

- 1 Contents
- 2 About
- 3 Editorial Board – Technical Support
- 4 Information for Peers – Guiding Principles
- # Electrical Engineering - Théorie
- 7 Very Small Partial Discharges and Charging Phenomena
Below Inception Voltage: An Effort for a Review and
a Proposal for a Unified Theory
M. G. Danikas, R. Sarathi



*This small European Journal is
In the Defense of Honesty in Science and Ethics in Engineering*

Publisher – otoiser—open transactions on independent scientific engineering research, www.otoiser.org—info@otoiser.org : Hauptstraße 52, 2831 Scheiblingkirchen, Austria

Language – We emphasize the origins of the Journal by using English, German and French, as well as, a Hellenic vignette in the cover page. However, since we recognize the dominance of US English in the technical literature, we adopted it as the Journal's language, although it is not our native language.

Focus – We consider Radio-FUNK, which still creates a vivid impression of the untouchable, and its Technology-TECHNIK, from an Advanced-PLUS point of view, Plus-PLUS Telecommunications Engineering, Electrical Engineering and Computer Science, that is, we dynamically focus at any related scientific-engineering research regarding Théorie, Expérimentation, Métrologie, Logiciel, ou Applications.

Scope – We emphasize this scope broadness by extending the title of the Journal with a Doppelkreuz-Zeichen # which we use as a placeholder for substitution of our Editorial Team disciplines: # Telecommunications etc. as above, or # High Voltage, # Software Engineering, # Simulation etc. as below.

Frequency – We publish 3 issues per year: on 31st of January, on 31st of May, and on 30th of September, as well as, an extra issue every 3 papers and a volume every 2 years.

Editions – We increase the edition number of an issue only when is needed to reform one or more of its papers—thus to increase their version numbers—but we keep unchanged its 1st edition date shown on its front page and we number its pages sequentially from 1. We count the editions of *About* separately.

Format – We use a fixed-space font, hyphenation, justification, unfixed word spacing, and the uncommon for Journals A5 (half A4) page size to achieve WYSIWYG printing and clear reading of 2 to 4 side-by-side pages on wide-screen displays.

Printing-on-Demand – We can email gratis PDF files at 300-4000 dpi in booklet page scaling of brochure and book type.

Copyright – We publish under a Creative Commons Attribution, CC-BY 3.0 Unported or CC-BY 4.0 International, License only.

Please download the latest *About* edition from
<http://about.ftpj.otoiser.org>

Editorial Team**# Electrical Engineering**

Professor Michael Danikas, mdanikas@ee.duth.gr
EECE, Democritus University of Thrace, Greece

High Voltage Engineering # Insulating Materials

Assistant Professor Athanasios Karlis, akarlis@ee.duth.gr
EECE, Democritus University of Thrace, Greece

Electrical Machines # Renewable Energies # Electric Vehicles**# Computer Science**

Professor Vasilis Katos, vkatos@bournemouth.ac.uk
Head of Computer and Informatics Dept, Bournemouth Univ, UK

Computer Engineering # Software Engineering # Cyber Security

Lecturer Sotirios Kontogiannis, skontog@gmail.com
Business Administration Dept, TEI, Western Macedonia, Greece

Internet Engineering # Learning Management Systems

Dr. Apostolos Syropoulos, asyropoulos@yahoo.com
BSc-Physics, MSc-Computer Science, PhD-Computer Science
Independent Researcher, Xanthi, Greece

Hypercomputation # Fuzzy Computation # Digital Typography**# Telecommunications Engineering**

Dr. Nikolaos Berketis, nberketis@gmail.com
BSc-Mathematics, MSc-Applied Maths, PhD-Applied Mathematics
Independent Researcher, Athens, Greece

Applied EM Electromagnetics # Applied Mathematics

Dr. Nikolitsa Yannopoulou, yin@arg.op4.eu [*]
Diploma Eng-EE, MEng-Telecom-EECE, PhD-Eng-Antennas-EECE
Independent Researcher, Scheiblingkirchen, Austria

Dr. Petros Zimourtopoulos, pez@arg.op4.eu [*]
BSc-Physics, MSc-Radio-Electronics, PhD-Antennas-EE
Independent Researcher, Scheiblingkirchen, Austria

Antennas # Metrology # EM Software # Simulation # Virtual Labs**# Applied EM # Education # FLOSS # Amateur Radio # Electronics***** Copy and Layout Editing, Proof Reading, Issue and Website Management, Paper and About Reprints, Volumes and Web Pages****Technical Support**

Konstantinos Kondylis, kkondylis@gmail.com
Diploma Eng-EECE, MEng-Telecom-EECE, Doha, Qatar
Christos Koutsos, ckoutsos@gmail.com
Diploma Eng-EECE, MEng-Telecom-EECE, Bratislava, SK

Information for Authors

This is a small, but independent, low profile Journal, in which we are all—Authors, Reviewers, Readers, and Editors—free at last to be Peers in Knowledge, without suffering from Journal roles or positions, Professional–Amateur–Academic statuses, or established "impact factorizations", under the following guiding principles:

Authors – We know what Work means, we respect the Work of the Independent Researcher in Science and Engineering and we want to exhibit his Work. Thus, we decided to found this Free and Open Access Journal in which to publish this Work. Furthermore, as we care indeed for the Work of the technical author—especially a young or a beginner one—we strongly support the publication of his Work, as follows:

- 1 We do not demand from the author to transfer his own copyright to us. Instead, we only consider papers resulting from original research work only, and only if the author can assure us that he owns the copyright of his own paper as well as that he submits to the Journal either an original copy or a revised version of his own paper, for possible publication after review—or even for immediate republication, if this paper has already been published after review—but, in any case under a Creative Commons Attribution, CC-BY 3 Unported or CC-BY 4 International, License, only.
- 2 We encourage the author to submit his own paper written just in Basic English plus Technical Terminology.
- 3 We encourage the author even to select a pen name, which may drop it at any time to reveal his identity.
- 4 We encourage the author to submit an accepted for publication paper, which he was forced to decline that publication because it would be based on a review with unacceptable evaluation or derogatory comments.
- 5 We encourage the author to submit any paper that was rejected after a poor, impotent, inadequate, unreasonable, irresponsible, incompetent, or "just ticking" review.
- 6 We encourage the author to submit an unreviewed paper of his own that he uploaded on some Open Access repository.
- 7 We encourage the author to upload his published paper in our Journal to at least one Truly Free Open Repository, e.g. such as <http://viXra.org> and <https://archive.org>.

