EXPERIMENT AND SIMULATION INVESTIGATION ON AIR BREAKDOWN IN UNIFORM AND NON-UNIFORM FIELD CONFIGURATION

NURUL NATASHA BINTI NGADIMAN

BACHELOR OF ELECTRICAL ENGINEERING
(INDUSTRIAL POWER)
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

“I hereby declare that I have read this report and in my opinion this project is sufficient in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering (Industrial Power) with Honors”

Signature : ……………………………………………………………..

Supervisor’s Name : Dr Hidayat bin Zainuddin

Date : 1st JUNE 2017

EXPERIMENT AND SIMULATION INVESTIGATION ON AIR BREAKDOWN IN UNIFORM AND NON-UNIFORM FIELD CONFIGURATION

NURUL NATASHA BINTI NGADIMAN

A thesis submitted in fulfillment

of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

"I declare that this report entitled "*Experiment and Simulation Investigation on Air Breakdown in Uniform and Non-Uniform Field Configuration"* is the results of my own research except cited in references. The report has not been accepted for any degree and is not currently submitted in candidate of any degree".

Signature : ………………………………………………

Name : Nurul Natasha bt. Ngadiman

Date : 1st JUNE 2017

Dedicate to my beloved parents and whole of family who always give me support, strength, and encouragement.

ACKNOWLEDGEMENT

First and foremost, I would like to thank Allah whom with His willing gives me the opportunity to complete this Final year Project with successfully before the deadline. Without His permission, I will not be able to reach this stage.

Secondly, I would like to express my appreciation and sincere gratitude to my supervisor, Dr. Hidayat Zainuddin for all this willingness to help me with his conscientious guidance and encouragement that have substantially helped in work. I have greatly benefited from his extensive knowledge and recognized experience in the field of high voltage engineering. It has been a great honour to work with and learn something worthwhile form these amazing people. A big thank you to all the staffs and lecturer in Faculty of Electrical Engineering (FKE), UTeM especially for lecturers from Department of Industrial Power (BEKP) for their useful tips and motivation to finish this study and report on time.

Lastly, I am also greatly thankful to my colleagues for meaningful helps, discussions, and opinions while performing the work in this research. Exceptional gratitude goes to my beloved parents, Hj Ngadiman bin Abd Hamid and Hjh Rosni bin Abdul Manan for their unconditional love and prays while patiently standing beside me along my degree journey. Last but not least, special devotion to my others family members for their endless affection and prays as well as continuous supports and motivations that inspiring my days until the end of the study.

ABSTRACT

This project is concerned with an experiment and simulation investigation on air breakdown in uniform and non-uniform field configuration. An advance improvement in power sector of nation has given a big chance to empower engineers to conserve the power equipment for reliable operation during their operating life. As the high voltage power equipment are mainly subjected with spark over voltage causes by the lightning strokes, a protective device is used to regulate the significant needed for proper insulation level. There are some objectives needed to be achieve in this project. In addition, a series of breakdown strength test was conducted by using AC voltages and the test should be compliance with the required standard, BS EN 60060-1 2010. There are two field configurations used in this study which is plane-plane field configuration with air gap length between 5 until 20 mm and rod-plane field configuration with air gap length between 10 until 50 mm. To determine the AC breakdown voltage, the test voltage is slowly increasing until it reached critical value and breakdown voltage will formed with the validation test of 50 times. 50% disruptive discharge voltage of a test object is used to ensure all measurements are valid according to the standard. U_{50} is prospective voltage value which has a 50 % probability of producing a disruptive discharge on the test object. The value of U_{50} before and after correction, the average, the maximum and minimum value of the field strength along the gap axis, when the breakdown voltage stresses the air gap are recorded and analysed. The results show that the distribution of the field in the gap was affected by the geometry and the arrangement of the gap. For uniform field configurations, as U_{50} was increased, the ability of air to withstand E_{max} (and high stress) was decreased while for non-uniform field configuration, E_{max} was occurred at the tip of the rod which is right on the central longitudinal axis of the rod. It is most likely location where the pre-discharges will occur and followed by air breakdown. The simulation results are compared with relative results of referent work.

