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Visual EM Simulator for 3D Antennas: VEMSA3D — FLOSS for MS Windows

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Abstract

This paper introduces the FLOSS Free Libre Open Source Software [VEMSA3D], a contraction of "Visual Electromagnetic Simulator for 3D Antennas", which are geometrically modeled, either exactly or approximately, as thin wire polygonal structures; presents its GUI Graphical User Interface capabilities, in interactive mode and/or in handling suitable formed antenna data files; demonstrates the effectiveness of its use in a number of practical antenna applications, with direct comparison to experimental measurements and other freeware results; and provides the inexperienced user with a specific list of instructions to successfully build the given source code by using only freely available IDE Integrated Development Environment tools—including a cross-platform one. The unrestricted access to source code, beyond the ability for immediate software improvement, offers to independent users and volunteer groups an expandable, in any way, visual antenna simulator, for a genuine research and development work in the field of antennas, adaptable to their needs.

Keywords

FLOSS, antennas, modeling, simulation

Introduction

A lot of amazing visual EM software simulators, both commercial and freeware, exist for many years now. However, to the best of authors' knowledge, none of these simulators has been ever released under an Open Source license—paid, free gratis or free libre. This situation, as it was discussed recently, precludes the independent users and volunteer groups with limited resources, like the authors' nonprofit group, from the genuine, state-of-the-art, scientific research, since, neither the code improvement, nor its adaptation to specific needs, is possible [1], [2].

For that reason, the authors decided to develop and release under the GNU public license their own Visual Electromagnetic Simulator for 3D Antennas [VEMSA3D], although it certainly is a less well-equipped software application for the moment—but still a fully expandable one. That release is now perfectly permissible, because in 2005 NASA released in the public domain the FORTRAN source code of the well-known MoM Method of Moments Thin-Wire Computer Program, by J. H. Richmond [3], [4]. This is exactly the code on which the authors' group based its freeware simulators: [RichWire], a CLI Command Line Interface, and [DA], a MS Quick-Win FORTRAN derivative of it. These two simulators are under uninterrupted revision, improvement, expansion, and redevelopment, since a long time ago [1], [2]. Therefore, the [Rich-Wire] FORTRAN code was translated—entirely, line-by-line, without using any paid or free translator—to C++, to form the core of scientific EM computations in [VEMSA3D].

On the other hand, the authors' group requirements for scientific accuracy in visual representation of the produced EM simulation antenna results from its simulators, were already enforced the software development of the Virtual Antennas, that is the Virtual Antennas laboratories, in VRML [5], [6], the FLOSS application [RadPat4W] for antenna radiation pattern presentation, in MS VB6 [2], [7], as well as, the recently developed visual antenna application for the Wolfram Demonstrations Project in Mathematica [8]. The visualization ideas implemented in the aforementioned graphics applications were also expressed—from the scratch—in C++, to use the Open Source cross-platform [wxWidgets] library with OpenGL and form the core of scientific EM graphics in [VEMSA3D] [9].

The authors, having taken into account that no familiarization with software use is possible without getting hands-on experience, restrict themselves to a brief discussion of the current [VEMSA3D] characteristics. The code, the antenna applications data, as well as, any other information, referenced open bugs or future code releases, will be always available in authors' group repositories, at "www.antennas.gr/floss" and in GoogleCode website, at "http://code.google.comp/p/rga/".

GUI Interactive Mode of Operation

It is assumed that the user has already some experience in the sketching of a polygonal wire outline model, for an antenna under consideration, consisting of numbered wire segments and nodes, with their 3D space coordinates, including the positions of any antenna circuit elements, that is voltage generators and lumped loads, and s/he wants then to key-in these model and circuit data into [VEMSA3D] using its GUI Graphical User Interface in interactive mode.

The GUI main window is shown in Fig. 1, while Fig. 2 shows the menu items along with their available submenu options numbered from 1 to 7.

The GUI itself is divided in three panels named [Antenna in space (3D)], [Anenna Elements], and [Data-sets]. The function of each panel is briefly described in the following.

The [Antenna in space (3D)] viewing panel is used to project all the generated 3D and 2D graphics. By default, the application starts with a simple linear dipole antenna in space, as it is shown in Fig. 1 from a viewpoint on the diagonal of trihedral angle OXYZ, where the usual letters associated with the Cartesian axes do not exist. Instead, a one-to-one correspondence implicitly exists between (X, Y, Z) axes and (R, G, B) colors [5]. The 3D image of any antenna can be manipulated through the [Study] options, as shown in Fig. 2.3.

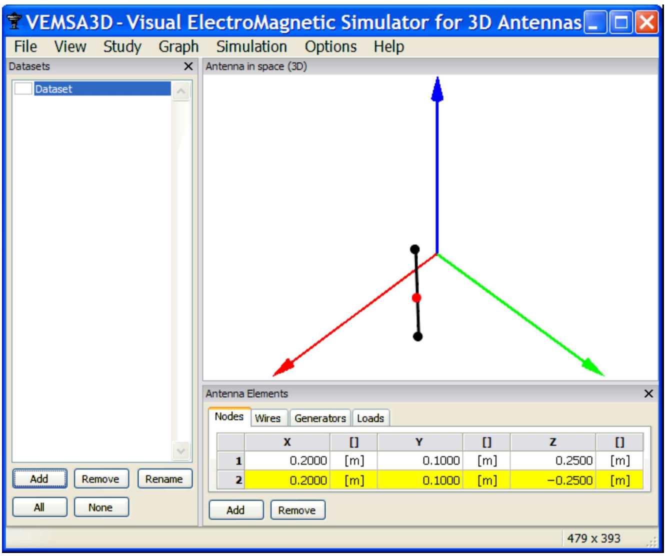

Fig. 1: GUI: The main window

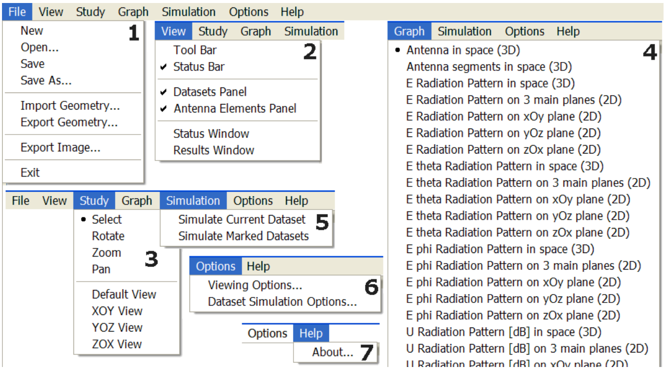

Fig. 2: Main window: The unfolded menu items

The [Antenna Elements] panel contains four tabs, corresponding to model and circuit data, in four self-explained building blocks. Instead of attempting to describe the block data in general the presentation continues with the default data:

[Nodes]: 2, with coordinates 1: (0.2, 0.1, 0.25), 2: (0.2, 0.1, −0.25), in meters [m] or in terms of wavelength λ [wl].