- 8 We provide the author with the ability to update, at any time, the reference links of his paper.
- 9 We provide the author with a decent, express, peer review process, of up to just 4 weeks, by at least 2, either anonymous or onymous, reviewers.
- 10 We provide the author with the option to choose from 2 review processes: the traditional, anonymous, close one, as well as, a contemporary, onymous, open review in our private mailing list for Peer Discussion.
- 11 Under the Clause 1 : We immediately accept for publication a research paper directly resulting from a Project Report, or a Diploma-, Master-, or PhD-thesis, which already the author has successfully defended before a committee of experts, as long as he can mention 2 members of this committee who approved his Work.
- 12 Under the Clause 1 : We immediately accept for publication any paper which is not Openly Accessible on the Internet.
- 13 We immediately publish online a paper, as soon as it is accepted for publication in the Journal.
- 14 We quickly publish an extra issue—that is in excess of the 3 issues we publish a year—as soon as the review process of 3 papers is completed.

Reviewers – Every peer may voluntarily become a reviewer of the Journal in his skillfulness for as long as he wishes. In addition, each author of the Journal must review one paper in his expertness for each one of his published papers.

Readers – Every reader is a potential post-reviewer: we welcome comments and post-reviews in our private mailing list for Peer Discussion.

Editors – Every editor owns a PhD degree—to objectively prove that he really has the working experience of passing through the dominant publishing system. An editor pre-reviews a paper in order to check its compliance to our guiding principles and to select the appropriate reviewers of it. We can accept for consideration papers only in the expertise areas currently shown in the Editorial Team page, above. However, since we are very willing to amplify and extend the Scope of the Journal, we welcome the volunteer expert, in any related subject, who wants to join the Editorial Team as long as he unreservedly accepts our guiding principles.

Electronic Publishing

We regularly use the Free Libre Open Source Software Libre Office with the Free Liberation Mono font and the Freewares PDFCreator and PDF-Xchange Viewer. We also use, with some basic html code of ours: the Free Open Source Software Open Journal System OJS by the Public Knowledge Project PKP installed in our website, and the Free Open Digital Library of Internet Archive website, where we upload the FTP#J Collection of Issues, Paper reprints, *About* documents, and Volumes, in both portrait and landscape orientations, for download or very clear online reading with the Free Open Source BookReader.

Submissions

We can only consider papers written in the preferable and recommended odt format of LibreOffice, or even a paper in the MS Office with MathType doc format, if it would be proved that it is fully compatible with LibreOffice indeed.

Legal Notice – It is taken for granted that the submitter–correspondent author accepts, without any reservation, the totality of our publication conditions as they are analytically detailed here, in this *About*, as well as, that he also carries, in the case of a paper by multiple authors, the independent will of each one of his co-authors to unreservedly accept all the aforementioned conditions for their paper.

Internet Addresses

Submissions : sub@ftpj.otoiser.org
Send Updates : updates@ftpj.otoiser.org
Printing-on-Demand : pod@ftpj.otoiser.org
Technical Support TS : technical-support@ftpj.otoiser.org
Principal Contact : principal-contact@ftpj.otoiser.org
Peer Discussion List : www.peers.ftpj.otoiser.org
Editorial Team & TS List : www.etts.ftpj.otoiser.org
The FTP#J Collection at Internet Archive Digital Library :
<https://archive.org/details/@funktechnikplusjournal>
Sample Paper Templates : www.template.ftpj.otoiser.org
Reference Link Updates : www.updates.ftpj.otoiser.org
Internet Publishing : www.ftpj.otoiser.org

This document is licensed under a Creative Commons Attribution 4.0 International License – <https://creativecommons.org/licenses/by/4.0>

Very Small Partial Discharges and Charging Phenomena Below Inception Voltage: An Effort for a Review and a Proposal for a Unified Theory

M. G. Danikas, R. Sarathi

Democritus University of Thrace, School of Engineering,
Department of Electrical and Computer Engineering,
Power Systems Laboratory, 67100 Xanthi, Greece [1]

Department of Electrical Engineering, High Voltage
Laboratory, Indian Institute of Technology Madras,
Chennai, India [2]

Abstract

In this paper a review is presented regarding the very small partial discharges and their possible influence on insulation degradation is discussed. Moreover, very small discharges are discussed in relation to possible charging phenomena observed below the so-called inception voltage. Thus the question of whether there is a danger of potential damage to insulation from charging phenomena below inception voltage is posed and discussed. Furthermore, an attempt is being made in order to present a unified theory regarding the charging phenomena below the inception voltage, PD and electrical treeing.

Keywords

Partial discharges, charging phenomena, streamer discharge, Townsend discharge, glow discharge, polythene, polyethylene, epoxy resin, chemical byproducts, insulation voids, insulation cavities, electrical treeing (the terms "insulation voids" and "insulation cavities" are used in the context of the present paper interchangeably)

Introduction

Many years ago, Bruning and colleagues published some papers questioning the valid-

ity of the statement that "below the inception voltage the insulation life is practically infinite", in other

words they questioned the "truth" that either very small partial discharges (PD) do not cause any appreciable insulation damage or that "below inception nothing of significance happens" [1 - 11]. It is true that, no matter how possibly interesting the research by Bruning and colleagues was, they just indicated that there may be charging phenomena below inception that may affect the insulation. They did not, however, prove anything since the number of their experiments was limited and they experimented only with certain insulating materials.

In this - not thorough as the title of this paper emphasizes - review, we will try to substantiate our view that there may be phenomena - called charging phenomena - worth studying below inception and/or that very small PD are not necessarily innocuous. We will search past literature and we will try to indicate that such ideas were not that foreign to researchers of previous generations. It was, however, Bruning and colleagues that insisted on this line of research.

