuron number in the input layer is determined by the input data dimensions, and the same is valid for the output layer.For this structure by a rule of thumb defined by Oja the optimal neuron number in the hidden layer can be determined. If with Z is denoted the hidden layer neuron number, with P number of samples in the training dataset, m is input numbers and n is the output layer dimension, then:

$$Z = \frac{P}{5(m+n)} \tag{3}$$

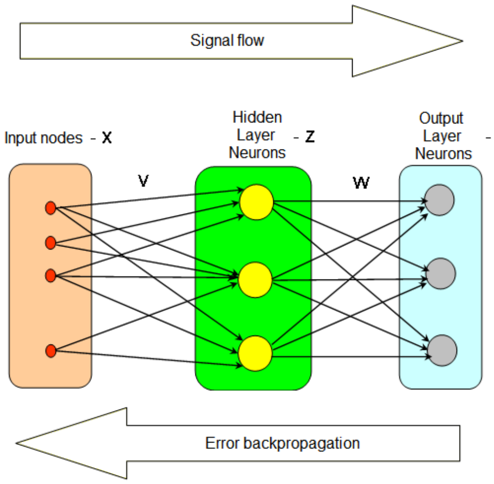


Fig. 2. Two layer Feedforward neural network architecture

3. SIMULATION MODELING AND RESULTS

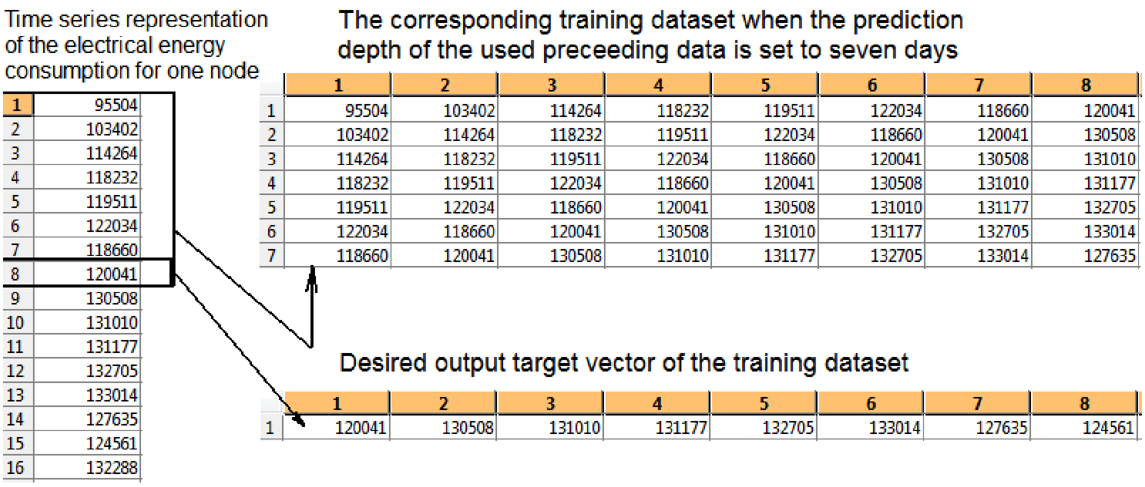
The forecasting results are based on data from preceding time intervals. For training the neural network we have the daily data of consumption in 24 high voltage nodes for year 2006 and the data from year 2007 is used for testing and validation. This data we have was in the for as shown on Table 1.

Table 1. Data from 24 high voltage nodes

Year	Month	Day	Node 1	Node 2	Node 3	Node 4	***	Node 22	Node 23	Node 24	P daily summed
2006	**1**	**1**	4293	4186	4026	3877	***	4301	4346	4335	**29364**
2006	**1**	**2**	4030	3823	3678	3571	***	4806	4809	4684	**29401**
2006	**1**	**3**	4307	4045	3897	3811	***	5017	5044	4868	**30989**
2006	**1**	**4**	4568	4319	4119	4024	***	5136	5229	4990	**32385**
2006	**1**	**5**	4625	4289	4128	4088	***	5248	5281	5045	**32704**
2006	**1**	**6**	4741	4412	4268	4183	***	5379	5389	5310	**33682**
2006	**1**	**7**	4872	4612	4445	4362	***	5107	5213	5147	**33758**
2006	**1**	**8**	4915	4614	4421	4282	***	5514	5631	5343	**34720**
2006	**1**	**9**	4936	4538	4494	4379	***	5609	5800	5512	**35268**
2006	**1**	**10**	5116	4775	4646	4589	***	5688	5806	5574	**36194**
2006	**1**	**11**	5139	4749	4652	4514	***	5801	5879	5593	**36327**

From this data that we have the training dataset is formed by packing every n number of days consecutive sequence as input sample and the next following sample as desired output. One example for the time series training dataset formation for forecast based on 7 preceding days and 8-th day used for desired output is shown on Fig. 3.

Generation of ANNs in MATLAB with the Neural Network Toolbox function newff for creation of multilayer feedforward networks was used. Then, after forming the training dataset a training is performed on the created structures. For the example when using prediction depth n=7 days for only next day forecast window, this results in 7 ANN inputs representing the preceding day 1, day 2, …, day 7 and one output neuron for day 8. The number of neurons in the hidden layer can be determined with (3), which in this particular case gives 9 neurons forming the hidden layer.



1	95504
2	103402
3	114264
4	118232
5	119511
6	122034
7	118660
8	120041
9	130508
10	131010
11	131177
12	132705
13	133014
14	127635
15	124561
16	132288

	1	2	3	4	5	6	7	8
1	95504	103402	114264	118232	119511	122034	118660	120041
2	103402	114264	118232	119511	122034	118660	120041	130508
3	114264	118232	119511	122034	118660	120041	130508	131010
4	118232	119511	122034	118660	120041	130508	131010	131177
5	119511	122034	118660	120041	130508	131010	131177	132705
6	122034	118660	120041	130508	131010	131177	132705	133014
7	118660	120041	130508	131010	131177	132705	133014	127635

	1	2	3	4	5	6	7	8
1	120041	130508	131010	131177	132705	133014	127635	124561

Fig. 3. Training dataset formation

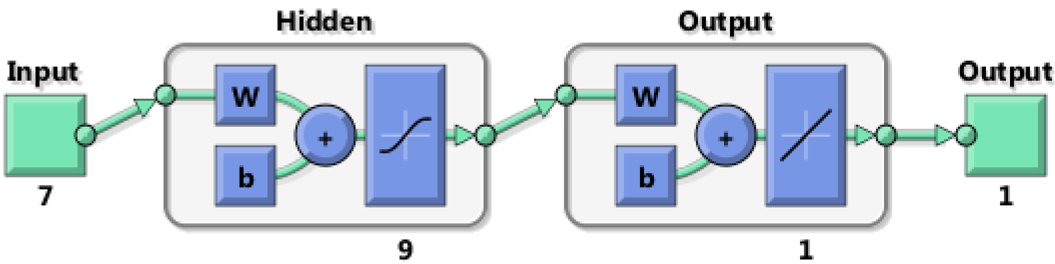


Fig. 4. ANN for daily forecast based on data from the preceding week

After training the ANN with data from year 2006 for testing the adequateness we used the data from 2007. On Fig. 5 is shown an result comparison between actual and predicted value for the energy consumption. From the graph easily is seen that the ANN approximates very well the data and that there are no big differences between predicted and actual data.

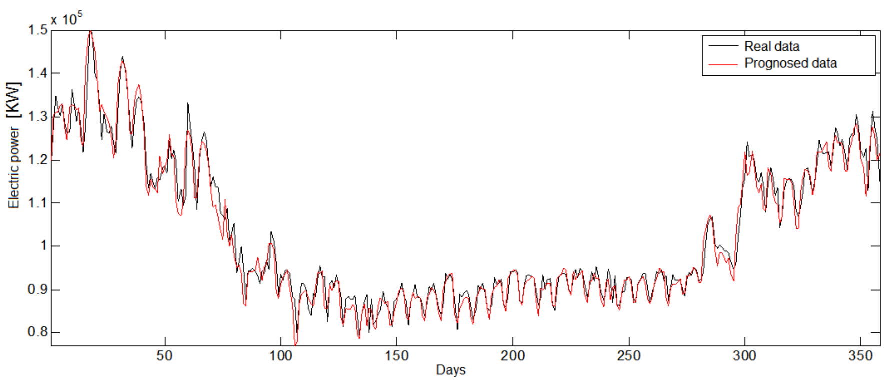


Fig. 5. Comparison of daily consumption between real and prognosed data in one node for one year

In the industry practice one simple method for electricity load consumption prediction is used with having the forecast being mean average of n preceding days:

$$P_{prognosed} = \frac{\sum_{day=1}^{n} P_{day}}{n} \tag{4}$$

A comparison with this technique showing the results on Fig.6 and Fig.7 was made. As it can be seen the ANN method is better as it yields more adequate and correct data forecast prediction. We also created a variation of the number of neurons in the hidden layer ranging them from -2 to +2 from the Oja rule (3) and variation on the prediction depth from 4 to 9 days. The results from the tested data and the corresponding percentage error are presented in Table 2 and they don’t vary much.

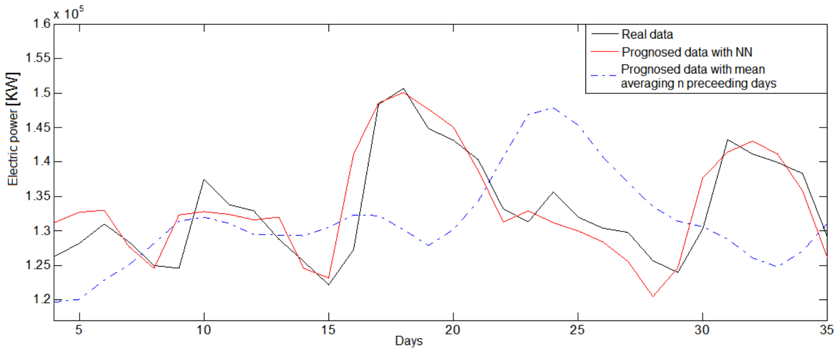


Fig. 6. Prediction methods comparison for n=4 days

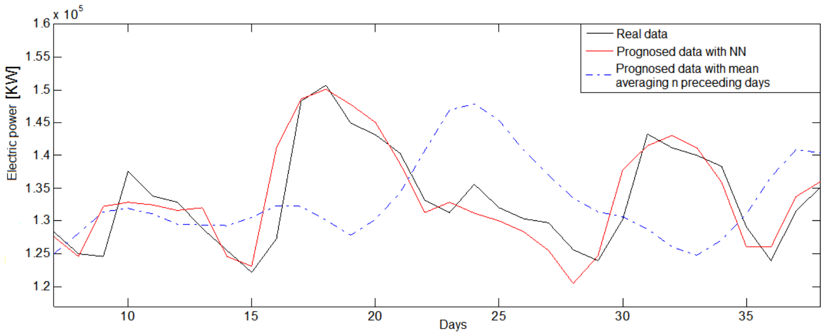
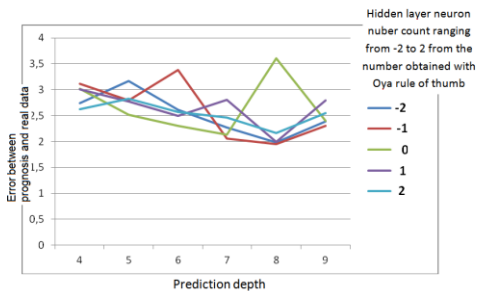


Fig. 7. Prediction methods comparison for n=7 days

Table 2. Percent error between forecast and actual data for ANN hidden layer neuron and prediction depth variation

		Prediction depth					
		4	5	6	7	8	9
Hidden layer neuron nuber count ranging from -2 to 2 from the number obtained with Oja rule of thumb	-2	2,74%	3,17%	2,61%	2,27%	1,98%	2,39%
	-1	3,12%	2,8%	3,38%	2,06%	1,95%	2,3%
	0	3,02%	2,52%	2,3%	2,13%	3,61%	2,4%
	1	3,01%	2,77%	2,5%	2,81%	1,99%	2,79%
	2	2,62%	2,83%	2,57%	2,46%	2,16%	2,55%



4. CONCLUSION

After making comparison with forecasting on the electricity consumption based on mean average of preceding days samples or with neural networks shows that the prognosis with neural networks are more accurate than the classical approach with mean average of several preceding days. The developed neural network model yield very satisfactory results and this leads to the conclusion that, the range of electricity consumption can be successfully predicted when needed.

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APPLICATION OF NEURAL NETWORKS IN FIRE DETECTION SYSTEMS

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Abstract. *Different people have different criteria for detecting a fire. In general the human recognize it correctly. Some of the criteria are: location of the flame, size of the flame, the amount of the generated smoke etc. Neural networks based systems use output of different sensors to obtain data about the parameters of the fire. This paper present a principle fire detection algorithms based on a neural network.*

Keywords: *fire detection, algorithm, neural network*

1. INTRODUCTION

In this study, the applications of neural networks in fire detection systems were reviewed for identifying smoke and flames from fires. Artificial neural networks (NN) are developed for years. The artificial neural networks are applicable even in these cases. Based on artificial neural networks there are some different algorithms applied in fire detection. These algorithms are applicable especially when fire can’t be detected using the classical fire detection approach using thermal channels.

Fire usually goes through three distinct stages, namely, the ignition phase, propagation phase, and extinction phase [1]. The prediction of fire danger is a desirable goal as regards the prevention of fire occurrence. Fire detection in the ignition stage or early in the propagation stage will be of great help regarding fire suppression.

Fire detection systems should have the ability to discriminate signatures between fire and non-fire sources. Data from 1980’s shows that 95% of smoke alarm signals were for non-hazardous conditions [2].

In high value installations such as semiconductor clean rooms and telephone central offices, it is obvious that reliable fire detection systems are needed, since usually these detection systems are used to activate fixed fire suppression systems, and false discharges are certainly undesirable. False alarms can cause unnecessary down time and undermine the operator’s confidence in the monitoring systems. In light of these, a new fire detection system using infrared diagnostics (FT-IR spectroscopy) together with advanced signal processing technique (artificial neural networks) has been developed [3,4].

2. HISTORY OF ARTIFICIAL NEURAL MODELS IN FIRE DETECTING SYSTEMS

McCulloch and Pitts (1943) developed models of neural networks based on their understanding of neurology. These models made several assumptions about how neurons worked.

Rosenblatt stirred considerable interest and activity in the field when he designed and developed the Perceptron. Another system was the Adaptive Linear Element which was developed in 1960 by Widrow and Hoff. The method used for learning was different to that of the Perceptron, it employed the Least-Mean-Squares (LMS) learning rule. In 1969 Minsky and Papert wrote a book in which they generalised the limitations of single layer Perceptrons to multilayered systems. Some view of the history os shown on Table 1 [2,3,5]

Table 1. A breaf history of neural networks and fire detection

year	***action***
1943	*McCulloch and Pitts developed models of neural networks.*
1954	*Farley and Clark (IBM reserchers) maintained closed contact with neuroscientists at McGill University.*
1956	*Rochester, Holland, Haibit and Duda*
1958	*Rosenblatt designed and developed the Perceptron.*
1960	*Widrow and Hoff (of Stanford University) ADALINE (ADAptive LInear Element) was developed .*
1969	*Minsky and Papert wrote a book in which they generalised the limitations of single layer Perceptrons to multilayered systems. The significant result of their book was to eliminate funding for research with neural network simulations.*
1988	*Steve Grossberg and Gail Carpenter developed the ART (Adaptive Resonance Theory) networks based on biologically plausible models.*
1972	*A. Henry Klopf developed a basis for learning in artificial neurons based on a biological principle for neuronal learning called heterostasis.*
1974	*Paul Werbos developed and used the back-propagation learning method.*
1975	*Fukushima Kunihiko developed a step wise trained multilayered neural network for interpretation of handwritten characters called the Cognitron.*
1992	*First attempts to incorporate a neural network into fire detection system*

During this period several paradigms were generated which modern work continues to enhance.Grossberg's (1988) influence founded a school of thought which explores resonating algorithms. They developed the ART (Adaptive Resonance Theory) networks based on biologically plausible models. Anderson and Kohonen developed associative techniques independent of each other. Klopf in 1972, developed a basis for learning in artificial neurons based on a biological principle for neuronal learning called heterostasis.

Werbos 1974 developed and used the back-propagation learning method, however several years passed before this approach was popularized. Fukushima (F. Kunihiko) developed a step wise trained multilayered neural network for interpretation of handwritten characters Neurally based chips are emerging and applications to complex problems developing. Clearly, today is a period of transition for neural network technology. Neural networks are in progress of developing in fire detection systems for better fire recognition.

3. A GENERAL VIEW OF A FIRE DETECTION SYSTEM CONTAINING AN ARTIFICIAL NEURAL NETWORK

Fig. 1 shows a block diagram of a fire detection system containing an artificial neural network [2]. As it shows, the neural network can't be the only element in the system which plays a role of importance for the properly fire detection.

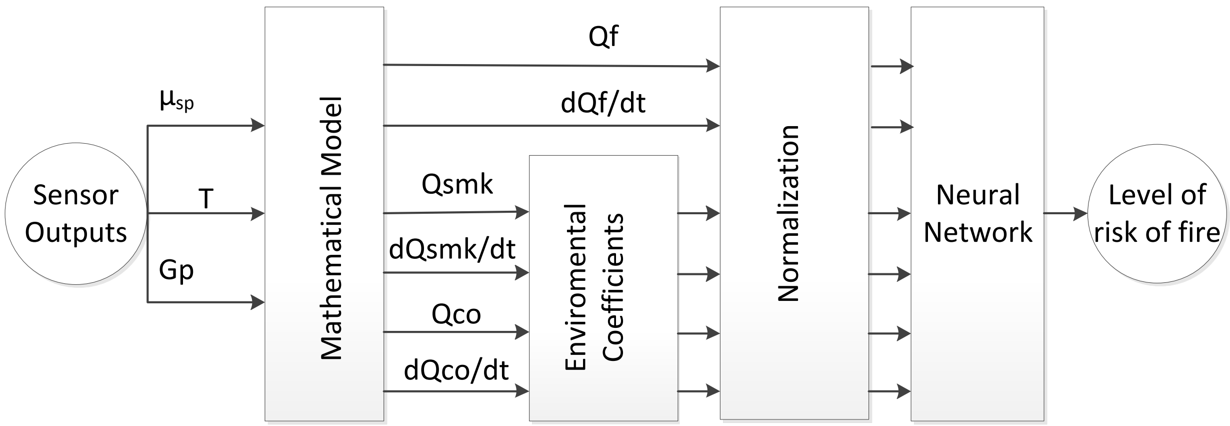

Fig. 1. Block diagram of fire detection system containing an artificial neural network

The sensor outputs deliver information about the temperature T, extinction coefficient μ_{sp} and gas concentration G_p. To receive the source information (data from the sensor), a mathematical fire model is used, which may be a simple zone model to calculate the average values for temperature, smoke concentration and gas concentration near the ceiling using as input the fire source conditions such as the heat release rate, smoke generation rate and gas generation rate. The presented model can be used as a "reverse" to obtain the source information of heat release rate Qf, smoke generation rate Q_{smk}, and gas generation rate Q_{CO} from the corresponding sensor outputs. The temporal differentials dQf/dt, dQ_{smk}/dt and dQ_{CO}/dt are also calculated. These quantities are then normalized with the relevant predetermined normalization coefficients. These normalized quantities are then applied to the neural network. On the final stage the neural network outputs the danger level of the fire.

4. THE PROBABILISTIC NEURAL NETWORK

The presented schema can be built by 3 layers of neurons. The first layer is the input layer with 6xn units. The second layer is a hidden layer with m units. The last layer (output) is with 1 unit.

The described neural network can consist of 6 different inputs corresponding to the actual quantities and their time differentials. On other side, the input layer shows the time of the delay circuit, which is a product of a delay units- delay time and delay count.

Assuming this group of input signals are applied at a certain point in time. The k-th unit has an internal condition u_k in the hidden layer and outputs as $f(u_k)$ [2]:

$$u_k = \sum_{i=1}^{6} \sum_{j=1}^{n} S_{i(n-j)} \omega_{i(n-j),k} \tag{1}$$

$$f(u_k) = \frac{1}{1 + \exp(-u_k + \theta_k)} \tag{2}$$

Where:

$\omega_{i(n-j),k}$ is the weight coefficient of the path between the input and the hidden layer,

θ_k is the threshold of the hidden layer.

The internal conditions are [2,5]:

$$u^* = \sum_{k=1}^{m} f(u_k) \omega^*_k \tag{3}$$

$$f(u^*) = \frac{1}{1 + \exp(-u^* + \theta^*)} \tag{4}$$

Where

ω^*_k is the weight coefficient of the paths between the hidden layer and the output layer,

θ^* is the threshold for the output layer.

The weight coefficients can be optimized by back- propagation method [3].

5. CONCLUSIONS

The neural network with a delay circuit, which handles the previously collected data as well as the actual data obtained from different sensors, can reduce false alarms caused by transient variation of output of a single sensor. Neural networks are able to learn representative examples by back propagating errors.

This paper leads to the next steps of exploring, simulating and producing fire detection systems based on neural networks.

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SOLVING NONLINEAR SYSTEMS VIA LINEAR PARAMETRIC MODELS

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Abstract: *Solving nonlinear systems of equations is a standard problem arising in the analysis of nonlinear dc circuits. The most popular method for global solution of nonlinear systems is the well-known interval Newton method using the interval Jacobean matrix of the system or the so-called interval slope matrix. In the present poster, a better approach is suggested which is based on the use of corresponding linear parametric models.*

Keywords: *Nonlinear DC circuits, Numerical analysis, Solving nonlinear systems*

1. INTRODUCTION

Solving nonlinear systems of equations is a standard problem arising in the global analysis of nonlinear dc circuits. More specifically, the problem considered is:

solve globally

$$f(x) = 0, \tag{1.a}$$

$$x \in \boldsymbol{x}^0 \subset R^n. \tag{1.b}$$

Global nonlinear dc circuit analysis is guaranteed if interval methods are used [1].

The most popular interval method for global solution of nonlinear systems is the well-known interval Newton method (or its versions): an iterative method using interval extension $\boldsymbol{J}(\boldsymbol{x})$ of the Jacobean matrix (or some modifications) for the currant box $\boldsymbol{x}$ belonging to $\boldsymbol{x}^0$ and related to a given iteration. The following interval system

$$\boldsymbol{A}(\boldsymbol{x})\, y = f(x) \tag{2}$$

is to be solved at each iteration where $\boldsymbol{A}(\boldsymbol{x})$ is an interval matrix (standing for the interval Jacobean matrix, interval slope matrix, the Hansen-Sengupta operator or some other modification) while $f(x)$ is a real vector.

An alternative approach was suggested in [2] using the following approximation

$$f(y) \in A(\boldsymbol{x})x + \boldsymbol{b}(\boldsymbol{x}), \quad x \in \boldsymbol{x} \tag{3}$$

where $A(\boldsymbol{x})$ is a real matrix while $\boldsymbol{b}(\boldsymbol{x})$ is an interval vector. The right side in (3)

$$L(\boldsymbol{x}) = A(\boldsymbol{x})x + \boldsymbol{b}(\boldsymbol{x}), \qquad x \in \boldsymbol{x}, \tag{4}$$

is known as a *linear interval approximation* (LIA). In this case solving (1) reduces to repeatedly solving the interval system

$$A(\boldsymbol{x})y = -\boldsymbol{b}(\boldsymbol{x}) \tag{5}$$

where, unlike (2), $A(\boldsymbol{x})$ is a real matrix. This determines the better performance of the LIA approach as compared to the standard approach (see [3]).

A new approach for global nonlinear dc circuit analysis, i.e. solving (1), will be suggested here (Section 2). It is based on various alternative approximations of f in $\boldsymbol{x}$ which are in linear parametric form. Now, we obtain a linear parametric system

$$A(p)(y-x)=-f(x), \quad p\in \boldsymbol{p} \tag{6a}$$

or, equivalently

$$A(p)z=b(x), \quad p\in \boldsymbol{p} \tag{6b}$$

where $A(p)$ is a parametric matrix. It will be shown that (6) is a better way to bound the solutions of (1) than the interval Newton method. System (6) will be referred to as a *linear parametric model* of $f(x)$ in $\boldsymbol{x}$.

The linear parametric model (6) will be extended to the analysis of nonlinear circuits containing resistors or other parameters given as intervals (Section 3).

2. SYSTEMS OF NONLINEAR (NONPARAMETRIC) EQUATIONS

2.1. Linear parametric approximation using slopes

This is yet another alternative linearization of nonlinear functions suggested in a different context for the first time in [3]. The novel approach is based on the use of the slope matrix $S(y,x)$ and the equality

$$f(y)= f(x)+S(y, x)\,(y - x), \tag{7}$$

where y and x have some fixed values (typically, x is a known solution x^0 of (1)). We now "free" the components y_k of y and consider them as components of a parameter vector p, i.e.

$$p = (y_1,\dots,y_n) \in \boldsymbol{x} = (\boldsymbol{x}_1,\dots,\boldsymbol{x}_n)\,. \tag{8}$$

Let

$$a_{ij}(p) = S_{ij}(p,x) \tag{9}$$

be the entries of the parametric matrix $A(p)$. On account of (7) to (9)

$$y \in f(x) + A(p)(y-x), \quad p \in \boldsymbol{x}\,. \tag{10}$$

The right-hand side of (10) is the novel *linear parametric approximation* (LPA) of f in $\boldsymbol{x}$. If y is a zero of f, then

$$A(p)(y-x) = -f(x), \quad p \in \boldsymbol{x} \tag{11a}$$

or, equivalently

$$A(p)z = b(x), \quad p \in \boldsymbol{x}\,. \tag{11b}$$

Thus, using the novel approximation, the *linear parametric model* (11) is obtained. Following [3], we show that (11*) is a better way than (2) to bound the solutions of (1)*. Indeed, introduce the solution sets

$$S_J = \{z:\ Jz = b\ ,\quad J \in \boldsymbol{J}(\boldsymbol{x})\}\ , \tag{12}$$

$$S_p = \{z:\ A(p)z = b\ ,\quad p \in \boldsymbol{x}\}\ . \tag{13}$$

It is seen that while $\boldsymbol{J}(\boldsymbol{x})$ depends on n^2 independent entries, there are only n independent elements in $A(p)$. Moreover, the methods for enclosing S_p account for the interdependencies between the components of $A(p)$. Thus, it follows from (12) and (13) that

$$S_p \subset S_J\ . \tag{14}$$

If Z_{out}^J and Z_{out}^p [4] denote some outer interval solution of (2) and (11b), respectively, then we can expect that also

$$Z_{\text{out}}^p \subset Z_{\text{out}}^J \tag{15}$$

but (15) is, however, not guaranteed.