[Wires]: 1, starting at node: 1, ending at node: 2, that is a directed segment.

[Segments] is either: (a) a positive integer, (b) a zero or (c) a number between 0.00 and 0.25, to respectively define the division of this wire in segments: (a) in the indicated number of segments, (b) in a calculated number of segments of length no longer than 0.05λ (that is 10 segments, in this case), (c) in segments with length no more to that number. Notably, no segment can be longer than 0.25λ [3].

[Generators]: 1, connected in the wire:1, at a distance of 0.5 times this wire length, from its starting node, with rms value of 1∡0° [V]. There can be only one generator on each wire.

[Loads]: Has the same structure as [Generators]. Resistors, inductors and capacitors are inputted in [Ω], [H] and [F], respectively. It is empty in this case, since no lamped loads exist.

Notably, the GUI has been developed in such a way that efficiently supports the interactive handling of the antenna modeling by the user on the screen. Thus, the selection of an element in any of these four tabs simultaneously highlights this element on the viewing [Antenna in space (3D)] panel—if the [Select] option under [Study] (Fig. 2.3) has been already chosen by the user, and this is the default selection in any case—and conversely: the selection of any element on this viewing [Antenna in space (3D)] panel highlights the element in its table. Consequently, a full control on the antenna modeling structure is achieved.

The [Datasets] panel may contain independent sets of model and circuit data for various antennas. Such a Dataset has its own [Dataset Simulation Options], which are chosen through submenu of Fig. 2.6, as the default selection of them is shown on the left part of Fig. 3.

A [Wire conductivity] of –1 corresponds to perfect wire conductivity, while the [Space conductivity] of 0 and the [Space dielectric constant] of 1 defines the Free Space EM environment. The [Integration steps] accepts a positive number for the steps of approximated integration used in the MoM impedance computations—a zero means closed-form integration.

Notably, the [Maximum segment length] affects the division of wires: the smaller this number is, the more segments will be considered. It is currently known that there is an implied, still programmatically unimproved, priority of the number of segments defined in [Wires] tab, over this selection—that is a bug, which may crash the application.

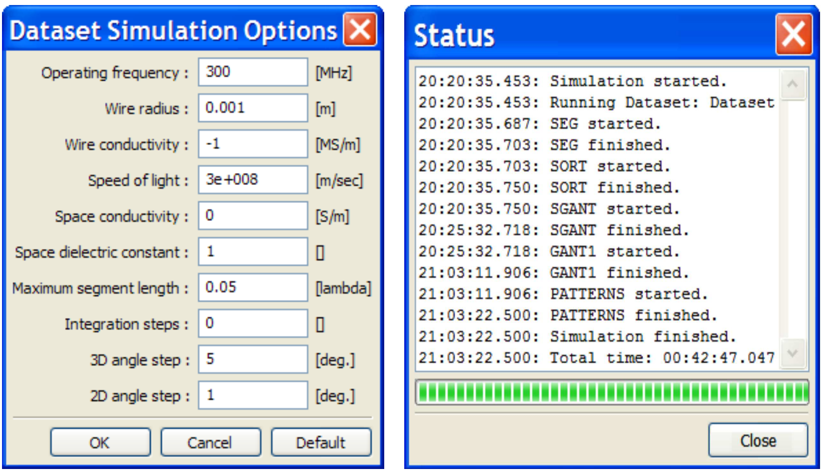

Fig. 3: Windows: [Dataset Simulation Options] – [Status]

The EM simulation of an antenna starts by selecting [Simulate Current Dataset], under [Simulation] (Fig. 2.5), while its progress is shown in the [Status] window, such as the one at the right of Fig. 3, which concerns the default dipole. Notably, multiple Datasets can be simulated, one after the other, through the [Simulate Marked Datasets] shown in Fig. 2.5.

The course of the simulation may be roughly described in five steps:

(1) Wires are automatically segmented, using the provided parameters, to produce the final model structure of points and segments

(2) Model structure is analyzed and adjacent segments are combined to form dipole current modes with sinusoidal distribution

(3) Impedances are calculated and the MoM algebraic system of equations is formed

(4) The system of equations is solved and the segment currents are calculated

(5) 3D and 2D radiation patterns are calculated, as well as other useful results like those shown in Fig. 4.

In Fig. 5, the [Viewing Options] under the [Options] (Fig. 2.6) is given with all of the available options for the graphics. Through [Graph] menu item (Fig. 2.4), a variety of 3D and 2D plots, which include either the normalized electric far field E radiation pattern or the relative radiation intensity U in dB, as well as their θ and φ parts, can be illustrated.

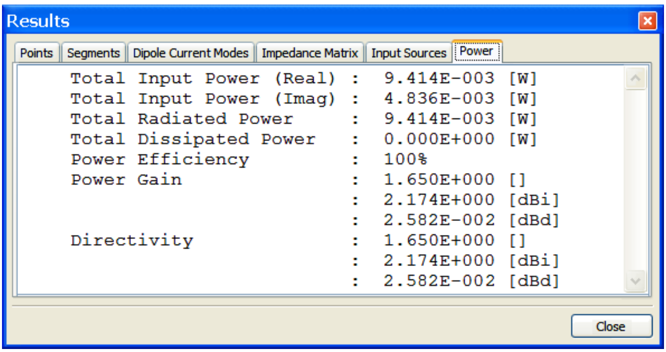

Fig. 4: Window: [Results] - Table: [Power]

The [Antenna segments in space (3D)] illustrates the final antenna structure with points, segments and segment currents in amplitude and phase, as shown in Fig. 6, where the resulting current distribution on default dipole it seems to be sinusoidal, that is as it was expected to be. The well-known 2D intersections of the 3D radiation patterns by the three main planes yOz, xOy, zOx, as well as these 3D patterns themselves are also shown for the default dipole.

Notably, modeled antennas can be imported and exported in [RichWire] data file format (Fig 2.1).