Partial discharges - Some comments

Many decades ago, Mason reported that in many labora-

tory tests, the PD intensity decreased to a low magnitude after a few minutes at twice the inception voltage. During the next hour, the PD recovered its original magnitude and it was then stable until the discharge intensity increased and became unstable [12]. In polyethylene samples, deposits of brown opaque resin were found in addition to some transparent resin. In yet another paper, the same author claimed that the time to breakdown depends on the local stress concentration in relation to the intrinsic strength, the discharge energy, the discharge repetition rate and the specimen thickness. He observed that in thin specimens the average breakdown stress approaches the intrinsic strength, so that the field at the end of PD channels is much less divergent than it would be for thicker specimens [13]. This is because there is less necessity for reconcentration of electric stress after initial penetration. This explains why in industrial electric strength test, partial breakdown channels are often detected in thick specimens, where the average breakdown strength is less than one-tenth of the intrinsic value, but in thin specimens there is either no observable damage or complete breakdown. The above can be

combined with later work, where it was noted that thicker specimens require a higher sensitivity of PD detector [14]. Questions as to how the above can relate to pitting PD parameters remain to be studied. It seems, however, that - with regard to pitting - PD energy is more important as a PD parameter. Conforming with the above, later work indicated that - working with polyethylene - "oxalic acid crystals are formed on the surface of the voids and these tend to concentrate the discharge energy into eroded pits" [15]. This suggests that the aforementioned formation is a prerequisite for pitting PD.

Further confirmation of the above came in a later paper, where the researchers working with polythene samples observed that the main chemical changes occurring in the insulation when exposed to PD were crosslinking, increase in unsaturation and hydrogen evolution. The rate of chemical change depends on the total PD energy and the concentration of the end products [16]. Later work on artificial voids showed that PD generally decrease in magnitude and repetition rate with time and that such a decrease occurs because of a voltage decrease on the side wall due to the decline of

the side wall resistance in the cylindrical void. The decrease with time is due to the discharging area which becomes narrow because of the development of low resistance in the inner void surfaces [17]. In their explanation and approach the authors of [17] were not that different from the researcher of [12, 13]. The chemical byproducts that are produced on the void walls because of the PD and their influence in turn on the further development of the PD was the subject of [17] as well as of other publications [18, 19]. The interplay between void pressure, weakly conducting layers on the inner void walls as well as void dimensions, was shown in [20, 21], where there was also mention of the role of the charges trapped on the surface of the inner void walls, affecting thus the extinction voltage.

The question of innocuous PD

Kelen [22] suggested that there is probably no safe threshold below which PD would be completely innocuous. Where insulation is subjected to heavy electrical stresses - as in cables and capacitors - the tendency is to avoid PD. In rotating machines and to some degree in transformer engineering there

is a greater tendency to accept the presence of PD during service. It is evident that generalizations of the type "innocuous below x pC" etc. have no particular meaning and that each case should be treated separately. Kelen distinguishes Townsend, streamer or space charge enhanced single avalanche type PD for the case of gas discharges against dielectric surfaces. Streamer discharge consists of the formation of a plasma channel from the inflow of electrons from secondary avalanches initiated in the gas near the head of the primary avalanche. The same author [23] went a step further by pointing out that if electrons penetrate beneath the insulation surface, the next PD of opposite polarity at the same site leaves a positive charge owing to deposition of positive ions or extraction of electrons. A double layer of opposed charges is thus formed. If the resulting field intensity exceeds the local breakdown strength of the surface layer, local breakdowns may occur and produce microscopic channels in the surface layer. The whole idea - as proposed by Kelen leads us to suggest that there is a relation of the above mechanism to the mechanism of pitting discharges.

Laurent and co-workers

[24] noted that there is a period when PD activity is low or even very low. PD are related to micro-channels developing from a cavity. This is a crucial observation since it has also been noticed by Mason [12], Kreuger [18] and Omal el Gendy [25]. It has also been noticed in a more recent publication [26] and also by Ashcraft and co-workers [27]. The authors of [24] distinguish several phases in the PD characteristics of electrical trees: a) the number of detected PD increases during the initial ageing, b) a decrease in PD number related to the appearance of a different kind of filament and c) a sudden increase of PD magnitude and number as soon as the filament reaches the ground electrode. In another more recent paper, the same authors [28] noted that current pulses during transition to electrical treeing had magnitudes with typical values between 0.04 pC and 0.1 pC with the PD magnitude increasing with the increasing tree length. Such small magnitudes may also go undetected.

A similar behavior is observed in artificial voids, as the decrease of PD number occurs simultaneously with the concentration of the PD near the void walls [29]. In yet another paper [30], it was

noted that typical PD pulse shapes for streamer, Townsend and pitting discharges are given. These mechanisms are related to three distinct ageing stages. Morshuis and Gulski pointed out that the consecutive stages in the PD patterns are not random but the result of physical changes induced by the ageing process. According to data presented, pitting discharges seem to be pulsive discharges [29, 31]. If we remember the disagreement between some researchers, as to the nature of the very small discharges (pulsive or pulseless) one realizes how important the fast time-resolved measurements are [32 - 34].

In yet another paper, Morshuis [35] noted that after several hours of PD activity, discharges with high repetition rate were observed. At that point in time, the increased conductivity of the void surface, combined with a field intensification at clusters of acid crystals result in a new discharge stage. Due to the spreading of the charge over the conductive surface, the voltage across the void very rapidly recovers after a discharge has occurred. This - in combination with the field intensification - leads to a high discharge repetition rate concentrated at specific loca-

tions of the void. The result is the start of severe degradation recognizable in the growth of pits. The PD level is very low because of the small area participating in the process. Such observations are in agreement with experimental data presented earlier, where work on polyethylene samples with well defined voids showed that there are occasions where failure of insulation may occur after many hundreds of hours of relative PD inactivity [36].

Low or very low PD activity has been noted by Tanaka [37], even smaller than 1 pC. Swarming micro-partial discharges (SWMPD) assume the consumption of oxygen in the cavity. They will generate pits rather than erode uniformly and will lead to the formation of electrical trees. There is a similarity between the observations of [35] and [37], the difference being in terminology. SWMPD (or Swarming Pulsive Micro-Discharges - SPMD) are apt to be missed from detection by conventional PD detectors and probably were misunderstood to be as self-extinction [38]. In fact, as was noted in [38], oxalic acid, nitric acid and related substances make the dielectric wall conductive. Such products can be dissociated by PD itself or active

species formed by PD. Kahle [39] indicated also that the appearance of very small PD (in the order of 10^{-12} C or even smaller) is possible. Such PD are very difficult to be measured. They can, however, be responsible for some ageing effects according to [39].