2.2. LPA using the Hansen-Sengupta operator in parametric form

The approach of § 2.1 is applicable only if $S(y, x)$ the slope matrix is available in analytical form. If this is not the case, then the Jacobian matrix in parametric form $J(p)$ can be used as suggested in [3]. Thus, (9) is replaced with

$$a_{ij}(p) = J_{ij}(p_1,,, p_n)\,,\ p_i \in \boldsymbol{p}_i = \boldsymbol{x}_i\,,\ i = 1,,, n\,. \tag{16}$$

It is seen that each element $a_{ij}(p)$ depends on all n parameters p_i. A better LPA is suggested here which is based on the Hansen-Sengupta operator [5]. In its standard (nonparametric) form, it encloses each function $f_i(y)$ by the following expression

$$f_i(y) \in f_i(x) + \sum_{j=1}^{n}\left(y_j - x_j\right) g_{ij}\left(\boldsymbol{x}_1,.., \boldsymbol{x}_j; x_{j+1},.., x_n\right). \tag{17}$$

We now write (17) in parametric form

$$f_i(y) \in f_i(x) + \sum_{j=1}^{n}\left(y_j - x_j\right) g_{ij}\left(p_1,.., p_j; x_{j+1},.., x_n\right),\ p_1 \in \boldsymbol{x}_1,.., p_j \in \boldsymbol{x}_j\,. \tag{18}$$

Hence, using the Hansen-Sengupta operator, we have to replace (16) with

$$a_{ij}(p) = g_{ij}(p_1,,, p_j)\,,\ p_k \in \boldsymbol{p}_k = \boldsymbol{x}_k\,,\ k = 1,.., j\,. \tag{19}$$

It is seen that, unlike (16) where all n parameters are intervals, now a fraction (1/2)(1-1/n) in (18) are real parameters. This determines the better performance of the Hansen-Sengupta LPA as compared to the Jacobian LPA.

2.3. Checking uniqueness

Another advantage of the LPA strategy over the standard strategy is in checking the uniqueness of a solution in $\boldsymbol{x}$. The standard approach is to check if

$$N(\boldsymbol{x}) \in \text{int}(\boldsymbol{x}) \tag{20}$$

is valid ($N(\boldsymbol{x})$ can be the Newton, Gauss-Seidel, Krawczyk, Hansen-Sengupta operator). It is to be stressed that no additional assumption is needed. The new approach is based on the assumption that *we have already established the presence of a solution* x^* *in* $\boldsymbol{x}$ *and it only remains to check for uniqueness of* x^* *in* $\boldsymbol{x}$. Very often in practice, this is really the case.

Theorem 1. Let $f(x)$ *be a continuously differentiable vector function. Let* $A(p)$ *be the parametric matrix defined in* $\boldsymbol{x}$ *by (16). If* x^* *is in* $\boldsymbol{x}$, $f(x^*) = 0$ *and* $A(p)$ *is a regular matrix in* $\boldsymbol{p} = \boldsymbol{x}$, *then* x^* *is the unique solution of* $f(x) = 0$ *in* $\boldsymbol{x}$.

The proof is based on Theorem 13.6.1 in [5].

Thus, we can *prove uniqueness by checking regularity (strong regularity) of* $A(p)$ in $\boldsymbol{x}$. A better choice is to check regularity of the slope matrix $S(p, x^*)$, $p \in \boldsymbol{x}$ by some method (a simple such test for regularity is given by Theorem 4, Section 3.2 in [3] but any better check for regularity of parametric matrices could be used.

3. SYSTEMS OF NONLINEAR PARAMETRIC EQUATIONS

We now extend some of the ideas considered earlier to the parametric case

$$f(x, p) = 0\,, \tag{21a}$$

$$p \in \boldsymbol{p} \subset R^m\,, \tag{21b}$$

$$x \in \boldsymbol{x}^0 \subset R^n\,. \tag{21c}$$

Assumption 1. A pair (x^0, p^0) satisfying (21b), (21c) is known which is a zero of f in (21a).

The vector p^0 is usually the centre of $\boldsymbol{p}$ and x^0 is the solution of (21a) for $p = p^0$.

The solution set of (21a), (21b) is the set

$$S_f(\boldsymbol{p}) := \{x : f(x, p) = 0, \quad p \in \boldsymbol{p}\}\,. \tag{22}$$

The interval hull of $S_f(\boldsymbol{p})$ will be denoted $\boldsymbol{x}^*$; any other interval $\boldsymbol{x}$ such that $\boldsymbol{x}^* \in \boldsymbol{x}$ is referred to as an interval (outer) bound on $S_f(\boldsymbol{p})$.

3.1. A basic problem

A basic problem is to determine $\boldsymbol{x}$ for a given f and $\boldsymbol{p}$. Finding $\boldsymbol{x}$ has been considered as a sensitivity analysis problem associated with (19a), (19b) (e.g., [5]). Various methods and algorithms are based on the parameterized versions of the Newton method and its variants. Now

$$f(y, p) \in f(x) + \boldsymbol{J}(\boldsymbol{x}, \boldsymbol{p})(y - x) \tag{23}$$

is used which becomes

$$\boldsymbol{J}(\boldsymbol{x}, \boldsymbol{p})(y - x) = -f(x, p) \tag{24}$$

if (y, p) is a zero of f. Another alternative idea is based on the use of (3) and (4) for linearizing non-linear functions applied to the function $f(u)$ when $u = (x, p)$ as well as on Assumption 1. Reference [6] seems to be the only paper where this approach has been developed to offer a method for determining $\boldsymbol{x}$.

3.2. A new linear parametric approximation (LPA) approach

This approach to solving the basic problem is reported for the first time here. In the case of the parametric equation (19a), for a fixed p formula (7) becomes

$$f(y, p) = f(x, p) + S(y, x, p)(y - x) \tag{25}$$

where most often x is the centre of $\boldsymbol{x}$. Once again, we "free" the components y_k of y to take on values in $\boldsymbol{x}$. Thus, we introduce the additional parameter vector

$$q = (y_1,\ldots,y_n) \in \boldsymbol{x} = (\boldsymbol{x}_1,\ldots,\boldsymbol{x}_n). \tag{26a}$$

and let

$$a_{ij}(q, p) = S_{ij}(q, x, p) \tag{26b}$$

be the entries of the parametric matrix $A(q, p)$, $q \in \boldsymbol{x}$, $p \in \boldsymbol{p}$ (x is fixed). For each $p \in \boldsymbol{p}$

$$f(y, p) \in f(x) + A(q, p)(y - x),\ q \in \boldsymbol{x},\ p \in \boldsymbol{p}. \tag{27}$$

If (y, p) is zero of f

$$A(q, p)z = b(p), \quad q \in \boldsymbol{x}, \quad p \in \boldsymbol{p} \tag{28}$$

where $z = y - x$ and $b(p) = -f(x,p)$. The linear parametric system (28) is the new LPA model suggested here to tackle the problem of obtaining an outer approximation $\boldsymbol{y}$ of the solution set $S_f(\boldsymbol{p})$. Indeed, consider the sets

$$S_{JP} = \{z: \quad J\, z = b, \quad J \in \boldsymbol{J}(\boldsymbol{x}, \boldsymbol{p})\}, \tag{29}$$

$$S_{pq} = \{z:\ A(q, p)z = b(p),\ q \in \boldsymbol{x}\ \ p \in \boldsymbol{p}\}. \tag{30}$$

Clearly,

$$S_{pq} \subset S_{JP} \tag{31}$$

($\boldsymbol{J}(\boldsymbol{x}, \boldsymbol{p})$ has n^2 independent entries, each being an interval extension of the function $J(x, p)$ of $n + m$ arguments, while there are only $n + m$ dependent elements in $A(q, p)$ and m dependent elements in $b(p)$.) Hence we can expect (28) to be a better model than (24).

If the slopes $S_{ij}(q, x, p)$ cannot be found in analytical form, then they should be replaced with the components $g_{ij}(q, p)$. In that case, the elements of the parametric matrix $A(q, p)$ are given not by (27) but as follows $a_{ij}(q, p) = \mathrm{g}_{ij}(q_1,..,q_j; p)$.

3.3. Determining an outer solution

Let $N_f(\boldsymbol{x},\boldsymbol{p})$ denote an outer interval solution of

$$A(q,p)(y-x)=b(p), \quad q\in \boldsymbol{x}, \quad p\in \boldsymbol{p}. \tag{32}$$

Consider the following iteration process

$$\boldsymbol{x}^{(k+1)}=N(\boldsymbol{x}^{(k)},\boldsymbol{p};\,\varepsilon_x^{(k)},\varepsilon_p^{(k)}),\ \boldsymbol{x}^{(0)}=x^0,\ k\geq 0 \tag{33}$$

where x^0 is the solution of *f* corresponding to p^0 (the centre of $\boldsymbol{p}$) while $\varepsilon_x^{(k)},\varepsilon_p^{(k)}$ are some parameters introduced to accelerate the convergence of the iterations. The iterations are terminated (if possible) as soon as

$$\boldsymbol{x}^{(k+1)}\subset \operatorname{int}(\boldsymbol{x}^{(k)}). \tag{34}$$

The outer solution $\boldsymbol{x}^b$ (containg $S_f(\boldsymbol{p})$) is given by $\boldsymbol{x}^{(k+1)}$. This is a rather general algorithm. Thus, according to [6] $\varepsilon_p^{(k)}=1$, $\varepsilon_x^{(k)}=1$ until stationarity $\boldsymbol{x}^{(k+1)}=\boldsymbol{x}^{(k)}$ is reached for some iteration number $\bar{k}$ and only then $\varepsilon_x^{(\bar{k}+1)}=1+\varepsilon$ with $\varepsilon=0.05$ for the examples considered. Perhaps, it would be useful to try with

$$\varepsilon_x^{(k+1)}=1+[1/(1+\varepsilon_1 k)]\varepsilon_2 \tag{35}$$

inflating $\boldsymbol{x}^{(k+1)}$ more drastically for the initial iterates.

A similar approach would be to vary $\varepsilon_p^{(k+1)}$ as in (35) (keeping $\varepsilon_x^{(k)}=1$) or to let both $\varepsilon_x^{(k+1)}$ and $\varepsilon_p^{(k+1)}$ change.

3.4. Uniqueness

Some of the methods for determining $\boldsymbol{x}^b$ guarantees uniqueness (i.e., $x(p)$ is unique in $\boldsymbol{x}^b$ for any $p\in\boldsymbol{p}$); others do not. In the latter case an additional test for uniqueness is needed. Here it is assumed that (i) Assumption 1 holds, (ii) an interval vector $\boldsymbol{x}$ is known to contain the interval hull x^* of (21). The problem is to establish whether any other zero (x, p), $p\neq p^0$ is unique in $\boldsymbol{x}$ for each $p\in\boldsymbol{p}$.

Theorem 2. Let the above assumptions be valid. Assume additionally that $f(x,p)$ is continuously differentiable in both $x\in\boldsymbol{x}$ and $p\in\boldsymbol{p}$. Let $J(x,p)$ denote the derivation of *f* wrt *x* (the Jacobian) while $A(q,p)$ is the parametric matrix which elements are defined by $A(q,p)=J_{ij}(q,p)$. If $A(q,p)$, $q\in\boldsymbol{x}$, $p\in\boldsymbol{p}$ is a regular interval parametric matrix, then:

a) there exists a continuous function $x=g(p)$, $p\in\boldsymbol{p}$ such that each $x\in S_f(\boldsymbol{p})$;

b) $S_f(\boldsymbol{p})$ is a connected set in $\boldsymbol{x}$.

The theorem improves on a result due to Hansen: Theorem 17.6.1 and Corollary 17.6.2 in [5].

Remark. The results obtained in § 2 and § 3 could be applied to the case of underdetermined systems (more variables than equations).

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HARMONIC DISTORTION ANALYSIS OF COMPACT FLUORESCENT LAMPS WITH INTEGRATED ELECTRONIC BALLAST

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Abstract: *Non-linear Volt-Amper characteristic of compact fluorescent lamps is a basic reason for the non-sinusoidal form of the current passed through them. Using electronic ballast limits this current during its work, but at the same time it generates high harmonics to the supplying electrical network. In the paper are made time and frequency analysis of compact fluorescent lamps with different power (7,8,9,15 and 20 W) about electro-magnetic compatibility. The results show that each analyzed lamp is up to the requirements of the standard for possible deviation of the coefficient THD and with sufficient precision of 7% it deviates from the standard for power factor λ.*

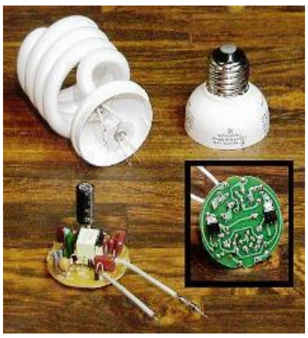
Key words: *compact fluorescent lamps, high harmonics, electromagnetic compatibility*

1. INRODUCTION

Compact fluorescent lamps (CFL) cannot work in direct connection to the supplying network. In this reason it uses electronic ballast (EB), which has a key role for their effective and optimal work. Main disadvantage of these lamps is generating the high harmonics to the network as a result of the using electronic scheme.

In admissible variation of the supplying voltage the parameters of the scheme and electric parameters of the lamps in working mode (current and power) have not exceed admissible limits [1, 2, 4].

Construction of the analyzed CFL with electronic ballast is shown on Fig. 1, but their block [5] and electric schemes – on Fig. 2a and 2b.



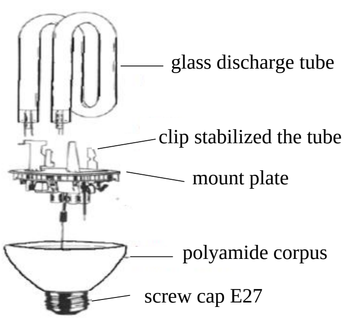


Fig. 1. CFL with electronic ballast

Decreasing harmonic distortion in admissible limits defined in international standards realizes by filter for reducing the disturbances. In practice, there are different schemes for power factor correction (Fig. 2) [4].

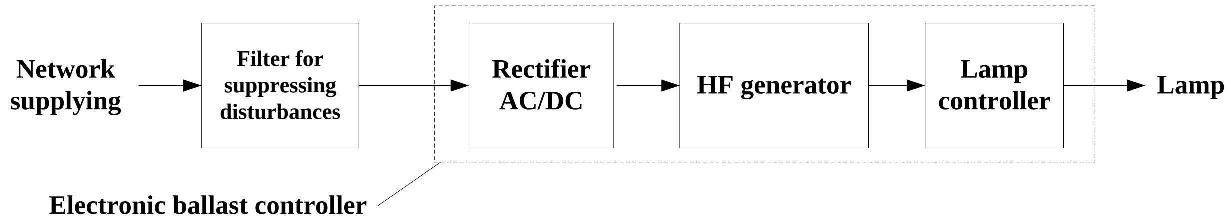


Fig. 2a. Block scheme of electronic ballast

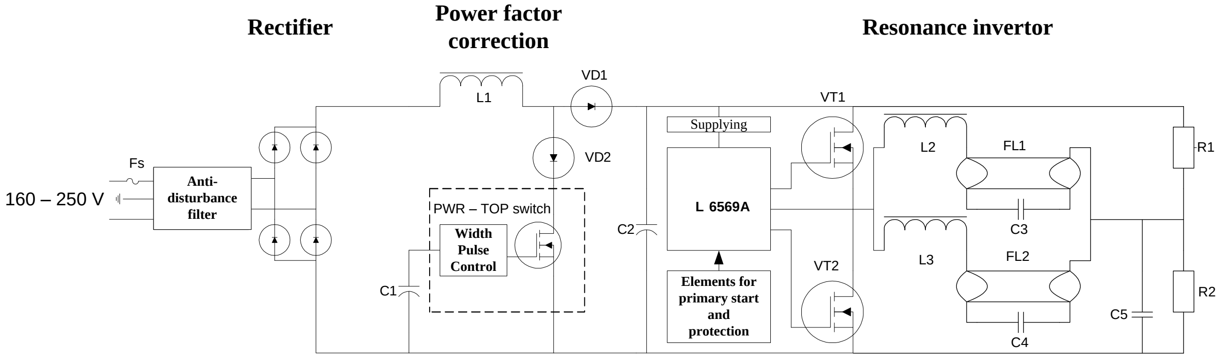


Fig. 2b. Electric scheme of electronic ballast

Main requirement to CFL with electronic ballast is the generated to the network disturbances to satisfy the standard БДС EN 55015, defining the conditions for electromagnetic compliability (EMC) [3].

Present paper is organized as follows. In section 2 are defined the coefficients of *Total Harmonic Distortion* (*THD*) and *power factor* (λ), which are indexes for quality assessment of the signal distortion with respect to the idea sine wave. In section 3 are presented requirements to the lighting devices for decreasing the high current's harmonics generating of them. In section 4 are analyzed different models CFL with electronic ballast in time and frequency domains. In first case are calculated the coefficients of the amplitude and the form of the current, passed through them, but in the second one are determined coefficients *THD* and λ. In conclusion are made some deductions about satisfying EMC standards from studied CFL with electronic ballast.

2. PROBLEM STATEMENT

Analysis of the existing in the system periodical non-sinusoidal signals can be made as in the time as in the frequency domains. The French physicians Fourier is proved that each time periodical function $x(t) = x(t + kT),\ k \in Z$ with period T can be presented as a sum of periodical harmonic (sinusoidal) functions as follows:

$$x(t) = x_0 + \sum_{k=1}^{n} x_{m(k)}.\sin\left(k\omega t + \psi_k\right),\ n \in Z^+ \qquad (1)$$

Then it uses appropriate filters which have to minimize the influence of the high harmonics $x_{(k)}(t) = x_{m(k)}.\sin(k\omega t + \psi_k),\ k \in Z^+$. In practice, the influence of the main harmonic $x_{(1)}(t) = x_{m(1)}.\sin(k\omega t + \psi_1)$ has a key role, because the harmonics variations fade away, i.e. the amplitude of the high harmonics decreases with increasing their number.

The form of the current from supplying network is as pulses (Fig. 3), i.e. non-sinusoidal form, as a result of rectifying and existing of the buffer capacitor.

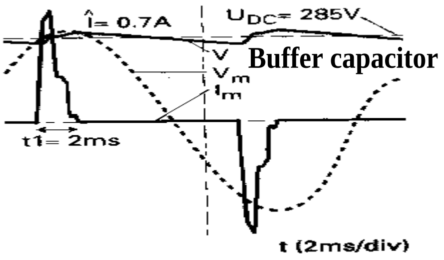


Fig. 3. Form of the current and voltage for two-way rectifier

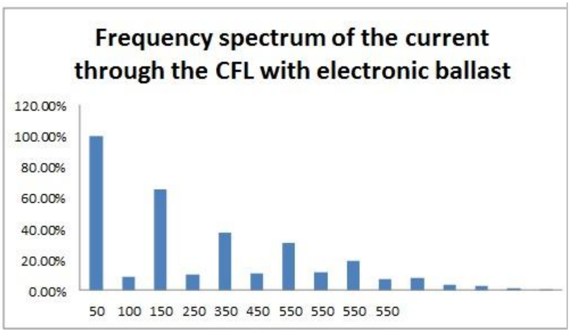


Fig. 4. Frequency spectrum of the current through the CFL with electronic ballast

Therefore, the respective frequency spectrum in Fourier series will be as shown on Fig. 4, where the amplitude of main harmonic is 100 %, but the respective maximums of high harmonics are presented as associated parts of it.

In International standards (IEC 555-2 and БДС EN 61000-3-2 [1]), are defined the limits about the quantity of the returning current's electro-magnetic disturbances to the supplying network. In some of electronic ballasts in Bulgarian market miss network filter and the harmonics with numbers upper than 3 exceed the requirements defined in these standards [1]. In Europe (till 1998) didn't allow limits about harmonic distortions resulting of the electronic ballasts for fluorescent lamps (with power $\leq$ 25 W) [4]. Therefore, the structure and parameters of the filters chose in this way, that the generated harmonics signals to satisfy standards for EMC.

For this reason defines the coefficient for total harmonic distortions (*THD*) [5] as follows:

$$THD = \sqrt{\frac{\sum_{k=2}^{\infty} I_k^2}{I_1^2}} = \sqrt{\frac{I_2^2 + I_3^2 + I_4^2 + \ldots}{I_1^2}} \qquad (2)$$

In lighting devices used the term *Power factor* (λ), which quality evaluates the degree of harmonic distortions, instead of *Power coefficient* ($\cos\varphi$). Because of that always on the electronic ballast have to be written the value of λ. Usually the supplying network voltage has almost sinusoidal form. Then the consumed active power is: $P = U_N . I_N . \cos\varphi$.

Remark: U_N and I_N are RMS values of the main harmonics of the supplying voltage and the input current for the considered electric circuit, respectively.

In practice, in electric circuits with CFL $0.93 \leq \cos\varphi \leq 1$. When determines the power factor λ, it is significant the angle between supplying voltage and main input current as well the coefficient of total harmonic distortion *THD*. If supplying voltage is sine wave, then power factor λ calculates as follows [2]:

$$\lambda = \frac{\cos\varphi}{\sqrt{1+THD^2}} \tag{3}$$

Therefore, electric circuits with different $\cos\varphi$ can have the same power factor λ.

Remark: In schemes with electronic ballast without power factor's correction λ*, the phase difference* φ is nearly to 0 and therefore $\cos\varphi = 1$. *Because of the fact that main input current has a large number of harmonics then* $THD \approx 1.44$ *and* $\lambda = 0.57$.

3. STANDARDS FOR LIGHTING DEVICES

Lighting devices are devices of class C with respect to the limitation of the harmonic distortion of the currents, passed through them. The requirements to these devices [1] are shown in Table 1 for cases when the consumed active power exceeds 25 *W*. In Table 2 are given the necessary limits in working of the fluorescent lamps with electronic ballast as a result only odd numbers' harmonics.

Table 1. Standard for current's harmonics for technic devices of class C

№	$K_{I_{r(k)}} = \frac{I_{(k)}}{I_{(1)}}.100,\ \%$
2	2
3	30.λ*
5	10
7	7
9	5
$11 \le № \le 39$	3

Table 2. Fluorescent lamps with electronic ballast

№	*f*, *Hz*	$I_{(k)}$, *mA*	$K_{I_{r(k)}} = \frac{I_{(k)}}{I_{(1)}}.100,\ \%$
1	50	96	100
2	100	0	0
3	150	89	92
5	250	74	77
7	350	57	59
9	450	40	41
≥ 11	550	25	26

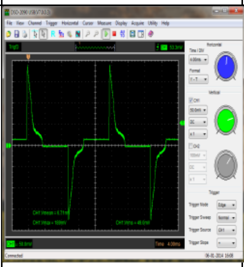
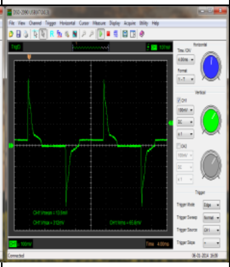
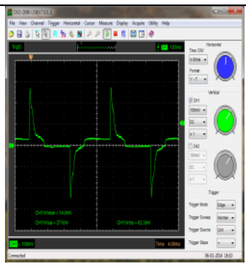
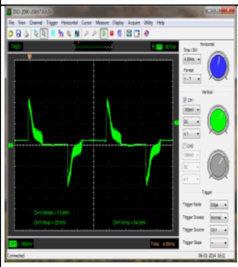
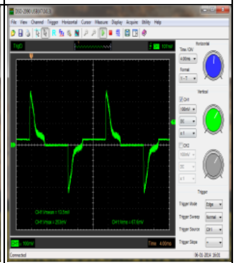
Remark: № – number of the harmonic; $K_{I_{r(k)}}$ *– ratio of the maximum admissible values of the* k^{th} *harmonic and the main harmonic of the consumed current, %; λ* – power factor. Usually the harmonics with numbers upper than 11 and even numbers almost don't influent on the current form. On this reason the standards of IEC define limits in respect of their total effect.*

4. ANALYSIS OF COMPACT FLUORESCENT LAMPS WITH ELECTRONIC BALLAST FOR DIFFERENT POWERS

It is analyzed different models CFL with electronic ballast. The graph of the input voltage and input current in time and frequency domains are experimentally measured. Current $i_N(t)$ have highly marked non-sinusoidal form.

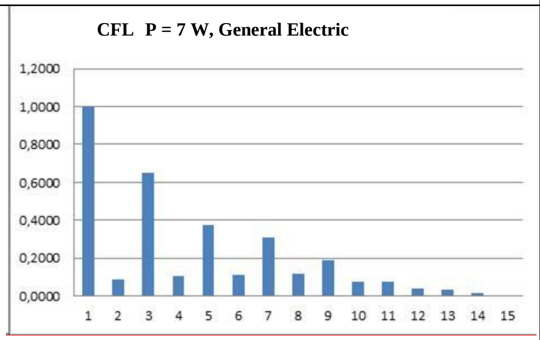
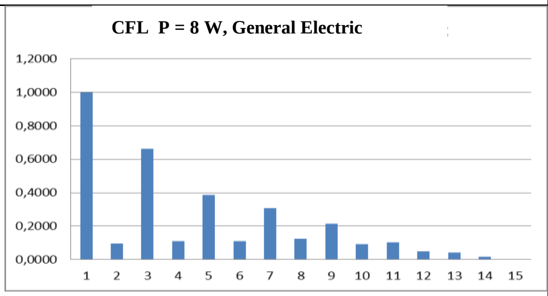
Quality assessment of the results from time domain analysis are amplitude coefficient ($k_A = I_m / I$, -) and form coefficient ($k_f = I / I_{cp.}$, -) of this current, which are shown in Table 3. These coefficient are not given with respect to the supplying voltage because it has almost sinusoidal form and $k_A \approx \sqrt{2} \approx 1.41$ and $k_f \approx 1.11$.

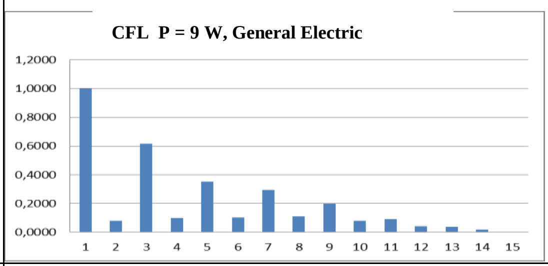
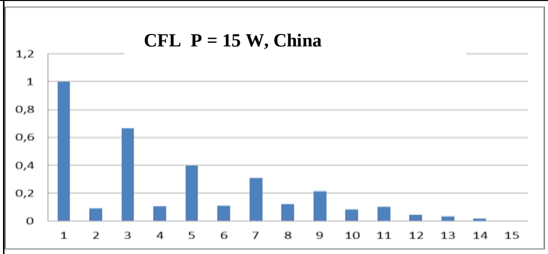
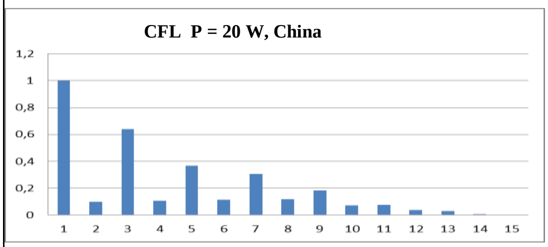
Table 3. Time analysis of CFL with electronic ballast

Investigated quantity	*CFL for different power*				
	7 *W*	**8 *W***	**9 *W***	**15 *W***	**20 *W***
$i_N(t)$					
k_A ,-	3,8579	4,7416	4,3499	4,1386	3,7426
k_f ,-	7,3025	4,8382	4,4501	3,8696	5,0074

The results from frequency analysis of the studied CFL are shown in Table 4.

