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C O N T E N T S

Assessment of magnetic field exposure above indoor transformer substation

Miodrag Milutinov, Anamarija Juhas, Neda Pekaric-Nad

This paper presents results of magnetic field calculations and measurements in the room above an indoor power distribution substation. The magnetic field calculation is based upon assumption that the majority of the field is generated by the current carrying conductors on the low voltage side of the transformer. The conductors are modeled as current filaments and the magnetic field calculation is based on the Biot-Savart law. The measurements are performed using EFA-300 measurement system. The substation considered in this work consists of two 630 kVA transformers, although during the measurements one of the transformers was not loaded. The results of the magnetic field calculations are in a good agreement with the results of measurements. This agreement suggests that for any new set of values of the phase currents on the low voltage side of the transformer, general public exposure can be determined via magnetic field calculation, which is less time-consuming than measurements.

Introduction

Increasing number of electrical devices and equipment are the cause of increasing level of magnetic field in our environment. A number of studies [1]-[6] presented results of the measurements of magnetic field generated by the parts of the power system, such as power lines, power distribution substations, power switches etc. According to [7] and [8] the reference levels for the magnetic flux density at 50 Hz are 100 µT for the general public and 500 µT for the occupational exposure. Serbian national rulebook [9] established the reference level of 40 µT at 50 Hz, which is 2.5 times lower than in European recommendation [8].

Numerous researchers studied transmission lines in vicinity of residential areas. Some of them considered the magnetic field inside residences generated by the outdoor power substations, but there is not so many data available about measurements and calculations of the magnetic field near indoor power distribution substations [10].

Nominal powers of the transformers in the power distribution substations of the Serbian national grid are 400 kVA, 630 kVA and 1000 kVA. Very often, in substations the transformers come in groups of two or three. The power distribution substation located inside the residential and office buildings raise public concern about possible health hazards. Hence, it is very important for the local authorities and decision makers to have information about the magnetic field levels in the apartments and offices.

This paper examines magnetic field above an indoor power distribution substation located in the basement of one of the University buildings in Novi Sad, Serbia. The nominal power of the substation is 2x630 kVA and it contains two 20/0.4 kV transformers.

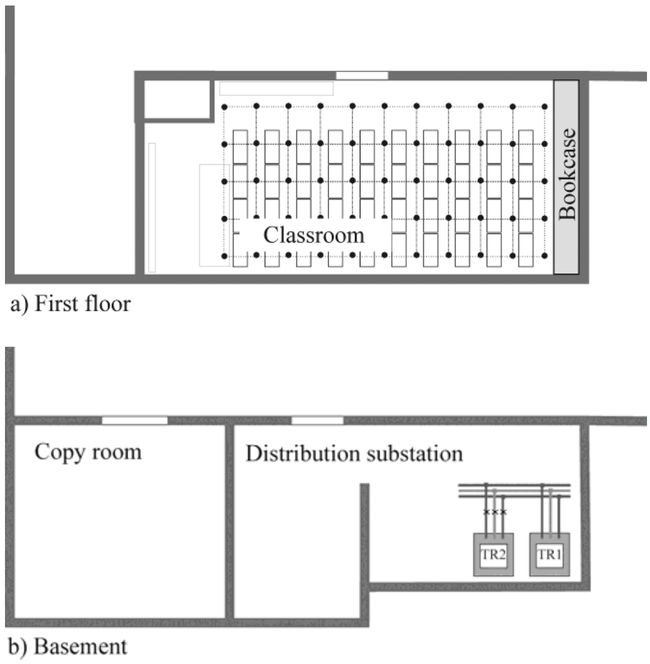

Fig. 1. The measurement sight: a) top view of the room with the grid of the measurement points and b) cross section of the basement with the location of the transformers.

Finite element improved transmission line model of a grounding grid

Rino Lucić, Ivica Jurić-Grgić, Alen Bernadić

This paper presents the improved transmission line (ITL) model for a grounding grid analysis based on the finite element method (FEM). The ITL model is developed using FEM applied to the system of multi-conductor transmission line (MTL) equations. In order to check accuracy of the proposed method, the results obtained using ITL approach has been compared to the results obtained by the electromagnetic field approach and very good correlation has been obtained.