There is always a question - posed in [24] - whether the PD localization is caused by the material structure or whether it is the localization phenomenon which creates a weak point in the structure. The approach of [24] goes in parallel with previously published work by Shibuya and co-workers [40], where it was noted that a tree may start from a tiny void, where the phenomenon takes place during the induction period, i.e. the interval between voltage application and the inception of the tree. Neither physical changes nor discharge pulses have been observed so far during this period. The logical following from the above is that if microscopic voids or cracks are present, they can grow due to the deterioration of the insulation produced by high energy electrons accelerated in the cavities, even without ionizing discharges. The question here is whether there is a relation between the high energy accelerated

electrons and the pitting discharges. Related to this question is the statement by Okamoto and co-workers, namely that degraded cavities may not differ from new ones and also Bartnikas' approach as to whether it is quite conceivable that in some cavities, the PD may disappear after a certain time and the ensuing breakdown would have little relation to the PD intensity initially observed at the beginning of the test [41 - 43]. Such views - albeit somehow differently - were also expressed in [29, 30]. Related to the above are also views published in [44], where the author claimed that an electric field produced at a stress concentration is sufficiently large in order to initiate PD in micrometer or sub-micrometer sized cavities located near the tip. The magnitude of the PD would be too small to be measured. Needless to say that the breakdown in a cavity requires initiating electrons for the PD. Such PD may well be related to pitting. Relations as to PD and the smallest cavity size and to Paschen's curve and the streamer criterion were investigated many years ago. It has been shown that a high electric field can break down cavities smaller than 0.01 mm according to Paschen's law [45]. Moreover, according to

[46], electrical trees have been found to be proportional to the cavity diameter of 1 to 30 μm . Others reported that the estimated distance within which injected electrons can interact with material to produce trees near a tip of a needle is $< 20 \mu\text{m}$ [47]. Furthermore, if one bears in mind that the mean free path in air for ambient pressure and temperature is $\sim 0.1 \mu\text{m}$, which implies that cavity size below this dimension would be unable to initiate a PD, one has to conclude that the general criterion for the cavity diameter below which Townsend PD can be considered innocuous should be based on the $0.1 \mu\text{m}$ limit [39, 48].

B. Florkowska experimenting with epoxy/mica insulation, noted that the dielectric conductivity γ_s increases after a PD action in the air up to about 10^{-9} S . The said insulation was subjected to both electrical and thermal stresses simultaneously. After stressing of more than 200 hours, it was observed an increase of the repetition rate of PD and a decrease of their magnitude. The value of extinction voltage in the void is then only slightly lower than that of the inception voltage whereas in the initial stage, it was much lower than the inception

voltage [49]. Such observations are valuable and can be related to previous publications [42]. The nature of the void plays presumably a vital role in determining the sequence of PD mechanisms. This is evident in the work by Kuttil and Froehlich [50], where the order of the appearance of the PD phenomena is not the same as in other papers. The authors used a slit instead of a spherical void. Low magnitude PD were firstly observed because the electric field inside the slit can only be compensated to a small extent according to the number of involved electrons and ions. Then there is a transition from Townsend to high magnitude (streamer) PD. A consequence of the continuous PD activity will be a high number of charge carriers to be accumulated in the slit walls. The wall conductivity becomes so high so that only surface current remains without pulsating PD. This may explain the observed breakdown after several minutes, if a significant ageing of the material also by the surface current is assumed. The "reverse" order of PD phenomena noted in [50], is due to the wall conductivity causing a superposition of pulsating PD and a surface current on the void walls. There are perhaps non-pulsating PD but this is due to the

void geometry.

Wall conductivity, void wall roughness are intimately related as was pointed out in [51], where it was shown that void roughness promotes the change of normal PD into SPMD, probably due to the increased supply of the initial electrons with the enhanced local field at the surface protrusions. SPMD were also noticed in an older publication [52], where it was reported that such small PD may go unnoticed by conventional PD detectors even though the material degradation continues. Such research is also related to the work of other researchers, who characterized the degradation of the polymer by broken chains - tending to gather in thin bubbles called "nodules" - by the growing of such "nodules" and also by morphological modifications of the large "nodules". The nodules tend to crystallize forming thus "clusters", which in turn enhance the electrical field. Bulk degradation similar to electrical trees start from such clusters [53]. The approach in [53] strongly reminds a similar earlier proposal based on the following cumulative model [54]: since defects exist in all insulating materials, at the initial stages of field stressing charge carriers of low energies can ex-

tend pre-existing defects and increase their density, so that clusters of interacting defects will take place. Such charge carriers can acquire higher energies from the applied field within these clusters because of longer "free paths". The clusters will grow into macroscopic defects in the direction of the applied field. As the process goes on, the density of charge carriers and their "free paths" will increase (and also the energies available to them) until the macroscopic defects form a single channel of high probability of continuous conduction between the electrodes. A high current density will follow from this channel leading to thermal destruction of the insulation. Related to [54] is also an earlier view, according to which tree initiation begins at a surface where field enhancement occurs due to macroscopic irregularities in the dielectric, pointed electrodes and surface charge concentrations [55].

Reference to PD which may cease completely for fairly long periods and to PD impulses that may occur in the form of "discharge packets" was made in [56], where it was pointed out that the structural strength of casting in the case of epoxy

resin is of paramount importance as well as the boundary layer between the filler and the resin matrix. Such views are not far off from some aspects of the work mentioned above [35]. The question as to whether PD in the order of 0.1 pC can be damaging for an insulation - consisted of polyethylene sheets having an artificial cavity - was raised more recently, where the resistivity of the inner cavity walls was at first infinite and at the end of the experiments was measured to be $600 - 900 \times 10^6 \Omega$ [57].

Charging phenomena in insulating materials even below the inception voltage

The previous cited publications substantiate the thought that it is difficult to envisage the existence of innocuous discharges. In fact, very small magnitude PD seem to play a role in the degradation of insulating systems as was indicated in [58]. Moreover, as was reported several years ago, extremely small signals corresponding to currents as small as 66 nA and charges as minute as 1.2 fC were measured [59, 60]. As was rightly noted, the detection of signals in the fC range demonstrated that "something" happens even in the absence of true partial discharges [61]. Publications

[59, 60] showed that signals could be measured without PD whereas publications [1, 2] indicated that chemical changes could result without PD activity. In a certain sense [1, 2] and [59, 60] were complementary parts of research. Tanaka also discussed the phenomena of pre-discharging, emphasizing the role of space charges, electric field enhancement and finally electrical tree initiation [62], as well as the "non-destructive current pulses" that may initiate tree formation [63]. Pre-PD signals were recorded in [61], many minutes prior to the visual appearance of an electrical tree. Such views were reinforced by later work from the same researchers, where it was reported that signals detected may precede partial discharges [64].