Table 4. Frequency analysis of CFL with electronic ballast

CFL	Investigated quantity		
	$I_N(f)$	***THD***	λ
7 *W*		**1.325**	**0.602**
8 *W*		**1.341**	**0.599**

9 *W*		**1.298**	**0.6103**
15 *W*		**1.346**	**0.5963**
20 *W*		**1.316**	**0.605**

Main input current in the studied electric circuit has non-sinusoidal form (see Table 3). The respective amplitude and form coefficients have value in the following intervals: $3.7416 \le k_A \le 5.6186$ (for ideal sine wave $k_A \approx \sqrt{2} \approx 1.44$) and $2.9755 \le k_f \le 7.3025$ (for ideal sine wave $k_f \approx 1.11$), which requires frequency analysis of this current. Results of this analysis (see Table 4) show, that generates high harmonics in the spectrum of the main input current in the circuit including CFL. The most considerable influence has the harmonics with odd numbers. It is sufficient to consider only these which have a number smaller or equal than 15. Result about the total harmonic distortion coefficient for analyzed CFL are in the interval $1.298 \le THD \le 1.396$. This satisfies the requirements for admissible value of $THD = 1.44$, defined in the EMC standards. Calculated values for power factor are in the interval $0.596 \le \lambda \le 0.610$. This result shows the variation of 7 % up the admissible value $\lambda = 0.57$ according to the EMC standards.

5. CONCLUSION

Usually in practice the disturbances suppresses by using limiting elements, filters, inductors and transformers. On the other side when the ballast constructs it sizing in such way that to minimize the generated disturbances, standing in normal work of the other devices in the network.

It studies the generated periodical non-sinusoidal signals as a result of the CFL's work. Analysis is made in both domains - time and frequency. Results show that when increases the number of harmonic the amplitude of the respective sine wave fades away. Based on the quality assessments from the harmonic analysis it calculates the values of *THD* and λ for each analyzed CFL. The results (according to the EMC standard) show that the values of *THD* are in admissible range, but these for λ deviate from its admissible value with 7 %. These results interpret with the fact that studied CFL are produced from large-scale manufacturers.

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[2] БДС EN 61547: 1996 Equipment for general lighting purposes – EMC immunity requirements.

[3] БДС EN 55015:2007 Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment.

[4] Анчев М. Х., Иванов З. А., Електронен пускорегулиращ апарат за луминесцентни лампи с висок фактор на мощност, сп. "Осветителни системи", бр. 3, 2001, "ABC Техника "ООД.

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Reviewer: Assoc. Prof. PhD S. Guninski

MATLAB / Simulink MODEL FOR TRAINING IN RESEARCH AND DESIGN OF SOLAR ALTERNATIVE SOURCES

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Abstract. *In this report is submitted an application to set up a model of a photovoltaic source with attached electrical load realized in Matlab/Simulink environment, as part of the learning process. Examines the need to ensure the active personal participation of the students during the training using the tools of computer modeling and simulation variant whereby, the student from a passive observer becomes an active participant in the learning process. Conclusions are made regarding the application of the created electronic model on the quality of training.*

Keywords: *modeling, software, learning process*

1. INTRODUCTION

Wider application of energy from PV renewable energy sources during the last years both globally as well in our country demands a more insightful training to future engineers to design optimal, rational use, implement, and competent to serve such type sources. Limited workload of classes, setting the ever - increasing share of academic material such as hours of self-made along with the traditional methods, the use of computers and technology main support tool in the learning process. Input in the process of learning, Simulation modeling of the studied classes circuits, processes and systems contributes to facilitate and mastering the material studied. Electronic education resources are universal means of providing didactic training in the new information environment, without which the conduct of quality engineering education is unthinkable.

Therefore, through traditional forms and methods of education with the progress of electronic information technologies increasingly successful impose so-called interactive methods for pursuing the high interaction between person and computer systems. The development of computer and information technology in recent years contribute significantly not only to improve the methodology of teaching in technical sciences, but also for a comprehensive rethinking of approaches to teaching [6]. This requires the use more and more new and universal software, the basic meaning of which is undoubtedly the cognitive and motivational.

Study conducted among universities shows that software tools such as Matlab, are becoming more wide application in the education, science and applied science activities developed by students and postgraduates [3]-[5].

Due to its comprehensive, flexible and comfortable to work environment, these products allow for modeling, design and study of objects and systems that are not available in a real learning environment, and non-existent objects. Through the introduction of computer technology in education paves way to more easily accessible and durable learning about the principles of operation of real systems containing multiple components together in a complex interaction. This report is structured as follows:

In the next section presents the basic theoretical dependencies and replacement schemes adopted in the development of a model of a photovoltaic source in MATLAB / Simulink environment.

In the section titled Testing the model are presented numerical and graphical results of the implemented research. Are presented comparative results

In the final section conclusions are displayed and recommendations made.

2. ELABORATION OF MATLAB / Simulink model

To develop a virtual model of a photovoltaic source, implemented in Matlab / Simulink environment by which to follow the process of converting solar energy into electrical energy and explore the production of electricity for the needs of energy management using a single diode replacement scheme [7]. The type of scheme used is shown in fig. №1

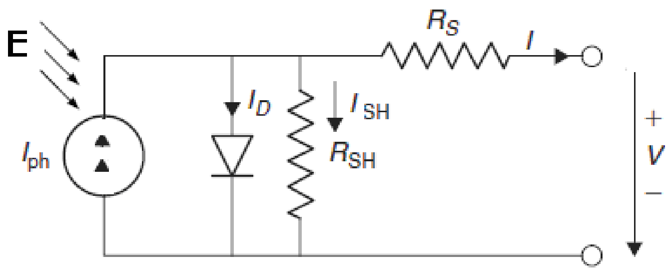

Fig. 1. Single diode replacement scheme

where: I_{ph} is the photo generated current; I_D - is the diode current, so-called current "dark"; R_{SH} - internal diode shunt opening resistance, indicating leakage currents as a result of structural and manufacturing defects of the semiconductor; R_S - consistent resistance representing the resistance of the module. The output current of the model is displayed by Kirchhoff's first law [1], [2]:

$$I = I_{ph} - I_D - I_{SH} \tag{1}$$

To determine the leakage current is applied Kirchhoff's second law, written to the output circuit:

$$IR_S + U - I_{SH} R_{SH} = 0 \tag{2}$$

or

$$I_{SH} = \frac{U + IR_S}{R_{SH}} \tag{3}$$

By substituting (3) into (2) to take account of (4)

$$I_D = I_S\left[\exp\left(\frac{q}{kT_C A}(U + IR)\right) - 1\right] \quad (4)$$

for the current source to give the final form (5)

$$I = I_{ph} - I_S\left[\exp\left(\frac{q}{kT_C A}(U + IR)\right) - 1\right] - \frac{U + IR_S}{R_{SH}} \quad (5)$$

where:

q – charge – $(=1.6x10^{-19}[\circ C])$; k – Boltzmann constant $(=1.38x10^{-23}[J/K])$; Tc – cell temperature; $[K]$; A – a coefficient dependent on the type of PV technology.

Ignoring the influence of the resistors R_{SH} ($R_{SH} = \infty$) and R_S ($R_S = 0$), equation (5) is converted to (6):

$$I = I_{ph} - I_S\left[\exp\left(\frac{qU}{kT_C A}\right) - 1\right] \quad (6)$$

Equation (6) applied to photovoltaic array consisting of - N_S series and Np parallel with connected modules is converted to the final presentation (7)

$$I = N_P I_{ph} - N_P I_S\left[\exp\left(\frac{qU}{N_S kT_C A}\right) - 1\right] \quad (7)$$

Based on the use of the equations $(1) \div (7)$, taking into account equation (8), representing a thermal mathematical model of photovoltaic source:

$$T_{PV}\left[{}^0C\right] = 0.943T_a + 0.028E - 1.528V_{speed} + 4{,}3 \quad (8)$$

where:

V_{speed} – is the wind speed $[m/s]$; E – solar radiation $[W/m^2]$ was realized model of the photovoltaic source, a general view presented in Fig. (2)

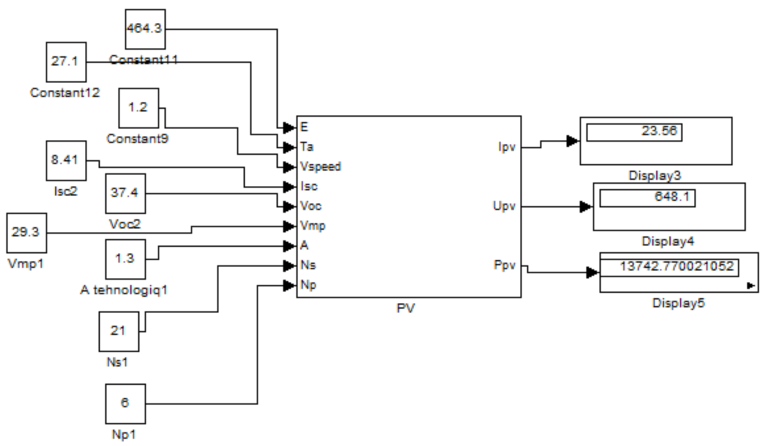

Fig. 2. General view

The type of internal structure is shown in Fig. 3.

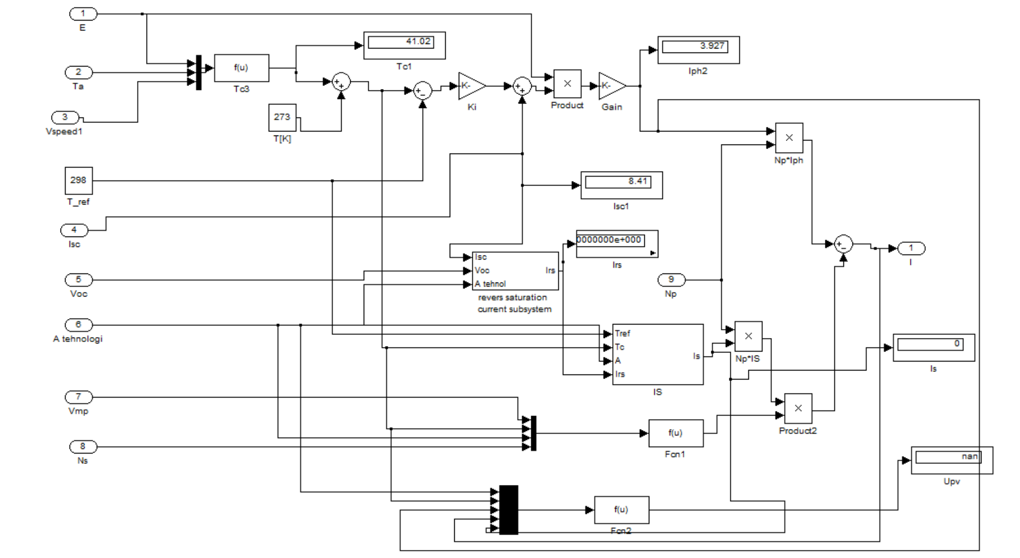

Fig. 3. Internal structure

Presented structure enables the use of model training, in stage of introducing with the principle of operation of photovoltaic sources using the *Display* block to visualize particulars corresponding to each step of basic equations $(1) \div (8)$.

3. TESTING ON MODEL

Efficiency of the model is demonstrated by performing experimental simulation and comparing the results with measurements from a real operating system.

To inputs are used catalog technical parameters of photovoltaic source object of study. These parameters are: short circuit current -I_{SC} $[A]$; voltage at idle -U_{OC} $[V]$; voltage at maximum power - U_{MP} $[V]$, kind of technology of construction of the panel -A.

According the values of the output current, voltage and power, which needs to be achieved to determine the number of sequential (N_S) and the number of parallel(N_P) associated modules.

Before starting the simulation are defined influencing parameters of the environment: solar radiation - E$[W/m^2]$; air temperature T_a $[^oC]$, wind speed -V_{speed} $[m/s]$.

By clicking *Start simulation* of the working window on the toolbox Simulink simulation starts.

Ranging the values of the input parameters of the environment, depending on the climatic operating conditions under which the study is given the opportunity to trace the directly operation of a photovoltaic analyzed system and determine the conditions under which was observed the optimal electrical performance.

For this purpose, with previously assigned input parameters corresponding to the specific weather conditions shown in Table №1, is done modeling of examined photovoltaic system

Table 1. Input parameters

Times of the day and night	**Solar radiation** $[W/m^2]$	**Air temperature** $[^oC]$
07:10:00	106,8	24,5
08:40:00	402	27,1
09:40:00	603,6	27.2
12:40:00	950,4	27,4
14:40:00	882	27,0
15:40:00	759.5	26.7

The data of the modeling can be displayed by measuring tool Display, in numerical form /tabl. 2/ or graphically /Fig. 4/.

Through exporting in Exel provides an opportunity for easy processing and storage of input-output data in a format xls.

Table 2. Numerical results

Time of day and night	Output power **P[W]**
07:10:00	3162.23
08:40:00	11 900.28
09:40:00	17864.11
12:40:00	28109,06
14:40:00	26098,27
15:40:00	22475.85

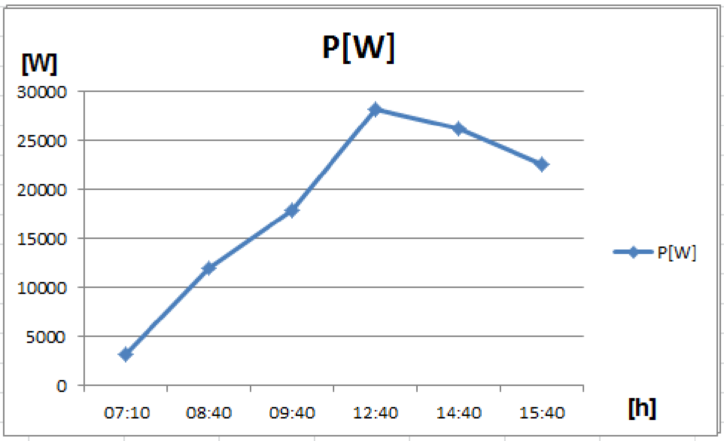

Fig. 4 Graphical representation

For proving working capacity of the model is necessary to make a comparison with a real working station. Comparison is made under identical input influencing parameters. The results obtained in graphical form, are presented in Fig. 5.

The presented method of research and education, by modeling of the behavior of the studied system allows the learner to form a sense that not only it is an object of study, but that actually works with it and experimented. In this way, without fear of any consequences, he can relax and fully develop his imagination and fantasy. Through simulation, with the ways of stimulation of various engineering problem situations expands the horizon of practical and theoretical knowledge and skills which in a real environment certainly leads to more - greater efficiency and speed in decision-making.

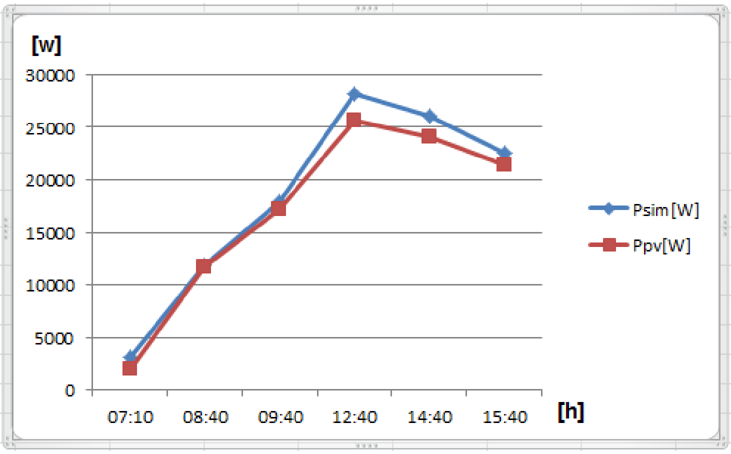

Fig. 5. Comparison between measured and simulated output power

4. CONCLUSIONS

As a result of the use of the model in the learning process can be derived following important conclusions:

- The flexibility of the model allows students to simulate the operation of a photovoltaic studied object at different changes in factors of environment other technology in the production of photovoltaic panels, different single and total output power, diverse connectivity configuration.
- Included in the learning process, MATLAB model, increases the interest and activity of students in the study of modern computer technology and renewable energy.
- By displaying the interim results of the different subsystems involved in the formulation of the model allows for the emphasis and thorough analysis, still in the process of teaching of the processes taking place in the studied PV system.

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Reviewer: Prof. PhD Zh. Georgiev

ABOUT QUALITY OF ELECTRICAL POWER IN GRIDS WITH CONNECTED PHOTOVOLTAIC SOURCES

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Abstract. *This report provides an analysis on the power quality in electrical grids with connected photovoltaic sources. Measurements were made of the main normed indicators of power quality in power grids for medium and low voltage. Comparisons are made between normed and measured values. Based on the obtained results are derived conclusions.*

Keywords*: electric power, DC-AC inverters, photovoltaic sources, higher harmonics, voltage levels*

1. INTRODUCTION

The large number of connected photovoltaic sources to electricity networks of low and medium voltage, during the last years inevitably also affected the operation of the electricity distribution network and to consumers connected to it. The connected decentralized sources to MV or LV grids have only a local influence as after transformation LV/MV, MV/HV, HV/UHV, the impact of small decentralized generating sources is negligible in HV and UHV grids and voltages in the HV and UHV grids is automatically maintained within limits in each substation [3].

The main problems that arise when working on electrical networks connected photovoltaic sources, along with the requirement for the regular operations of the system is the need for high quality of supplied electricity to consumers. With the advent in households and industry more sensitive electronic and communication technique, more increased requirements for quality of power supply.

Accession of photovoltaic sources to electricity networks through inverter DC-AC converters containing elements with nonlinear characteristics are sources of non-sinusoidal interference. Therefore require a detailed assessment of the overall behavior of the electricity distribution network connected photovoltaic containing sources as well to assess the consequences which would arise as a result of using the same type inverters or inverters with poor technical parameters [2]. Made in this regard, research suggests that levels of harmonics in the network increases significantly when inverters are the same type, while the use of inverters of different types lead to a reduction in the level of generated harmonics [4], [5].

A need for accurate assessment of the level of arisen electromagnetic interference that degrade the quality indicators of electrical devices.

Depending on the point of connection and working conditions are affecting at the level a voltage in the network.

Results in [6] show that in case of failure of the voltage, the output voltage of the inverter before it is turned off, can exceed 200% of the nominal value. The peak of the voltage is obtained then the photovoltaic production of electricity. Power is greater than the power consumption at the moment before the drop of voltage. The overvoltage is so the greater, as the greater is disbalance between production and consumption. Upon consumption greater than production observed decrease of the voltage [6].

Realized are "auxiliary tasks" consisting in improving the stability of power distribution networks and maintain an appropriate level of tension in the connected nodes, which would save additional capital investments for their compensation.

The report is structured as follows:

In the next part presents dependencies directly determine the quality of electricity.

In the part titled Results are presented summarizes measurements made in different branches of the distribution network medium and low voltage.

The last part provides conclusions and recommendations.

2.THEORETICAL DEPENDENCE

2.1. Non-sinusoidal modes of the voltage

Non-sinusoidal regimes electric circuits arise in a electrical circuit in the following cases:

– Where in the circuit has sources of non-sinusoidal voltages and currents, and all elements are linear i.e. does not depend on the value of the current.

– Where in the circuit has sources of sinusoidal electromotive voltages and currents, but the elements are nonlinear i.e. have periodic changing parameter.

Upon the harmonic analysis of electric circuits used forms of development in order Fourier [1]:

$$u(t) = \sum_{k=0}^{\infty} u_{km} \sin(k\omega t + \psi_{Ku}) \tag{1}$$

or

$$u(t) = \frac{A_o}{2} + \sum_{k=1}^{\infty} (A_k \cos k\omega t + C_k \sin k\omega t) \tag{2}$$

where: u_{km} is the amplitude value of the k- harmonic, and ψ_{Ku} - its starting phase.

The total coefficient of distortion (clear factor) of the mains voltage, calculated by:

$$THD = \frac{\sqrt{\sum_{\nu=2}^{n} (U_\nu)^2}}{U_1} \tag{3}$$

need to be in the range $\pm 8\%$ (U_υ is the effective value of the harmonics with order number $\upsilon \geq 2$, but, U_1 the effective value of the first harmonic.

For experimental determination and presentation graphically of dependence of the amplitudes and phases of harmonics of frequency when non-sinusoidal function is in the form of an electrical signal using harmonic analysts. The measured results must satisfy the requirements of EN 50160.

2.2. Size and change of the supply voltage

Grids for low and medium voltage under normal operating conditions, with the exception of condition due to damage or interruption of voltage:

– 95% of the average effective value of the supply voltage for 10 minutes should be in the range of $Un \pm 10\%$ of each period of one week.

The range of variation of the nominal voltage is given by:

$$Un = \frac{+10\%}{-15\%} \tag{4}$$

Upon remote areas with long lines voltage can be calculated beyond (4) [7].

3. RESULTS

We have measured the quality of the electricity in different branches of distribution grid for low and medium voltage , with connected photovoltaic sources. The measurements were performed with a network analyzer meeting the requirements of standard IEC 61000-4-30 relating to measurements of power quality.

For purposes of analysis takes into account the requirements of limits values according to Standard EN 50160, by which is made a description of the electrical characteristics of power distribution grids.

3.1. Summarized measurements made in the electrical medium voltage networks

For a nominal reference voltage in determining the limits is accepted voltage 20kV. Analysis of the overall results for the voltages in the three phases shows the mean statistical distribution of the voltage near to upper limit value and, in isolated cases, and in excess of them. The results of the tests for the three phases separately are shown in Fig. 1 – Fig. 3.

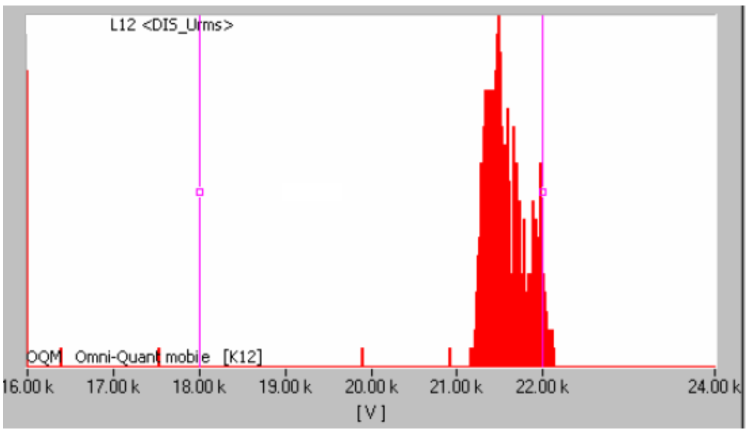

Fig. 1

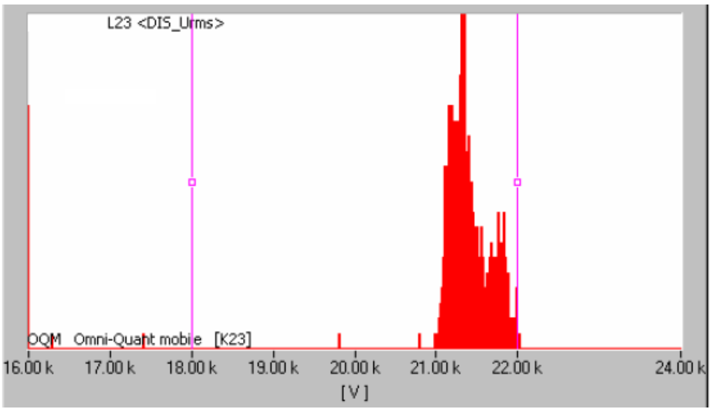

Fig. 2

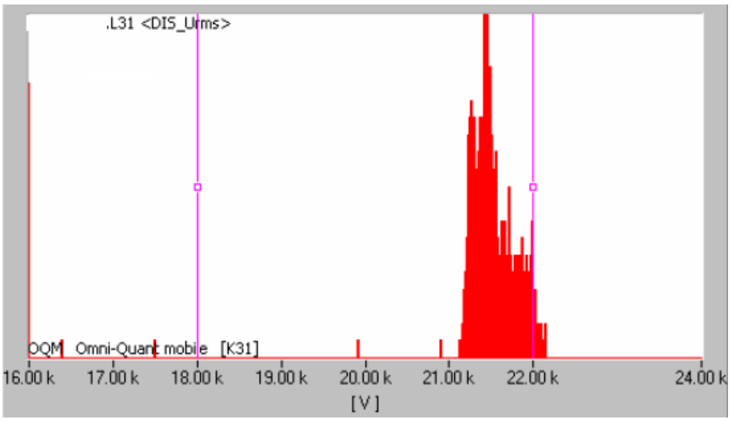

Fig. 3

The made statistical tests to harmonics THD of three phases, ranging set values in the range 2-5%. In rare cases, observed values above the limit of 8%.

3.2 Summarized measurements made in low voltage electrical networks.

For a nominal reference voltage in setting the limit values used support rated voltage of 230V. Overall results of the analysis for the three phase voltages show the mean statistical distribution of their values near to their nominal value. The results of the study of the magnitudes of the phase voltages are presented in fig. 4 – fig. 6.