ABSTRAK

Projek ini adalah berkaitan dengan siasatan ujikaji dan simulasi voltan jatuhan udara ketika konfigurasi seragam dan tidak seragam. Peningkatan awal dalam sektor tenaga telah memberi peluang besar kepada para jurutera untuk memelihara peralatan kuasa bagi operasi yang boleh dipercayai semasa hayatnya. Peralatan kuasa voltan tinggi tertakluk kepada percikan lebihan voltan disebabkan panahan kilat , maka peranti pelindug digunakan bagi mengawal kesan ketara yang untuk tahap penebat yang betul. Terdapat beberapa objektif yang perlu dicapai dalam projek ini. Di samping itu, satu siri ujian kekuatan telah dijalankan dengan menggunakan voltan AC dan ujian itu haruslah mematuhi standard yang diperlukan iaitu BS EN 60060-1 2010. Terdapat dua konfigurasi medan yang digunakan dalam kajian ini iaitu 'plane to plane' elektrod dengan jurang antara 5 hingga 20 mm dan 'rod to plane' elektrod dengan jurang antara 10 hingga 50 mm. Untuk menentukan AC voltan jatuhan, ujian akan perlahan-lahan meningkat sehingga ia mencapai nilai kritikal dan voltan jatuhan akan terhasil dengan ujian pengesahan daripada 50 kali. 50% pelepasan gangguan voltan objek ujian digunakan untuk memastikan semua ukuran adalah sah mengikut piawaian. U_{50} adalah nilai voltan yang mempunyai kebarangkalian 50% daripada pelepasan gangguan voltan objek ujian. Nilai U_{50} sebelum dan selepas pembetulan, purata, nilai minimum dan maksima kekuatan medan sepanjang paksi direkodkan dan dianalisis. Keputusan menunjukkan bahawa pengagihan bidang dalam jurang terjejas oleh geometri dan susunan jurang. Untuk konfigurasi seragam, apabila U_{50} meningkat, keupayaan E_{max} dalam udara untuk bertahan telah menurun manakala bagi konfigurasi tidak seragam, E_{max} telah berlaku di hujung rod yang tepat pada paksi membujur tengah rod. Ia merupakan lokasi di mana pra-pelepasan akan berlaku dan diikuti oleh voltan udara jatuhan. Keputusan simulasi dibandingkan dengan keputusan relatif kerja rujukan.

Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

AC	Alternating Current
ACB	Air Circuit Breaker
AEM	Analytical Element Method
AIS	Air Insulated Substation
BEM	Boundary Element Method
CSM	Charge Simulation Method
FDM	Finite Difference Method
FEM	Finite Element Method
GIS	Gas Insulated Switchgear
HV	High Voltage
OCB	Oil Circuit Breaker
OT	Operating Terminal
SSM	Surface Charge Simulation Method
SF_6	Sulphur Hexafluoride
$U_{50\%}$	50% of breakdown voltage

LIST OF APPENDIX

CHAPTER 1

INTRODUCTION

1.1 Introduction

An advance improvement in power sector of nation has given a big chance to empower engineers to conserve the power equipment for reliable operation during their operating life. It has been seen that the main problem in high voltage power (HV) equipment is the deterioration of the insulation quality of power equipment. As the high voltage power equipment is mainly subjected with spark over voltage causes by the lightning strokes, a protective device is used to regulate the significant needed for proper insulation level [1]. Air at atmospheric pressure is the most necessary gas used for insulating purposes, it has a unique feature of being universally and immediately available at no cost. Furthermore, air has been recommended as environmentally uncritical insulation media for gas insulated electrical power equipment [2], [3]. The resistivity of air can be considered as infinite under normal conditions when there is no ionization [4]. The breakdown of air is very importance to design engineers of power transmission lines and power apparatus [2].