Several years ago, the notion of charge packets, i.e. of discrete pulse or charge generation in contradistinction to continuous charge generation, was reviewed [65]. According to [65], a deeper understanding of electrode-polymer interface is needed. The author speculated as to the possibility of aging effects as the charge packets move. On the other hand, gas conductivity inside a cavity is also vital as was shown in [1, 2, 5]. That was confirmed in [66], where it was re-

ported that in minute cavities, PD may have very long statistical time lag and the number of initial electrons may indeed be very small. In low voltages, ionization processes of low energy may occur, which means that charges appearing in the cavity may result in clusters of space charges on the cavity walls. These space charges result in an additional electric field to the insulation together with the applied electric field [67]. In [66], it was also remarked that the number of initial electrons prior to the first discharge in a cavity may depend on its dimensions and, therefore, may be very small if the cavity is in the order of micrometers. This is in accordance with [39, 48, 68], where it was indicated that the general criterion for a cavity diameter below which Townsend discharges can be taken as harmless should be based on the 0.1 μm limit. The latter limit is far more restrictive than the one based on the streamer criterion, where a cavity diameter larger than 0.4 mm is needed for a streamer discharge [68, 69].

Considering another point of view, it can be remarked that having an enclosed cavity in polyethylene, a conducting path may ensue with currents in the range of 1-10

mA [3], a range that is significantly lower than current pulses of about 1 A measured with other more conventional experimental arrangements [70]. Consequently, there are approaches that suggest the possibility of very small currents (or small charge displacements) inside a dielectric that cause events that may go undetected and still be able to cause damage. As was mentioned before, "the discussion of the pulsive or non-pulsive nature of partial discharge phenomena at and/or above inception voltage is shifted to a more fundamental question whether charge movement inside the dielectric causes deterioration, even below the inception voltage" [11, 71].

From the above approaches, a general picture may emerge as to the charging phenomena below the inception voltage, PD and electrical treeing. A picture that may take into account Bruning's and co-workers' research [1 - 10], Tanaka's theory of charge injection and extraction on tree initiation [47, 72, 73], Dis-sado's and co-workers' work on charge packets [65, 74], Bernstein's and co-workers' experimental work on TR-XLPE insulation [61, 64] as well as Zeller's and co-workers' research on pre-treeing events [75, 76]. Needless to empha-

size that all the above mentioned research - which refers to phenomena below inception voltage - requires the full use of all available diagnostics, both electrical and non-electrical [77, 78]. It also goes without say that PD detection and related equipment sensitivity regarding PD registration above inception as well as charging phenomena below inception is of vital importance for the correct recording [18, 32, 77, 79 - 84]. Such a general picture may as well include older research, according to which there is a transition of pulse-type discharges to pulseless discharges, which in turn do not minimize the danger for the insulation [85, 86]. It may also include more recent work which indicated that in enclosed cavities in epoxy resin samples, a fast reduction of the pressure inside the cavity relates well with a short expected lifetime of the sample, whereas a slow reduction of the pressure means a longer lifetime [87]. Moreover, with further experimental work, it was remarked that the speed of ageing of an insulation is de-

termined by the total sum of the various types of PD. It was observed, that the current that is due to PD decreases with time, whereas, the light emission from the PD remains constant. It is probable that part of the PD changes to PD of extremely small magnitudes or to glow-PD and, consequently, their detection is very difficult or even impossible with conventional detecting systems [87 - 89].

Conclusion

In the present paper, past work has been reviewed regarding the very small PD as well as charging phenomena below the so-called inception voltage. There are indications that even very small PD may start damaging the insulation. Charging phenomena below inception seem to be not that harmless. An attempt is being made as to combine theories and experimental results into a unified approach. Needless to say that the sensitivity of PD detecting equipment is of paramount importance in studying phenomena above and below inception voltage.

References

- [1] Bruning A. M., Kasture D. G., Campbell F. G., Turner, N. H., "Effect of cavity sub-corona current on polymer insulation life", IEEE Transactions on Electrical Insulation, Vol. 26, No. 4, 1991, pp. 826 - 836
- [2] Bruning A. M., "Design of electrical insulation systems", Ph.D. Dissertation, University of Missouri, Columbia, USA, May 1984
- [3] Bruning A. M., Danikas M. G., "Observations on discharges above and below CIV in polymer insulation", Annual Report on Conference of Electrical Insulation and Dielectric Phenomena (CEIDP), 20-23 October, 1991, Knoxville, Tennessee, USA, pp. 638 - 647
- [4] Turner N. H., Campbell F. G., Bruning A. M., Kasture D. G., "Surface chemical changes of polymer cavities with currents above and below corona inception voltage", Annual Report on Conference of Electrical Insulation and Dielectric Phenomena (CEIDP), 18-21 October, Victoria, B.C., Canada, 1992, pp. 687 - 693
- [5] Danikas M. G., Bruning A. M., "Comparison of several theoretical sub-corona to corona transition relations with recent experimental results", Conference record of the IEEE International Symposium record of the IEEE International Symposium on Electrical Insulation, 7-10 June, Baltimore, USA, 1992, pp. 383 - 388
- [6] Bruning A. M., Danikas M. G., "Report on continuing work on parallel and nonparallel electric field chemical aging of polymer cavities", Proceedings of the 4th International Conference on Conduction and Breakdown in Solid Dielectrics, 22-25 June, Sestri Levante, Italy, 1992, pp. 241 - 245
- [7] Danikas M. G., Pitsa D., "Detection and registration of partial discharge events below the so-called inception voltage: The case of small air gaps", Journal of Electrical Engineering, Vol. 59, No. 3, 2008 pp. 160 - 164
- [8] Danikas M. G., Zhao X., Cheng Y.-H., "Experimental data on epoxy resin samples: Small partial discharges at inception voltage and some thoughts on the existence of charging phenomena below inception voltage", Journal of Electrical Engineering, Vol. 62, No. 5, 2011, pp. 292 - 296

