DEVELOPMENT OF A MOSFET BASED ELECTROSTATICS FIELD DETECTION TECHNIQUE

BY

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ABSTRACT

The destructive nature of high voltage has been noticeable for a long time in history. The friction of the object or the electrostatic induction can generate electric charges anywhere at any time, leading to the origination of high voltage electrostatic (HVES) fields. Unexpectedly HVES fields cause damage to buildings, fires in the oil and gas industry, explosions in the ammunition and pyrotechnics industries, and catastrophes in the electronics industry every year. Today's advanced human civilization is mainly dependent on electronic technology. For this reason, early detection and the study of the effects of the HVES field on electronic devices have become imperative from the electronic device manufacturing industries to the user level. Existing systems for HVES field detection, neutralization, and testing systems are not convenient to use, as they are expensive, bulky, and not readily available. To overcome these problems, this research has proposed a modified version of the HVES field detection technique based on the Metal Oxide Semiconductor Field Effect Transistor (MOSFET). The channel conductivity of a MOSFET and the drain current depends on its gate voltage or electric field; this feature has been utilized to develop the proposed HVES field detection system. The proposed system is a low-voltage battery-operated portable non-contract system capable of detecting the HVES field and its polarity. A prototype of the proposed system has been developed on a printed circuit board (PCB), and its effectiveness has been tested experimentally. Experimental results show that the average sensitivity of the device is 0.1 kV/cm, and it is capable of displaying field readings and polarity numerically on an LCD panel. It has been observed that there is a reasonable consensus of experimental and theoretical results. Thus, the proposed design and its results can help researchers advance research in the HVES field detection technology area.

خلاصة البحث

إنّ الطبيعة المدمرة للجهد الكهربائي العالي كان لها أثر ملحوظ خلال فترة طويلة من الزمن. وسبب ذلك أنّ احتكاك الأجسام أو الحث الكهرسكوني يمكن أن يولد شحنات كهربائية في أي مكان وفي أي وقت، الأمر الذي يمكن أن يؤدي إلى نشوء حقول الكهرباء الساكنة عالية الجهد (HVES). وبشكل غير متوقع، تسبب حقول (HVES) أضراراً للمباني، وحرائق في صناعة النفط والغاز، وانفجارات في مخازن الذخائر الحربية والألعاب النارية، وكوارث في صناعة الإلكترونيات في كل عام. والحضارة الإنسانية المتقدمة في عصرنا الحالي تعتمد بشكل كبير على التكنولوجيا الإلكترونية؛ لهذا السبب، أصبح الكشف المبكر عن حقل (HVES) ودراسة آثاره على الأجهزة الإلكترونية أمراً ضرورياً على نطاق واسع، بدءاً من صناعات الأجهزة الإلكترونية وانتهاءً بالمستخدم. من الملاحظ أن الأنظمة الموجودة حالياً بالنسبة للكشف عن حقول (HVES)، والتحييد، والاختبار، ليست ملائمة للاستخدام، كما أنها باهظة الثمن، وضخمة، وغير متاحة بسهولة. وللتغلب على هذه المشاكل، اقترح هذا البحث نسخة معدلة من تقنية الكشف عن حقل (HVES) تعتمد على ترانزستور تأثير المجال المصنوع من أشباه الموصلات وأكسيد المعدن (MOSFET). إنّ موصلية القناة لترانزستور (MOSFET)، وكذلك تيار الصرف، يعتمدان على جهد البوابة أو المجال الكهربائي؛ وقد استخدمت هذه الميزة لتطوير نظام كشف حقل (HVES) المقترح في هذا البحث. والنظام المقترح هو نظام يعمل بالبطارية ذات الجهد المنخفض، وهو نظام محمول لا تلامسي قادر على اكتشاف حقل (HVES) وقطبيته. وقد تم تطوير نموذج أولي من النظام المقترح على لوحة دوائر مطبوعة (PCB) وتم اختبار فاعليته تجريبياً. وأظهرت النتائج التجريبية أن متوسط حساسية الجهاز هو 0.1 كيلو فولت / سم، وهو قادر على عرض قراءات المجال والقطبية عددياً على شاشة (LCD). وقد لوحظ أن هناك إجماعاً جيداً على النتائج التجريبية والنظرية. وهكذا، فإن التصميم المقترح ونتائجه سيساعدان الباحثين على إجراء مزيد من البحث في مجال تقنية كشف حقل الكهرباء الساكنة عالية الجهد (HVES).