Introduction

Several numerical methods could be used for the grounding grid transient analysis. Those numerical methods could be divided on those based on the frequency and on the time domain approach. Methods of the first category, based on the electromagnetic field approach, solve a system of equations for every single frequency with subsequent transformation of the solution obtained in the frequency domain to the time domain using inverse fast Fourier transformation (IFFT) [1]-[2].

The frequency domain numerical techniques are usually seen as the best suited for the methods based on a full electromagnetic theory approach [3]. However, this procedure significantly increases computational time required. Methods of the second category usually use a transmission line model of a grounding grid solving the system of Telegrapher equations using the finite difference time domain (FDTD) method [4]-[5], or using a number of series connected circuits [6]-[9]. A new general solution method for multi-conductor transmission line (MTL) problem, based on FEM in the time domain, has been presented in the paper [10].

The proposed ITL model is developed by the FEM applied to the system of multi-conductor Telegrapher equations using per-unit parameters of MTL obtained using average potential method based on the image principle [11]. Since the ITL model of grounding grid, which includes an electromagnetic coupling between segments of a grid, has been already established via FDTD, this paper offers a progress to the ITL model of grounding grid based on FEM. In this way the ITL model allows us to take into account electromagnetic couplings of all grounding grid segments and at the same time allows us to exploit all advantages coming with FEM.

By the proposed approach, a soil ionization effect that has an important role in the grounding grid transient behavior could be straightforwardly taken into account that is not a case with the electromagnetic field approach so far described in literature. Although the electromagnetic field approach, by its definition, is to be more accurate, the proposed approach is good enough and even competitive due to its simplicity compared to the electromagnetic field approach as it is reported in [12]. Frequency dependent per-unit length parameters will be taken into consideration in a future research since they are not of a crucial importance in a grounding grid analysis, except probably in some special cases including very fast transients. Nevertheless, the proposed approach from the electrical engineers point of view is a simple enough for quick applications, and at the same time, it predicts all the important features of grounding grid transient behavior.

The transmission line finite element method

Propagation of traveling waves on MTL in the time-domain is governed by the MTL equations in terms of voltage and current waves in the time domain.

$$(1)\qquad \begin{aligned} -\frac{\partial\{u\}}{\partial x} &= [R]\cdot\{i\}+[L]\cdot\frac{\partial\{i\}}{\partial t} \\ -\frac{\partial\{i\}}{\partial x} &= [G]\cdot\{u\}+[C]\cdot\frac{\partial\{u\}}{\partial t} \end{aligned}$$

where [R], [L], [C] and [G] are a resistance, inductance, capacitance and conductance per-unit length frequency independent matrices, respectively.

Least squares estimation of double exponential function parameters

Dino Lovrić, Slavko Vujević, Tonći Modrić

In this paper an effective numerical algorithm for computation of double-exponential function parameters based on the available input data is presented. The parameter estimation is achieved using the Marquardt least squares method.

Introduction

In the field of electromagnetic analysis of lightning phenomena a number of mathematical functions are available for modelling the channel-base lightning current [1]. The simplest of these functions is the double-exponential function [2], which, despite its numerous drawbacks, continues to be in use mainly due to its simplicity.

In this paper, an algorithm for estimation of double-exponential function parameters is presented, which is based on a similar algorithm applied on the Heidler function [3]. The algorithm enables simultaneous solving of a system of two, three or four nonlinear equations depending on the available input data: current peak value, front duration, time to half value, charge transfer at the striking point and specific energy.

Lightning return stroke current

The lightning current approximation of the first return stroke is depicted in Fig. 1, where I_0 is the current peak value, t_0 is the virtual starting time, t_1 is the time to 10 % of peak value, t_2 is the time to 90 % of peak value, t_h is the total time to half value of the peak value, t_{max} is the time to the peak value, T_1 is the front duration and T_2 is the time to half value [4].

