PULSE WAVE SHAPES CHARACTERISATION IN NONTHERMAL PULSE ELECTRIC FIELD METHOD FOR FOOD PRESERVATION

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DEDICATION

This thesis is dedicated to all humanity as the knowledge acquired here is beneficial to be implemented and applied for the sake of producing fresh and healthy food. It is my gift to all of us and a bet for me to face the good end of the hereafter. May Allah bless me and forgive all my sins.

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ABSTRACT

Pulsed Electric Field (PEF) is a technique that does not use any heating element in inactivating food borne pathogens and spoilage microorganisms. The advantage of this technique is that it can preserve the physical properties of food, such as colour, flavour, and nutritional value while extending its shelf life. With the straightforward working principle and well-known advantages, this technique can replace the traditional method for food pasteurisation which uses heat. However, existing PEF devices lack several features: low voltage amplitude, limited control of pulse properties, and expensive besides no optimal range of treatment parameters clearly defined for specific foods. These shortcomings limit their function in the subset of pulse applications. Therefore, this study was conducted to fill the available innovation space to solve or at least reduce the shortcomings in PEF devices today. In this thesis, a compact high-voltage pulse generator was developed by implementing the concept of capacitor discharge to produce a square pulse (mono polar fashion) to inactivate microbes inherently in raw goat's milk. The development phase began with a simulation study regarding the design of a compact high voltage pulse generator circuit and a treatment chamber that produced the desired results. Then, it was tested practically on sodium chloride (NaCl) solution with the conductivity of 100 mS/m, and the result was the same as the simulation with few insignificant differences. From the experiments performed on raw goat's milk, the results obtained suggest that a frequency of 10 Hz, a voltage amplitude of 4 kV, and a pulse width between 1 – 4 μs promise the best results in the treatment process. The inherent microorganisms have been successfully reduced from 2.98×10^6 Colony Forming Unit (CFU)/ml to 1.64×10^6 CFU/ml, an almost 60% reduction or 0.55 survival ratio. This thesis also suggests that the compact high-voltage pulse generator has a vast potential to inactivate other types of microorganisms in various kinds of liquid food. This is due to the flexibility and reliability offered by the compact high voltage pulse generator developed in this study.

ABSTRAK

Medan Elektrik Terdenyut (PEF) merupakan teknik yang tidak menggunakan sebarang unsur pemanasan dalam menyahaktifkan patogen bawaan makanan dan mikroorganisma pembusuk. Kelebihan teknik ini ialah ia dapat mengekalkan sifat fizikal makanan, seperti warna, rasa, dan nilai pemakanan disamping memanjangkan jangka hayatnya. Dengan prinsip kerja yang mudah dan kelebihan yang telah dikenali, teknik ini boleh menggantikan kaedah tradisional untuk pempasteuran makanan yang menggunakan haba. Walau bagaimanapun, peranti PEF sedia ada kekurangan beberapa ciri: amplitud voltan rendah, kawalan sifat dedenyut yang terhad, dan mahal selain tiada julat optimum parameter rawatan yang ditakrifkan dengan jelas untuk makanan tertentu. Kelemahan ini mengehadkan fungsinya dalam subset aplikasi dedenyut. Oleh itu, kajian ini dijalankan bagi mengisi ruang inovasi yang ada untuk menyelesaikan atau sekurang-kurangnya mengurangkan kekurangan pada peranti PEF yang sedia ada. Dalam tesis ini, penjana dedenyut voltan tinggi padat telah dibangunkan dengan melaksanakan konsep nyahcas kapasitor untuk menghasilkan dedenyut persegi (fesyen monopolar) untuk menyahaktifkan mikrob yang wujud dalam susu kambing mentah. Fasa pembangunan dimulakan dengan kajian simulasi berkaitan reka bentuk litar penjana dedenyut voltan tinggi padat dan ruang rawatan yang menghasilkan keputusan yang diinginkan. Kemudian, ia diuji secara praktikal pada larutan natrium klorida (NaCl) dengan kekonduksian 100 mS/m, dan hasilnya adalah sama dengan simulasi, cuma dengan sedikit perbezaan yang tidak ketara. Daripada eksperimen yang dilakukan terhadap susu kambing mentah, keputusan yang diperoleh menunjukkan bahawa frekuensi 10 Hz, amplitud voltan 4 kV, dan lebar dedenyut antara 1 – 4 μs menjanjikan hasil terbaik dalam proses rawatan. Mikroorganisma yang wujud telah berjaya dikurangkan daripada 2.98×10^6 Colony Forming Unit (CFU)/ml kepada 1.64×10^6 CFU/ml, pengurangan hampir 60%. Tesis ini juga mencadangkan bahawa penjana dedenyut voltan tinggi padat ini mempunyai potensi besar untuk menyahaktifkan jenis mikroorganisma lain dalam pelbagai jenis makanan cecair. Ini disebabkan oleh fleksibiliti dan kebolehpercayaan yang ditawarkan oleh penjana dedenyut voltan tinggi padat yang dibangunkan dalam kajian ini.