The electric breakdown strength of an air-insulated gap between different metal electrodes can be enhanced considerably by an experiment. In the past decades ago, a lot of research work have been done to improve the understanding about the fundamental characteristics of the electrical breakdown. Therefore, electrical breakdown characteristic of small air gap under the different applied voltage has its great significance for the design of overhead line, substation equipment and various air insulated high voltage equipment [1]. The electrically live conductors are supported on insulating materials and sufficient air clearances are provided to avoid flashover or short circuits between the live parts of the system and the grounded structures.

The knowledge of electric fields is very basic in numerous high voltage applications. Electric field analysis provides big roles for the development of design and analysis of high voltage equipment, as well as the analysis of various discharge phenomena. The examples of electrode geometries are plane and rod [5]. In order to reproduce the air breakdown voltage has been studied experimentally in high voltage laboratory at Universiti Teknikal Malaysia Melaka (UTeM), brass metal rod of diameter 12 mm and plane of diameter 100 mm are used for measurement of air breakdown voltages and maximum electric field of the high voltage equipment. All the experiments are conducted at the normal temperature and pressure. In addition, the simulation of maximum electric field has been carried out in the COMSOL Multiphysics software. Finally, the experimental results have been compared with theoretical, and simulation results.

1.2 Motivation and Problem Statement

1.2.1 Analytical method

A technique of determining electric field is needed to understand fully behaviour of air under certain electric field profiles. It is difficult to measure properly electric field at all locations between two electrodes. Despite fact the result of experiment test is very accurate and it can validate the simulation results, however in order to conduct each experiment test, a lot of problems will come out especially the equipment needed, cost of maintenance handling and other technical problems. In some electrode geometries, the electric fields can easily be expressed analytically in a closed form solution, but for some cases the electric field problem is complex because of the refined boundary conditions, including media with different permittivity and conductivity [5],[6]. Analytical methods are most choices for simple physical systems as the solving precision and general implementation in most of problems occurred. But, it does not recommended to determine the electric field distributions in the complex arrangements, sometimes in three dimensions [6].

1.2.2 Numerical method

Therefore, to continue this study, it is really recommended to use simulation rather than experiment which is low cost and easy to install. This is because this technique using commercially available electromagnetic software which provides cost effective way and more practical to perform the measurements. Besides, this allows the user to avoid expensive and complex trial-and-error laboratory experiments which are often very difficult to carry out [7]. In order to make comparison between experiment and simulation results, numerical methods are tailored to solve specific problems, usually involving complex geometries where the analytical solution is very complicated or impossible [6]. Although [8] determined the electric field between two spheres by the method of images, numerical simulation techniques, as used by [9], are the preferred method. The comparison between analytical and numerical method as shown in Table 1.1 below.

Table 1.1: The comparison between analytical and numerical method [10].

Analytical Method	Numerical Method
Solve a partial difference equation with initial and boundary conditions.	Replace partial derivative with algebraic equation.
Need solution for each particular problem	One solution can handle multiple problems
Only available for relatively simple problems (homogeneous, simple geometry)	Heterogeneous as well as complex geometry
Example: Analytical Element Method (AEM)	Example: Finite Difference Method (FDM), Finite Element Method (FEM)

The calculation of electrostatic fields requires the solution of Poisson's and Laplace's equations with boundary condition satisfied. There are some numerical techniques that have been used in the literature in for solving Laplace's and Poisson's equations for the fields between complex electrode arrangements. The Poisson equation, widely used in numerical methods, is the main mathematical tool to model the field of the topologies in Fourier series [11]. One of the most successful numerical methods for solving electrostatics field problems is finite element method (FEM). FEM can be employed successfully for the computation of an electric field between electrodes in a medium where one or more dielectrics are involved. The problem solving of the electric field by FEM is based on the fact, known from variation calculus, while Laplace's equation is achieved when the total energy functional is minimal [5].