Double-exponential function can be used to approximate the lightning return stroke current and is described by the following expression:

(1) $$i(t) = \frac{I_0}{\eta} \cdot \left(e^{-\alpha \cdot t} - e^{-\beta \cdot t} \right)$$

where η is the correction coefficient of the current peak value, α and β are the parameters of the double-exponential function.

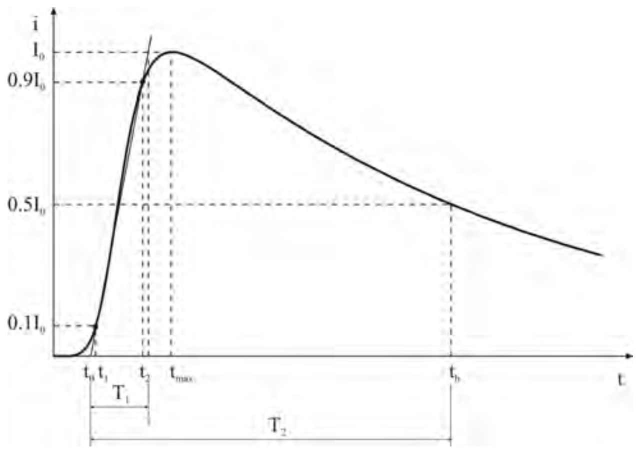

Fig.1. Lightning current approximation of the first return stroke.

According to Fig. 1, two basic requirements for the estimation of double-exponential function parameters η, α and β can be written as:

(2) $$i = 0.9 \cdot I_0 \quad for \quad t = t_2$$

(3) $$i = 0.5 \cdot I_0 \quad for \quad t = t_h$$

Two additional requirements can be deduced from the charge transfer at the striking point Q_0 and the specific energy W_0:

(4) $$\int_0^\infty i \cdot dt = Q_0$$

(5) $$\int_0^\infty i^2 \cdot dt = W_0$$

From equations (2-5), the following four normalized nonlinear equations can be obtained:

(6) $$R_1 = \frac{1}{0.9 \cdot \eta} \cdot \left(e^{-\alpha \cdot t_2} - e^{-\beta \cdot t_2} \right) - 1$$

Nondestructive characterization of materials using Lorentz force eddy current testing

Hartmut Brauer, Robert P. Uhlig, Mladen Zec, Matthias Carlstedt, Konstantin Porzig, Marek Ziolkowski, Hannes Toepfer

A novel electromagnetic nondestructive evaluation technique, so-called Lorentz force eddy current testing (LET), is presented. The technique enables the detection of defects lying deep inside a moving nonmagnetic conducting material and the determination of the electrical conductivity of the specimen as well, both in contactless manner. In the paper, both the detection of subsurface defects and estimation of the electrical conductivity of nonmagnetic conductors are discussed. The numerical simulation as well as the experimental verification of the LET method are applied to test problems using several aluminium specimen.

Introduction

Computations of eddy current problems involving parts in motion have undergone an extensive research over the past decades. A keen interest in this area has been demonstrated by numerous publications in many fields of research concerning coupled multiphysics problems. They mainly include different types of electromechanical devices in applications such as electrical machine design [1], inductive heating [2], magnetohydrodynamics [3], and nondestructive testing [4].

Beside of the defect detection the techniques can be applied to determine the material characteristics as well. The four-point-method proposed by *van der Pauw* is usually applied if the electrical conductivity of the specimen has to be determined [5]. We present a novel contactless, nondestructive technique for the detection of single defects deep inside a non-magnetic conductor. Furthermore, by means of the measurements of the Lorentz force exerting on the permanent magnet, the electrical conductivity of the specimen can be determined.

Problem Description

Basic Principles

The Lorentz force eddy current testing technique (LET) represents a modification of the common eddy current testing (ECT) [6]. The eddy currents are induced in the conductor under test due to its motion in the primary (static) magnetic field. If there is a defect in the material, the perturbation of induced currents or its secondary magnetic field can be related by means of changes of the Lorentz force acting on the permanent magnet (Fig. 1).