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LIST OF ABBREVIATIONS

CAD	-	Computer-Aided Design
CFU	-	Colony Forming Unit
CMOS	-	Complementary Metal Oxide Semiconductor
FEA	-	Finite Element Analysis
FEM	-	Finite Element Method
HPP	-	High-Pressure Processing
IGBT	-	Insulated Gate Bipolar Transistor
MOSFET	-	Metal-oxide Silicon Field Effect Transistor
OCnA/B	-	Output Compare A/B
OCRnA/B	-	Output Compare Register A/B
PARDISO	-	Parallel Direct Solver
PCB	-	Printed Circuit Board
PDE	-	Partial Differential Equation
PEF	-	Pulsed Electric Field
PFN	-	Pulse Forming Network
PWM	-	Pulse Width Modulation
Re	-	Reynolds Number
TCCRnA/B	-	Timer/Counter Control Register
TCNTn	-	Timer/Counter
TFTC	-	Too Few To Count
TNTC	-	Too Numerous To Count
TTL	-	Transistor Transistor Logic

LIST OF SYMBOLS

$\Delta\varphi$ - Transmembrane Potential
μ - Dynamic Viscosity
A - Effective Area of The Electrode
C - Capacitance
C_{DG} - G-D Capacitance
C_{GS} - G-S Capacitance
C_{JO} - Junction Oxide Capacitance
C_m - Capacitance of The Membrane per Unit Area
C_P - Specific Fluid Heat Capacity
d - Diameter
E - Electric Field Strength
F - Microorganism Shape Factor
f - Pulse Frequency
g - Gravitation Accelaration Constant
I - Current Flows
I_D - Drain Current (Continuous)
I_{DP} - Drain Current (Pulse)
I_S - Leakage Current
k - Thermal Conductivity
K_P - Transconductance
k_T - Turbulent Thermal Conductivity
l - Length of The Treatment Area
$lambda$ - Channel Length Modulation
M - Junction Grading Coefficient
n - Number of Pulses
N - Number of Colonies After PEF Treatment
N_o - Number of Colonies Before PEF Treatment
P - Pulse Power
P_e - Electrocompressive Force
P_m - Mechanical Restoring Force
Q - Charge Accumulated
Q_{pulse} - Each Pulse Energy Delivered
Q_{total} - Total Pulse Energy Delivered

r_c - Cell’s Radius

R_{ch} - Treatment Chamber Resistance

R_{DS} - On Resistance

R_s - Switch Resistance

R_t - Total Resistance

S_x - Fraction of Surviving Cells

t - Time

v - Fluid Flow Velocity

V - Voltage Applied

V_{ch} - Voltage Across Treatment Chamber

V_{DS} - Drain – Source Voltage

V_J - Junction Voltage Drop

V_{TO} - Zero Bias Gate Threshold

W - Energy Stored

Y - Elastic Modulus of The Membrane

δ - Thickness of The Membrane Cell

δ_0 - Initial Membrane Thickness

ε_0 - Permittivity of Free Space

ε_m - Relative Permittivity of The Cell Membrane

ε_r - Relative Permittivity of The Dielectric Material

θ - Angle

ρ - Fluid Density

σ_e - Electrical Conductivity of The External Medium

σ_i - Electrical Conductivity of The Cytoplasm

σ_m - Electrical Conductivity of The Cell Membrane

τ - Pulse Width

τ_m - Characteristic Time Constant

φ - Multiplication Factor

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CHAPTER 1

INTRODUCTION

1.1 Background Study

In food processing, pasteurisation kills pathogens and extends shelf life by using moderate heat, usually less than 100 °C. Through this process, all organisms and enzymes liable to contribute to food spoilage or foodborne illness, including vegetative bacteria, are killed (or destroyed if possible) (Tewari and Juneja, 2008; Fellows, 2009). It is undeniable that there are advantages to the process. However, there are also disadvantages, as processed food changes its physical properties, such as colour, flavour, and nutritional value (Lado and Yousef, 2002; Toepfl *et al.*, 2006; Kishore *et al.*, 2007; Chauhan and Unni, 2015).