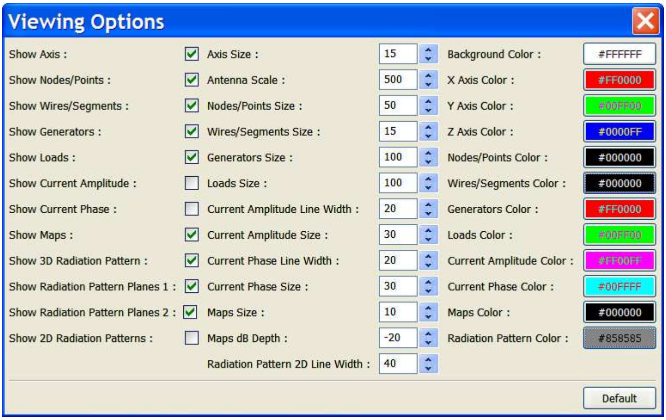

Fig. 5: [Viewing Options]

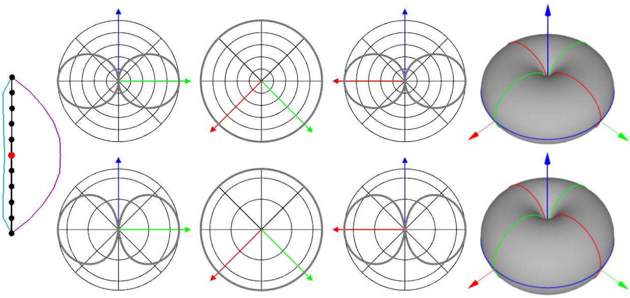

Fig. 6: GUI: Default dipole results

Build under MS Windows XP

To build [VESMA3D] MS Windows executables, the use of IDE CodeBlocks with GCC/Mingw is suggested [10]:

```
Set below as X:\ the system disk, e.g. X:\ -> C:\

1 Download (~20MB), Install (~110MB):
  http://sourceforge.net/projects/codeblocks/files/Binaries/
 [View all files][Binaries][8.02]
  codeblocks-8.02mingw-setup.exe
  Select: [Full], [Run], Compiler: [GCC/Mingw]

2 Download wxWidgets (~20MB), Extract (~120MB):
  http://sourceforge.net/projects/wxwindows/files/2.8.11/
 [View all files] wxWidgets-2.8.11.zip
  wxWidgets-2.8.11.zip-> X:\ [Yes to All]

3 IDE CodeBlocks, Open:
  X:\wxWidgets-2.8.11\include\wx\msw\setup0.h
  Replace, at line 1006:
 #define wxUSE_GLCANVAS 0 -> 1
  Repeat it, to file: setup.h

4 At system variable [path]:
 [My Computer][Properties][Advanced]
 [Environment Variables][System Variables]
  Path[Edit][Variable value], Add:
 ";X:\Program Files\CodeBlocks\MinGW\bin;"

5 Command Prompt: >cd\
 >cd X:\wxWidgets-2.8.11\build\msw
 >mingw32-make -f makefile.gcc MONOLITHIC=0
  SHARED=0 UNICODE=0 USE_OPENGL=1
  BUILD=release

  Re-Command, with option:
  BUILD=release -> BUILD=debug

6 Download (~100KB), Extract (~700KB):
  http://code.google.com/p/rga/downloads/
  VEMSA3D_source_1.zip -> X:\

7 IDE CodeBlocks, [File][Open]:
  X:\VEMSA3D\build\win-cb\VEMSA3D.workspace

   * If system disk is not C:\ then:
 (#)[Project][Build options...][VEMSA3D]
  * [Search directories] Correct in each of:
  * [Compiler],[Linker],[Resource compiler]
  * C:\ -> X:\ [Yes]
  * Repeat from (#), for [Release]
  * Repeat from (#), for [Debug]

 [Build][Select target][Release][Build]
 [Build][Select target][Debug][Build]
```

This process results in [VEMSA3D] executables of ~35 MB Debug and of ~5MB Release versions, which run under NT4, W2K and WXP, at least.

Alternatively, the use of the freeware IDE MS Visual Studio Express with C++ 2008 Compiler is also suggested. For that, first download MS Visual Studio 2008 Express iso-image from Microsoft website, burn it into a CD-R, and install it. Then, download from our repositories the file [VEMSA3Dfiles-4win-cb.zip], extract it, and follow the included setup instructions. This process results in [VEMSA3D] executables of ~5MB Debug and of ~2MB Release versions, which run under W2K and WXP, at least, but definitely do not run under NT4.

Practical Antenna Applications and Results

This section presents the implementation of [VEMSA3D] to produce eight antenna models, from simple to more complicated structures. The input data were imported through [Import Geometry] of the [File] menu (Fig. 2.1).

Fig. 7 shows an array of 2 dipoles for operation at the frequency of 1111 MHz, distanced by 0.85λ, constructed by bare copper wire of 1 mm (0.0037λ) radius, and measured. In the same figure, the 3D radiation intensity pattern and its 2D main plane cuts are shown [11]. The continuous line represents [VEMSA3D] results, the dashed line, analytically produced patterns, and the dots, measurements made using the authors' group VNA system [12], [13].

Fig. 8 illustrates the results for a constructed and measured improved Hentenna model, at 1110 MHz, with height of λ/2, width of λ/6, and with the active element at a distance 7λ/12 from its bottom [14].

The third antenna consists of a λ/4 monopole (5.83 cm) at 1286 MHz over a circular counterpoise of 14 cm radius. The monopole was constructed by 2 mm diameter copper wire and the counterpoise has been printed on a circuit board of 29 cm x 29 cm, as a circle with four radials of 2 mm width [15]. In Fig. 9, the left 3D and 2D patterns are for vertical polarization, while the right ones for horizontal. For a better representation, the patterns have been normalized.

A somehow more complicated antenna is shown in Fig. 10. The left 3D and 2D patterns correspond to the vertical polarization of a monopole over circular counterpoise with 16 radials, while the right column patterns are the corresponding 3D and 2D patterns for the same antenna, but with an additional grounded disc below it, and without electrical connection to the counterpoise antenna, at a distance of 0.9 cm. The grounded disc was constructed from thin copper sheet and was modeled in [VEMSA3D] with 5 concentric circles and 64 radials [15].