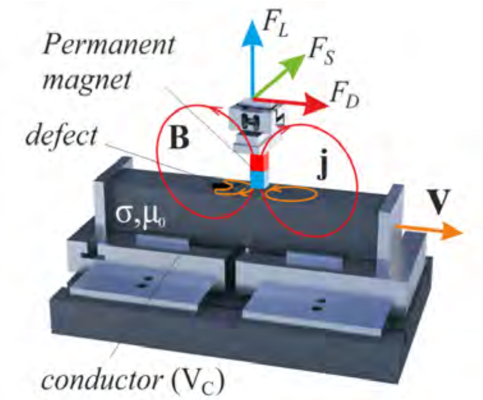

Fig. 1. Lorentz force eddy current testing principle: a specimen is moving with velocity v in the static (primary) magnetic field $\boldsymbol{B_p}$*, causing the Lorentz force (drag force* F_D*, lateral force* F_S*, lift force* F_L*) exerting on the magnet due to the secondary magnetic field* $\boldsymbol{B_s}$*.*

Motion Induced Eddy Currents

Lorentz force eddy current differs from ECT in the way the eddy currents are induced. ECT requires alternating current (AC) driven coils to induce eddy currents into the specimen according to Faraday's induction law:

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \tag{1}$$

where ***E*** is the electrical field, ***B*** the magnetic flux density. However, the time-varying magnetic field can be generated by a relative motion between the specimen and a DC magnetic field source as well. These motion induced eddy currents are described by

PM locating for cogging torque reduction in a single-phase surface-mounted PM motor

Jawad Faiz, A.H. Tavakol-zadeh, Gh. Shahgholian

Surface-mounted permanent magnet (PM) is a well-known structure in PM machines. Low armature reaction and capability of standing high power load can be achieved by choosing the slotted surface PMs in machines. This structure has uniform air gap. Existing slots leads to a cogging toque which can be alleviated using different methods. Most design-based methods are: skewing PMs slots, changing PM arc length, changing radial depth of pole shoe, and using small slots in each pole. It is shown that PMs skewing by an half pole pitch is a proper technique in redcing the cogging torque. However, this technique needs structural changes which can decrease or vary the amplitude of the main torque. Most cogging torque alleviation techniques reduce the back emf, and therefore the starting torque. So, key point in the motor design is minimizing the cogging torque and maximizing the output torque of the motor.

Introduction

Permanent magnet (PM) motors are widely used electrical motors because of their high torque density and efficiency. Although a surface-mounted PM (SMPM) motor has a simple structure compared to an inset-PM type motor, it has some drawbacks such as difficulty in its demagnetization. Also, the SMPM motor is under heavy centrifugal force. PM merely covers full pole pitch, because the flux passing N and S poles penetrates between the poles with no link with the stator windings. Generally, cogging torque presented in this motor must be minimized using analytical [1] or numerical methods. Impact of slot and stator design on the cogging torque has been studied in [2], [3]. The effect of both slot opening shifting and pole arc length on the cogging torque has been proposed in [4]. A four sliced method on an SMPM motor has been applied in [5]. Slot shapes and various windings topologies impacts on the cogging torque have been considered in [6]. A frozen permeability FEM has been applied to show the load effect upon the cogging torque and back-emf waveform [7]. Furthermore, the effectiveness of the rotor skew on the minimization of the cogging torque has been shown in [8].

This paper describes the cogging torque and its causes and gives the methods of torque and cogging torque evaluation. Different reshaped PMs are employed and compared in a smooth pole single-phase PM motor with distributed winding in order to reduce the cogging torque. The merits of SMPM motor in this respect are described and the results of applications of cogging torque reduction methods are compared.

Surface-mounted PM Machines

Slot-less electrical motors can develop a smooth torque leading to a low-noise machines. In the case of slot-less and tooth-less structure, there is a large air gap for current dependent magnetic field of the windings. This can diminish armature reaction leading to a better performance in over-loads region. Back-electromotive force (emf) in the stator windings does not vary by the change of motor load. Motor with low inductance needs a large switching frequency converter which increases the converter losses. If motor structure has slots, Ferrite PMs approaches a reasonable torque density and this reduces the materials volume and core losses. The residual flux within the core can reduce the required iron volume in the motor.