- [9] Danikas M. G., Vardakis G. E., Sarathi R., "Space charges as pre-breakdown phenomena in solid dielectrics: A concise approach and some critical comments", *Engineering, Technology & Applied Science Research*, Vol. 10, No. 4, 2020, pp. 5992 - 5997
- [10] Zhang Y., Danikas M. G., Zhao X., Cheng Y.-H. "Charging phenomena below the inception voltage: Effects of nano-fillers on epoxy", *Malaysian Polymer Journal*, Vol. 7, No. 2, 2012, pp. 68 - 73
- [11] Vardakis G. E., Danikas M. G., Nterekas A., "Partial discharges in cavities and their connection with dipoles, space charges, and some phenomena below inception voltage", *Engineering, Technology & Applied Science Research*, Vol. 10, No. 4, 2020, pp. 5869 - 5874
- [12] Mason J. H., "The deterioration and breakdown of dielectrics resulting from internal discharges", *Proceedings of IEE*, Vol. 98, Part I, 1951, pp. 44 - 59
- [13] Mason J. H., "Breakdown of solid dielectrics in divergent fields", *Proceedings of IEE*, Vol. 102, Part C, 1955, pp. 254 - 263
- [14] Danikas M. G., "Some possible new applications of a partial discharge (PD) model and its relation to PD detection sensitivity", *European Transactions on Electrical Power (ETEP)*, Vol. 6, No. 6, 1996, pp. 445 - 448
- [15] Reynolds S. I., "On the behavior of natural and artificial voids in insulation under internal discharges", *AIEE Transactions on Power, Apparatus and Systems*, Vol. PAS-77, Part III, 1959, pp. 1604 - 1608
- [16] Meats R. J., Stannett A. W., "Degradation of insulation materials by electrical discharges", *IEEE Transactions on Power, Apparatus and Systems*, Vol. PAS-83, 1964, pp. 49 - 54
- [17] Tanaka T., Ikeda Y., "Internal discharges in polyethylene with an artificial void", *IEEE Transactions on Power, Apparatus and Systems*, Vol. PAS-90, No. 4-6, 1971, pp. 2692 - 2702
- [18] Kreuger F. H., "Discharge detection in high voltage equipment", *Eds. Heywood London, UK*, 1964, pp. 105 - 125
- [19] Kreuger F. H., "Industrial high voltage (Electric fields, Dielectrics, Construction)", *Eds. Delft University Press, Delft, The Netherlands*, 1991, pp. 123 - 131
- [20] Selvakumar S., Nema R. S., "Low pressure discharges in narrow cylindrical voids", *Proceedings of the 3rd International Conference on Dielectrics, Materials, Measurements and Applications*, 10-13 September, 1979, Birmingham, UK, IEE Conference Publication No. 177, pp. 113 - 115
- [21] Stenerhag B., Danemar A., "Partial discharge characteristics of some liquid impregnated systems", *Proceedings of the 3rd International Conference on Dielectrics, Materials, Measurements and Applications*, 10-13 September, 1979, Birmingham, UK, IEE Conference Publication No. 177, pp. 26 - 29
- [22] Kelen A., "Studies on partial discharges on solid dielectrics: A contribution to the discharge resistance testing of insulating materials", *Acta Polytechnica Scandinavica, Monograph with a total of 138 pages, Electrical Engineering Series No. 16*, 1967
- [23] Kelen A., Danikas M. G., "Evidence and presumption in PD diagnostics", *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 2, No. 5, 1995, pp. 780 - 795
- [24] Laurent C., Mayoux C., Sergent A., "Electrical breakdown due to discharges in different types of insulation", *IEEE Transactions on Electrical Insulation*, Vol. 16, No. 1, 1981, pp. 52 - 58
- [25] El Gendy Omal, "Study of the effects of internal discharges on epoxy resins using a scanning electron microscope", *Ph.D. Dissertation, The University of Edinburgh*, 1977
- [26] Danikas M. G., Adamidis G., "Partial discharges in epoxy resin voids and the interpretational possibilities and limitations of Pedersen's model", *Archiv fuer Elektrotechnik*, Vol. 80, No. 2, 1997, pp. 105 - 110
- [27] Ashcraft A. C., Eichhorn R. M., Shaw R. G., "Laboratory studies of treeing in solid dielectrics and voltage stabilization in polyethylene", *Proceedings of the IEEE International Conference on Electrical Insulation*, 14-16 June, Montreal, Canada, 1976, pp. 213 - 218
- [28] Laurent C., Mayoux C., "From initiation to propagation in electric treeing", *Proceedings of International Conference on Partial Discharge*, 28-30 September, Canterbury, UK, 1993, pp. 7 - 8