In addition to the problems faced, consumer awareness of food content and processing methods also contributed to searching for new food treatment approaches (Evans and Cox, 2006; Mohamed and Eissa, 2012). As a result, electrical engineers and food technologists collaborate to develop alternative methods that remove thermal elements involved in food processing to resolve the stated problems and ensure that consumers get healthier and fresher food. Therefore, a nonthermal technique approach is proposed.

Several nonthermal techniques have been studied recently because of their potential for inactivating pathogenic microorganisms. It is therefore explored globally, causing research on it to increase. Ultimately, all of this is done to ensure consumers are provided with a microbiologically safe product. Table 1.1 shows some of the known nonthermal methods with their comparisons that have prospective as an alternative to conventional methods.

Table 1.1 Summary of known nonthermal methods by comparison

Technology	Intensity	Type of food		Approval	Reference
		Solid	**Liquid**		
Pulsed electric field	5-55 kV/cm	Beef muscles, potato tubers	Fruit juice, liquid eggs, milk	Limited approval in the US (FDA, no objection letter from 07/07/1995)	(Faridnia, 2015; Qin *et al.*, 1996)
High-pressure processing	100-1000 MPa	Ham, seafood	Fruit juice, guacamole, jam, salad dressing, milk	Japan, North America, Europe	(Hoover *et al.*, 1989; Smelt, 1998)
Ultraviolet radiation	0.5-20 J/m^2	Meat surface, shell egg surface	Orange juice	Approval pending in the US	(Bintsis *et al.*, 2000; Kuo *et al.*, 1997)
Gamma irradiation	2-10 kGy	Raw poultry meat, raw	Liquid eggs	More than 41 countries	(Farkas, 1998; Agrawal and Goyal, 2017)

The nonthermal methods showcased in Table 1.1 are recognised as a novel process due to their ability to inactivate microorganisms at ambient, sub-ambient, or slightly above ambient temperature (Butz and Tauscher, 2002; Kumar *et al.*, 2016). These techniques are specifically designed to eliminate thermal components in processing while maintaining food's flavour, appearance, and nutritional value (Barbosa-Canovas *et al.*, 1999; Jambari, 2014).

Among the nonthermal methods presented here, the pulsed electric field (PEF) appears to be the most extensively studied in addition to high hydrostatic pressure (HPP) and high-intensity ultrasound combined with pressure. It is due to the short treatment time, which reduces the heating effect compared to other technologies. On the other hand, regarding gamma irradiation, although it has a high potential for commercialisation, this method has been hampered by the bad perception of society in the past (Resurreccion *et al.*, 1995).

1.2 Overview of Pulsed Electric Field

The PEF approach has been used in studies since the 1960s to take advantage of its influence on the inactivation of microorganisms, mainly bacteria found in liquid foods. On the other hand, Sale and Hamilton were among the first to give a thorough and scientific study of this method in a series of papers published in 1967 and 1968 (Sale and Hamilton, 1967; Hamilton and Sale, 1967; Sale and Hamilton, 1968). Later, Zimmerman and his colleagues expanded on this work by establishing the theory of dielectric rupture and publishing several papers (Coster and Zimmermann, 1975; Zimmermann *et al.*, 1976). Their research was performed in the 1970s at the University of Wurzburg in Germany.

Since then, scholars have become increasingly passionate about PEF research, gaining traction. This topic rapidly grew in popularity, with published papers delivering discussion after discussion. The study of PEF treatment technology encompasses a wide range of subjects, including the characteristics of suitable microorganisms, the construction of modern electroporators and their deployment in the industry, as well as food safety policies (Campbell *et al.*, 2008; Reberšek and Miklavčič, 2011b; Toepfl, 2011; Stankevič *et al.*, 2013; Raso *et al.*, 2016).