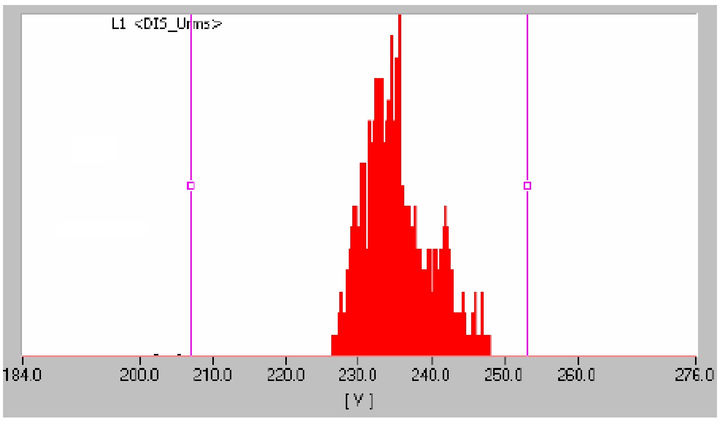

Fig. 4

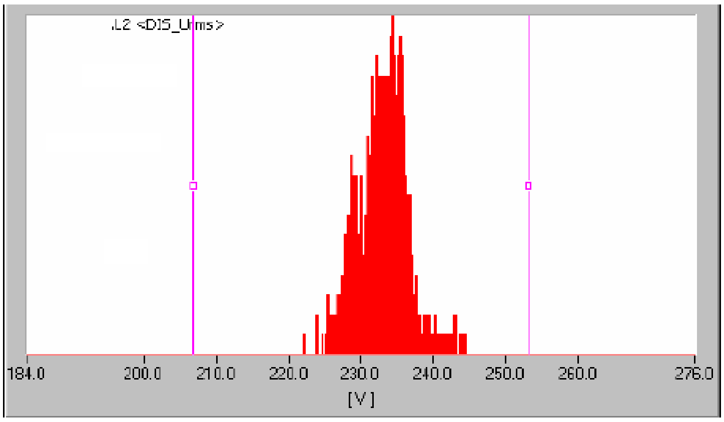

Fig. 5

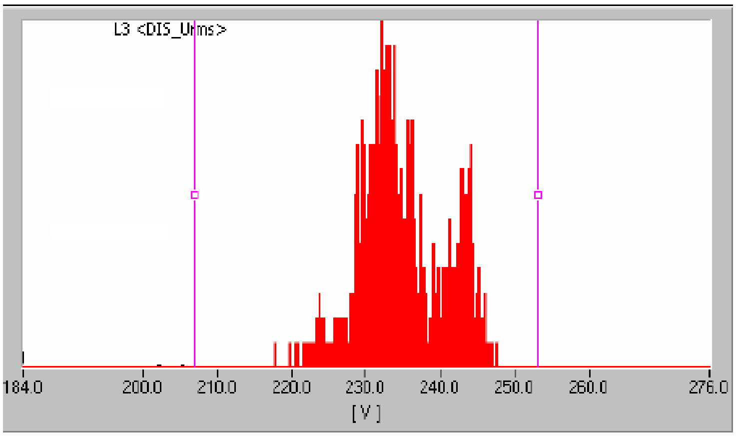

Fig. 6

The content of harmonics THD in three phases, is within 1.2-2.5%. In rare cases, for short periods observed peak levels over the limit 8%.

4. CONCLUSIONS

Based on research and summary results can be drawn the following conclusions:

- Effective voltage values in the studied branches of low voltage networks connected photovoltaic sources do not exceed the limit values, while the medium voltage exist a case of a voltage exceeding the maximum permissible limit.
- The quality of electricity concerning the t maintenance of voltage within the limit values is satisfactory.
- It is necessary to refine the level of penetration of photovoltaic energy in medium voltage networks to limit permanent overvoltage's
- In terms of presence of harmonics in networks connected photovoltaic power source quality of energy is good.

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Reviewer: Assoc. Prof. PhD I. Iatcheva

SUBSTATION TRANSFORMERS MONITORING FOR ANALYSIS AND CLASSIFICATION OF PARTIAL DISCHARGES

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Abstract: *In this paper the instructions for preparing a partial discharge signal analysis are given. The algorithm is applied to discover the correct position of partial discharge in power transformer. The program solution and all modules in MS Visual Studio are implemented.*

Key words: *partial discharge, measuring system, power transformer.*

1. INTRODUCTION

The electrical partial discharge measurement is the most suitable method for assessing the condition of insulation systems in high voltage equipment. Conventional partial discharge measurement systems have proven to have some difficulties in the measurements, particularly in online conditions and noisy environments.

2. MODULE SYSTEM CONFIGURATION

The measurement of the partial discharge begins with the sensors placement around the transformer, where their outputs are linked to the software monitoring system – Transformer Diagnostic Expert System. During the process of sensors positioning, the power transformer should be switch off from the electricity network. When the measurement system is connected, the signals from partial discharges (PD) are registered and transferred to the Comparison Module. There are obtained the time delay between registered PDs from each measuring channel as well as the time of their occurrence. This information is then transferred into the Calculation Module, where the approximate position of PD is established. This position of the PD is visualized through the Visualization Module and an expert determines the part of the transformer that the partial discharge occurs, based on the technical design of the transformer. Using the partial discharge signal structure, the Module of Classification determines the type of the partial discharge.

Together with the chemical condition of the oil in the power transformer, the final decision is taken in the Module of Decision.

Software of Transformer Diagnostic Expert System starts with a window which is shown in Fig. 1.

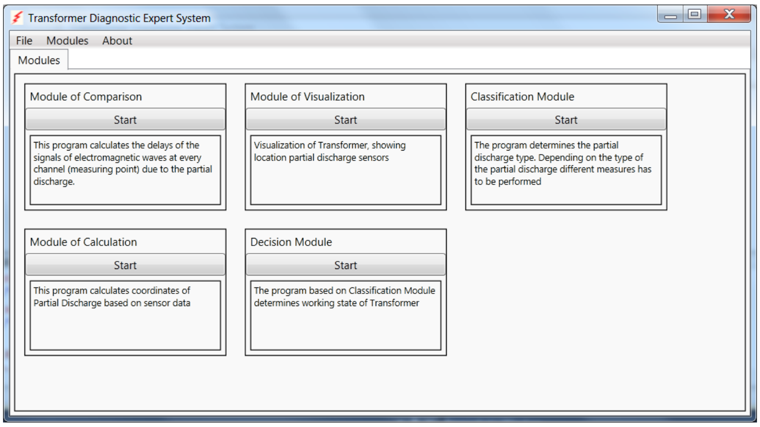

Fig. 1. Transformer Diagnostic Expert System

2.1. Module of Comparison

When the button “Start” of Module of Comparison is pushed, first window from Module of Comparison is appeared and it has to choose folder with data (measured signals), for example folder with name “TEST1”. Then OK should be pushed [1].

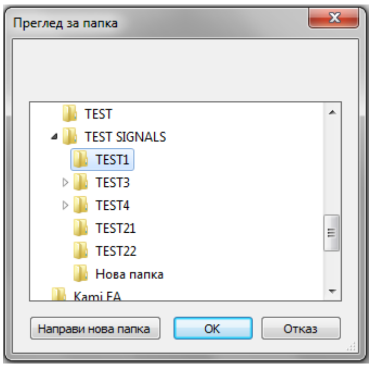

Fig. 2. Module of Comparison – first window

The input data are load from the computer folder “TEST1” and press “CALCULATE RESULT”. The software will generate the results and time delays between signals (Delta T) are calculated, which is shown in Fig. 3:

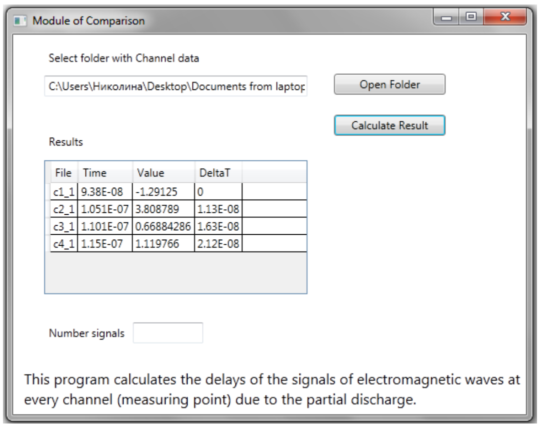

Fig. 3. Module of Comparison – screenshot with data

Results explanation/description:
c1_1 ÷ c4_1 –name of measurement channels, which are four for TEST1
Time – time delay for each channel;
Value – the voltage value of the measurement signal for this point, which describes time delay;
Delta T – time delay between signals

2.2. Module of Calculation

When the button "Start" of Module of Calculation is pushed, first window from Module of Calculation is appeared.

Then the data should be entered, required by the software:

- n – number of measurement sensors (in this example the sensors are four);
- V– speed of the electromagnetic wave (in this example V is the average speed of passing through each one of the materials that the power transformer is made of – copper, steal, oil, barrier oil, paper and others);
- Xi, Yi, Zi – coordinates of the sensors;
- Delta Ti – time delay for each sensor.

In the Calculation Module all parameters have to be given in International System (SI). The results are the coordinates of partial discharges in the power transformer volume, i.e., there is information for the estimated position of the fault with the exact coordinates x, y and z.

After all the sensors coordinates are provided, the "CALCULATE" button is selected and then the program calculates the coordinates of the partial discharge in the transformer volume, which are shown in down left corner in Fig. 4:

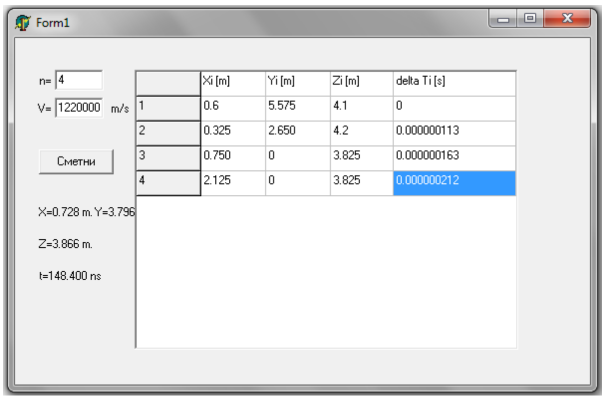

Fig. 4. Calculation Module – screenshot with data

2.3. Module of Visualization

When the icon with button "Start" of Module of Visualization is chosen, the basic window from Module of Visualization is appeared. If the button "File" is pressed than three functions are appear – "Open model", "Save model" and "Save model as".

These functions allowed opening a model of transformer, which is done. It is possible to save changes or make new different models. If it is chosen “File”, “Open model”, “Transformer model” and push button “Open”, then the model from Module of Visualization are appear [1].

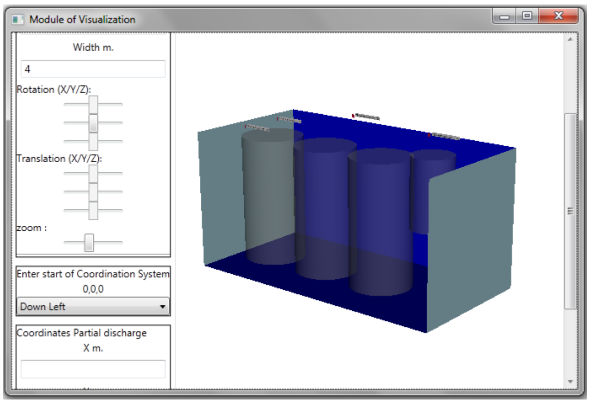

Fig. 5. Module of Visualization with Transformer model

When “Model parameters” is chosen, then two functions are allowed - “Coils” and “Sensors”. The geometric parameters of coils and sensors could be entered. The data is shown at Fig. 6 and Fig. 7.

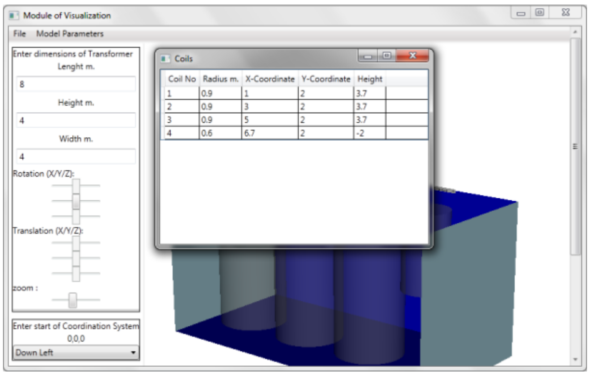

Fig. 6. Module of Visualization with Coils data

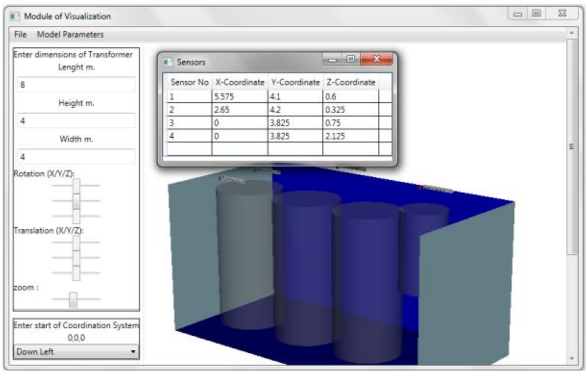

Fig. 7. Module of Visualization with Sensors data

After all data has been entered, the button “Visualize” should be pressed. The software generates the graphical representation of the partial discharge (red point), as in Fig. 8.

At the end of this module the operator decides where the partial discharge occurs, e.g. tap changer, tank, leads, winds or other.

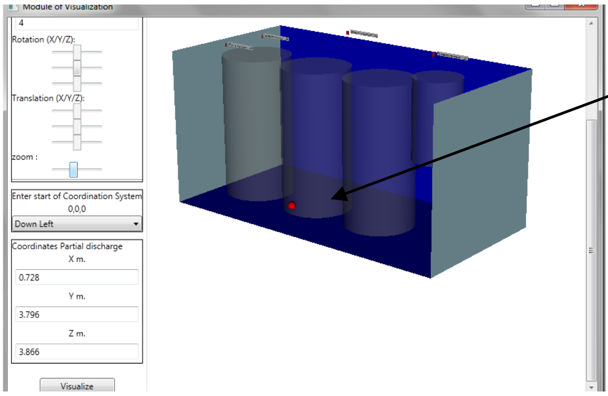

Fig. 8. Module of Visualization –position of PD

2.4. Module of Classification

When the button “Start” of Module of Classification is chosen, the general window from Module of Classification is appeared.

The user has to choose the following parameters: location of discharge on test waveform, variability of response, relative magnitude of discharges, test voltage and time of application. After that the button “Calculate” have to be pressed. Then like output data, this module generates result – one of the most popular cases of PD appears - from A to N which is given in [2].

In the specific case, for example “Transformer model”, the input data is:

- Location of discharge: most pulses in advance of the voltage peaks.
- Variability of Response: random movement.
- Relative Magnitude of discharge: different magnitude on two half cycles.
- Test voltage: rises with test voltage.
- Time of application: constant with time.

The output data is the result case “H”**:**

In case “H”, discharges that occur in advance of the test voltage peaks are described and these discharges on one half cycle of the test waveform are greater in number and smaller in magnitude than on the other half cycle. The amplitude difference on the two half cycles may be as low as 3:1, however a difference of 10:1 is possible if the applied voltage is raised. There is a degree of random variation in both amplitude and location [2].

Indication: Internal discharges between metal or carbon and dielectric in a number of cavities of various sizes are possible. It is often difficult to ensure that a response of this type indicates cavities between metal or carbon and dielectric, as cavities within the dielectric may have metallic or carbonaceous inclusions or non-uniform surface conductivity [2].

There are surface discharges taking place between external metal or carbon and dielectric surfaces and internal discharges in a dielectric-bounded cavity.

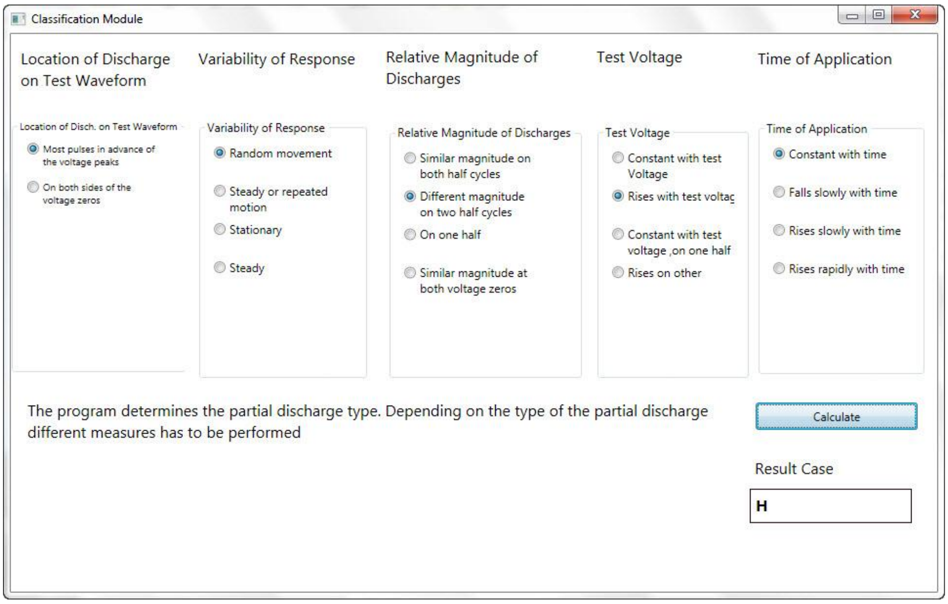

Fig. 9. Classification Module with data

2.5. Decision Module

If the expert chose “Start” of Decision Module Start, the first window from Module of Decision is appeared. Then the correct data for the next parameters: case of PD occurrence, partial discharge location and oil condition have to be selected. It depends on the output data from previous modules. After that the button “Calculate” have to be pressed and the software determines the level of criticality of the power transformer state.

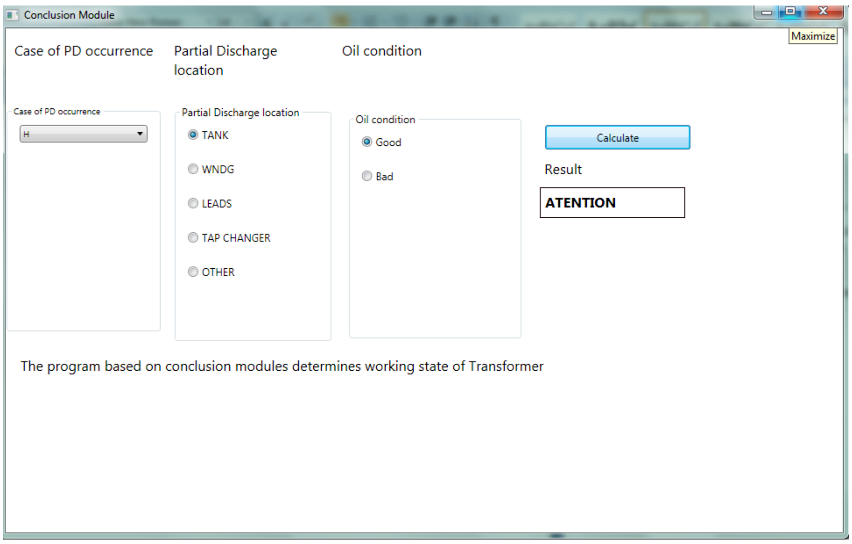

Fig. 10. Conclusion Module– screenshot

The output data is related to the state of the transformer. It can be: Work, Attention or Danger.

For our example “Transformer model”, the software result was: ATTENTION.

It means attention should be paid till the transformer should be open for maintenance checking.

3. CONCLUSION

The system for uninterrupted monitoring provides an early warning for any impending damages, which assures a long enough period of time for bringing out of operation, and do maintenance or repair, which guarantees that little problems will not be turned into bigger ones.

4. ACKNOWLEDGEMENT

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Reviewer: Assoc. Prof. PhD Sn. Terzieva

SYNTHESIS AND ANALYSIS OF A MEMRISTOR-BASED RECTIFYING CIRCUITS IN MATLAB AND SIMSCAPE

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Abstract: *The main purpose of this paper is to propose a new memristor-based rectifying circuits for hard-switching mode. It is specified that when the memristor operates in hard-switching mode for high-level signals with low frequency then the current-voltage characteristics are non-symmetrical and the element can rectify sine-wave and other bipolar signals. For hard-switching mode the state variable of the memristor element reaches the boundaries of the memristor and the state-flux characteristic is multi-valued. The rectifying properties of the memristor element depends primarily on the ratio between the resistances of the memristor in fully-open and fully–closed states. For the analysis of several rectifying memristor-based circuits a modified MATLAB and SIMSCAPE memristor model with nonlinear dopant drift is proposed. It is based on the Joglekar Model and on Boundary-Condition Memristor Model (BCM) respectively.*

Keywords: *memristor, window function, rectifying circuit, hard-switching mode*

1. INTRODUCTION

The memristor element was predicted in 1971 by Prof. Leon Chua as the fourth nonlinear circuit element [1]. Its prototype based on titanium-dioxide was invented in 2008 by Stanley Williams in the HP research labs [2]. Several prototypes based on different technologies were also invented – like polymeric, spintronic and other realizations [2, 3, 4, 5]. The asymmetric current-voltage relation for hard-switching mode is a precondition for investigation of the memristor-based rectifiers [6, 7, 8, 9].

In Section 2 a modified memristor model with nonlinear dopant drift appropriate for simulating hard-switching mode is proposed and the pseudo-code based algorithm for its description is presented. In Section 3 two rectifying circuits based on the classical diode realizations are analyzed using the new SIMSCAPE memristor model, based on the previous pseudo-code, and the new rectifying circuits are compared with their diode analogs. In Section 4 the concluding remarks are presented.

2. A NEW MEMRISTOR MODEL WITH NONLINEAR DOPANT DRIFT

The structure scheme of the Williams' memristor is presented in Fig. 1. The length of the doped region is denoted with w and the length of the memristor is D [2].

The state variable x is equal to the ratio between the length of the doped region w and the length of the whole memristor D [2]:

$$x = \frac{w}{D} \quad (1)$$

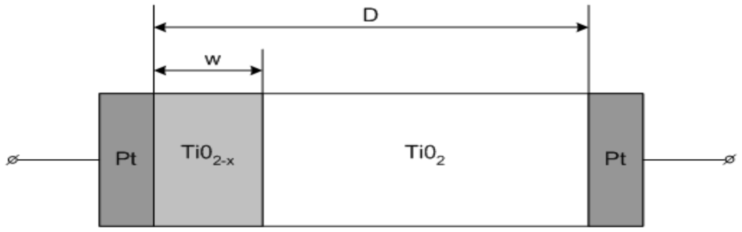

Fig. 1. Structure scheme of the Williams' memristor element

The minimal value of the state variable x according to [2] and [3] should have been $x_{min} = 0$. This announcement will be mathematically true if the minimal length of the doped region is $w = 0$. One of the new ideas in the present paper is based on physical and chemical considerations. Actually when we apply a voltage in reverse direction for a long time then the doped region will shrink but the oxygen vacancies will remain in the same section. The oxygen vacancies are generated in the initial process of electroforming the memristor and they cannot vanish. Due to this the length of the doped region could have a very small minimal length but this length cannot be zero. So the minimal value of the state variable x will have, for example, a value of $x_{min} = 0.05$. The maximal value of the state variable x_{max} could be equal to unity. The last statement is physically possible because the oxygen vacancies could reach the right boundary of the memristor. According to this reason we have: $x \in [x_{\min}, 1]$. The derivative of the state variable x with respect to time t is [2, 3]:

$$\frac{dx}{dt} = kif\left(x\right) \tag{2}$$

The coefficient k depends on memristor parameters and it is [2]:

$$k = \frac{\mu R_{ON}}{D^2} \tag{3}$$

The quantity $R_{ON} = 100\ \Omega$ is the resistance of the memristor in a fully closed state. The quantity μ is the average value of the oxygen vacancies mobility. It could be different for the special realizations and materials of the memristor element. The window function used in (2) is proposed by Joglekar [3]:

$$f\left(x\right) = 1 - \left(2x - 1\right)^{2p} \tag{4}$$

The Joglekar window function in the nonlinear ionic drift memristor model is used for presenting the nonlinear relationship between the velocity of the oxygen vacancies v and the memristor current i for high-intensity electric field. The exponent in this case is $p = 1$. If we choose $p > 1$ the problem is analytically unsolvable but only in Gaussian hyper-geometric forms. The basic current-voltage relation is [2]:

$$v = Mi = \left[R_{ON}x + R_{OFF}\left(1 - x\right)\right]i \tag{5}$$

The quantity M is called “memristance” and it presents the resistance of the memristor. The quantity R_{OFF} = 16 $k\Omega$ is the resistance of the element in a fully open state. Actually $R_{OFF} >> R_{ON}$. Then the following approximation is used for (5) [2]:

$$R_{ON} - R_{OFF} \approx -R_{OFF} \tag{6}$$

After expressing the current i from (2) and substituting in (5) we obtain the basic differential equation of the memristor:

$$vdt = \frac{R_{OFF}}{4k}\frac{1}{x}dx \tag{7}$$

The solution of (7) with respect to state variable x is:

$$x = x_0 \exp\left[\frac{4k}{R_{OFF}}\int_{t_0}^{t} v(t')\,dt'\right] \tag{8}$$

It is important to denote that formula (8) is valid for the soft-switching operating mode. Then the state variable x does not reach its limit values: $x \in (x_{\min}, 1)$. The memristor element operates in soft-switching mode when the memristor voltage has a low-level magnitude and comparatively high frequency. The state-flux characteristic of the memristor element for this mode is a single-valued function and the operating point is moving on the curve described by (8). The current-voltage relation is symmetrical. Let’s the initial value of the state variable is x_0. When we have a signal with high magnitude and low frequency the flux linkage has high level. Then the state variable x could reach its limiting positions [5, 6, 7]. The memristor element operates in the so called hard-switching mode. For this mode the current-voltage characteristic is asymmetrical. Follows the pseudo code algorithm for simulating the memristor model with nonlinear dopant drift, based on Eq. (1) – (8). In the code presented below the basic memristor and voltage source parameters are given. The basic formula used for the code generation is the differential equation (7). For the pseudo-code the differential of time dt is substituted with the limited step value Δt.

```
Procedure: A modified memristor model with nonlinear dopant drift
 Given: Voltage source with instantaneous value v(t)
 Given: The duration of the simulation T = tmax - tmin
 Given: The number of samples N
 Given: The sample step time: deltat = T / N
 Given: Memristor parameters: Ron = 100; Roff = 16e3;
        mu = 1e-13; D = xmax = 10e-9; xmin = 0.05;
        k = mu*Ron/(D^2); const = (4*k) / Roff;
 Given: The initial value of the state variable x0
      set x = x0  for t = 0
       for t = tmin:deltat:tmax
          psi = int(v(t)dt,-∞,t);
       for n=1,  x1=x0;
       for n=2:1:N+1, x1(n)=x1(n-1)+const*u(n-1)*x1(n-1)*deltat;
         if x1(n)<=xmin  AND  u(n)<=0,  then  x1(n)=xmin;
         if x1(n)>=xmax  AND  u(n)>=0,  then  x1(n)=xmax;
```

```
          else  x1(n)=x1(n-1)+const*u(n-1)*x1(n-1)*deltat;
        end cycle
      return u,i,psi, x, M;
end procedure
```

Verifying the modified memristor model in MATLAB

The state-flux characteristic for hard-switching mode in given in Fig. 2. The current-voltage relation of the memristor is presented in Fig. 3.