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Electronics Engineering)

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DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF ABBREVIATIONS

AC	Alternate Current
ADC	AC to DC converter
AREF	Analog Reference
CMOS	Complementary Metal-Oxide Semiconductor
DC	Direct Current
$\boldsymbol{E_{oxide}}$	Oxide dielectric constant
EFS	Electric Field Sensor
ESFM	ELECTRO Statics Field Meter
FET	Field Effect Transistor
GND	Ground
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronics Engineering
IoT	Internet of Things
LCD	Liquid Crystal Display
LiNbO3	Lithium niobate
MEMS	Micro-Electro-Mechanical Systems
MOSFET	Metal-Oxide Field Effect Transistor
PMOS	P-channel metal-oxide-semiconductor
NMOS	N-channel metal-oxide-semiconductor
P_D	Power Dissipation
PWM	Pulse-Width-Modulation
RC	Resistor–Capacitor
SiO_2	Silicon Dioxide
SPI	Serial Peripheral Interface
T_{STG}	Junction temperature Range

LIST OF SYMBOLS

ε_0	Permittivity
A	Amp
C	Capacitor
D	Diode
f	Resonate frequency
f_s	Switching frequency of MOSFET
G	Gate
HVES	High Voltage Electrostatic
Hz	Hertz
I	Current
Ic	Collector current
Is	Reverse saturation current
I_D	Drain current
kHz	Kilohertz
kV	Kilo Volt
L	Transistor length
Mv	Milli Volt
mV	Millivolts
P	Power
Pmax	Maximum power
R	Resistor
t	Time

V	Voltage
Vdd	Power supply
V_{DS}	Drain source voltage
V_{GS}	Gate source voltage
Vin	Input Voltage
Vout	Desire output voltage
$\boldsymbol{V_r}$	Regulation voltage
Vth	Threshold voltage
W	Transistor width
$\boldsymbol{\pi}$	3.141592653593

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Electrostatic field measurement is currently considered one of the significant phenomena over recent decades. Measurement is an essential matter in many applications, such as electrostatic precipitators (Jaworek et al., 2018), statics control system (Li et al., 2019), for manufacturing, electrophotography, electrostatics flow system, electrostatics spraying, atmospheric studies (Sankaran et al., 2019). An extreme high voltage electric field causes potential health risks due to electrostatic discharge or high voltage shock, which can also destroy sensitive electronic components. The measurement of electric fields in a high voltage area in a power system is necessary to avoid undesirable or dangerous situations like an electric shock. The electrostatic field detector is used to improve protection systems and prevent human injury and equipment safety in live-line maintenance (Xiao et al., 2018).

Nowadays, industry and modern engineering labs use sophisticated electrical and electronic devices, so monitoring the electrostatic field is essential to protect them from static charge injury. Electrostatics field meters reported as contact electric field measurements usually connect concerning a ground reference or contact electric field measurement expressed in volts per distance. Typical commercial applications of non-contact static (DC) electric field measurements include a surface charge on materials near electronic equipment. With the development of electronic devices, this is very important to analyze electric field sensors' performance because monitoring issues and sensors are the necessary essential components of all circuits and devices. However, most of the earlier sensors have been used for the measured electric field with complex structures and expensive. Since this device and machines have high sensitivity towards the electrostatic field, it will also lead to economic loss. Thus, critical to the sensor industry, the development of ESFM has been hindered by the lack of cost-effective sensitive materials that can make sensitivity more towards the electric field is needed. Because of its simple and low cost, in most cases, classical electroscopes are used. However, these devices are bulky, low sensitive, and not capable of correct measurement. To overcome this problem, a non-contact capacitive sensing system with compact and sensitive electronic-electrostatic field detection technique with MOSFET based has been proposed, which can display the reading on a microcontroller-based LCD system.