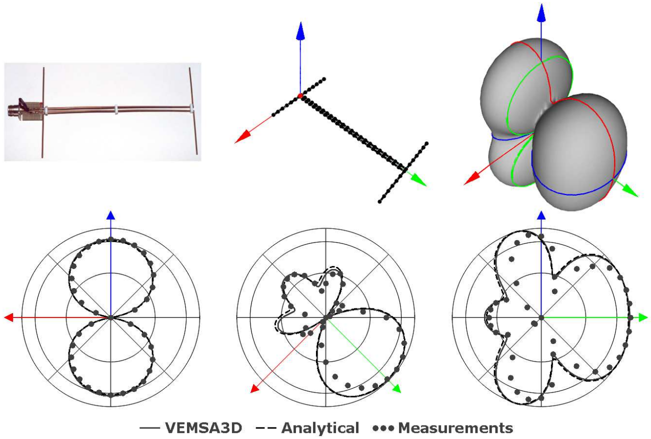

Fig. 7: Array of 2 dipoles: 73 dipole current modes

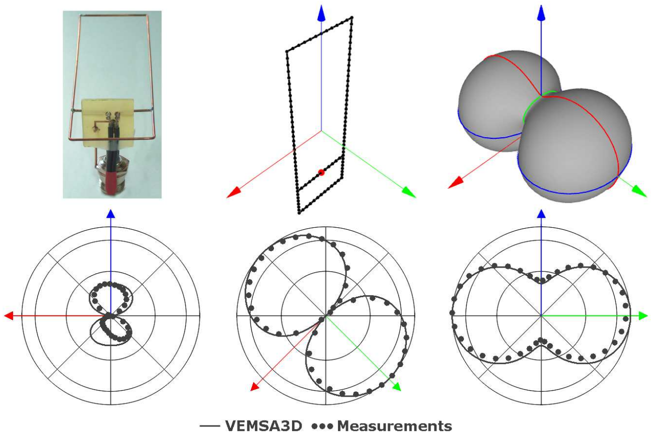

Fig. 8: Hentenna: 109 dipole current modes

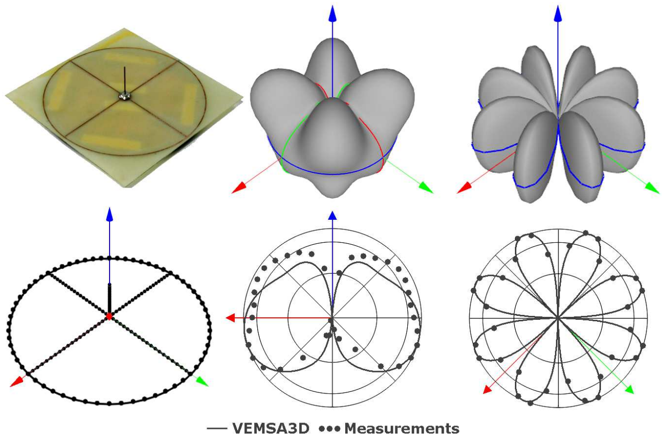

Fig. 9: Monopole over a counterpoise with 4 radials:
167 dipole current modes

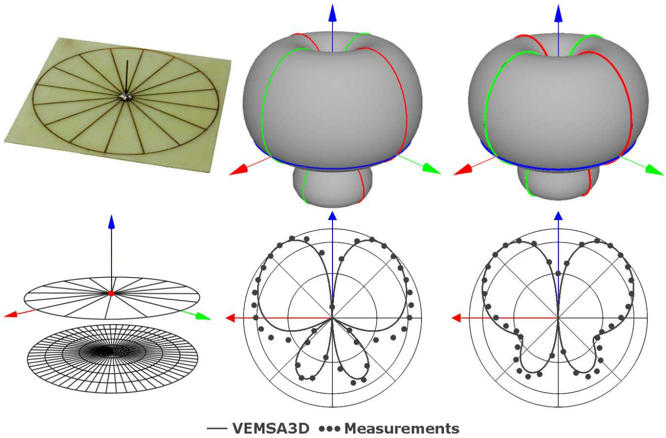

Fig. 10: Monopole over a counterpoise with 16 radials:
419 dipole current modes.
Monopole over a counterpoise with 16 radials over
a grounded disc: 2594 dipole current modes

In Fig. 11, the results of [VEMSA3D] for a commercial UHF antenna are shown [16]. The antenna model is presented in detail and separately, for the active element system, as well for the wire-frame reflector. The patterns correspond to the center frequency of its operation at 650 MHz.

Fig. 12 illustrates the model of a small jet airplane from the well-known freeware [4NEC2X] antenna simulator [17]. Simulation was carried out at the frequency of 10 MHz with the same number of points and segments in both simulators. There is a good agreement between them for the radiation intensity patterns although some deviation in input impedance and directivity is observed.

Fig. 13 shows the results for a horn antenna with dimensions proposed by K. Pitra and Z. Raida [18]. A small bow-tie feeder with a triangular perimeter of 0.47λ and flare angle 37.50°, is considered. The antenna was initially simulated at the frequency of 40 GHz in both [4NEC2X] and [VEMSA3D] simulators, with 1205 segments to be consistent with the restricted maximum number of 1500 segments of [4NEC2X]. There is a good agreement between the produced results.

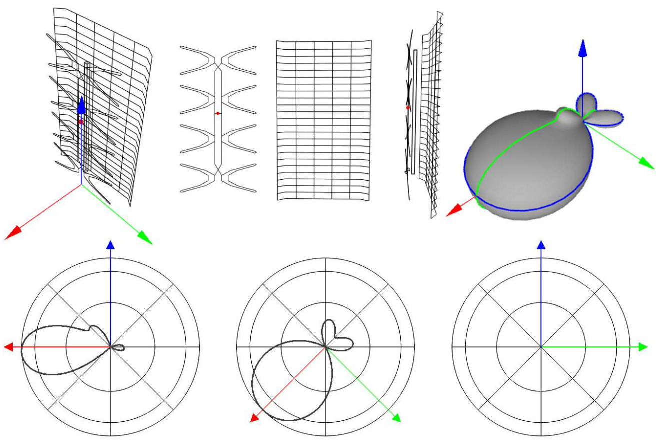

Fig. 11: Typical commercial TV UHF antenna: 723 dipole current modes.

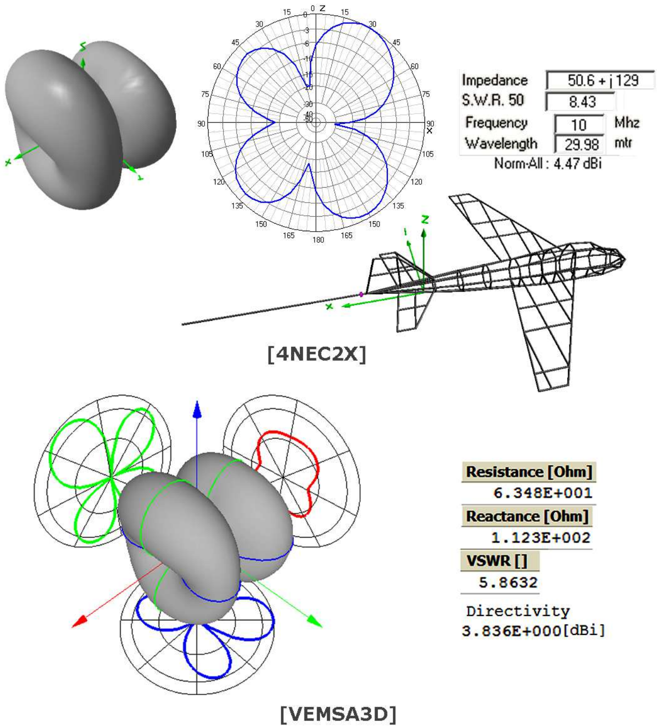

Fig. 12: Jet airplane modeled in [4NEC2X] and [VEMSA3D]: 391 dipole current modes