The fundamental principles of PEF technology can be defined by applying short electrical pulses to food located between electrodes separated by an insulator. The electrical pulses can range between microseconds to milliseconds and typically yield an electric field intensity of 10 - 80 kV/cm. This approach is commonly used to treat liquid foods, but there is no doubting that it may also be used to treat semi-solid and solid foods (Ramaswamy *et al.*, 2005).

PEF technology is more suitable for pasteurizing liquid foods such as milk, juices, yoghurt, soups, and liquid eggs (Vega-Mercado *et al.*, 1997; Bendicho *et al.*, 2003; Puc *et al.*, 2004). It is because of the fluid properties that can transfer electricity due to the presence of several ions and causing it to obtain a certain degree of electrical conductivity. Therefore, the electric current flowing is scattered to every point in the liquid due to the presence of the charged molecules (Zhang *et al.*, 1995).

PEF treatment involves a phenomenon known as electroporation or electro-permeabilisation, which is the permeability of cell membranes as a result of being subjected to an electric field (Jordan *et al.*, 2013). If the applied field strength exceeds the critical field strength, it may experience cell disintegration; otherwise, it may revert to its original state. These circumstances could have both reversible and irreversible effects on the cell membrane, demonstrating that the impact of PEF treatment can be well controlled depending on its application by accurately altering the field strength.

The benefits of using PEF treatment technology are no longer foreign as it can preserve a high-quality fresh-like natural flavour, high nutritional value, and extend shelf life (Castro *et al.*, 1993; Qin, 1995). It is achieved by eliminating pathogens and spoilage microorganisms without using thermal elements. However, some foods, such as fruit juice, must be refrigerated after being treated to retain their aroma and flavour and increase their shelf life (Ramaswamy *et al.*, 2005; Jambari, 2014).

Studies also show that PEF treatment techniques can reduce energy consumption by 10% for each treatment compared to thermal processing (Charles-Rodríguez *et al.*, 2007). This scenario occurs because the temperature increase of each treatment is minimal and is highly dependent on the total pulse delivered, pulse width, frequency, and velocity of the food flow (in a continuous system). This 10% reduction in energy use may pique the interest of industry participants because it is a source of profit for them in the long run and may reduce manufacturing expenses. As a result, PEF-treated food can be sold at competitive rates.

1.3 Problem Statement

Implementing PEF in inactivating microorganisms is now a phenomenon and attracts researchers' interest. This method causes minimal impact on the physical properties of food; among them are flavour, colour, and nutritional value. In addition, it causes the quality and freshness of the food to be well preserved. With all its advantages, it is seen to be raised as an alternative way to replace conventional food treatment methods that use heat as the main instrument. To achieve this, it is inevitable to have a high-powered pulse generator capable of producing consistent pulses whose properties can be controlled.

Pulse generators available today consist of two types of power electronic converter circuits: conventional and non-conventional. Transmission lines and PFNs are among the popular conventional circuits while Multi Stacked MOSFETs and Cascade H-Bridge Multilevel Inverters are among the emerging non-conventional techniques for generating high voltage pulses (Baker and Johnson, 1993; Roodenburg *et al.*, 2005; Sun and Wang, 2014; Jambari, 2014). However, most of the proposed circuits implement many components which end with complex system of circuitry and control. Some of it use more than one MOSFET to generate high voltage and high current pulses which results in intricate triggering algorithm and employing numerous MOSFET's drivers. Not only that, the use of transmission lines and spark gaps restricts the flexibility to produce a wide range of pulse widths and slow switching which constrain the generation of nanosecond pulse. The use of transformers to obtain high voltage limit the compactness of the pulse generator, thus, result in expensive, heavy, and bulky generator as well as consume more space. Furthermore, employment of transformers requires maintenance from time to time and increasing the system power loss due to higher number of winding coils.

Referring to the stated problem, this study proposes the use of capacitor-discharge technique with MOSFET implementation for fast switching and microcontroller to generate flexible pulse properties. This suggested solution can improve the ability of PEF treatment to achieve effective food pasteurisation while also being able to change pulse properties to achieve desired pulse specifications for specific pulse applications. In addition, this capacitor discharge technique uses less components which makes it easier to control and does not require a complex algorithm because a single high-power MOSFET unit is implemented. As well, this method does not require transformers to obtain high voltage pulses because it can be achieved using flyback transformers that are small but high durability and do not require maintenance yet easy to control. Therefore, the finish product can be compacted, low power consumption, low cost, and flexible compared to transmission line, PFN, Multi Stacked MOSFETs, and Cascade H-Bridge Multilevel Inverters techniques. Non-complex circuit layout allows it to be comfortably packed, easy to install and can have portable features.