Different methods may be applied to reduce the cogging torque and its relevant noise. SMPM motor has negligible armature reaction and it can stand the over-load. An uniform air gap, in slot-less SMPM leads to a low stator inductance which is traditionally desirable in the design of a fast torque controller for motor. It is clear that there are saliencies in the SMPM motors but PM motors with inset PMs have characteristics similar with salient pole synchronous machines. An SMPM motor with conventional winding has no reluctance torque; therefore, its

Testing immunity to ESD of electric energy meters during their development phase

Tatjana Preradović, Mićo Gaćanović

Electric energy meters are devices used to measure the consumption of electrical energy, and are an integral part of every household and industry. Since their accuracy is in first place it is necessary to ensure that the device is functioning properly, particularly regarding any electromagnetic interference. This paper describes the importance of testing electromagnetic compatibility of devices such as electricity meters, with a special regard on immunity to electrostatic discharge. The short description of the ESD phenomena is given, and how it is modeled for testing purposes. The basic guidelines for testing method and equipment are given in relevant standard IEC/EN 61000-4-2. The manufacturing standards IEC/EN 62052-11 further specifies the method and conditions of testing. The process of testing the device under development is described, as well as testing results. It is pointed to the flaws in the design of the device, and how these oversights were corrected in order to device ultimately satisfy the test.

Introduction

Energy meters are devices used to measure the consumption of electrical energy, and are an integral part of every household and industry. The development of electronics and microprocessor technology has led to the improvement of electrical energy measuring, so that we now have smart meters with additional features such as remote sensing, display of active and reactive power, multi-tariff billing, events recording with a time stamp as well as many other power quality monitoring features.

As the electric meters are primarily measuring devices, their accuracy is in first place. It is therefore necessary to ensure that the device is functioning properly, particularly regarding any electromagnetic interference. The device itself can be a source of electromagnetic energy, but also lightning, electrostatic discharge, and the presence of telecommunication, radio and video signals contributes to the increased activity of certain types of EMI. Bearing in mind all this, it is necessary to design and manufacture devices that will be electromagnetically compatible, ie. they should be neither a source of EMI nor affected by any EMI.

The IEC/EN series of standards for electricity measuring cover the electricity measuring devices, protocols that they use, and set of tests relating to electromagnetic compatibility. These tests can be generally divided into emission tests that examine the influence of the device to its environment, and immunity tests that examine the device immunity to interference from the environment [1]. In the latter falls the test of immunity to electrostatic discharge, which will be described in this paper.

ESD

Static electricity can be created in many ways, but the most common is by contact and subsequent separation of materials. This method is referred to as triboelectric charging. The result is an accumulation of static charge on the surface of the object [2]. When a static charge moves from one surface to another, then we talk about an electrostatic discharge - ESD. It occurs when the voltage differential between the two surfaces is sufficiently high to break down the dielectric strenght of the medium separating the two surfaces [3]. Electrostatic potential V of an object is expressed in volts [V] (1),

$$V = \frac{Q}{C} \quad (1)$$

For the ESD test of device three major test methods are widely used today, whereby each of them describes a case in a real environment:

Human Body Model (*HBM*) which simulates the action of a human body discharging accumulated static charge through a device to ground.

Machine Model (*MM*) which simulates a machine discharging accumulated static charge through a device to ground.

Currents induced in frame wire structures in a plane wave electromagnetic field

Vesna Javor, Milan Šaranac

Abstract: Induced currents in conductive structures in external electromagnetic field may present significant electromagnetic disturbance and interference source. Depending on the aspect of interest, this problem might be observed in electronic devices, electric circuits, electrical networks, lightning protection systems or other conductive structures as staffolds, pipes and cranes in electromagnetic fields of MF transmitters. Results, presented in this paper, for the induced currents and voltages in frame wire structures are obtained based on antenna theory and electric field integro-differential equation (EFIE).