Finally, the most complicated antenna model, which is presented, corresponds to the same horn antenna at the same frequency of 40 GHz, with a dense wire-frame consisting of 3266 points and 4362 segments. The model is shown in Fig. 14. The total number of dipole current modes is 5458, as shown in Fig. 15. The process time ranges from ~40 min in an AMD Phenom X2 550 3.11 GHz CPU to ~220 min, in an Intel Pentium 4 1.7 GHz CPU. Fig. 16 illustrates the resulting radiation patterns and Fig 17 the current amplitude and phase.

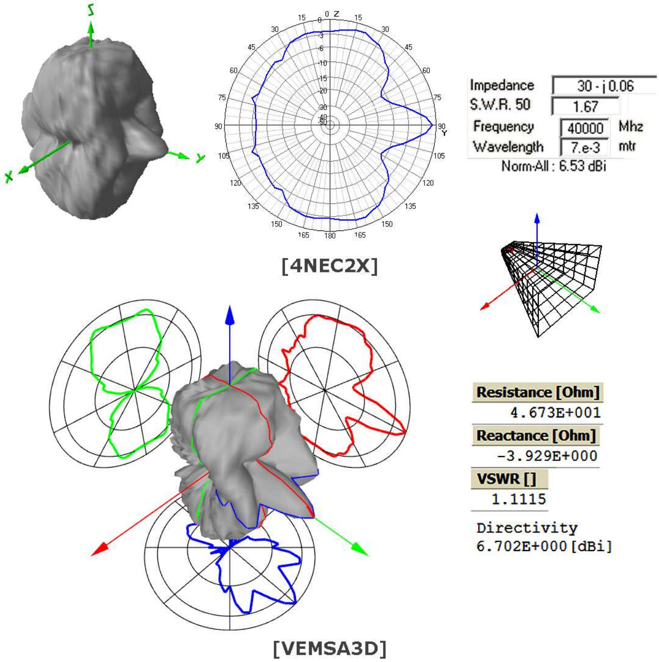

Fig. 13: Horn antenna with bow-tie feeder modeled in [4NEC2X] and [VEMSA3D]: 1370 dipole current modes