1.3 Objectives

The objectives of this report are:

1) To determine the air breakdown voltage and maximum electric field in uniform and non-uniform field configurations.

2) To analyse the experiment results statistically for different electrode configuration.

3) To simulate the electric field for different electrodes configurations by using COMSOL Multiphysics software.

4) To compare the results between an experimental testing and simulation method.

1.4 Scope of Works

The scopes of this study are:

1) Tests on air breakdown voltage is carried out to investigate U_{50} and the results are corrected according to the correction factors defined by the standard in BS EN 60060-1 2010 (high-voltage test techniques) to ensure the accuracy of the results are reliable.

2) Gap length between electrode configurations start with 5 mm, 10 mm, 20 mm, 30 mm, 40 mm and 50 mm are used to measure the air breakdown voltage and maximum electric field of high voltage equipment.

3) The simulation of maximum electric field using uniform and non-uniform field configurations (plane-plane and rod-plane electrode configurations) is simulated by using COMSOL Multiphysics software.

CHAPTER 2

LITERATURE REVIEWS

2.1 Introduction

This chapter contains a literature review that related to this research. All information and related theory such as the power system applications, air breakdown mechanism, classical gas laws, estimation and control of electric stress and numerical methods for computation of electric field are studied and discussed in this chapter. Furthermore, the review of previous related works regarding to this research are also discussed. Although many experimental works and tests have been carried out and presented by researchers, there are still gaps that needed to be filled in order to convince the working committee to make comparison of maximum electric field using different electrodes configuration.

2.2 Power System Applications

2.2.1 Circuit breaker application

Air circuit breaker (ACB) has brilliant function as to provide short circuit and overcurrent protection for circuits ranging from 800A to 10,000A. There are two types of air circuit breaker which is air circuit breaker and air blast circuit breaker. ACB has completely replaced by oil circuit breaker (OCB). The use of air circuit breaker is usually used in low voltage applications below 450V while air blast circuit breaker is high capacity breakers and can be used substations above 132kV. Furthermore, the operation between these two circuit breakers are quite different and in different countries, ACB still a preferable choice as there is no chance of oil fire like in OCB [12]. The operation and construction of ACB are easy, simple and inexpensive. Fire hazards will not occur in case of insulation damage of the cabinet as in the case of OCB. The other applications of ACB such as protection of plants, electrical machines and also used for protection of transformers, capacitors and generators [12].

2.2.2 Air- Insulated Substation (AIS) application

AIS uses air as the main dielectric from phase to phase, and phase to ground insulation. AIS also had been used for a long time before the introduction of gas insulated substation (GIS). Furthermore, AIS is more comprehensive use in areas where space, weather conditions and environmental concerns are not a big issue such as rural areas, and favourable terrain [13]. AIS is also an essential choice for areas with a large space, low cost of system constructions and low maintenance as all the equipment is within view. However, due to modern technology and economic nowadays, GIS offers the best choice rather than AIS. For the engineers and technician, the choice between GIS and AIS depends on the pros and cons between these two [13].

2.3 Air Breakdown Mechanism

2.3.1 Collision Processes

There are two types of collisions which are elastic collisions and inelastic collisions. Elastics collisions are collisions when only kinetic energy gets readjusted while there is no change takes place in the internal energy of the particles. When electrons strike with gas molecules, a single electron traces a zig-zag path during its journey. Since electrons are very light in weight, they send only a part of kinetic energy to the much heavier ion or gas molecules with which they collide. Inelastic collisions are those in which internal changes in energy take place within an atom or a molecule at the expense of the total kinetic energy of colliding particle. The structure of the atom depends on the collision results [2].