In recent, MOSFET gained the highest research interest in sensing technology from today's application panorama. The non-contact capacitive sensing method is measuring electrical capacitance in terms of the coupling plates being used. Thus, the principle makes a scope of research that can detect and measure the electrostatic field. MOSFET's capacitance is directly proportional to the sensor surface area and inversely proportional to the plates' distance (Zheng et al., 2014). Solidity, reliability, inexpensive, tiny size, and low-power characteristics make the MOSFET ideal circuit components for this research (Chakraborty et al., 2018). Therefore, it is the main aim of this research to design and of a MOSFET-based electric field sensor. Many researchers are still trying to improve device performance by introducing new components and new switching technology. However, there are still some issues in this system due to the high voltage, high-frequency switching time, measurement accuracy, etc., making the research more challenging. However, to use ESFM as an electric field monitor, a significant increase in sensitivity with safe distance is also required, reported by (Ando et al., 2013). Combine the capacitive sensing method with an electric field induction probe; a new technical model can address this issue. This new concept was developed and verified by using OrCAD 16.5 simulation software. A programming code was then developed with Arduino IDE software for the Arduino UNO R3 microcontroller to interface the MOSFET circuit. Finally, a prototype is designed to measure the electric field and verify its performance with other researchers' work.

1.2 CURRENT STATE OF TECHNOLOGY

Accurately detecting and measuring the high voltage electrostatic field is crucial for some typical safety applications, like controlling the process on industrial machinery, predicting the weather, or ensuring people who work on high-voltage electricity lines (Velasquez et al., 2018). From a technological perspective, this is no easy task based on safety awareness and ongoing safety reviews. Recently, a wide range of accurate electric fields measuring digital technology can measure from secondary voltage to transmission voltages. Nevertheless, these types of devices need to connect either line to ground or line to line measurement. The procedure is not safe as well as not convenient in terms of long ground conductor. A voltage detector measures the presence of voltage conductor distribution generally worn on the user's body as an indication in the general area (Xiao et al., 2018). This indication warning is helpful even live-saving but not useful with entire overhead lines. A more sensing electrode means a more sophisticated detector. However, the typical work environment not always consists of a single conductor; sometimes, multiple three-phase overbuilds or underbuilds make for an electrically complicated situation.

A direct contact voltage detector indicates the presence of AC voltage. It makes direct contact with the energized conductor. In contrast, the proximity voltage detector also measures AC voltage on a short distance away from the conductor, even well outside the minimum working distance, typically one and a half meter distance. This device has a fixed or variable threshold voltage setting. Electrostatics field measurements need to undergo further digital processing to recompense for conductor diameter, local ionization, other corona effects, etc. Moreover, IEEE and other organizations now require both visual and audible indication voltage detectors.

1.3 PROBLEM STATEMENT

There are several requirements to measure the electrostatic field in a high voltage environment in the lab and the industries. The typical approach to addressing these issues is the field mill contact method (Montanyà, J. et at., 2007). However, this method triggered numerous fundamental problems because of the direct contact between the probe and the environment. However, the following are some common problems associated with measuring the HVES field:

1. Typical HVES field instruments use the traditional electrostatic force measurement method, which is larger in size and less sensitive.
2. Most HVES field instruments are passive, and they do not have amplification and numerical display facility.
3. Active HVES field instruments are complex, require multiple sensing electrodes and high voltages to operate.
4. It is difficult to measure the HVES field that has changed frequently over time, as there is no simple refresh system on typical instruments.

1.4 RESEARCH OBJECTIVES

This research focuses primarily on developing an active electrostatic field detection technique based on MOSFET properties. To achieve the main goal, first determined the controlling parameters and system procedure, then the following individual objective has been considered in this research work:

1. To design and simulate a MOSFET-based non-contact active electrostatic field monitoring and measurement system, which is capable of displaying reading numerically.

2. To develop a prototype system on PCB based on photolithography and etching processes.

3. To develop a machine language programming code to interface a microcontroller with the MOSFET sensor circuit and numerically display readout data.

4. To verify the performance of the proposed circuit by experimental data.

1.5 RESEARCH METHODOLOGY

The following steps have been methodically followed to achieve the main objective of the proposed study.

- The research began with detailed documentary analysis of existing electrostatic field monitoring and measurement techniques by analyzing and investigating the sensory systems.
- A low-frequency sensing system circuit has been designed for electrostatics field detection systems using OrCAD16.5 (PSpice) and Proteus simulation software.
- A PCB for the MOSFET sensor circuit has been developed by photolithography and chemical etching process. The components of the whole circuit have been soldered together into a PCB board.
- The machine language programming code of the Arduino UNO microcontroller has been developed and uploaded to interface the MOSFET sensor circuit and display the readout data numerically on an LCD panel.
- Experimental data have been collected with the help of a Wimshurst high voltage electrostatic generator, Henley's electrometer, and the fabricated prototype device to verify the proposed design's effectiveness.