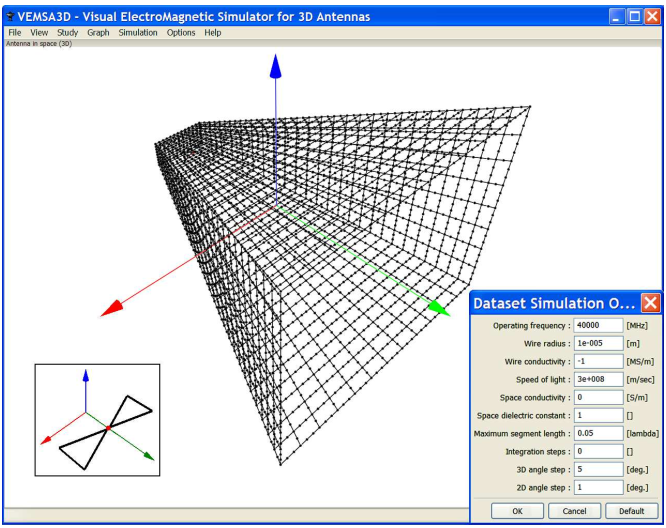

Fig. 14: Horn antenna with bow-tie feeder: 4362 segments

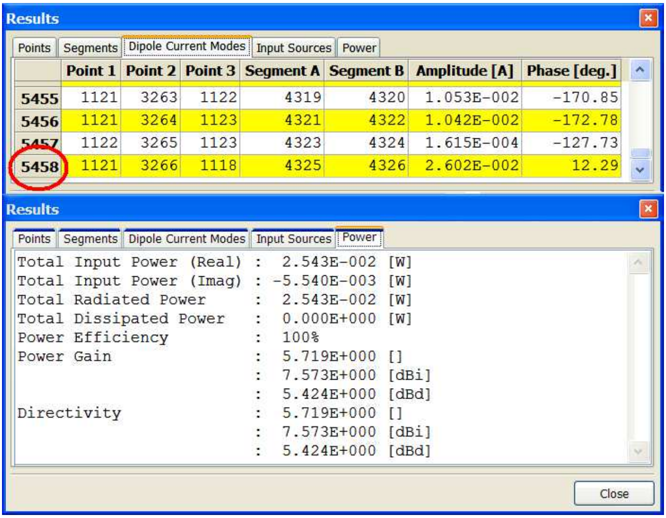

Fig. 15: Horn antenna with bow-tie feeder: 5458 dipole current modes

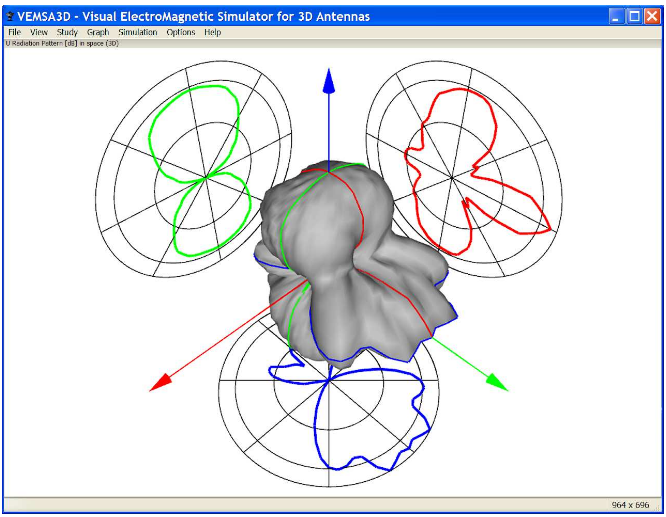

Fig. 16: Horn antenna with bow-tie feeder: Radiation intensity

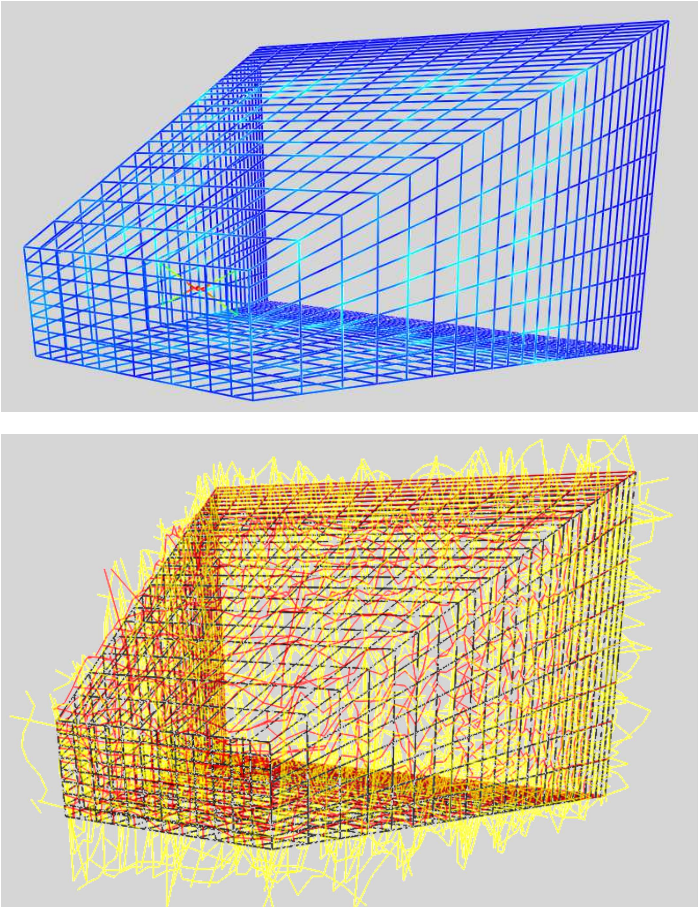

Fig. 17: Horn antenna with bow-tie feeder:
Current Amplitude and Phase

Conclusion

The first stable version of a visual EM simulator has been developed and released as FLOSS. The computational results of its use were found to be in good agreement with experimental measurements as well with the comparable free-ware simulator [4NEC2X]. Since the number of possible modifications and additions to the attributes of [VEMSA3D] seems to be endless, no attempt will be made to suggest a particular direction for its future development: any contribution from the antenna community is very welcomed.

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"A FLOSS Visual EM Simulator for 3D Antennas"

Christos A. Koutsos, Nikolitsa I. Yannopoulou,
Petros E. Zimourtopoulos
"http://arxiv.org/abs/1006.0031"

Proceedings of 33rd International Conference on
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Baden near Vienna, Austria, pp. 432-437

Follow-Up Research Paper

Not until now

Previous Publication in FUNKTECHNIKPLUS # JOURNAL

"Antenna Radiation Patterns:
RadPat4W – FLOSS for MS Windows or Wine Linux",
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Diagnostic Techniques in Transformer Oils: Factors Affecting the Lifetime of Transformer Oil in Transformers of 150/20 kV and the Problem of Relating Diagnostics Data with their Pre-history

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Abstract

The aim of this paper is the study of various parameters affecting the lifetime of transformer oil in transformers of 150/20 kV. Fifty (50) samples of oil were taken from such transformers in the major Athens area, Greece. The parameters investigated – according to international standards – were breakdown strength, oil color, humidity, interfacial tension and tanδ. Thermal and mechanical stresses have as result the oxidation of transformer oil and the deterioration of its insulating properties. Humidity and foreign particles also consist factors contributing to the lowering of the breakdown strength of transformer oil. In most examined samples the breakdown strength and tanδ were satisfactory. It is shown that the slightest contact with the atmospheric air may affect humidity. A color index of 3 does not necessarily mean that the oil is bad. Foreign particle presence combined with humidity may decrease the interfacial tension. Generally speaking, the 50 investigated transformers were in a satisfactory state and none of them was required to have its oil replaced. A main conclusion of this work is that we should not base our judgment about the oil quality on only one or two parameters but on a combination of more parameters.

Keywords

Transformer oil, partial discharges, diagnostic tools, breakdown voltage, dielectric strength

Introduction

Transformer oil is a very important component of a transformer. It must have good thermal and insulating properties [1]. The insulating oil is used for providing insulation between the live parts of the transformer and the grounded parts as well as for carrying out the heat from the transformer to the atmosphere [2]. Faults in transformers are rare (1%-2% per year in power transmission and distribution systems), but they can be very costly in terms of economic and technical consequences. Faults can due, among others, to lightning and switching overvoltages, insulation failure, humidity, foreign particles and bad maintenance. The latter is a significant factor for the lifetime of a transformer [3], [4]. The main factors which may accelerate the ageing of the oil are humidity, temperature variations, oxidation and foreign particles. Various factors affecting the breakdown strength of transformer oils have been discussed and analyzed [5], [6]. There is no single measurement which can deliver enough information as to the ageing and/or deterioration of transformer oil, mainly because transformer insulation is a dynamic system, in which e.g. humidity may migrate from the oil to paper insulation and from paper insulation back to the oil [3], [7]. With this in mind, a variety of diagnostic methods were employed in order to study the state of fifty transformers of 150/20 kV. The whole work was carried out with the aid of the Public Power Corporation (PPC) Transformer Division in Athens, Greece. The fifty investigated transformers were from the major Athens area.

Diagnostic Methods

Warning signs about the state of a transformer are, among others, a big increase of partial discharges (>> 2500 pC), a visible deterioration because of foreign metallic and carbon particles, the presence of humidity in the solid insulation about 3-4% and the presence of sludge. The latter is the last visible state of deterioration. Experience indicates that the breakdown behavior and breakdown voltage are determined much more from the above mentioned factors than that of pure insulating liquids [4], [8], [9].

Several diagnostic methods were used in order to see the quality of the transformers in question. The characterization of the oil color (DIN 51517 – ASTM 155) was performed through a device (chromometer) including standard glass disks and two glass jars with lid. The control of breakdown voltage was measured by a typical Foster test cell, according to IEC 156/95 (Fig. 1).

The control of humidity in the oil was measured by a Metrohm – 684 KF Coulometer, which consisted of a glass container with a stirrer titration in which the reagent from container storage is added.

Fig. 1: The test cell for breakdown voltage measurements

The device is fully automated and once the experimenter gives the settings, it measures the moisture content of the oil. The measurements were performed according to IEC 814. The control of interfacial tension (ASTM D971 – 91) was performed via a tensimeter, which gives the value in dynes per centimeter in a direct reading.