2.3.2 Townsend's Mechanism

Townsend's mechanism is based upon:

- Ionization collision in the gas
- Ionization collision on the surface of the electrodes
- Photo-ionization

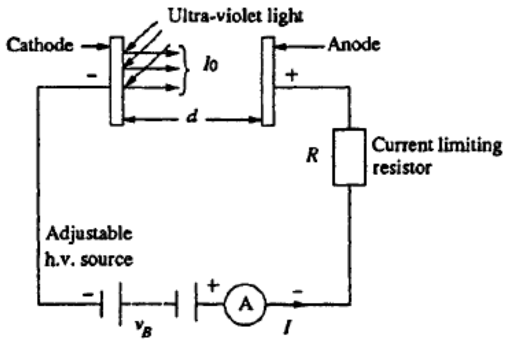

Figure 2.1: Arrangement for study of a Townsend discharge [2].

Figure 2.1 shows the arrangement for Townsend's discharge. Ionization is the way towards an electron from a gas particle with the synchronous generation of a positive particle. In the process of ionization by collision, a free electron collides with a neutral gas particle and offers to another electron and positive ion. Based on Figure 2.8, when there is low pressure column in which an electric field E is applied across two plane parallel electrodes on that point, any electron starting at the cathode will be accelerated among collisions with different gas molecules during its travel towards the anode [2]. Ionization will be happen if the energy (ε) obtained during this travel between collisions higher than the ionization potential, V_i as the process can be represented as below

$$e^- + A \xrightarrow{\varepsilon > V_i} e^- + A^+ + e^- \tag{2.1}$$

where, A is the atom, A^+ is the positive ion and e^- is the electron.

The additional electron, then, themselves make 'ionizing collisions' and thus the process repeats itself. This represents an increase in the electron current, since the number of electrons is reaching the anode per unit time is greater than those liberated at the cathode. In addition, the positive ions also reach the cathode and on bombardment on the cathode give rise to secondary electrons. Figure 2.2 shows the current-voltage relationship based on Townsend theory and have four stages during the process to breakdown [2].

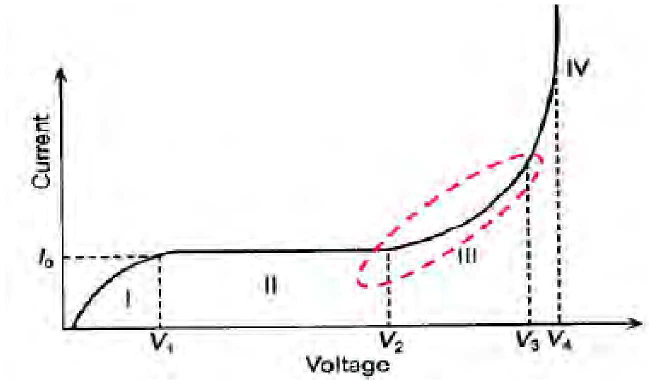

Figure 2.2: The current-voltage relationship based on Townsend Theory [2].

Townsend's mechanism process has several stages to breakdown occur. When the region I, at the low voltage, current increased linearly (not steady) with the voltage up to saturation level (I_O) when all electron available are conducting.

When the region II, the current is almost constant while region III, after V_2, the current rises exponentially. The exponential current to ionization of the gas by electron collision. As the field rises, electrons leaving the cathode are accelerated vigorously between collisions until they get enough energy to cause ionization on collision with gas molecules or atoms [14]. As the gap voltage, V increases in the gap, the electric field, E (E=V/d usually defined in kV/cm or V/cm) increases. Thus, the probability of the ionization increases due to the collision of electron with uncharged particle. The rapid increases of ionization processes in the gap region are called avalanches process.

When the region IV, anode current will be increased sharply. The current magnitude could reach infinity and the value is limited only by the external resistance. Even the current behaviour would not change even if the UV light source is removed and the process is independent. Finally, the gas is to be breakdown [2].

Drawbacks of Townsend Theory

Townsend mechanism explains the breakdown phenomena only at low pressure, corresponding to gas pressure x gap distance (p x d) values of 1000torr-cm and below (1 atm = 760 torr). In