Introduction

Conductive structures may act as unintentional receiving antennas in some electromagnetic field, either unwanted or produced for another purpose. Induced currents may be significantly large so to endanger human life or to cause malfunction in the electric circuit or automation system, or to trigger a surge protective device. There were cases of electromagnetic interference (EMI) that range from common, as annoyances due to crackles on broadcast reception, to the fatal accidents due to corruption of safety control systems [1]-[3].

Sources of electromagnetic (EM) disturbances can be of natural or artificial origin. Main natural sources of EM disturbances are lightning atmospheric discharges occurring about 100 times each second on the Earth, but also EM waves originating from out of the Earth, such as emissions from the Sun. Human made disturbances are electromagnetic waves generated by radio transmitters, radars, high-voltage power transmission lines, relays, electric motors, fluorescent lamps, various electrical devices, so as those generated by digital electronic devices, computers and systems.

Some sources produce electromagnetic emissions mainly in a narrow band of frequencies, such as industrial frequencies of 50Hz or 60Hz (depending on the country), and some are very rich in spectral content, e.g. lightning discharges, and especially those associated with the short transition times as in turning on/off of different pulses, sparks and arc. This is also valid for digital electronic devices that utilize pulses to signify a binary 1 or 0. Frequencies of use in digital electronics products are constantly increasing, and nowadays there are very few electrical devices not containing them. Even in analog systems the frequencies are reaching the GHz range. The electromagnetic pollution interferes with electrical or electronic system and is influenced by it.

Radiated susceptibility is particularly important in the vicinity of high-power transmitters, radars, or other emitters. Conducted susceptibility is important especially in the case of lightning induced transients when interference signals can enter the product via power cables. Electromagnetic phenomena which can interfere with control systems are supply voltage interruptions, surges and fluctuations, transient over-voltages on supply, signal and control lines, RF fields, both pulsed or continuous, coupled with the equipment or with the connected cables, electrostatic discharge from an object or a person, low frequency electric and magnetic fields, etc. An electrostatic discharge (ESD) phenomenon occurs when the discharge is built-up on a person's body or some other point when somebody touches the electrical device or equipment, which can cause large currents momentarily flow. It has become increasingly important with integrated circuit technology, as it can cause IC memories to clear, machines to reset, etc. The tests for the ESD susceptibility are made by subjecting some device or equipment to a controlled ESD event and checking if it still operates successfully.

Functional characteristics of the equipment also have to be preserved, the limits for human exposure to electromagnetic fields have to be taken into account, and potentially life-threatening consequences have to be avoided. There are different health and safety limits for electric and magnetic field strengths and power

Partial element equivalent circuit model for a perfect conductor excited by a current source

Andrijana Kuhar, Radoslav Jankoski, Vesna Arnautovski-Toseva, Lidija Ololoska-Gagoska, Leonid Grcev

The Partial Element Equivalent Circuit (PEEC) method provides a way to transform electromagnetic problems into electric circuit theory problems which can be analyzed using widely spread SPICElike solvers. In this research a Partial Element Equivalent Circuit (PEEC) model is applied in order to determine the current distribution along a perfect conductor placed in a conductive medium, using the thin wire approximation. A heterogeneous mixed circuit was created with equivalent elements (impedances, admittances and sources) that take into account the electromagnetic properties of the system. A parametric analysis of the current distribution is performed by implementation of the Modified Nodal Approach (MNA) in the frequency domain, while the conductor is excited at one end by a current source. The obtained results are compared with those calculated by applying the Method of Moments on the Mixed Potential Integral Equation and show satisfactory agreement.