- [29] Morshuis P. H. F., "Partial discharge mechanisms", Ph.D. Dissertation, Delft University of Technology, The Netherlands, Delft University Press, 1993, ISBN 90-6275-931-9
- [30] Morshuis P. H. F., Gulski E., "Diagnostic tools for condition monitoring of insulating materials", Annual Report of the Conference on Electrical Insulation and Dielectric Phenomena, 22-25 October, Virginia beach, VA, USA, 1995, <https://doi.org/10.1109/CEIDP.1995.483730>
- [31] Gulski E., "Computer-aided recognition of partial discharges using statistical tools", Ph.D. Dissertation, Delft University of Technology, The Netherlands, Delft University Press, 1991, ISBN 90-6275-728-6
- [32] Kreuger F. H., "Industrial High Voltage: Coordinating, Measuring, Testing", Eds. Delft University Press, Delft, The Netherlands, 1992, pp. 151 - 155
- [33] Morshuis P. H. F., "Assessment of dielectric degradation by ultrawide-band PD detection", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 2, No. 5, 1995, pp. 744 - 760
- [34] Danikas M. G., "Fast measurements of partial discharges in polyethylene cavities with the aid of a subdivided electrode arrangement: A study of circuit parameters on the wave-shape of the detected PD currents", Journal of Electrical Engineering, Vol. 51, No. 3-4, 2000, pp. 75 - 80
- [35] Morshuis P. H. F., "Time-resolved discharge measurements", Proceedings of International Conference on Partial Discharge, 28-30 September, Canterbury, UK, 1993, pp. 43 - 46
- [36] Reynders J. P., "Electrical detection of degradation caused by partial discharges in polythene", Proceedings of International Conference on Dielectric Materials, Measurements and Applications, 21-25 July, Cambridge, UK, 1975, pp. 19 - 22
- [37] Tanaka T., "Internal partial discharge and material degradation", IEEE Transactions on Electrical Insulation, Vol. 21, No. 6, 1986, pp. 899 - 905
- [38] Izeki N., "A proposal on mechanism of partial discharge deterioration of organic insulating materials", ETG Fachberichte 16 (Long-term performance of high voltage insulations), Eds. vde-verlag, Berlin-Offenbach, Germany, 1985, pp. 14 - 18
- [39] Kahle M., "Elektrische Isoliertechnik", Eds. VEB-Verlag Technik, Berlin, Germany, 1988, pp. 140 - 158
- [40] Shibuya Y., Zoledziowski S., Calderwood J. H., "Void formation and electrical breakdown in epoxy resin", IEEE Transactions on Power, Apparatus and Systems, Vol. 96, No. 1, 1977, pp. 198 - 206
- [41] Okamoto H., Kanazashi M., Tanaka T., "Deterioration of insulating materials by internal discharge", IEEE Transactions on Power, Apparatus and Systems, Vol. 96, No. 1, 1977, pp. 166 - 177 (and also the discussion by R. Bartnikas of the said paper)
- [42] Bartnikas R., Novak J. P., "On the spark to pseudoglow and glow transition mechanism and discharge detectability", IEEE Transactions on Electrical Insulation, Vol. 27, No. 1, 1992, pp. 3 - 14
- [43] Danikas M. G., Bartnikas R., Novak J. P., "On the spark to pseudoglow and glow transition mechanism and discharge detectability", IEEE Transactions on Electrical Insulation, Vol. 28, No. 3, 1993, pp. 429 - 431 (discussion of [42])
- [44] Densley R. J., "An investigation into the growth of electrical trees in XLPE cable insulation", IEEE Transactions on Electrical Insulation, Vol. 14, No. 3, 1979, pp. 148 - 158
- [45] Danikas M. G., Nelson J. K., "Assessment of deterioration in epoxy/mica machine insulation" (discussion), IEEE Transactions on Electrical Insulation, Vol. 28, No. 2, 1993, pp. 303 - 305
- [46] Billing J. W., Groves D. J., "Treeing in mechanically strained HV cable polymers using conducting polymer electrodes", Proceedings of IEE, Vol. 121, No. 11, 1974, pp. 1451 - 1456
- [47] Tanaka T., Greenwood A., "Effects of charge injection and extraction on tree initiation in polyethylene", IEEE Transactions on Power, Apparatus and Systems, Vol. 97, No. 5, 1978, pp. 1749 - 1759

- [48] Kuffel E., Zaengl W. S., "HV Engineering Fundamentals", Eds. Pergamon Press, Oxford, UK, 1984 pp. 407 - 410 and p. 417
- [49] Florkowska B., "A study of the partial discharge mechanism during the aging of epoxy/mica insulation", Annual Report of 1995 Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), 22-25 October, Virginia Beach, VA, USA, 1995, pp. 331 - 334
- [50] Kutil A., Froehlich K., "Partial discharge phenomena in composite insulation materials", Annual Report of 1995 Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), 22-25 October, Virginia Beach, VA, USA, 1995, pp. 343 - 346
- [51] Ishida T., Mizuno Y., Nagao M., Kosaki M., "Computer aided partial discharge analyzing system for detection of swarming pulsive micro-discharges", Proceedings of International Conference on Partial Discharge, 28-30 September, Canterbury, UK, 1993, pp. 99 - 100
- [52] Kitamura Y., Hirabayashi S., "Partial discharge deterioration of epoxy resin for electronic parts", Annual Report of 1985 Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), 20-24 October, Amherst, NY, USA, 1985, pp. 485 - 490
- [53] Dejean H., Dejean P. P. F., Foulon-Belkacemi N., Goldman M., Goldman A., "New electrical method of identification of polymer ageing kinetics", Proceedings of International Conference on Partial Discharge, 28-30 September, Canterbury, UK, 1993, pp. 19 - 20
- [54] Jonscher A. K., lacoste R., "On a cumulative model of dielectric breakdown in solids", IEEE Transactions on Electrical Insulation, Vol. 19, No. 6, 1984, pp. 567 - 577
- [55] Budenstein P., "On the mechanism of dielectric breakdown of solids", IEEE Transactions on Electrical Insulation, Vol. 15, No. 3, 1980, pp. 225 - 240
- [56] Bammert U, Beyer M., "Determination of the partial discharge (PD) behavior of filled epoxy resin and polyethylene in inhomogeneous A.C. field using automatically measured parameters", Proceedings of the 5th International Symposium on High Voltage Engineering, 24-28 August, Braunschweig, Germany, Vol. 2, 1987, paper 41.05
- [57] Danikas M. G., Karlis A. D., "Some observations on the dielectric breakdown and the importance of cavities in insulating materials used for cables and electrical machines", Advances in Electrical and Computer Engineering, Vol. 11, No. 2, 2011, pp. 123 - 126
- [58] Pearmain A. J. Danikas M. G., "A study of the behavior of a uniaxially oriented polyethylene tape/oil insulating system subjected to electrical and thermal stresses", IEEE Transactions on Electrical Insulation, Vol. 22, No. 4, 1987, pp. 373 - 382
- [59] Dorris D. L., Pace M. O., Blalock T. V., Alexeff I., "Current pulses during water treeing detection system", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 3, No. 4, 1996, pp. 515 - 522
- [60] Dorris D. L., Pace M. O., Blalock T. V., Alexeff I., "Current pulses during water treeing procedures and results", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 3, No. 4, 1996, pp. 523 - 528
- [61] Morel O., Srinivas N., Bernstein B., "Partial discharge signals from TR-XLPE insulated cable", Conference Record of the 2004 IEEE International Symposium on Electrical Insulation, 19-22 September, Indianapolis, USA, 2004, pp. 466 - 470
- [62] Tanaka T., "Space charge injected via interfaces and tree initiation in polymers", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 8, No. 5, 2001, pp. 733 - 743
- [63] Okamoto T., Tanaka T., "Detection of non-destructive pulses in polyethylene prior to its dielectric breakdown", IEEE Transactions on Electrical Insulation, Vol. 20, No. 3, 1985, pp. 643 - 645
- [64] Srinivas N., Bernstein B., "Condition assessment of power cable systems in the energized state", Proceedings of JICABLE 07, 24-28 June, Versailles, France, Session C.7.2 "Diagnostic & Maintenance", 2007, Paper No. 16
- [65] Dissado L. A., "The origin and nature of 'charge packets': A short review", Proceedings of the IEEE International Conference on Solid Dielectrics, 4-9 July, Potsdam, Germany, 2010, pp. 641 - 646