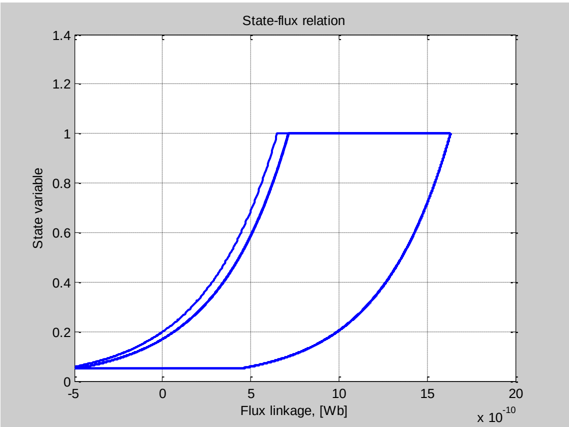

Fig. 2. State-flux relation for hard-switching mode

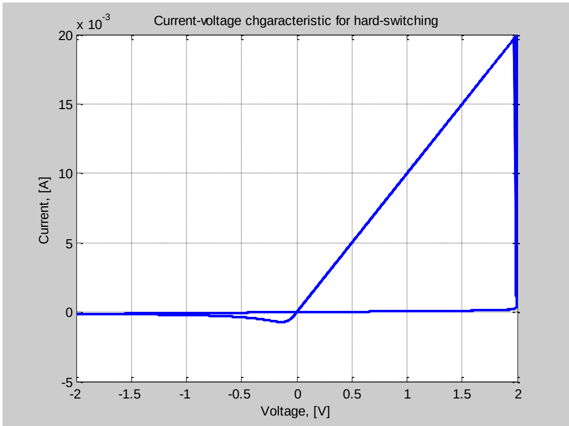

Fig. 3. Current-voltage relationship for hard-switching mode

The state-flux and current-voltage characteristics are compared with previous-published results in [3, 4, 6] and the comparison verifies the abilities of the modified memristor model for using both in soft-switching and hard-switching simulation.

3. ANALYSIS OF MEMRISTOR-BASED RECTIFYING CIRCUITS IN MATLAB

The classical half-wave diode rectifier with a capacitive filter is given in Fig. 4. The new memristor-based half-wave rectifier is presented in Fig. 5. The SIMULINK model of the circuit presented in Fig. 5 is given in Fig. 6. The SIMSCAPE modified memristor library model is based on the pseudo-code presented above. The SIMULINK model of the diode rectifier is similar to the model of the memristor rectifier [6, 7, 8, 9]. The capacitors have a capacitance of 100 μF and the resistors have a resistance of 2,2 $k\Omega$.

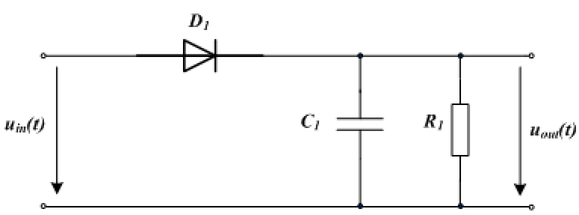

Fig. 4. A half-wave diode rectifier

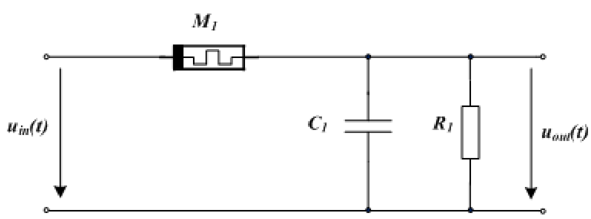

Fig. 5. A half-wave memristor rectifier

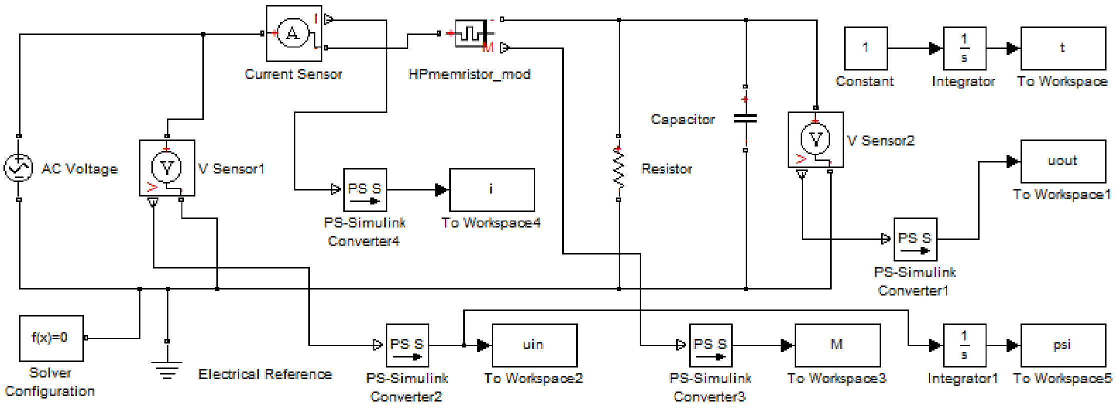

Fig. 6. SIMSCAPE and SIMULINK schematic of the circuit given in Fig. 5

The time diagrams of the output voltage for the diode and memristor rectifying circuits are given in Fig. 7. It is clear that the transient in the memristor circuit has a long duration and the output voltage is less than the output voltage of the diode rectifier. The memductance-flux relation of the memristor element is given in Fig. 8.

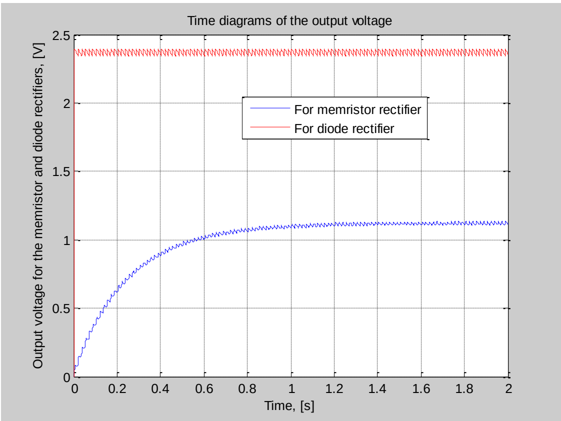

Fig. 7. Time diagram of the output voltage of the half-wave rectifying circuits

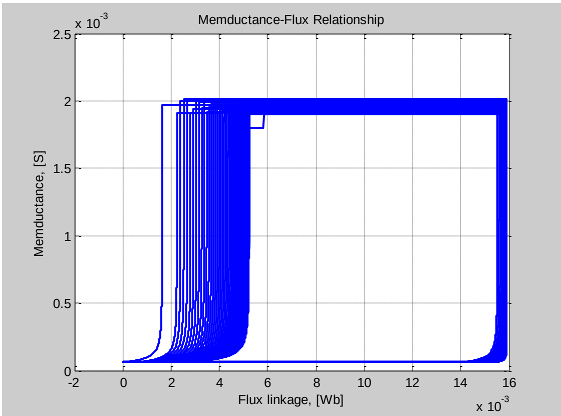

Fig. 8. Memductance-flux relationship for hard-switching mode

Follows the Graetz bridge rectifying circuits with diodes and memristors, which circuits are given in Fig. 9 and Fig. 10, respectively [8, 9]. The capacitors have a capacitance of 100 μF and the resistors have a resistance of 2,2 $k\Omega$. The output voltages for sine wave input signal with amplitude 10 V are given in Fig. 11.

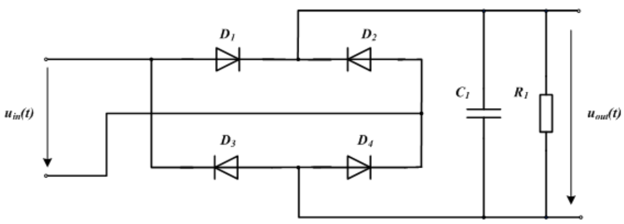

Fig. 9. A Graetz rectifying circuit with diodes

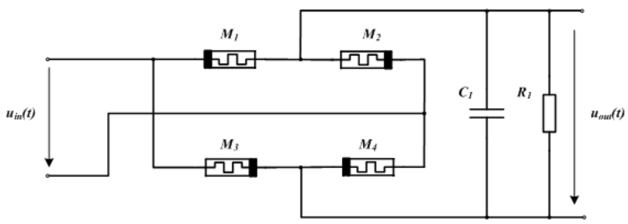

Fig. 10. A Graetz rectifying circuit with memristors

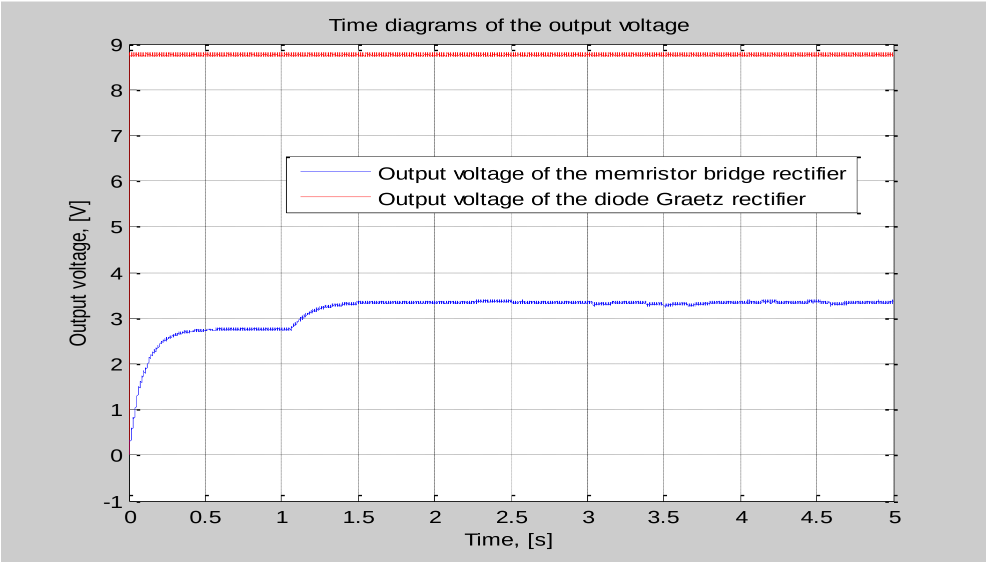

Fig. 11. Time diagrams of the output voltages of the Graetz rectifying circuits

4. CONCLUSIONS

The results from the simulations of the memristor-based circuits presented above confirm that the memristor elements could be used in rectifying circuits if they are operating in hard-switching mode. Really the ratio between the high-resistance and low-resistance states for the memristor is less than the same ratio for the classical semiconductor diode. The output voltage of the memristor-based rectifiers has about two times less value than the value of the output voltage of the diode rectifiers. But the memristor element has several different advantages – good scalability and possibility for integrating with the CMOS technology.

ACKNOWLEDGEMENTS:

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DETECTION OF SIGNAL P300 IN THE PROCESSING OF EEG DATA

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Abstract. *The Electroencephalogram (EEG) is a powerful instrument to collect vast quantities of data about human brain activity. A typical EEG experiment can produce a data matrix related to the human neuronal activity every millisecond. The lie detector is the most common method used by law enforcement agencies to detect fraud. Detection of signal P300 is a step towards the development of safer methods. Test data using EEG controlled experiment by neuroheadset "Emotiv EPOC". It has developed an automated system to extract information about features of EEG signals to detect signal type P300, which is implemented in MATLAB. In the presence of P300 signal to determine whether the studied object is associated with a specific event or problem. In this paper, an experiment is presented to the detection of signal P300.*

Keywords: *detection, EEG signals, signal type P300, MATLAB*

1. INTRODUCTION

This thesis proposes a P300-based BCI system using a inexpensive commercial neuroheadset "Emotiv EPOC". The research work studies and reviews the literature for the state-of-the-art of P300 wave evoking and detection approaches and algorithms. This research uses these algorithms and approaches to develop the proposed BCI system. Finally, this thesis describes results from tests of the reliability and performance of the proposed system in simple control applications.

To clarify the ability of such sensors, first, the P300 brain wave has to be guaranteed to exist among signals that are acquired from the human brain using these sensors. That requires efficient visual paradigms that keep the user engaged and attended for such a purpose. Second, adequate data processing and classification algorithms have to be used to efficiently detect the P300 wave among these noisy signals.

The main objective of the study in this thesis is to develop an affordable P300-based BCI system that uses an Emotiv Epoc headset to control different computer based processes. Then, the next goal is to review specific P300-based BCI data processing and classification algorithms, test, and compare them using well-known benchmark P300 datasets from the BCI.

2. EEG DATA PROPERTIES

Electroencephalography (EEG) is the recording of electrical activity of the human brain. EEG refers to the recording of the brain's instant electrical activity for short periods of time as recorded from multiple electrodes placed on the scalp. That is, the type of neural oscillations that can be observed in EEG signals. [1]

The International so-called 10-20 system is usually employed to record the spontaneous EEG. Odd numbers indicate electrodes located on the left side of the head. Even numbers indicate electrodes located on the right side of the head. Capital letters are used to reference each cortical zone, namely frontal (F), central (C), parietal (P), temporal (T), and occipital (O). Fp and A letters stand for frontal pole and auricular. The designation 10-20 comes from the percentage ratio of the inter-electrode distance with respect to the nasion-inion distance [2].

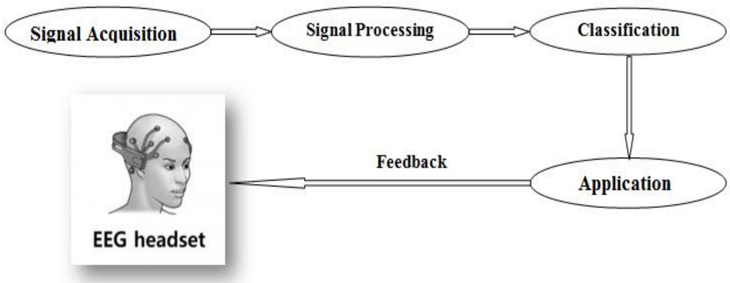

Fig. 1. General block diagram of a BCI system

On figure 1 is presented general block diagram of a BCI system. A subject performs a specific cognitive task or concentrates on a specific stimulus. Brain signals are acquired and then processed with signal processing and classification algorithms. The outcome of the classification is fed into an application. The application generates feedback to inform the subject about the outcome of classification.

As a result, it is difficult to use only the EEG to infer the activity of small brain regions, let alone the activity of single brain neurons [3].

2.1. Data acquisition

In BCI application, working with raw data is essential. Proper data is needed to apply some filtering process and converting raw data into the digital form. Digitized data is used in applications after it is classified.

Applications in this thesis are used both offline and online data acquired from Emotiv Headset. Offline data is recorded in edf file format and used in MATLAB to work with. Online data is used with the application that is written for real time control.

2.2. Feature selection

Feature selection is the first step of the classification. Classification of the data set is impossible in some cases. Feature selection is important because it provides a transformation to different space where data can be classified.

EEG signals are complex signals seem like noise, so gathering information from the time domain is hard. In time domain data seems irrelevant, but it is possible to gather information from that data.

Different spaces give different eigenvectors of this space and different conditions can be shown by the linear combination of these eigenvectors. Transforming data to other spaces obtain different features. Using different spaces guarantee that two different features are not linearly dependent.

Time domain is the main space of the EEG data collected as shown in figure 2 Frequency is also used as a feature space as shown in figure 3 Various transforms can be possible for gathering information on different spaces.

EEG data in time domain is separated in distinct interval parts. These intervals are called Window Length which is also a parameter for classification. Window Lengths should be power of two because FFT (Fast Fourier Transform) transform is faster if the time series length is power of two.

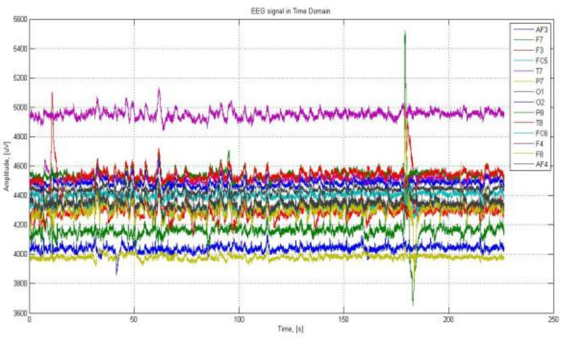

Fig. 2. EEG Signals for every channel separately in Time Domain

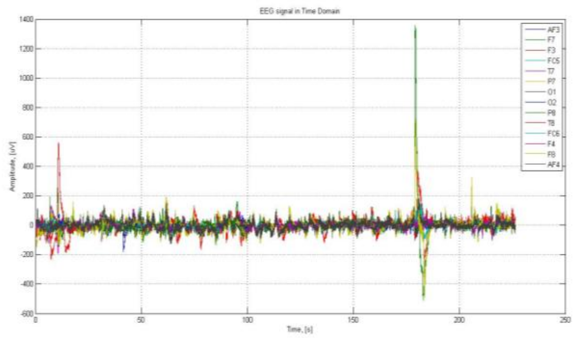

Fig. 3 Average EEG Signals for every channel in Time Domain

3. SIGNAL TYPE P300

The accurate detection of deception or lying is a challenge to experts in many scientific branches. [4]

Signal type P300 is a positive peak in the EEG, observed approximately 300 ms after the stimulus presentation. A typical pattern of P300 response can be seen in figure 4. [5]

The P300 wave is an event-related potential (ERP) which can be recorded via EEG. [6] Discovery of the P300 event-related potential (ERP) stimulated the use of human brain recording methods to evaluate brainwaves and thinks. The P300 component is measured by assessing its amplitude. Amplitude (μV) usually is defined as the difference between the mean baseline voltage and the largest positive peak of the ERP waveform within a time window.

Signal type P300 human scalp distribution is characterized as the amplitude change over the midline electrodes (Fz, Cz, Pz) that increases from the frontal to parietal electrode sites for target influences. [7]

The detection of P300 waves remains a very challenging problem for both the machine learning and neuroscience communities. [6]

4. HARDWARE USED TO DETECTION

Based on the latest developments in neuro-technology, one Swiss based company called "Emotiv" developed a cheap new interface for human interaction with the computer wirelessly.

The "Emotiv EPOC" device (Fig. 5) has 16 sensors which come into contact with the scalp of the head and using the conventional technology - electroencephalography, by detecting electric signals from the surface of the scalp and making them appear on the screen. [8]

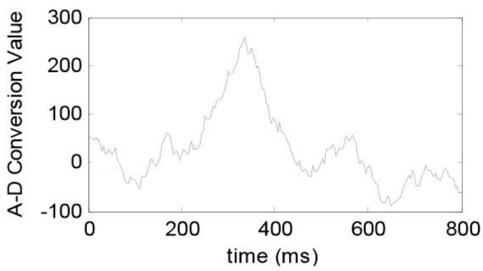

Fig. 4. A typical signal type P300

Fig. 5. Emotiv EPOC neuroheadset

The "Emotiv EPOC" is an EEG neuroheadset which supplies 14 channels EEG data and 2 gyros for 2 dimensional controls. The advantage is that it is wireless cable free solution with long autonomous operation time. The "Emotiv EPOC" sends EEG data to computer with USB receiver via Bluetooth interface.

The academic version of the "Emotiv" software can access the raw data which is decrypted using Control Panel and can save the extracted data. The "Research Edition SDK" includes a research headset: a 14 channel (plus CMS/DRL references, P3/P4 locations). The channel names based on the International 10-20 locations are: AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4 (shown in Fig. 6). Other specifications are listed below (Table. 1). [1]

Table 1. "Emotiv EPOC" Specifications:

Number of channels	**14 (plus CMS/DRL references)**
Channel names (International 10-20 locations)	AF3, AF4, F3, F4, F7, F8, FC5, FC6, P7, P8, T7, T8, O1, O2
Sampling method	Sequential sampling, Single ADC
Sampling rate	~ 128 Hz (2048 Hz internal)
Resolution	16 bits (14 effective) 1 LSB = 1.95 uV
Bandwidth	0.2 – 45 Hz; digital notch filters at 40 Hz and 60 Hz
Dynamic range (input referred)	256 mV (pp)
Coupling mode	AC coupled
Connectivity	Proprietary wireless, 2.4 GHz band
Battery type	Li-poly
Battery life	12 hours
Impedance measurement	Real-time contact quality using patented system

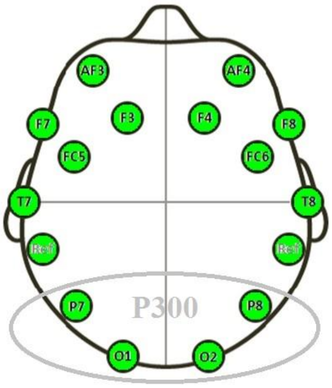

Fig. 6. Emotiv EPOC's Sensors Layout

5. DETECTION OF P300 RHYTHM

5.1. Detection

Detection is mostly used in P300 type evoked potential applications. Detection of the stimulus is important to understand the function of the focused responses then these responses can be classified more accurately. Activity patterns usually stimulate the upper cortex of the brain where a good quality of the EEG signals can be measured.

5.2. Classification

EEG signals are complex signals because of its nature. That makes working with EEG data harder. Classifying the data of EEG signal requires some techniques to determine differences between signals. Classification can be done on different domains such as frequency or time. Methods using classification and feature extraction differ from problems characteristic. Classification is implemented on the windowed data to extract the eigen values of signals for selected feature. After determination of the eigenvalues and preparation of the data set are completed, the packet of data and eigenvalues is sent to the classifier. Several classifiers are used for classification of EEG data. Classifiers are run for each data packet recorded for certain window length.

6. EEG SIGNAL PROCESSING AND RESULTS IN MATLAB

The display screen "Emotiv EPOC" during an experiment is shown in figures from 7 to 11. At the time of recording the research subject is asked a series of test questions. Recording is stopped when questions stopped and the final result is obtained.

7. CONCLUSIONS

This paper presented an experiment on P300 detection based on brain wavelet analysis in MATLAB using the "Emotiv EPOC" neuroheadset. The results presented in this paper are part of a project with the ultimate goal of designing and developing "Lie Detector". The proposed method is suitable for integration into a brain-computer interface and information control for external devices with BCI applications. It has presented part of offline classification system for P300 based brain computer interface. This is classification system and it can improve.

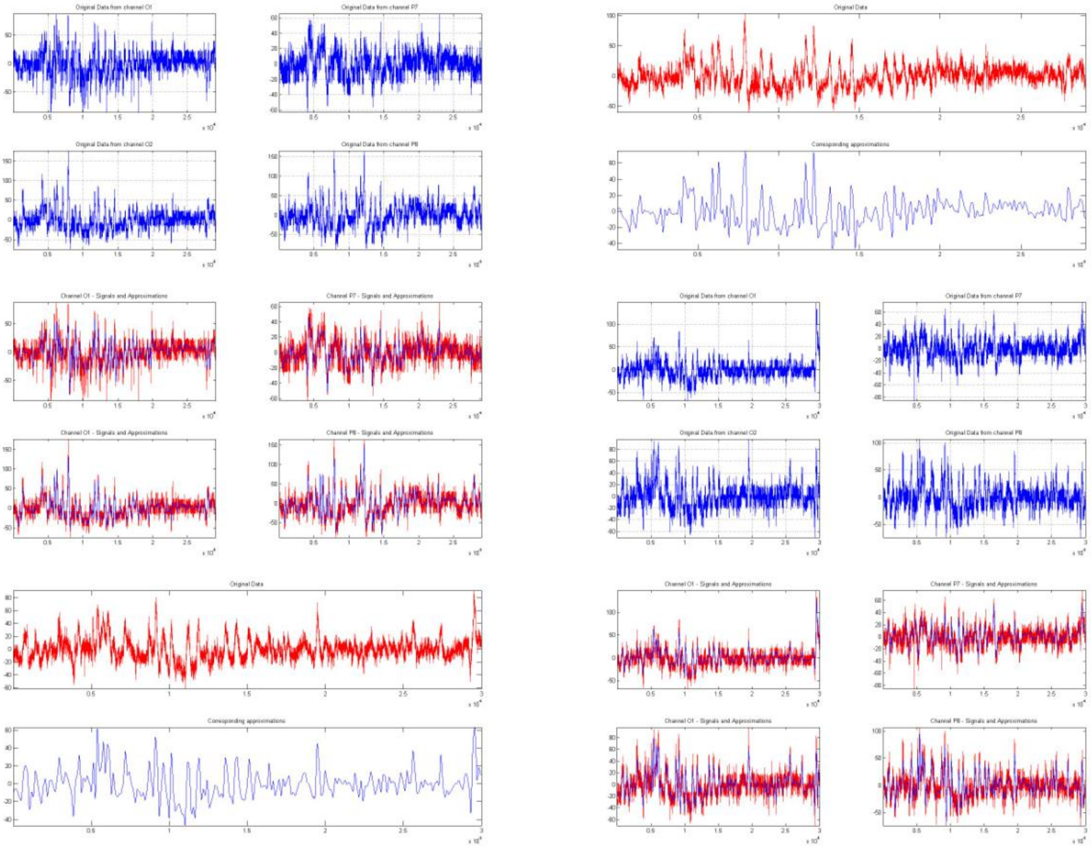

Fig. 7-11 Emotiv EPOC's screen during an experiment – original and approximated signals (in left – when saying LIE // in right – when saying TRUTH)

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SIMULATION OF FAILURE IN TRANSFORMERS USING MATLAB

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Abstract: *Simulation of failures in transformers based on MATLAB environment is presented in this paper. Sensors positions are initially defined. Random number generator for time delay between the measurement impedances and possible failures are used in the simulation. The results so obtained can be used for real practical analysis and diagnostic purposes.*

Key words: *MATLAB simulation, transformers, failure position.*

1. INTRODUCTION

One of the main equipment in transmission and distribution of electrical power in electrical substations are transformers. Their reliable operation requires an optimum preventive diagnostic and maintenance schedule to be applied. It is important to know the condition of the transformers and their components to make the expected performance quantifiable, and to make risks and costs predictable and controllable [1]. One of the most important criteria for the transformer's state is the presence of failure.

Because of the diversity of transformers in now days, the failure modes of transformers have been well studied. Failures in transformers can usually be connect with the failure of a constituent element. It can be occur in the bushings, windings, core, tap changer or the tank shield (screen) and dielectric transformer oil [2].

The main idea of this work is to create an algorithm for predicting the probability of failure in transformer using MATLAB.

2. METHOD FOR DISCOVERING OF FAILURE

The methods for discovering and evaluating the failure are based on the power exchange. This exchange can be electromagnetic wave, chemical reaction, impulse current, dielectric losses, sound, gas overpressure and etc. Random number generator for time delay between the measurement impedances and possible failures are used in the simulation. The oldest and most accessible method is found on measuring the sound level during the discharge, but there are difficulties persistent in isolating the discharge typical sound from the aside noises, especially when the measurement are taken in operation conditions.

For achieving localization of the failure source six measurement impedances are used. The bushing insulators of transformers have measurement outputs (PIN), which are suitable for connecting measurement impedances. Suitable places for mounting additional measuring impedances are the metal parts of the tank of the transformer, which are connected with bolt junctions (revision outlets, flanges of the coolers and others). It is reasonable one or two flanges of the cooling system in the bottom part of the tank of the transformer to be chosen.

2.1. Theoretical description

If (x_i, y_i, z_i), $i=1,\dots,n$ are coordinate of measure impedance i with delay of electromagnetic wave Δt_i, $i=1,\dots,n$ which are due to failure then distance from failure to measure impedance with coordinate (x_i, y_i, z_i) will be:

$$r_i = \sqrt{(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2} \,. \tag{1}$$

Otherwise it can be established with delay of electromagnetic wave Δt_i , $r_i(t)=V(\Delta t_i+t)$, where V is the speed of electromagnetic wave and t is equal for all points of the measurement.