The device that performed measurements of tanδ and of resistivity, is the BAUR-DTL fully automated device for measuring dielectric losses of oils. Such a system has a fully automated process for measuring dielectric loss, relative dielectric constant and resistivity (Fig. 2). The measurements were performed according to IEC 247. The density of oil was performed according to DIN 51517, with the aid of a pipe of 250 ml, an electronic thermometer and a glass cylinder.

Fig.2: Device for measurement of tanδ and resistivity

It is true that no single diagnostic method can give full information as to the state of the transformer oil. The aforementioned methods may give a better picture of its state.

Results

The sampling was done according to specification ASTM D 923. Sampling should take place in clean conditions (absence of humidity and pollution), suitable glass vessels should be used and the latter should be kept clean and hermetically closed. Every sample should be kept away from light according to VDE 0370/ 9.61. Every sample should be taken while the oil is warm.

In Tab. 1 a classification of values of the various investigated parameters of insulating oil is given. An oil can be classified as good, acceptable or bad according to Tab. 1 [10].

Tab. 1: Classification of insulating oils

Oil Parameters	Good	Acceptable	Poor
Color	< 2	—	> 2
Breakdown Voltage (kV)	> 40	30 — 40	< 30
Humidity [ppm]	< 10	10 — 25	> 25
Interfacial Tension (mN/m)	> 28	22 — 28	< 22
tanδ	< 0.1	0.1 — 0.5	> 0.5
Resistivity (ρ) (GΩ·m)	> 3	0.2 — 3.0	< 0.2

The sampling of oil from the fifty transformers 150/20 kV was done with due care and according to the standard practice. In Figures 3-7, the results of the measurements are shown, regarding tanδ, color, humidity and interfacial tension respectively. Green color symbolizes the good samples, yellow color the acceptable samples whereas the red color shows the bad samples. From Figs. 3 and 4, it is clear that the breakdown voltage and tanδ values of most of the samples are very good. This is due to systematic control of the oil and the good maintenance. Figs. 3 and 4 indicate that these two factors, which are related to ageing and oxidation, are relatively stable.

In Fig. 5, humidity is in relatively acceptable levels. Only a small percentage of the transformers (4%) seems to have high humidity. Most of the samples are within the limits prescribed by the international standards. It must be emphasized that the humidity level is a parameter which changes easily, since the slightest contact of the oil with the atmosphere may change its characteristics. In Figs. 6 and 7 the results regarding the color as well as the interfacial tension are shown.

As time passes by, the oxidation products change the oil color. Most of the samples had a rather acceptable color. Even a color index of 3 does not necessarily consist an objective indication of the oil quality. For this reason, color measurements should in fact be accompanied by other parameter measurements. In fact, although 36% of the samples showed a rather dark color (Fig. 6) other parameter measurements indicated that these samples were good or acceptable. The presence of foreign particles in combination with humidity may reduce the interfacial tension of the oil. In the investigated samples, a percentage of 28% (Fig. 7) is characterized as poor. This, however, is not particularly annoying, if we take into account for these samples also the other parameter measurements.

The density of the investigated oil samples was measured in the generally acceptable values, i.e. between 0.85 and 0.92 gr/ml (with the lowest recorded being 0.85 gr/ml, whereas the highest was 0.91 gr/ml). Although the oil density does not consist per se an individual characteristic of the examined sample, its increase may imply an increase of degradation by-products. In the context of the present work the oil density was used for the calculation of the interfacial tension [11], [12].

It can be said that, in general, the state of the investigated transformer oil samples was more or less satisfactory. In a few cases, there is a need of further filtering and possibly a second sampling it should be carried out. Whereas no transformer functioned with a particularly bad oil, it is true that, with transformer ageing, the oil suffers from solid impurities, free and dissolved water particles and dissolved air. Frequent sampling is necessary in order to ensure the good functioning of such transformers. The results reported here are in line with those published before [11]. Although a statistical approach of the whole subject is desirable (i.e. to try to correlate the data collected here as well as from previous published work with the pre-history of each individual transformer), it is difficult to be realized since the Greek Electricity System has transformers from a variety of manufacturers. This inhomogeneity of suppliers certainly renders the relation between the data collected with the pre-history of transformers very difficult. It also should be noted that with the term "pre-history" we mean the detailed registration of all faults, faulty conditions, lightning strokes, switching overvoltages etc. which have occurred in a transformer. Previous work done in this direction was only partially successful since at that time, pre-history of transformers was only related to one parameter, namely that of breakdown strength [13], [14], [15].