- [66] Avinash S., Rajagopala K., "Some aspects of stress distribution and effect of voids having different gases in MV power cables", IOSR Journal of Electrical and Electronics Engineering, vol. 5, No. 6, 2013, pp. 16 - 22, <https://www.slideshare.net/IOSR/b0561622>
- [67] Haque S. M., Rey J. A. A., Umar Y., "Electrical properties of different polymeric materials and their applications: The influence of electric field," in "Polymer Dielectrics: Properties and applications of polymer dielectrics", Rijeka, Croatia, Eds. IntechOpen, 2017, pp. 41 - 63
- [68] Danikas M. G., Tanaka T., "Aging and related phenomena in modern electric Power systems" (discussion), IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 1, No. 2, 1994, pp. 548 - 549
- [69] Danikas M. G., "The definitions used for partial discharge phenomena", IEEE Transactions on Electrical Insulation, Vol. 28, No. 6, 1993, pp. 1075 - 1081
- [70] Danikas M. G., "Some further comments on the fast measurements of partial discharges in polyethylene voids", Proceedings of the 20th Electrical Electronics Insulation Conference, 7-10 October, Boston, MA, USA, 1991, pp. 220 - 224
- [71] Vardakis G. E., Danikas M. G., Achillides Z., "A short review on charge packets and space charge properties inside dielectrics", Engineering, Tehnology & Applied Science Research, Vol. 13, No. 6, 2023, pp. 12211 - 12219
- [72] Tanaka T., Greenwood A., "Advanced power cable technology: Volume I - Basic concepts and testing", Eds. CRC Press Inc., Boca Raton, Florida, USA, 1983, p. 99
- [73] Tanaka T., Greenwood A., "Advanced power cable technology: Volume II - Present and future", Eds. CRC Press Inc., Boca Raton, Florida, USA, 1983, pp. 35 - 51
- [74] Fabiani D., Montanari G.-C., Dissado L. A., Laurent C., Teyssedre T., "Fast and slow charge packets in polymeric materials under DC stress", IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 16, No. 1, 2009, pp. 241 - 250
- [75] Baumann Th., Fruth B., Stucki F., Zeller H. R., "Field enhancement defects in polymeric insulators causing dielectric aging", IEEE Transactions on Electrical Insulation, Vol. 24, No. 6, 1989, pp. 1071 - 1076
- [76] Zeller H. R., "Pre-breakdown in divergent fields", Annual Report of 1990 Conference on Electrical Insulation and Dielectric Phenomena (CEIDP), 28-31 October, Pocono Manor, Pennsylvania, USA, 1990, pp. 457 - 464
- [77] Koenig D., Rao Y. N., "Teilentladungen in Betriebsmitteln der Energietechnik", Eds. Vde-Verlag, Berlin, Germany, 1993, pp. 41 - 62 and pp. 85 - 104
- [78] Muhr M., Schwarz R., "Experience with optical partial discharge detection", Materials Science - Poland, Vol. 27, No. 4/2, 2009, pp. 1139 - 1146
- [79] Bartnikas R., "Effect of pulse rise time on the response of corona detectors", IEEE transactions on Electrical Insulation, Vol. 7, No. 1, 1972, pp. 3 - 8
- [80] Curdts E. B., "Fundamentals of partial discharge detection: System sensitivity and calibration", Engineering Dielectrics Vol. I, Corona Measurements and Interpretation, ASTM Special Technical Publication 669, 1979, pp. 68 - 100
- [81] Mason J. H., "Discharges", IEEE Transactions on Electrical Insulation, Vol. 13, No. 4, 1978, pp. 211 - 238
- [82] Ramachandra B., Nema R. S., "Characterization of partial discharge pulses in artificial voids in polypropylene films used in capacitors", Conference Record of the 1996 IEEE International Symposium on Electrical Insulation, 16-19 June, Montreal, Canada, 1996, pp. 517 - 520
- [83] Florkowski M., Florkowska B., "Phase-resolved rise-time based discrimination of partial discharges", IET generation, Transmission and Distribution, Vol. 3, No. 1, 2009, pp. 115 - 124
- [84] Soomro I. A., Baharom M. N. R., "Comparison between partial discharge in paper and impregnated paper insulators used in power transformer winding based on ultra-high frequency (UHF) detection method", International Journal of Advances in Management, Technology & Engineering Sciences, Vol. II, No. 12 (III), 2013, pp. 13 - 16
- [85] Koenig D., "Impulslose Teilentladungen in Hohlraumen von Epoxyd-harzformstoff Isolierungen", ETZ-A, Vol. 90, 1969, pp. 156 - 158

- [86] Koenig D., "Erfassung von Teilentladungen in Hohlräumen von Epoxyd-harzplatten zur Beurteilung des Alterungsverhaltens bei Wechselspannung", Ph.D. Dissertation, Abteilung der Elektrotechnik, Technische Universität Braunschweig, Germany, 1968
- [87] Gjaerde A.-C., "Multi-factor ageing of epoxy - The combined effect of temperature and partial discharges", Ph.D. Dissertation, Norwegian University of Science and Technology (NTNU), Department of Electrical Power Engineering, Trondheim, Norway, 1994
- [88] Gjaerde A.-C., Sletbak J., "Influence of partial discharges on void gas pressure", Proceedings of International Conference on Partial Discharge, 28-30 September, Canterbury, UK, 1993, pp.119 - 120
- [89] Gjaerde A.-C., "A phenomenological insulation ageing model for combined thermal and electrical stress", Proceedings of Nordic Insulation Symposium (NORD-IS 94), 13-15 June, Vaasa, Finland, 1994, Paper 3.1, pp. 1 - 8

[This Page Intentionally Left Blank]

[This Page Intentionally Left Blank]

In case of any doubt,
download the genuine papers from
genuine.ftpj.otoiser.org

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](https://commons.wikimedia.org/wiki/File:Warrior_MAR_Palermo_NI2134.jpg)

ARG NfP AoI

Antennas Research Group

Not-for-Profit Association of Individuals [*]

www.arg.op4.eu – arg@op4.eu

Hauptstraße 52, 2831 Scheiblingkirchen, Austria

Telephone: 0 6646311483 – International: 0043 6646311483

* The Constitution of Greece, Article 12(3) – 2008:

www.hellenicparliament.gr/en/Vouli-ton-Ellinon/To-Politevma

* The Hellenic Supreme Court of Civil and Penal Law:

www.areiospagos.gr/en – Court Rulings:Civil|A1|511|2008