Location of failure could be found if in the every measurement point i, $i=1, 2, \dots, n$, where are registered delay Δt_i , a sphere with radius $r(0)=V.\Delta t$ are made. With consequent step of t are made different spheres till they crossed.

This procedure could be present with solving of this minimization expression:

$$\min_{(x,y,z,t)} \sum_{i=1}^{n} \left[(x-x_i)^2 + (y-y_i)^2 + (z-z_i)^2 - (V\Delta t_i + Vt)^2 \right] \tag{2}$$

Where unknown are the coordination of failure and the value of consequent step.

2.2. Practical implementation and MATLAB description

This method is applied for an example for determining the damage with testing a power transformer 400/220 кV. Electromagnetic waves are registered from six measurement impedances.

Measurement impedances are posed on the 400кV side bushing insulator, two of them are on the bushing insulators on the side 220 кV, on the bushing insulator of the neutral point, on the screen and on a flange of the cooling system.

After establishing the presence of failure, the time delay of the electromagnetic waves to each one of the measurement impedances is registered. If the transformer is presented like rectangular parallelepiped and the theoretical method in MATLAB is applied. Optimization problem is solved by the algorihm which is shown in Fig. 1.

After applying the method in MATLAB and discovering the minimum volume of spheres intersection, the place of the failure on Fig. 3 and Fig. 4 is shown.

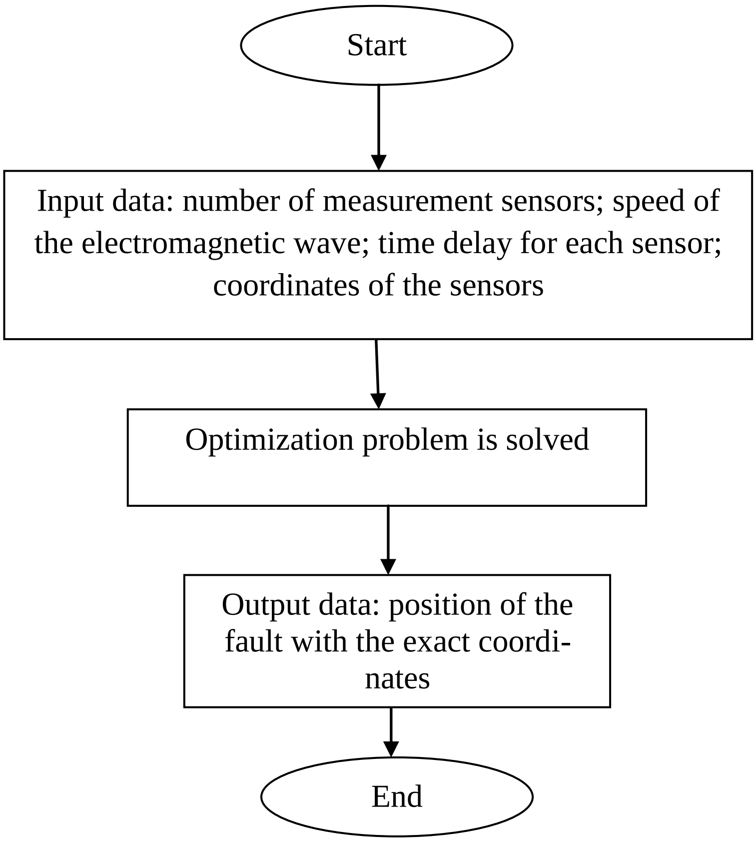

Fig. 1. Applied algorithm

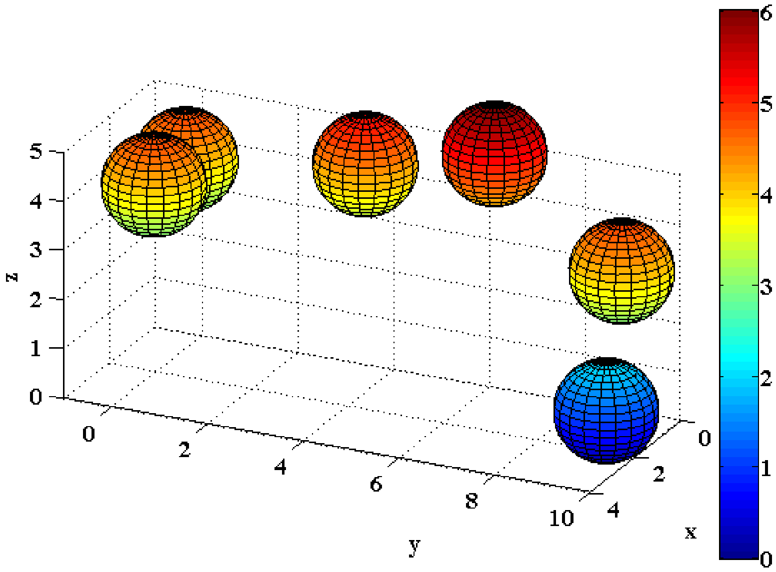

Fig. 2. Transformer model with measurement impedances

The significant role of the power transformers for the power system leads to the necessity of being aware of the causes and locations of their break-up. It is ascertained, that the most often damages are 40% in the tap-changers, 35% in the magnetic core, 14% in the bushing insulator, 6% in the tank and 5% in other parts of the transformer [3].

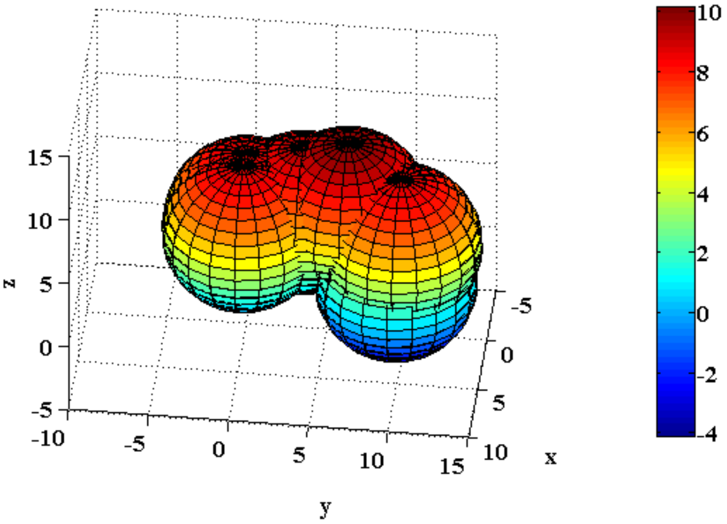

Fig. 3. Localization of failure

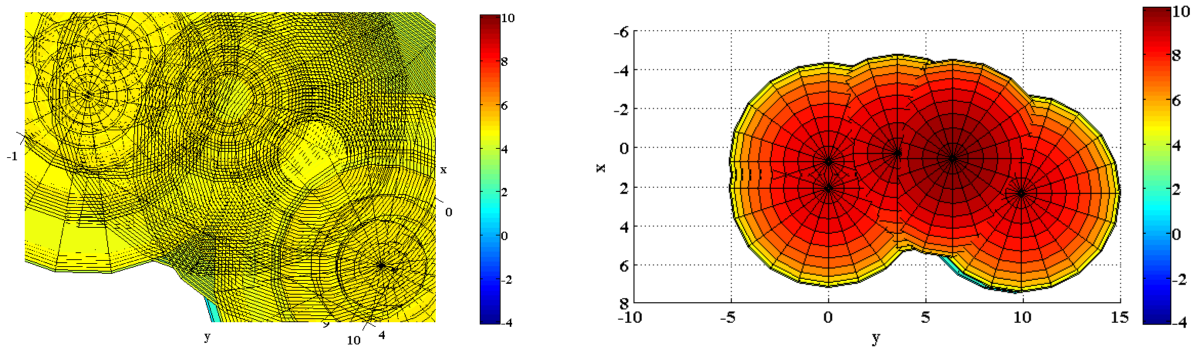

Fig. 4. Crossed area of all spheres

3. CONCLUSION

As a result of the applied method for determining the place of failure and making use of the construction draft, the seriousness of the damage is analyzed and the necessary measures for its elimination are taken.

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THE RSFQ TECHNIQUE – AN ALTERNATIVE OF THE CONVENTIONAL SEMICONDUCTOR TECHNOLOGY

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Abstract. *Superconducting Rapid Single-Flux Quantum (RSFQ) electronics is a well-established technique for digital signal processing, which is a serious alternative to the conventional semiconductor technology. RSFQ circuits are very promising for high-speed operation with low power consumption for digital systems in the medical science, telecommunications, quantum computing, etc. The basic switching element of the RSFQ electronic is the Josephson junction, where on the boundary between two superconductors separated by very thin insulating layer flows super current, in spite of the dielectric barrier between them. In this paper some of the main features of the RSFQ technique are described as well as some of its advantages and disadvantages.*

Keywords: *Rapid Single-Flux Quantum (RSFQ), SFQ pulse, Josephson junction*

1. INTRODUCTION

One of the first attempts to create high-speed devices using superconducting electronic was launched in the mid 1970s and early 1980s from IBM Corporation starting their “Josephson Computer Technology Project” [1].

Superconductors were first proposed for digital circuit by D. Buck [2] in 1956 when he reported switching devices, which could be switched from a superconducting to a normal conducting state by application of magnetic fields. The satisfactory explanation of a superconducting theory is given by Bardeen, Cooper, and Schrieffer in 1957 in their now famous BCS theory of superconductivity [3]. This theory postulates that electrons in a superconductor are grouped in pairs, so-called Cooper pairs, when they are cooled to temperatures near absolute zero. These Cooper pairs can behave very differently from single electrons and act more like bosons, which can condense into the same energy level [4].

IBM began its Josephson junction studies following the mid-1960's demonstration by Juri Matisoo that the devices could serve in digital electronic circuits [5]. A Josephson junction begins with two strips of metallic superconductor, such as lead separated from one another by a layer of insulating material. It switches from superconductive to resistive state very fast in the order of *ps*, when the input current is applied but the transition from resistive to superconductive state is in order of *1ns.* This restricts the processor’s working frequency of about 1GHz and the project was finished in 1983.

The new approach in superconductive electronics was developed by Russian physics K. K. Likharev, O. A. Mukhanov and V. K. Semenov in 1985 [6]. The logical level are coded with presence of SFQ pulse for logical "1" and absence of such a pulse for logical "0" contrary to conventional CMOS electronics and the IBM's Josephson's computer project. Overdamped Josephson junction is used as a switching element in this technique. Rapid Single Flux Quantum Logic (RSFQ) deals with the generation and manipulation of magnetic flux quanta in the form of short voltage pulses across a Josephson weak link interrupting a superconducting loop. The fast switching time of Josephson junctions of the order of picoseconds, and the low power dissipation make them suitable for high speed data processing in wire-less technology, military applications, high speed computing and digital signal processing circuits.

2. JOSEPHSON JUNCTION

Two superconductors, S1 and S2 separated by a thin insulating layer Fig. 1 form a Josephson junction. Tunneling of super current in the form of Cooper pairs across the barrier without applying any voltage was predicted by Josephson in 1962. The magnitude of the super current is given by

$$I_s = I_c \sin(\theta_1 - \theta_2) \tag{1}$$

where I_c is the maximum value of the super current, which can flow through the junction without developing any voltage, called critical current Fig. 2. $\theta_1 - \theta_2 = \phi$ is the phase difference between the wave functions in the two superconductors.

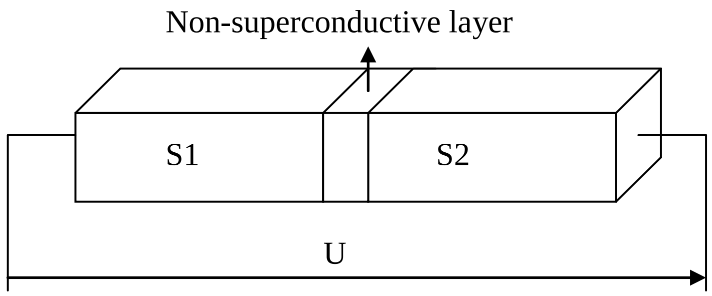

Fig. 1. Josephson junction

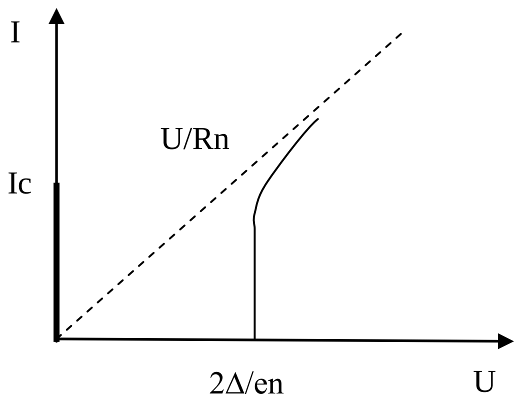

Fig. 2. Voltage-current curve for a classiacal junction

The magnitude of the critical current, which can be derived from the microscopic theory [7], is given by

$$I_c = \frac{\pi\Delta}{2eR_n} \qquad \text{for } T \ll T_c \qquad (2)$$

where Δ is the superconducting energy gap and R_n is the normal state resistance. When a dc voltage is applied across the junction, the phase difference oscillates according to

$$\frac{d\ (t)}{dt} = \frac{4\pi e}{h}U(t) = \frac{2\pi}{\Phi_0}U(t) \qquad (3)$$

A real junction Fig. 3 is considered as an ideal junction connected in parallel with a resistor, R representing the normal electron current and a capacitor C contributing the displacement current. This model describing the current flow through a practical junction is known as the Resistively and Capacitively Shunted Junction (RCSJ) model.

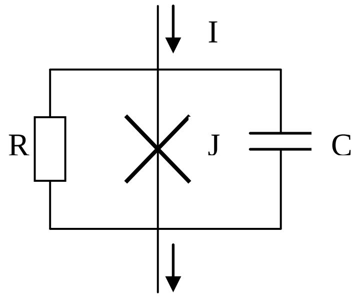

Fig. 3. Equivelent circuit of Josephson junction

From Eq. (3) Φ_0 = h/2e ≈ 2.07 mV.ps is being fundamental physical constant named the magnetic flux quantum.

A transient process during which ϕ changes with 2π is called a switching of the junction and a voltage pulses generated during such a switching can be derived by integrating:

$$\int_0^\infty U(t)d(t) = \Phi_0 \qquad (4)$$

i.e. such a pulse carries exactly one magnetic flux quantum Φ_0. The typical shape of an SFQ pulse is shown on Fig. 4.

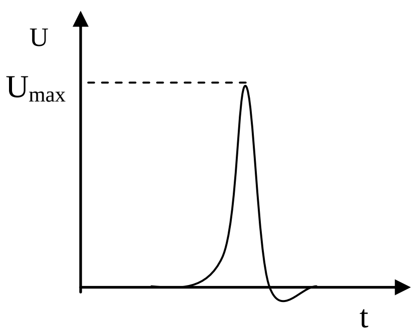

Fig. 4. Typical shape of an SFQ pulse

3. RSFQ TECHNIQUE

Superconductive Rapid Single-Flux Quantum (RSFQ) electronics [8] is characterized with some unique features:

– extreme high operation speed – the tunnelling Josephson junction with its switching time of about 1-2*ps* allows RSFQ circuit operating in sub THz frequencies;

– low power consumption – the energy dissipated during one switching of single Josephson junction with I_c=250μA is $\Delta W \approx \Phi_0 I_c \approx 5*10^{-19}$ *J/bit* it is about 5 *nW/GHz*, while the signals are communicated via superconductive transmission lines;

– a binary information is represented by naturally flux quantization pulses and they propagate through superconductive passive transmission lines with speed closely to speed of light - 150*μm/ps;*

– signals using for binary coding are with very low energy amplitude. Thus counts as an advantage for creating a quantum computer but when needed to shield against electromagnetic fields and noises it is a disadvantage;

– RSFQ circuits are self switching which makes asynchronous approach suitable for this technique.

The asynchronous circuits [9] have lower power consumption than synchronous because the switching occurs only in the part of the circuit involved in current computation [10]. There is no need of a global clock distribution signal. Thus also leads to reduced emissions of electromagnetic noise and sensitivity towards environment variations (temperature, voltage supply). However in more complex RSFQ circuit, where there are different paths through which a given signal can reach a signal competition occurs [11], [12]. The most reliable asynchronous communication is provided by Dual-Rail data coding (DR) shown schematically in Fig. 5. It is based on two signal lines where a pulse on the one represents logical “1” and the pulse on the other one represents a logical “0”. A simultaneous propagation of pulses on both one is forbidden. The Dual-Rail coding allows synchronous blocks to be easily included into the asynchronous architecture.

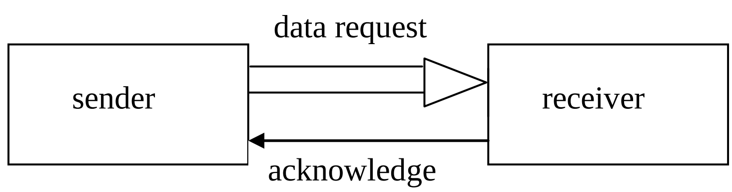

Fig. 5. Asynchronous data exchange between two circuit blocks

Currently the companies and universities involved in high-level synthesis of complex circuit have developed and tested the entire cell library of basic RSFQ cells [13-16]. The library contains schematics, layouts, transient simulation, logical model. The fabrication of Josephson tunnel junctions is based on well-developed $Nb/AlO_x/Nb$ technology.

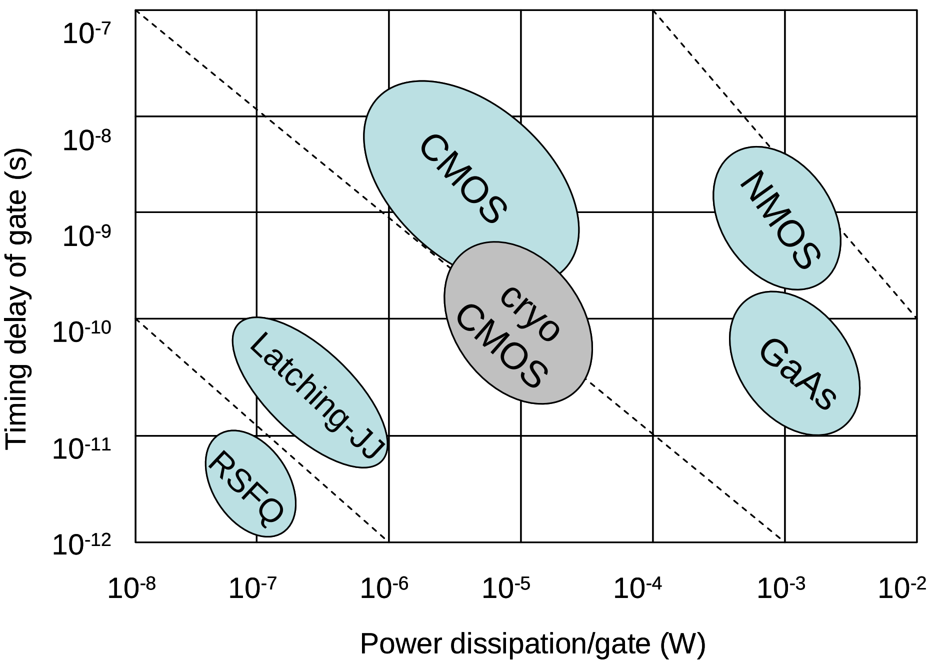

Fig. 6. Comparison between different fabrication technologies based on timing delay – power dissipation per gate.

4. CONCLUSIONS

RSFQ circuits are very promising for high-speed operation with low power consumption. Nevertheless RSFQ circuit requires cryogenic cooling (mostly with liquid helium) to temperature of about 4K, which is the main drawback of these circuits. Comparison between different technologies is given on Fig. 6.

Non-equilibrium structures and interfaces, in particular, may provide an important route to novel superconductors. The successful finding of a material superconducting near room temperature would have enormous technological impact, for example, help to solve the world's energy problems and provide for faster computers.

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Reviewer: Prof. PhD Zh. Georgiev

ELECTROMAGNETIC FIELD MODELLING IN VICINITY OF A POWER LINE

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Abstract: *The electromagnetic field distribution in vicinity of a power line has been studied in the paper. The problem was considered as time-harmonic, 2D plane-parallel and field distribution has been numerically modelled using finite element method and software package QuickField 5.6. The three-phase power line consists of three conductors of circular cross section with time varying currents, shifted in phase by* 120^0*. The study was carried out for different distances between the conductors. The results for current density distribution in the conductors and magnetic field in points with specified coordinates have been obtained for different currents of 50 Hz frequency.*

Keywords: *electromagnetic field modeling, power line, finite element method*

1. INTRODUCTION

The creation of high technology, energy-efficient and reliable electromagnetic devices and systems that do not harm the environment is of significant importance for our new and modern society. Nowadays, special attention has been paid to the possible harmful effects on the environment arising from the electromagnetic fields generated in the vicinity of power lines [1], [2], [3].

Transmission of electricity is accompanied by the generation of low-frequency electromagnetic fields. These fields can affect both the reliable work of electrical and electronic equipment and devices that are close to them and also to have a significant impact on variety of living organisms. The good understanding of these effects allows predicting and therefore avoiding the negative consequences both for equipment and for living organisms [4]. It is important to know that there are many studies that examine the impact of induced currents in living organisms and in particular on the human body. According the studies maximum allowable magnetic field is 0.04μT [5].

The main goal of the presented work is investigation of electromagnetic field distribution in vicinity of a power line. The aim is field modelling in points with specified coordinates in vicinity of line. Since the field distribution depends on line currents, geometry of the lines and distances from the conductors the study is carried out for different currents of 50 Hz frequency and for different distances between the conductors.

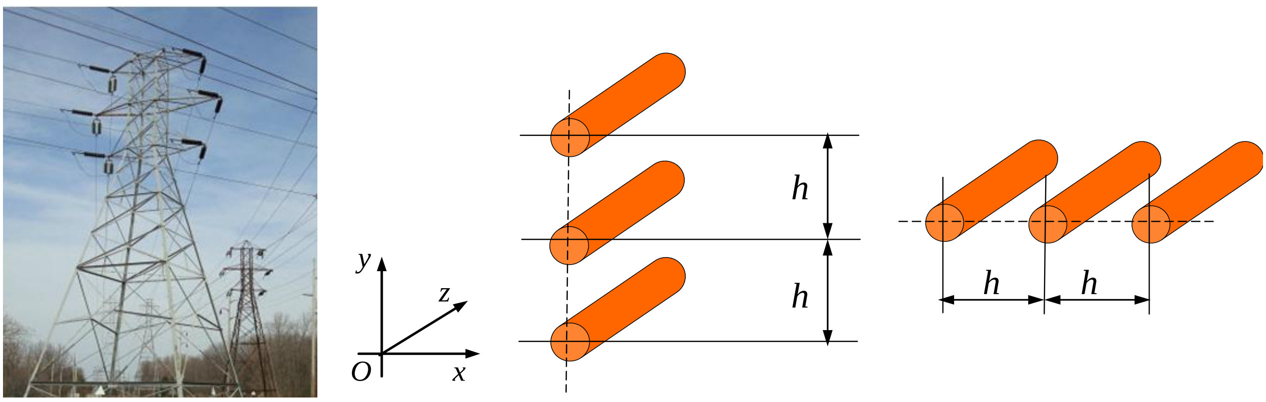
In many papers similar problem has been studied using analytical expressions, based on the Biot-Savart law and superposition of the fields. This approach involves a lot of idealizations and does not allow examining the real environment, taking into account the existence of other material objects in the investigated regions.

In the presented work field distribution has been numerically modelled using finite element method (FEM) and commercial software package QuickField 5.6. Using this numerical method for solving of the task, makes it possible to take into account of the real environment and distortions of the field distribution due to the presence of objects with different material properties. The field quantities and characteristics can been easy obtained in any point of observation.

2. DESCRIPTION OF THE STUDIED PROBLEM AND MATHEMATICAL FORMULATION

2.1. Investigated power line

The principal geometry of the investigated system is shown in Fig. 1. Two main design variants of the power line have been considered in the presented work – vertical (Fig.1a) and horizontal (Fig.1b). In the both variants the three-phase power line consists of three conductors of circular cross section with time varying currents, shifted in phase by 120^0. The study is carried out for different distances ***h*** between the conductors (***h=2m***÷ 6m) and for different 50 Hz currents ***I*** (***I=5A***÷ 15A). The field distribution has been observed in control points with specified coordinates.



a) vertical b) horizontal

Fig. 1. Two main variants of possible geometry of the investigated system

2.2. Mathematical formulation

The problem of electromagnetic field distribution of the power line is considered as time-harmonic, two-dimensional, plane-parallel in plane *xOy*. The problem is formulated and solved for the complex amplitude of vector magnetic potential $\vec{A}$, where

$$\vec{B} = rot\,\vec{A}, \qquad (1)$$

– $\vec{B}$ is a vector of magnetic flux density.

The flux density lies in the plane of model (*xOy*), while the vector of electric current density $\vec{J}$ and the vector potential $\vec{A}$ are orthogonal to it and have components only in z-direction J_z and A_z. The electromagnetic field is modelled using complex magnetic potential $\dot{A}_z$ by equation:

$$\frac{\partial^2 \dot{A}_z}{\partial x^2} + \frac{\partial^2 \dot{A}_z}{\partial y^2} - j\omega\mu\sigma \dot{A}_z = -\mu \dot{J}_z \qquad (2)$$

where σ is electric conductivity, μ is magnetic permeability and $\dot{J}_z$ is the complex of the current density z-component J_z.

3. FEM MODELLING OF A THREE-PHASE POWER LINE

Numerical investigations of electromagnetic field distribution have been made using FEM and QuickField 5.6 software package [6].

Study was carried out for different design parameters, shown in Table 1, like distances between conductors and values of the phase currents. The field in special control points has been determined. Analysis of the results gives possibilities to estimate field values according their possible effects on the electrical equipment and living organisms and make reasonable choice in order to avoid negative affects.

The finite element mesh, used for the analysis of vertical variant of power line is shown in Fig. 2.