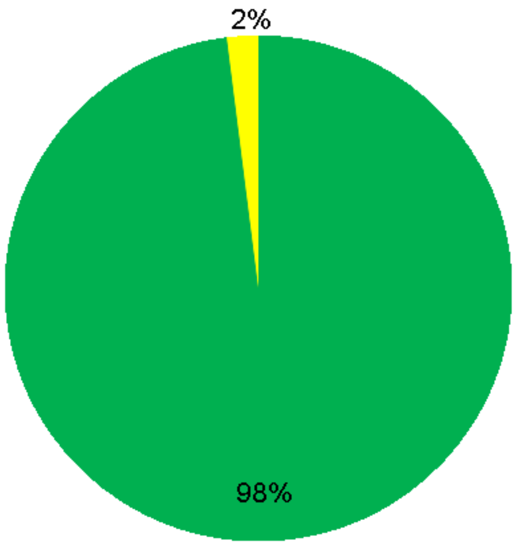

Fig.3: Graph of breakdown voltage results

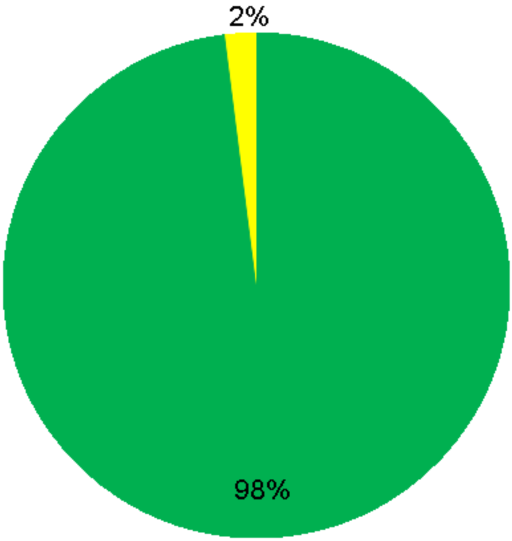

Fig.4: Graph of tanδ results

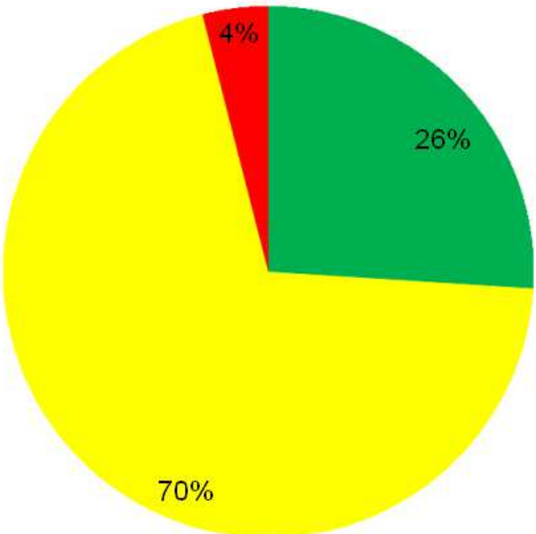

Fig.5: Graph of humidity results

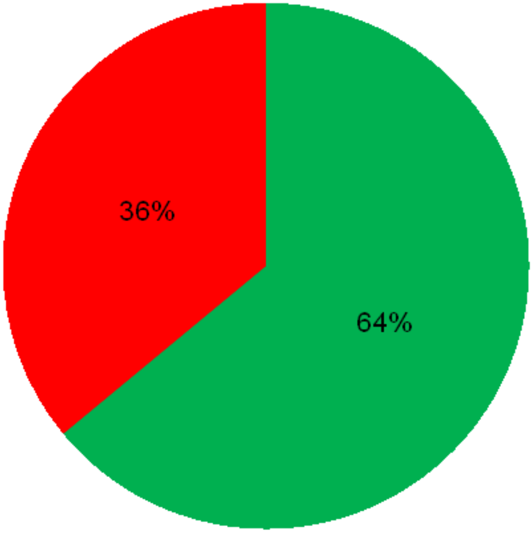

Fig.6: Graph of color results

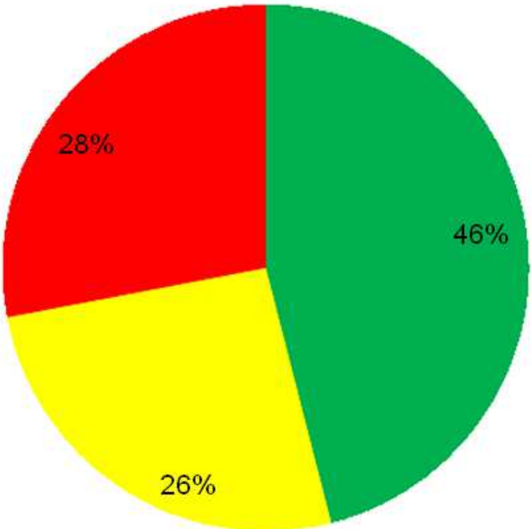

Fig.7: Graph of interfacial tension results

It can be said that this piece of work here does not consist per se an original piece of research. This paper does not claim to have explored new inroads regarding the mechanisms of breakdown of dielectric liquids, as for example in [16], or novel directions regarding new diagnostic methods, as for example in [17]. The whole purpose of this paper is, however, to show that monitoring work is necessary – not to say essential – for the correct maintenance of transformer oil in bigger transformers. An attempt to also relate the present state of transformer oil in the above mentioned transformers with their previous history will follow.

Some Further Remarks

One may ask which from the parameters investigated, are the most important. It is a difficult question to answer. However, if one has to choose between the aforementioned parameters, he would most probably select two of them, namely humidity and breakdown strength. If one looks carefully Fig. 3 (referring to breakdown voltage results) and Fig. 5 (regarding humidity results), one may see that 98% of the investigated transformers had good oil breakdown strength and 96% of the investigated transformers had good or acceptable levels of humidity. This means that Fig. 3 and Fig. 5 are in more or less good agreement. Humidity plays a critical role, since it can contribute to a dramatic lowering of breakdown strength, as was also indicated in some older but nevertheless classical publications [18], [19], [20]. Generally speaking, inclusions of humidity more than about 10 ppm (at normal temperature) cause a lowering of breakdown strength. A low oil breakdown strength may imply that there are foreign particles and/or admixtures in the oil. On the other hand, a high breakdown strength does not necessarily mean that the oil is good. It may be possible that the quantity of foreign particles may not be sufficiently large, so that it can influence the breakdown voltage [21].

The interfacial tension, although it gives an idea of the concentration of oxidation by-products in a transformer oil, is not necessarily an indicator for definite conclusions about the oil under investigation. This is because in warmer periods of the year, the oil temperature increases and humidity may affect the oil more than in cooler periods [22].

Change of the oil color

may mean the existence of by-products or the presence of foreign particles. Although such a change may imply a certain degree of pollution of the oil under investigation, the color by itself may not be considered as a very reliable indicator of the oil quality, as was shown in this paper and was also reported in [23].

Tanδ results (Fig. 4) match very well with Fig. 3 results of breakdown strength. Tanδ changes as the oil degrades. Although tanδ measurements cannot be taken as a sole criterion of oil quality, its results match extremely well with the breakdown strength data, in the context of the present paper. The low value of tanδ depends on the nature of the oil as well as on its processing [22], [24].

A last remark should be made concerning the monitoring of both transformers of 150/20 kV and of distribution transformers (both kinds of transformers in the major Athens area): it seems that the former have a larger percentage of good/acceptable oil than the latter [25]. To validate, however, this point, more work has to be done with transformers of both kinds from the major Athens area.

Conclusion

Insulating oil samples from transformers of 150/20 kV have been investigated. In the context of this work, several parameters – through the appropriate diagnostic techniques – affecting the state and lifetime of transformer oil have been studied. No single parameter can fully describe the state of the oil of a transformer. The variety of parameters investigated here may give a more complete picture. In the context of this work, the majority of the investigated transformer oil samples were found to be good or acceptable. This points out to the further continuing sampling at regular intervals.

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FRONT COVER VIGNETTE

A faded synthesis of an anthemion rooted in a meandros

The thirteen-leaf is a symbol for a life tree leaf.
"Herakles and Kerberos", ca. 530–500 BC,
by Paseas, the Kerberos Painter,
Museum of Fine Arts, Boston.

www.mfa.org/collections/object/plate-153852

The simple meandros is a symbol for eternal immortality.
"Warrior with a phiale", ca. 480–460 BC,
by Berliner Maler,
Museo Archeologico Regionale "Antonio Salinas" di Palermo.

commons.wikimedia.org/wiki/File:Warrior_MAR_Palermo_NI2134.jpg