Introduction

The essence of the Partial Element Equivalent Circuit (PEEC) method [1] is to create an equivalent electric circuit from a full-wave solution of the Maxwell's equations for a certain electromagnetic problem. The heterogeneous equivalent circuit is consisted of equivalent elements (impedances, admittances and sources) that take into account the electromagnetic properties of the system, as well as coupling between segments and propagation effects. The circuit based modeling has the advantage of simple inclusion of additional circuit elements when using the PEEC method with commercial circuit simulation software. Another advantage of the PEEC method is the possibility to implement the same circuit model for both time- and frequency- domain analysis. This kind of numerical modeling is useful in several areas of engineering, for example, product research and development of integrated electronic circuits (enabling prevention from Electromagnetic Interference (EMI)), design of complex grounding systems and analysis of transient potentials in them [2], etc. A typical case in which implementation of a combined electromagnetic circuit is required is, for example, in systems with geometries that are comparable to the wavelength of the corresponding frequencies. As a result, the conductors and interconnections in the system start to act like antennas - radiating or receiving electromagnetic energy and thus producing EMI. Another important application of the PEEC method is, for example, lightning surge analysis [3].

In this paper we apply the Partial Element Equivalent Circuit (PEEC) model on a perfect conductor placed in a conductive medium, using the thin wire approximation. The conductor is excited at one end by a current source. The current distribution along the conductor is determined in the frequency domain by implementation of the Modified Nodal Approach (MNA) [4]. The values for the current along the conductor are then compared with results from ref. [5], calculated by applying the Method of Moments on the Mixed Potential Integral Equation. The comparison of the obtained results is presented for different parameters of the analyzed system and shows satisfactory agreement.

Current distribution calculations

PEEC model for a perfect conductor using the thin wire approximation

The analyzed system is consisted of a perfect conductor placed in an unbounded conductive medium, excited by a current source. The geometry of the conductor with radius a, length L and the location of the source is presented in Fig. 1.

ПРОЕКТЪТ СЕ ОСЪЩЕСТВЯВА С ФИНАНСОВАТА ПОДКРЕПА НА ОПЕРАТИВНА ПРОГРАМА „РАЗВИТИЕ НА ЧОВЕШКИТЕ РЕСУРСИ“, СЪФИНАНСИРАНА ОТ ЕВРОПЕЙСКИЯ СОЦИАЛЕН ФОНД НА ЕВРОПЕЙСКИЯ СЪЮЗ

Европейски съюз

ЕСФ България
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„Развитие потенциала на докторанти, постдокторанти, млади учени и специализанти от инженерните науки в ТУ - Варна и техния принос за развитие на икономика, базирана на знанието“

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По представения проект, финансиран от оперативна програма „Развитие на човешките ресурси”, са постигнати значителни резултати за 2012, 2013 и 2014 година.

Подпомогнати участници от целевите групи за 2012 - 2014 година:

Участия на членове от целевите групи в научни форуми и конференции - 25 през 2012 година и 28 през 2013 година.

Проведени консултации от експерти за подпомагане на целевите групи - 30 през 2012 година и 32 през 2013 година.

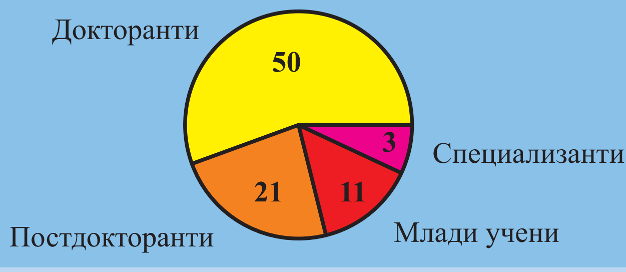
Мобилности на членове от целевите групи в международни и наши институции - 5 през 2012 година и 18 през 2013 година.

Закупени развойни системи за ВЕИ

Закупена развойна система за зелени технологии

Проведено е докторантско училище в рамките на проекта с участие на 24 докторанти и 5 млади учени. Участници в докторантското училище – 25 експерти и лектори. Изнесени 32 часа лекции и проведени 48 часа парктически занятия.

Публикации на участниците в целевите групи по проекта за 2012 и 2013 година са:



През 2014 година е издаден сборник с научни доклади на членове на целевите групи:

Издадени - 2 броя учебни пособия и 2 броя студии в рамките на проекта.

Закупена специализирана научна литература – 23 бр.

Направен абонамент за списания /периодика/ – 8 бр. за 2014 година.

Създаден е интернет сайт и е изготвен рекламен банер за проекта.

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