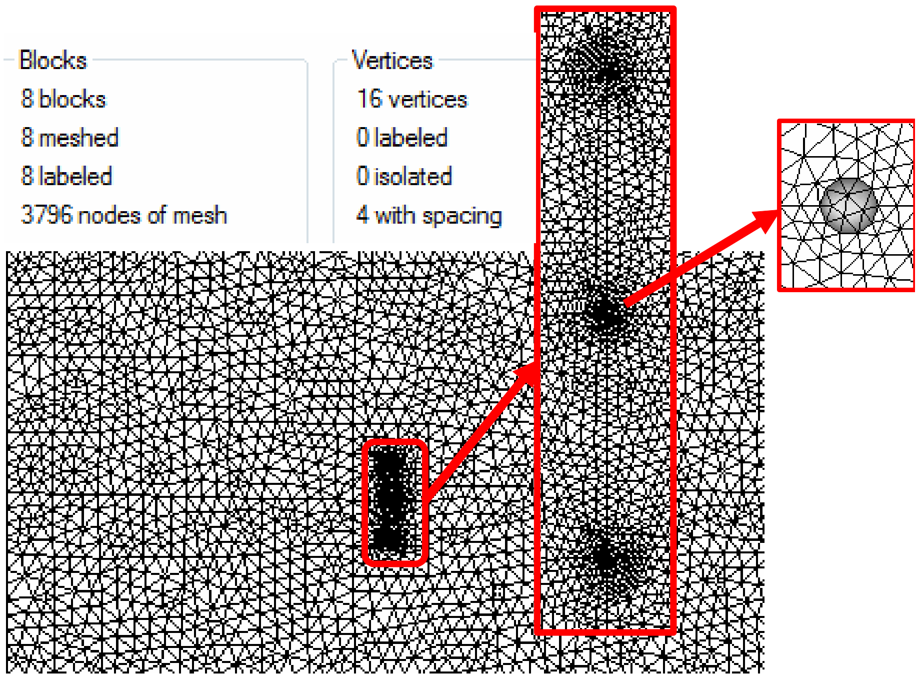


Fig. 2. Finite element mesh, used for the analysis of vertical variant of power line consists of 3796 nodes

The magnetic field distribution for the vertical and horizontal line geometry are shown in Fig. 3 and Fig. 4, when design parameters are: distance h=5m and current is I= 10A. In Fig. 5 and Fig.6 current density distribution is shown for the same variants of investigation. These figures also illustrate determination of the total current in conductors - the current of the first phase (I=10A, $\varphi = +120^0$)in Fig.5 and in Fig.6 determination of the current density distribution in case of vertical geometry and total current in the current of the third phase (I=10A, $\varphi = -120^0$)

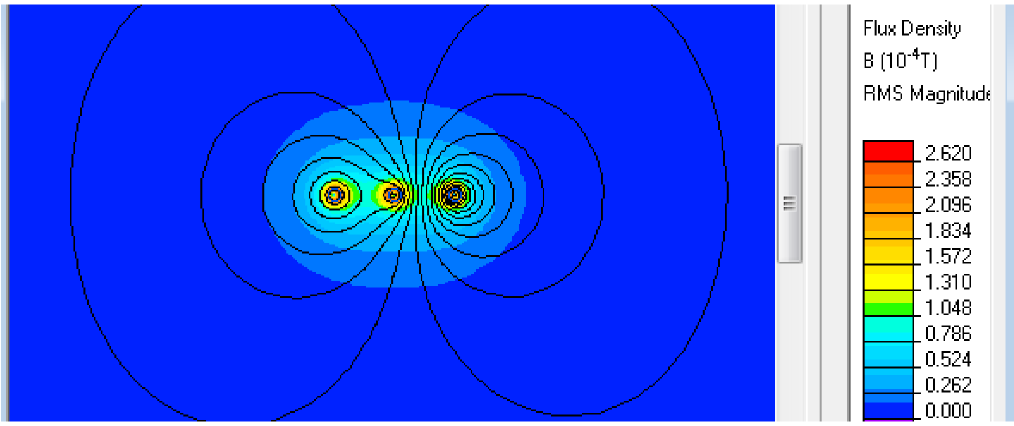


Fig. 3. Magnetic field distribution in the vicinity of a power line in case of horizontal geometry

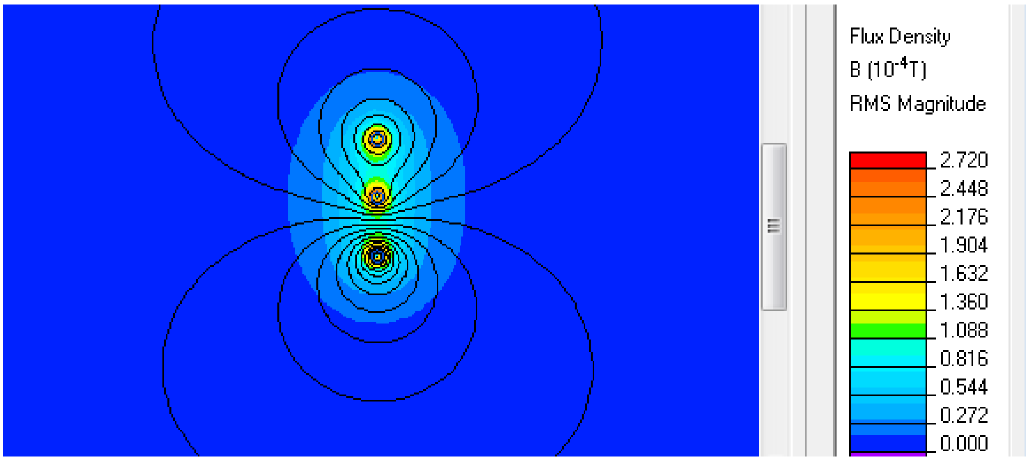


Fig. 4. Magnetic field distribution in the vicinity of a power line in case of vertical geometry

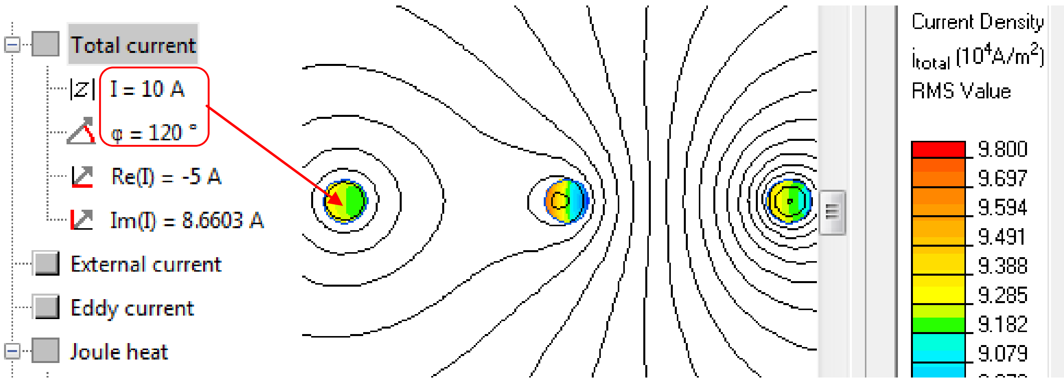


Fig. 5. Determination of the current density distribution in case of horizontal geometry and total current in the current of the first phase

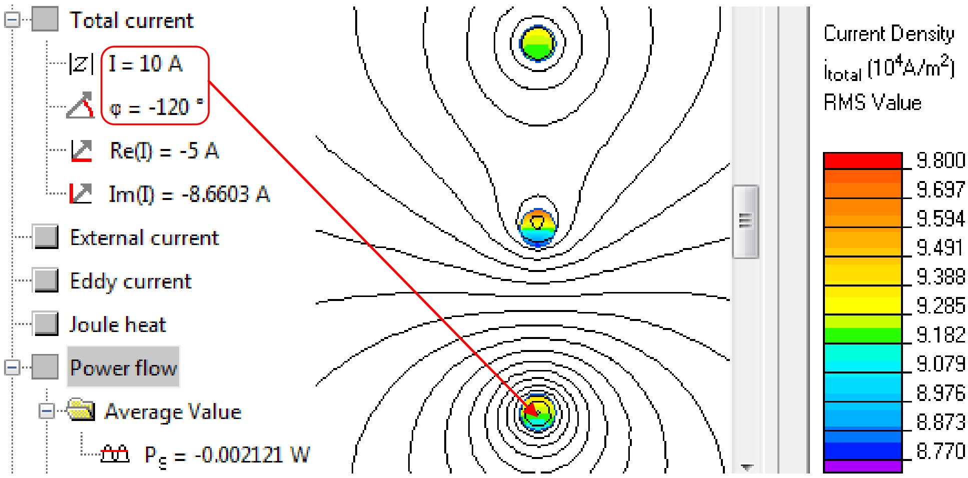


Fig. 6. Determination of the current density distribution in case of vertical geometry and total current in the current of the third phase

The main goal of the analysis of obtained results is field modeling in the vicinity of power line. The results for magnetic flux density values in points with specified coordinates are shown in Fig. 7 and Fig. 8 for two different distances between conductors.

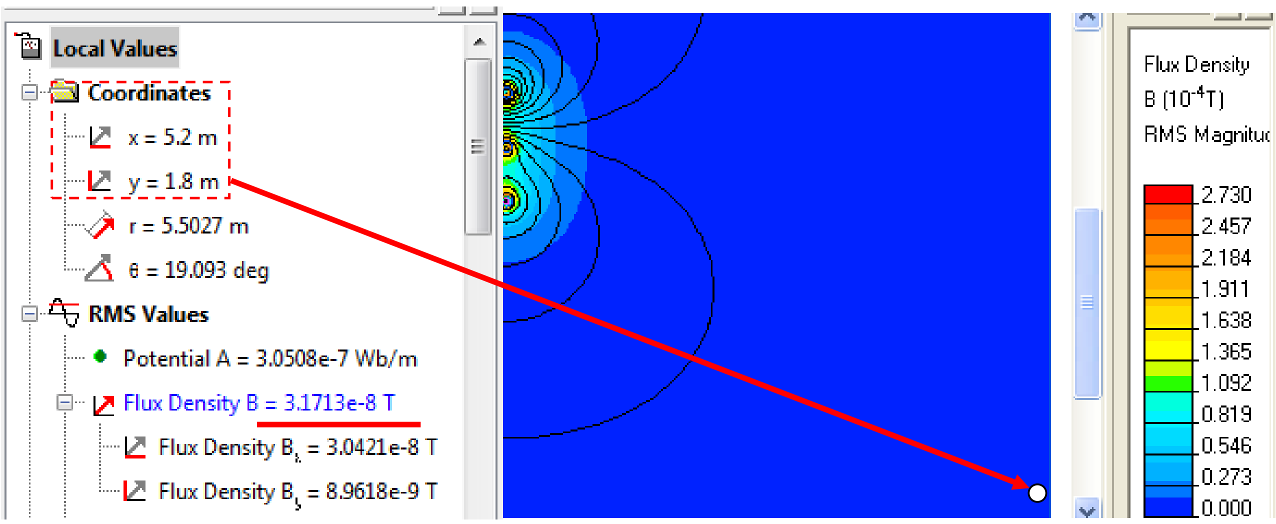


Fig. 7. Magnetic field distribution in the vicinity of a power line and magnetic flux density values in points with coordinates x=5.2m, y=1.8m

4. CONCLUSION

In this work detailed investigation of electromagnetic field distribution in vicinity of a power line has been done for different values of phase current, line geometry and distances between the conductors. The aim of the study is field modelling in points with specified coordinates in order to estimate field values according their possible negative effects on the electrical equipment and living organisms. It gives possibilities for reasonable choice of the line parameters in order to avoid harmful affects.

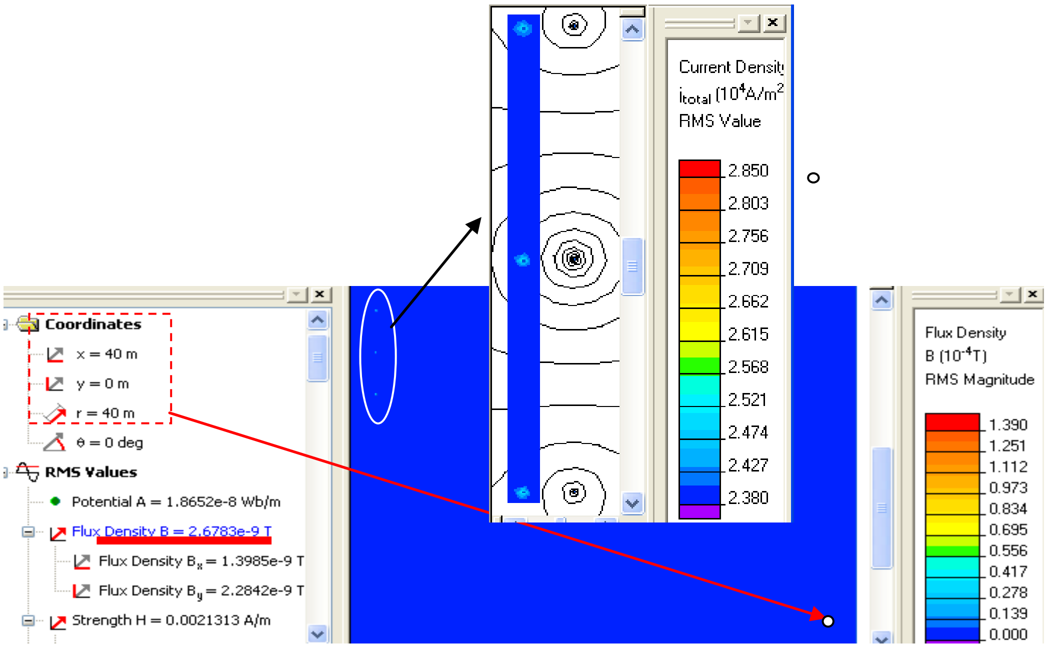


Fig. 8. Magnetic field distribution in the vicinity of a power line and magnetic flux density values in points with coordinates x=40m, y=0m

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DEVELOPMENT AND APPLICATION OF DATABASE OF HARMONIZED STANDARDS RELATED TO ELECTROMAGNETIC COMPATIBILITY

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Abstract. *The free movement of products in the area of the United European market is assuring through implementation of the normative acts of European Union. The Directive 2004/108/EC of the European Parliament and of the Council on the approximation of the laws of the Member States relating to electromagnetic compatibility and repealing Directive 89/336/EEC is a main directive in a European technical legislation which covers a big number of contemporary products. The essential requirements specified by it can be provided by means of using of harmonized European standards.*

In this paper the authors presented the possibility for development and implementation of database of harmonized standards for the needs of assurance the field about electromagnetic compatibility. The application of the realized database has an aim to help manufacturers of the products, which are covered form the directive 2004/108/EC.

Keywords: *electromagnetic compatibility, harmonized standards, database*

1. INTRODUCTION

The technical harmonization of the national laws and standards of the Member States of European Union (EU) has an aim to regulate the significant legislative object of the European law - establishment of the European Single Market (ESM) with free movement of products, services, people and capital. As a result, it should be achieved [1]:

– Each Member State to produce and export products that meet the technical requirements defined in EU regulations;

– Each Member State to ensure the free movement of products from the other Member States to its market.

2. LEGISLATIVE REQUIREMENTS

To ensure the functioning of the ESM, Directive 2004/108/EC on electromagnetic compatibility regulates the electromagnetic compatibility of equipment. The "Equipment" means any kind of mobile apparatus or fixed installation [2]. This Directive does not affect the application of technical legislation which relates to the safety of the equipment. Member States are obliged to take the necessary measures to sell and bring into play only equipment complying with the Directive under proper installation, maintenance and use.

In order to ensure the free movement of mobile electrical and electronic equipment, the national provisions of the Member States which provide protection against electromagnetic interference must be harmonized. As the equipment covered by Directive 2004/108/EC includes both mobile apparatus and fixed installations, separate provisions for both varieties are provided. Mobile devices may move freely within the EU and fixed installations are installed for permanent use at a predefined location as assemblies of various mobile phones and other devices.

The mobile devices can be placed on the market or put into service only when it is designed and manufactured according to the requirements of the Directive. It is marked with "CE" sign in order to demonstrate compliance. Although conformity assessment can be performed by the manufacturer, without requiring the involvement of a notified body, it is also given the possibility to manufacturers to use that authority. Assessment relating to electromagnetic compatibility of equipment is made to determine whether it meets the requirements for protection under the Directive.

Fixed installations, including large machines and networks can lead to the generation of electromagnetic interference or to be their object. Interface relation between fixed installations and mobile apparatus is possible, as the electromagnetic disturbances produced by fixed installations may affect mobile apparatus, and vice versa. In terms of electromagnetic compatibility, it is irrelevant whether the installation or equipment produces electromagnetic interference.

Due to their specific characteristics, fixed installations are not marked with "CE" sign and they are not accompanied by a declaration of conformity.

3. HARMONIZED STANDARDS

The harmonized standards are European standards, adopted by the European standardization organizations - European Committee for Standardization (CEN), European Committee for Electro-technical Standardization (CENELEC) and European Telecommunications Standards Institute (ETSI). These three organizations are recognized as competent institutions on the adoption of harmonized standards in Directive 2004/108/EC. The standards are developed in accordance with the general guidelines for cooperation between the three European standardization organizations and the EU Commission as well as the procedure of Directive 98/34/EC laying down a procedure for the provision of information in the field of technical standards and regulations (Directive as last amended by the Act of Accession 2003)

Harmonized standards [3] are not specific category among all European standards. The terminology used in the directives is a legal definition of technical specifications in existing European standards, but to which it has been given special meaning of these directives. These standards have the status of voluntary application within the scope of the directives.

After approval of the harmonized standards of the European standard organizations, the Commission publishes a statement thereof in the Official Journal of the EU. With this act they actually acquire the status of harmonized to a directive.

European standards harmonized to Directive 2004/108/EC reflect the generally recognized current status, which refers to the electromagnetic compatibility of equipment. They should meet the essential requirements of the Directive [4] and to have features that are defined by standardization mandates from the EU Commission. The mandate should also be consistent with the directive that the implementation of the harmonized standard in the design, manufacture and control of the equipment leads to a presumption of conformity with the essential requirements. In the mandate most completely and accurately describes what the standard should contain. The harmonized standard may contain provisions which do not relate to the essential requirements. Then these clauses must be clearly distinguished from those covering the essential requirements. It is not necessary the harmonized standards to cover all the essential requirements. In this case, it depends on the manufacturer how to fill the gap between the harmonized standards and the essential requirements to meet the requirements of the Directive.

4. DATABASE – NATURE AND TECHNOLOGIES FOR DEVELOPMENT

Nowadays the application of engineering and technology is closely related to the activity of human resources in all sectors of the economy. Not least, it should be noted the engineering, which is an activity through which many engineering problems are solved in which in order to achieve the end result processing of large amount of information and/or the execution of multiple computing and optimization procedures should be done. In this aspect, the engineering community would accept positively the establishment of adequate applications through which the work of engineers will be facilitated and the solution of engineering problems will be supported through the use and application of modern tools and technologies. All this should be done with the main goal - reducing the resources invested in the activities: human, time, financial, energy. The environment known as "Internet" offers virtually unlimited opportunities for development and use of applications useful these days.

4.1. Database

According to [5] database is a "kind of organized collection of facts". Databases provide the core functionality of data storage and manipulation of them. Much of the database is called relational and use SQL [6] as the main language.

Relational database is composed of tables interconnected by set by the developer of the system criteria. Each table contains information about each object stored in it. The order contains the data for a single object and it is composed of columns describing the characteristics of the object. Each database file can contain many sheets. Tables are available through view - logical subset of a table or combination of tables. The view defines how to access and review the data in the table, but it does not contain data and it allows creating further logical relationships between tables without creating further copies of the data.

Widely used system for creating databases is "MySQL". "MySQL" is relational, control system database using SQL. "MySQL" is "Open source" and it has the ability to add data to the database. "MySQL" stands out from other available database with speed, security and flexibility.

The advantages of "MySQL" as a system of relational databases are:

1) Provides an application programming interface (API) for C, C++, Java, Perl, PHP, Python.
2) "MySQL" is "the Open sourc" and it is compatible with Linux, UNIX and Windows operating systems.
3) to "MySQL" has an interest of Oracle, IBM, and Informix.
4) Recent trends in software development is "MySQL" fully support the standard ANSI 99 (ISO / IEC 9075-1: 1999) and its parts.

The main disadvantage is that "MySQL" works best only in the management of content and without any input-output information processing on the data contained in it, but modern trends of development of the system are in the direction of elimination of this disadvantage.

4.2. PHP (***H***ypertext ***P***re***p***rocessor)

PHP [7] is a scripting language whose syntax is based on C and Perl. It is used most often in Web programming environment for the realization of a wide range of services. PHP is released under an open license which license allows free distribution of the source code of the interpreter of the language, and creates derivative interpreters under other licenses on condition that they cannot include "PHP" in its name. Free distribution of PHP makes it very suitable for a build Web server based on Linux, Apache, MySQL. In "inquiry" by a user, PHP is interpreted by the Web server where it is uploaded, and the result returns to the Web browser. Access to the contents of the PHP code is difficult, and thus a particular attention to information security is paid.

5. DATABASE OF HARMONIZED STANDARDS FOR ELECTROMAGNETIC COMPATIBILITY OF EQUIPMENT – DEVELOPMENT AND APPLICATION

5.1. Database Structure

The database development is based on information presented in [8]. The proposal presented in this publication is to develop a relative database composed of three tables. Structure of the database is presented in Fig. 1.

The database is structured by three tables, the contents of which describe different necessity for engineering activities related to electromagnetic compatibility parameters. Database 1 ("Keywords") in this database introduces information about keywords, through which the search will be performed. The analysis of keywords is subjective, based on the expertise and experience in the field of electromagnetic compatibility of equipment. Based on it, a list with selected search words in the relevant field is prepared. Database 2 ("Standards") is a database of numbers and names of the harmonized standards relating to electromagnetic compatibility of equipment under the Directive. Database 3 ("Generalization") is a database that summarizes information about the correlation between keywords and their containment in the relevant harmonized standards. Links between databases are bidirectional. All interconnected in order to ensure the information security of consumers applying standards relating to equipment and brought it to electromagnetic compatibility requirements.

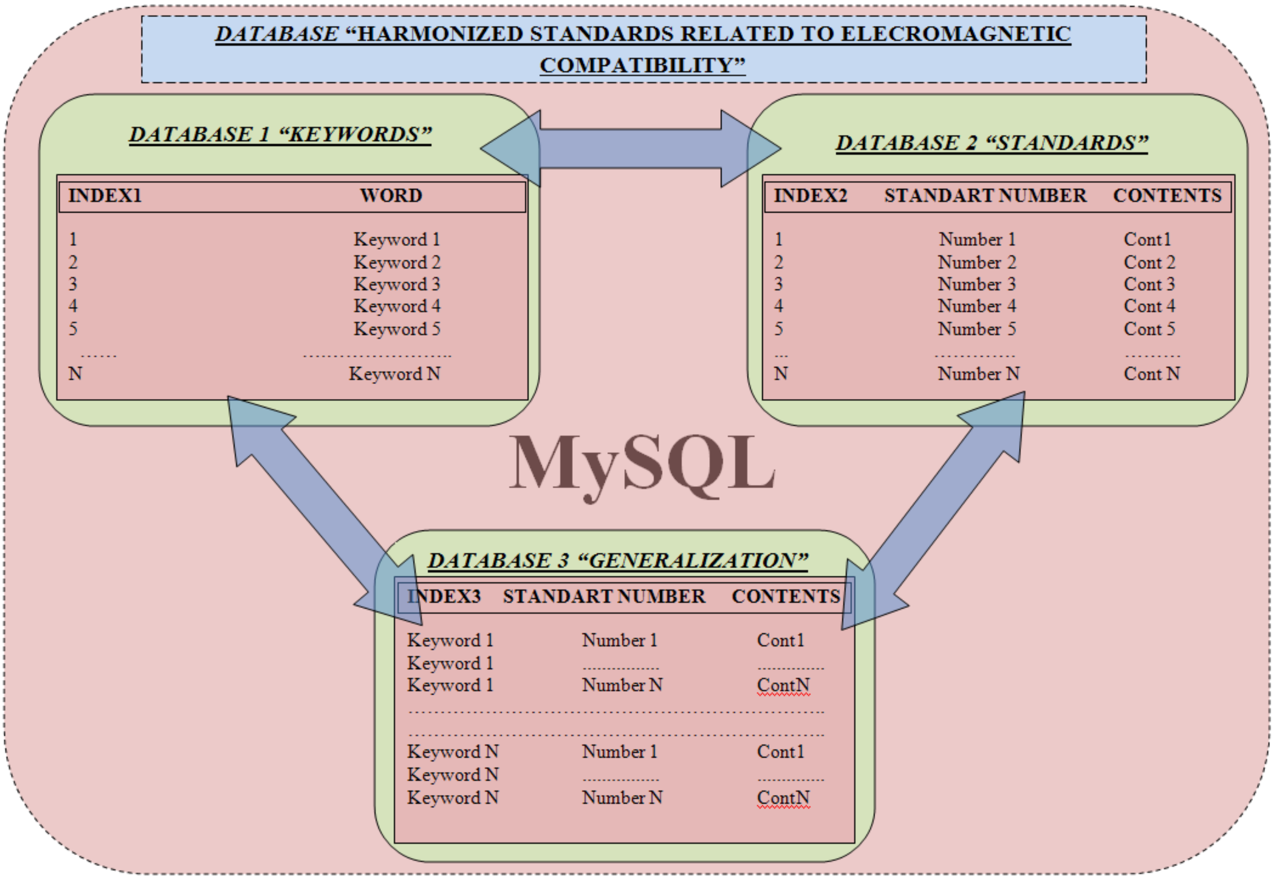

Fig. 1. Database Structure

5.2. Database development

On the Fig. 2 it is shown a step of the development of the database. Its components and connections between them are presented. Later its applications will be upgraded.

6. CONCLUSION

In this paper the authors make an analysis of the legal requirements relating to electromagnetic compatibility in order to justify the need to create a database of harmonized standards in this area. Thus the proposed database developed in MySQL, would be useful for manufacturers to design and manufacture their products.

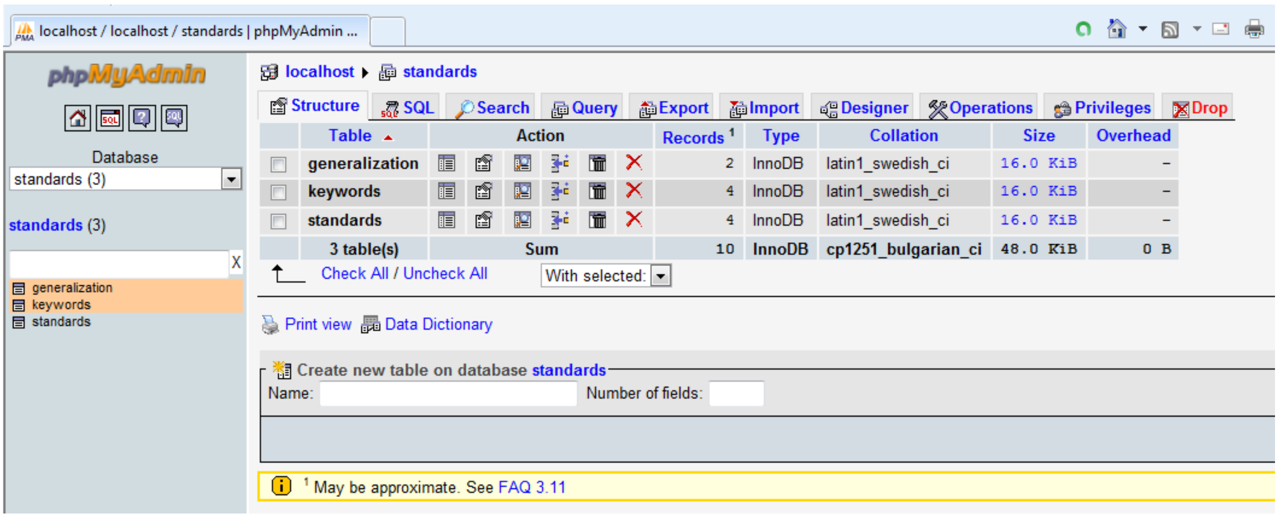

Fig. 2. Database in development process

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Reviewer: Assoc. Prof. PhD I. Bozev

RECOMMENDED FOUNDATIONAL KNOWLEDGE IN THEORETICAL ELECTRICAL ENGINEERING FOR MOST UNIVERSITY STUDENTS

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Abstract: *The continuing changes during the last 10-15 years in the Physic syllabus of Bulgarian ordinary high schools and in the Theoretical Electrical Engineering (TEE) syllabus of the Technical University – Sofia lead to cut off some meaningful parts of the teaching content. Thus the continuity between high-school and university education has been seriously disrupted. Apart from that the number of teaching hours for these subjects concerning both types of educational institutions mentioned above has been dramatically reduced. This reality has been hampering university students from understanding the complex TEE content. Their more effective integration in the TEE teaching process demands the adding of a number of preliminary lessons and labs before TU students start studying the discipline TEE.*

Keywords: *education, electrical engineering, syllabus, ordinary high schools, professional high schools.*

1. INTRODUCTION

The initial knowledge about the basics of „Electricity“ and „Electromagnetism“ Bulgarian students acquire in the 7th grade as a part of the school subject „Physics and Astronomy“. The topics discussed are: electric current, electric circuits, electric power and magnetic influence of the electric current. Ohm’s and Joule-Lentz’s laws are studied in the same grade [1].