1.6 RESEARCH SCOPE

The research scope has been limited to design and developed an active MOSFET-based HVES field detection system, which mainly aims to detect the static and slow time-varying electric field up to 20 kV/m. A 9 V battery-operated simple Arduino UNO microcontroller-based LCD has been developed to display the readout data numerically.

1.7 THESIS ORGANIZATION

To simplify the description of this research work, the whole thesis has been organized into five chapters which are described as follows:

Chapter One: This chapter is the mainframe of the whole work. It describes the background of the research importance, a brief idea about the high voltage electrostatic field detection technique, objectives of the research, problem statement and a brief description of the research methodology finally, the scope of the research.

Chapter Two: This chapter reviews the literature on the main research topic and the detailed study of various technologies or methods for measuring and detecting an electrostatic field. From this chapter, the best method of achieving the desired results has been selected.

Chapter Three: This chapter describes the development of a design method and simulation framework for this proposed research's experimental work. This chapter has also described the prototype development procedure.

Chapter Four: This chapter describes details of the experimental and simulation results numerically and with graphs. The results analysis follows various methods and finally summarizes all the findings at the end of the chapter.

Chapter Five: This chapter reviews the research conclusion, limits that affect the projects, troubleshooting faced during the project, and highlights the relevant achievements. Also, it recommends some future work.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter describes a literature review of different types of electrostatic field detection methods and related works. This chapter's main objective is to clear the theoretical framework of the electrostatic field meter (ESFM). The research concept has been taken from previous academic sources such as articles, journals, books, etc. The electrostatic field, its detection, measurement techniques, and classification have been overviewed in this section. Relevant research works have been divided into several categories to simplify the discussion and highlight the research's strengths and limitations. At the end of the chapter, a comparison table is provided for summarizing the literature review of all related papers.

2.2 ECTROSTATICS FIELD

High voltage equipment is always surrounded by a strong electric field that can be fatally harmful to life. All matter is made up of atoms, and all atoms are made up of negatively charged electrons and positively charged proton particles. Thus, due to friction and electrostatic induction, electrons can escape from the atom and convert the object into a static electric charge body. The charge body creates a static electric field around it that causes severe damage to sensitive electronic devices and unexpectedly ignites flammable substances by sparking. Direct measurement of the static electric field around an electrically charged body is still a difficult task. However, Coulomb's law's mathematical methods provide a way to calculate the electric field's value. The electric field or e-field (R. John, 2016) is the physical field surrounding each electric charge or charged body and exerts a force on all other charges in the field, either attracting or repelling them. It is a vector quantity. According to Coulomb's law, the electric force ***F*** acts on two-point charge body ***Q1***, and ***Q2*** is proportional to the amount of electrostatic charge on each of them and inversely proportional to the square of their distance (Safari et al., 2019), as shown in Figure 2.1.

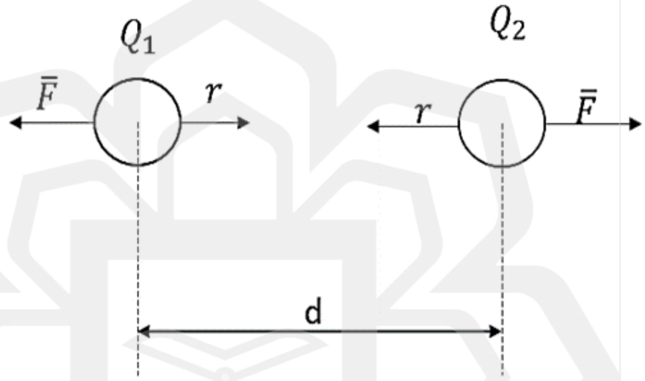

Figure 2.1 The electrostatic force between two charges

The mathematical relationship is known as Coulomb's law is,

$$\vec{F} = k\frac{Q_1 Q_2}{d^2}\hat{r} \tag{2.1}$$

where, $\hat{r}$ is the vector nature of the force. The proportionality constant k depends on the unit system used and k as,

$$k = \frac{1}{4\pi E_0} \tag{2.2}$$

where, ε_0 is the permittivity in a vacuum = 8.8541878×10^{-12}. Figure 2.1 shows that the electric field creates a force $\vec{F}$ on charge $Q_1 on\ Q_2$. The charges $Q_1\ and\ Q_2$ are called the source of the field. Now consider in the electric field $\vec{E}$, a charge distribution is