The same topics are taught more profoundly and in a greater detail in the 9th grade. The volume and the extent to which this educational content is studied depend on the type of the particular high-school. In the language and ordinary high-schools the themes mentioned above are studied as a part of the Physics syllabus [1].

The situation is very different at the professional high-schools (PHSs) like „John Atanasov“ PHS, the Telecommunications College or the Technological School “Electronic Systems” (TU-ES) associated with the TU-Sofia. Apart from the standard Physics syllabus students in the 9th grade of these PHSs study the subject “Electrical Engineering” with quite an extended syllabus [2]. This discipline is aimed at building an adequate basis for teaching the technical subjects which follow “Electrical Engineering” at PHSs. It also builds the initial knowledge “Theoretical Electrical Engineering” (TEE) syllabuses in Technical Universities count on.

This paper aims at determining the particular levels of knowledge of students coming from different types of Bulgarian high-schools and at spotting the areas where an initial knowledge deficiency is observed from the university TEE point of view.

2. THE ELECTRICAL THEMES IN THE PHYSICS SYLLABUS FOR BULGARIAN ORDINARY HIGH SCHOOLS

Most students entering the TU-Sofia in the last years have been graduated from ordinary high-schools (OHSs) or mathematics and language high-schools where electrical engineering topics make a small part of the Physics syllabus studied in the only 8 out of the 72 Physics teaching hours (t.h.) in the 9th or the 10th grade [1].

The basic quantities taught are: electric current, voltage, power, resistance and capacitance. Students are introduced to the basic electrical elements: resistors, capacitors, coils and transformers theoretically only and also to the Ohm's law (look at Table 1).

Table 1

Teaching hours	*Lesson subject*
1	Capacitors
1	Ohm's law
1	Resistance and electric current
1	Serial and parallel connection of resistors
1	DC electrical source
1	Electrical power
1	Problem solving
1	AC components: coils and transformers

Until 2005 the syllabus for OHSs included additional t.h. for labs during which the class was divided into two groups of not more than 15 students so that individual involvement was possible. In the last 10 years the lack of practice leads to increasing the number of students who study without understanding. This tendency may also be due to the growing lack of demonstration equipment at OHSs. Only 2 out of the 72 Physics t.h. are intended for practicing or demonstrations. The electrical components are not shown physically the students, they are only presented by the teachers in a theoretical manner, as an illustration to the physics laws and formulae [3]. Their function in electrical appliances is not discussed at all.

The knowledge about electrical quantities and components obtained by the students during these 8 t.h. plus the optional 2 hours for demonstration/practice included in the current Physics syllabus for the 9th grade obviously forms an insufficient theoretical base for studying the TEE by students of Technical Universities.

Moreover there is at least a four-year gap between the 9th school grade and the second year at the TU-Sofia when the subject TEE is studied.

3. THE SUBJECT ”ELECTRICAL ENGINEERING” AT BULGARIAN PROFESSIONAL HIGH SCHOOLS

The students of the PHSs study „Electrical Engineering” as a separate discipline with 54 to 126 t.h. in the 9th grade depending on their specialty [2]. The students of the Technological School “Electronic Systems” associated with the TU-Sofia study two disciplines in the 9th grade namely:

- „Electrical Engineering and Electrical Measurement” with 72 t.h.;
- „Electric Circuits“ with 72 t.h.

In the course of study capacitors are not only introduced and their structure explained, but also circuits of capacitors connected in series and in parallel are taught. Equivalent capacitances as well as voltages across the circuit elements are calculated. The electrical quantities: current, voltage, power and resistance are not only introduced and calculated, but also measured by the students during the labs in the 10th grade.

The ways of connecting resistors in DC circuits as well as Ohm‘s and Kirchhoff‘s laws are taught, then students calculate the electrical currents, voltages and powers in simple DC circuits and after that they measure these quantities during the labs. This complex process of introducing theoretical knowledge and having practice with electrical measuring tools in the lab helps students understand the processes in the electric circuits in depth and teaches them to visually distinguish the elements of the electric circuits and the measuring instruments they use during the labs.

Simple AC circuits with resistors, capacitors and coils are also studied and their performance is visualized by graphs. Currents and voltages are calculated using the common high-school level of mathematics avoiding the symbolic method with complex numbers. The students are acquainted with the resonance phenomenon in serial and parallel R-L-C circuits. The labs are incorporated in the theoretical course at „John Atanasov“ professional high school or they form a separate discipline in the 10th grade at TU-ES following the two disciplines studied in the 9th grade.

4. WHERE DOES THE KNOWLEDGE GAP COME FROM?

As a conclusion from the facts stated above, the students in TU-Sofia come with very different levels of knowledge about the electric components, circuits and some or more often none practical experience. In fact the largest number of students comes from OHSs having not even seen how the electric components look like and having no idea about the ways of connecting these components and how to measure electric resistance, currents and voltages.

In [4] the authors have explored in depth a number of factors influencing TEE students’ performance and the reasons why their results have been worsening in the last 10 years after the TEE tutorials in TU-Sofia were reduced by 30 % although the topics taught remained almost the same.

In order to be adequately integrated in the TEE studying process these students need a number of preliminary lessons and labs to acquire the knowledge and experience which students from PHSs already have. In this way they will have the chance to see the electric elements, to connect them in different kinds of circuits, to calculate the expected values of the currents and voltages and finally to measure these values themselves, thus gaining priceless practical experience and understanding.

Such a preliminary module of TEE has to teach the laws and methods for investigating DC resistor circuits and show students how to calculate the equivalent capacitance of connected capacitors and the DC voltage on each of them. It is very important for students coming from ordinary high schools to acquire practical experience with handling measuring tools, switching among their different modes of measuring and connecting these tools to the electric circuits.

This can help breaking the barriers most of students come with and eliminate the fear of being inadequate in comparison with the students coming from PHSs.

5. CONCLUSION

As mentioned, in [4] the problems students encounter during their transition from high-school to university level of education are discussed. Even the students coming from PHSs who have studied additional subjects like „Electrical engineering" and „Electric Circuits" have difficulties in understanding the complex TEE teaching content in the second TU year. It's not hard to imagine how the students coming from OHSs feel having studied only 8 t.h. electrical engineering teaching content incorporated in their 9^{th} grade Physics syllabus.

The lack of a solid and profound basis due to the very few teaching hours and the scarce teaching content leads to a dramatically hard adjustment of these students to the complexity of the academic discipline TEE. The transition from the elementary level of studying of the themes mentioned above at the high-school level to the academic demands of the university level is additionally hampered by the students' insufficient level of mathematics knowledge.

That is why the authors propose the introduction of a preliminary teaching module aiming at smoothing the transition of students from high-school to university level and filling the knowledge gap most of them come with.

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Reviewer: Prof. DSc B. Lalov

TRANSLATION OF THE TERMINOLOGY BULGARIAN STATE STANDARDS IN BULGARIAN LANGUAGE - NECESSARY CONDITION TO IMPROVE THE QUALITY OF EDUCATION PROCESS AND BULGARIAN TECHNICAL LITERATURE

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Abstract: *This report examined some existing differences between the established traditional graphic symbols and terms in Bulgarian technical literature and harmonized with European standards, Bulgarian state standards. This examination is done to clarify the problems that arise in translating the standards of Bulgarian language and to specify which standards are most important for improving the quality of technical education and technical literature in Bulgarian in the field of electrical engineering. For this purpose analyzed the activities of key organizations (International Organization for Standardization, ISO), (International Electrotechnical Commission, IEC), (traditionally French - Bureau International des Poids et Mesures, BIPM), (International Telecommunication Union, ITU), dealing with standardization, their relationships and organization of the standardization process. As a result of the examination are given Bulgarian state standards, the Bulgarian translation of which is essential. After analyzing the structure and operation of the Bulgarian Institute for Standardization (BDS, Български институт за стандартизация, БИС) is proposed to establish a working group to organize the translation of terminology standards. At the end of the report indicated that the implementation of this activity in deadlines of priority it is necessary to search for an external funding for BDS.*

Keywords: *standards, technical education, technical literature.*

1. INTRODUCTION

International Standards bring technological, economic and societal benefits. They help to harmonize technical specifications of products and services, making industry more efficient and breaking down barriers to international trade. International Standards also contribute effectively to sustainability, by providing good practices on the use of technologies and the management of processes affecting economic, social and environmental aspects.

Educational institutions are increasingly recognizing these benefits and international standardization features in many curricula. They have a vital contribution to raising awareness about standardization and the desire to support the work of standardization bodies.

Globalization of science and technology requires constant updating of standardized terms and definitions in order to easier, clearer and of course uniquely identify the relevant information.

2. PROBLEM STATEMENT

Currently in Europe, but also worldwide run harmonization of standards. In Bulgaria introduces harmonized European standards as the standard text in English, of a Bulgarian language is translated only the title of the standard.

The International Organization for Standardization (ISO) [1] is an international standard-setting body composed of representatives from various national standards organizations. Founded on 23 February 1947, the organization promotes worldwide proprietary, industrial and commercial standards. It is headquartered in Geneva, Switzerland, and as of 2013 works in 164 countries. It was one of the first organizations granted general consultative status with the United Nations Economic and Social Council.

The International Electrotechnical Commission (IEC; Commission électrotechnique internationale (CEI), in French) is a non-profit, non-governmental international standards organization that prepares and publishes International Standards for all electrical, electronic and related technologies – collectively known as "electrotechnology" [2]. The IEC standards cover a vast range of technologies from power generation, transmission and distribution to home appliances and office equipment, semiconductors, fibre optics, batteries, solar energy, nanotechnology and marine energy as well as many others. The IEC also manages three global conformity assessment systems that certify whether equipment, system or components conform to its International Standards. The IEC is founded in 1906.

The ITU coordinates the shared global use of the radio spectrum, promotes international cooperation in assigning satellite orbits, works to improve telecommunication infrastructure in the developing world, and assists in the development and coordination of worldwide technical standards [3] . The ITU is active in areas including broadband Internet, latest-generation wireless technologies, aeronautical and maritime navigation, radio astronomy, satellite-based meteorology, convergence in fixed-mobile phone, Internet access, data, voice, TV broadcasting, and next-generation networks. ITU was formed in 1865 at the International Telegraph Convention. ITU became a United Nations specialized agency in 1947. Its membership includes 193 Member States and around 700 public and private sector companies as well as international and regional telecommunication entities, known as Sector Members and Associates, which undertake most of the work of each Sector.

The International Bureau of Weights and Measures (French: Bureau international des poids et mesures), is an international standards organisation, one of three such organisations established to maintain the International System of Units (SI) under the terms of the Metre Convention (Convention du Mètre). The organisation is usually referred to by its French initialism, BIPM [4].

The other organisations that maintain the SI system, also known by their French initialisms are the General Conference on Weights and Measures (French: Conférence générale des poids et mesures) (CGPM) [5] and the International Committee for Weights and Measures (French: Comité international des poids et mesures) (CIPM) [6].

The above organizations organize standardization at world level (Fig. 1 – W.L.).

At the European level (Figure 1. - E.L.) standardization involved the following organizations:

The European Committee for Standardization (CEN, French: Comité Européen de Normalisation) is a non-profit organisation whose mission is to foster the European economy in global trading, the welfare of European citizens and the environment by providing an efficient infrastructure to interested parties for the development, maintenance and distribution of coherent sets of standards and specifications [7].

The CEN was founded in 1961. Its thirty three national members work together to develop European Standards (ENs) in various sectors to build a European internal market for goods and services and to position Europe in the global economy. CEN is officially recognised as a European standards body by the European Union; the other official European standards bodies are the European Committee for Electrotechnical Standardization (CENELEC) [8] and the European Telecommunications Standards Institute (ETSI) [9]. The ETSI is a non-profit organization that establishes telecommunications standards for Europe. The CENELEC was founded in 1973 and is responsible for European standardization in the area of electrical engineering.

At the national Bulgarian level (Figure 1. - N.L.). standardization involved the following organizations:

The Bulgarian Institute for Standardization (BDS) is the national executive body for standardization in the Republic of Bulgaria [10]. BDS develops, accepts and approves Bulgarian standards, participates in the work of international and European organizations for standardization, as its main target is to defend the Bulgarian interests in that sphere.

Bulgarian Institute of Metrology (BIM) is a state independent body to the Council of Ministers according to the Law on Measurements and the Rules of Procedure of BIM (Decree No 109 of the Council of Ministers dated 8 May 2006, published in the State Gazette No 40 of 16 May, 2006) [11].

All organizations under the leadership of ISO use the same common symbols, terms, graphics, script symbols, etc.

Basic terminology standards are:

БДС EN ISO 80000-(1-14) Quantities and units

БДС EN ISO 80000-1:2013 Quantities and units - Part 1: General

БДС EN ISO 80000-13:2008 Quantities and units - Part 13: Information science and technology.

БДС EN 80000-6:2008 Quantities and units - Part 6: Electromagnetism

Series of standards БДС EN 60027-1 to 7 refers to letter symbols used in electrical engineering.

These standards here are only available in English not in Bulgarian.

Due to repeated changes in standardization policy in Bulgaria in the period since 1990 to 2006. In the technical literature are most different terms mean the same thing.

In two previous publications the author has specified the differently in Bulgarian literature and newly introduced technical standards [12], [13].

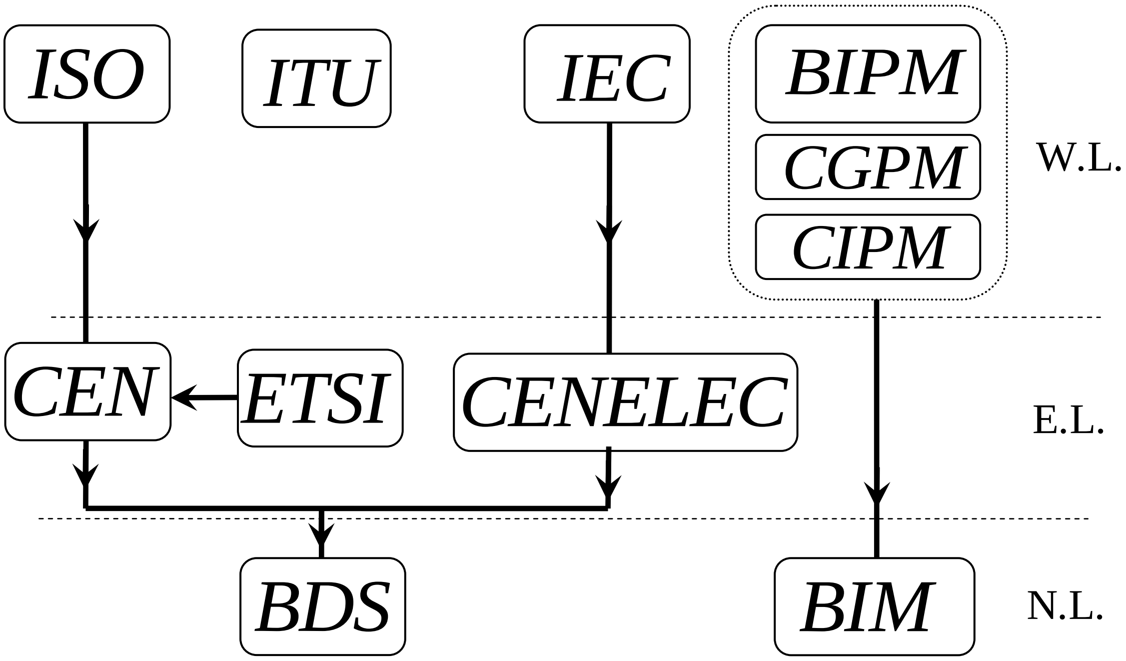

Figure1.

In education and technical literature in order to avoid this ambiguity needs to be translated into Bulgarian language basic terminology standards in the field of electrical engineering. For electrical engineering with the general standard terminology glossary of Electrical Engineering IEC 60050 (Elektropediya). This standard is very high. For the needs of the fundamental disciplines is sufficient to translate only the initial sections, from 101 to 314

101 Mathematics
102 Mathematics - General concepts and linear algebra
103 Mathematics - Functions
112 Quantities and units
113 Physics for electrotechnology
114 Electrochemistry
121 Electromagnetism
131 Circuit theory
141 Polyphase systems and circuits
151 Electrical and magnetic devices
161 Electromagnetic compatibility
191 Dependability and quality of service
195 Earthing and protection against electric shock
212 Electrical insulating solids, liquids and gases
221 Magnetic materials and components
311 Electrical and electronic measurements - General terms relating to measurements

312 Electrical and electronic measurements - General terms relating to electrical measurements

313 Electrical and electronic measurements - Types of electrical measuring instruments

314 Electrical and electronic measurements - Specific terms according to the type of instrument

For electrical engineering it is important to be translated especially chapters 101 to 151 and from 311 to 314.

Some of the sections of the standard have been translated into Bulgarian language. These are

БДС IEC 60050-161:2001 Electromagnetic compatibility

БДС IEC 60050-321:2003 Instrument transformers

БДС IEC 60050-411:1999 Rotating machinery

БДС IEC 60050-441:2007 Switchgear, controlgear and fuses

БДС IEC 60050-446:2010 Elementary relays

БДС IEC 60050-481:1999 Primary cells and batteries.

БДС IEC 60050-486:1997 secondary cells and batteries

IEC 60050-482: Primary and secondary cells and batteries

БДС IEC 60050-601:2003 Generation, transmission and distribution of electricity – General; -602:2006 …– Generation; -603:2004…- Power systems planning and management.

БДС IEC 60050-826:2002 Electrical installations.

In the translated standards meet inaccurate translations of terms that will be seen in the translation of the other sections that are in the beginning. There are translated standards and the original standard of then has been changed.

Important for theoretical electrical engineering is to be translated the standard БДС EN 60375:2006 Conventions concerning electric and magnetic circuits. (IEC 60375:2003), where defined terms and definitions differ significantly from the established in the technical literature until now.

Development (translation) of standards is carried out by branch technical committees at the request of interested users. Membership in these committees is voluntary. Members of the technical committees can be persons nominated by companies and organizations interested in the work of relevant technical committee. The membership fee is paid by the enterprise (organization), offered the member. The text of the standards adopt by a vote of the members of the relevant Technical Committee. The terms that are used in a number of standards shall be described in the terminology standards. At present the main terminological standards are not maintained in Bulgarian.

From the preliminary studies in BDS, for the possibility of translation of terminology standards, concludes that it is possible if make special ad hoc working group, but the financing of this group at the moment can only be done with funds external to the BDS.

3. RESULTS

The report is a survey of translated in Bulgarian terminological standards in electrical engineering. As a result of the study made by the author are indicated the most important Bulgarian standards, which must be translated into Bulgarian language. In making this translation will determine many of the terms that currently have modified definitions. This will lead to a significant improvement of the educational process in electrical fields and improve the quality of the electrical literature. The translation of the terminology of the standards can be done by a specially created working group. Funding for this group must be with funds outside the BDS.

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Reviewer: Assoc. Prof. PhD I. Nikolova

COMBINATION OF THE PRINCIPLES OF SUPERPOSITION AND RECIPROCITY AS A METHOD FOR ANALYSIS OF ELECTRIC CIRCUITS

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Abstract. *The principles of superposition and reciprocity are well known basic principles, which are often used in the analysis of linear electric circuits. In this paper we use a new approach and offer a new efficient method for the analysis of electrical DC or AC circuit.*

With combination of the both principles, any complex electric circuit containing several sources shall be analyzed only once, as in the principle of superposition, under the action of one of the sources. From the obtained results with applying the principle of proportionality are calculated directly unknown branch currents (voltage).

Keywords: *superposition, reciprocity, analysis of electric circuits*

1. THE PRINCIPLE OF SUPERPOSITION

According to the method of superposition, the branch currents and the voltages between arbitrary pairs of points in a complex linear circuit can be defined as the algebraic sum of the corresponding branch currents and voltages, generated by the independent action of the individual sources [1, 2].

Sources which do not participate in the analysis are replaced by their internal resistances:

1) The voltage sources are replaced by a perfect conductor (short circuit);
2) Branches with current sources are disconnected (open circuit).

For the determination of the individual components of the branch currents and voltages can be used all methods of analysis. Because in practice it is necessary to analyze the circuits with a single source, so the most commonly used method to convert equivalent passive sections - series and parallel resistances, and using Ohm's and Kirchhoff's law.

The superposition helps reduce complex circuits to simpler circuits but has one disadvantage - require more work.

2. THE PRINCIPLE OF RECIPROCITY

2.1. In action of a voltage source

If a voltage source, only one for complex linear circuit, acting in the branch k of the circuit, produces the current i_m' in another branch m (Fig.1.a), the same source acting in the second branch m, it will produce the same current i_k'' in the first branch k (Fig.1.b) and it is satisfied

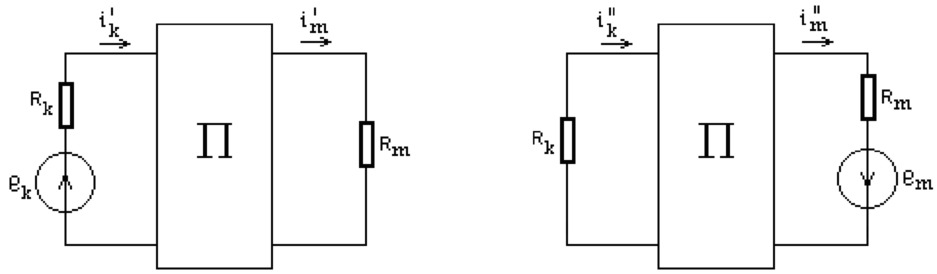
$$i_k'' = i_m'. \tag{1}$$

If in the branches acting different voltage sources, is valid the following equation

$$\frac{e_k}{e_m} = \frac{i_m'}{i_k''} \tag{2}$$

or

$$i_k'' = i_m' \frac{e_m}{e_k}. \tag{3}$$



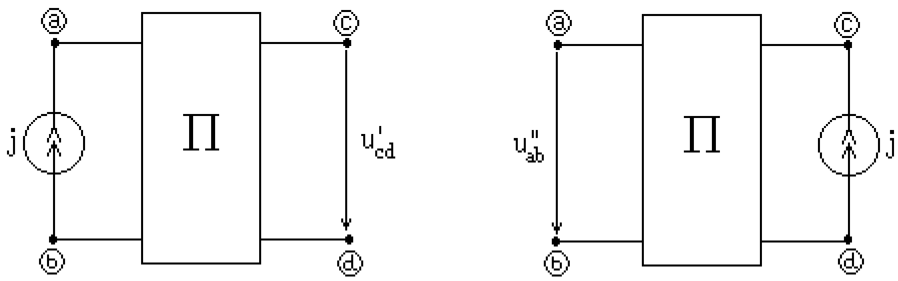
a) b)

Fig. 1

2.2. In action of a current source

If a current source, only one for complex linear circuit, acting between points *a* and *b* of the circuit, produces the voltage u_{cd}' between another points *c* and *d* (Fig.2a), the same source acting between points *c* and *d*, it will produce the same voltage u_{ab}'' between *a* and *b* (Fig.2b) and it is satisfied

$$u_{ab}'' = u_{cd}'. \tag{4}$$



a) b)

Fig. 2

If in the branches acting different current sources, is valid the following equation

$$\frac{j_k}{j_m} = \frac{u_{cd}'}{u_{ab}''} \tag{5}$$

or

$$u_{ab}'' = u_{cd}' \frac{j_m}{j_k}. \tag{6}$$

The principle of proportionality is convenient for the analysis of circuits to find a single branch current or voltage. With success can also be used in the analysis of bridge circuits.

3. THE COMBINATION OF THE BOTH PRINCIPLES – AS A METHOD FOR ANALYSIS OF ELECTRIC CIRCUITS

The combination of the two both above-mentioned principles - the principle of superposition and the principle of reciprocity - can be used as an efficient method for determining the current and voltage in a complex electric circuit.

Below is an example to illustrate the proposed method. For the circuit shown in Fig.3 find current i_2.

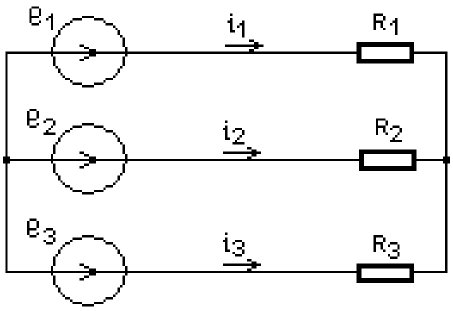


Fig. 3

Consider the circuit in Fig.4. When acting only voltage source e_2, like method of superposition, and determine the branch currents i_1', i_2' and i_3'.

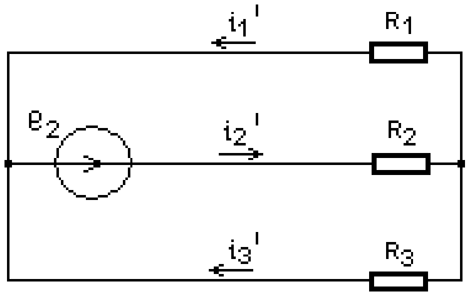


Fig. 4

Applying the principle of reciprocity for different voltage sources (2), (3), expression for the current i_2 obtain

$$i_2 = i_2' - i_1' \frac{e_1}{e_2} - i_3' \frac{e_3}{e_2}. \tag{7}$$

Thus by a single analysis of the circuit obtain the value of the desired unknown current. The procedure can be repeated for the other branch currents.

References

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