1.4 Research Objectives

The objectives of the research are:

(a) To develop a compact high-voltage pulse generator using a capacitor discharge approach to generate complete control over square wave pulse properties for PEF treatment applications.

(b) To verify the operation of the whole system of the pulse generator via simulation and hardware implementation to obtain optimum development by reducing the effect of parasitic circuit elements.

(c) To analyse the performance of the compact high voltage pulse generator in delivering the intended pulse properties and inactivating pathogens and spoilage microorganisms present in raw goat milk including characterizing the best pulse parameters for it.

1.5 Scope of Research

This research highlights the overall development of a compact high voltage pulse generator using the capacitor discharge method. Despite underutilised components, this method also can guarantee the generation of a square pulse whose properties can be controlled accordingly - the width and frequency can vary in a broad domain selection. Square pulse in pulsed electric field treatment technology is superior due to its significant advantage in inactivating microorganisms than other pulse forms such as exponential decay and oscillation.

This study considers the implementation of microcontrollers regarding pulse signal controllers. The well-known advantages and low price are the main reasons it is chosen. With suitable programming methods and algorithms, it can generate pulse signals that can be controlled easily and systematically. In addition, the generated pulse signal is TTL and CMOS compatible, which can be used to drive any solid-state switching device such as IGBTs and MOSFETs. Since the production of nanosecond pulses requires a fast-switching device, the implementation of MOSFETs is employed.

The PEF treatment system is incomplete without the treatment chamber. A treatment chamber is a place where food is treated. It can be batch or continuous; though, continuous is more suitable for implementation in the industry due to production demands. However, the treatment chamber is not merely for food accommodation but also to house electrodes. The electrode arrangement may be in the order of parallel, coaxial, or collinear. Usually, they are positioned in parallel to obtain the most uniform electric field distribution compared to coaxial and colinear.

The treatment media or the food to be treated habitually comes in a liquid form. It does not deny that this PEF method can treat semi-solid and solid foods, but it works better with liquid food. The liquid owns a certain degree of electrical conductivity due to the presence of several ions, which result in the flow of electrical current to every point in it. Therefore, this research appointed raw goat’s milk as a test subject. However, no specific microorganisms have been identified for inactivation but rather to kill any pathogens and spoilage microorganisms so that it is safe to consume.

1.6 Research Significant

PEF treatment technology has demonstrated its ability and reliability in killing the vegetative cells while colours, flavours, and nutrients are well preserved. Besides, there is no evidence of toxicity involved in using this method. Meanwhile, it consumes a relatively short treatment time to treat the media. Also, it can be used to decontaminate heat-sensitive foods suitable for the type of liquid diet. Research has shown beyond doubt about the pasteurisation of fruit juices, soups, liquid eggs, and milk. The most important thing is it offers no environmental hazard.

This study’s result will help promote the implementation of PEF treatment technology on an industrial scale. The primary concern of industrial consortium interested in PEF implementation is initial investments. This issue is one of the most important topics. To the present day, only several countries adopt the PEF method in producing safe, nutritious, and high-quality products, such as Pure Pulse Technologies, USA, and Thomson-CSF, France. Therefore, this study aims to reduce its development cost while optimizing the critical process factors.

1.7 Contributions to Knowledge

This research contributes to a wide range of knowledge as it incorporates several disciplines of expertise, including high voltage and high current, power electronics, and food technology.

From the point of view of high voltage and high current fields, it contributed to the development of compact high voltage pulse generators that can be used in various pulse applications. In addition to low development costs and reliable results, it is also successfully compacted so that it can be taken anywhere. The success of developing this compact high voltage pulse generator is a superior manifestation of how high voltage and high current are well regulated.

Whereas from the point of view of the field of power electronics, it shows success in generating pulse signals whose properties can be modified as needed. The use of a microcontroller along with its complex programming algorithms has been successfully utilised to change the properties of a pulse in terms of its pulse width and frequency. Pulses as small as 63 ns and as wide as 4 ms with frequencies as low as 1 Hz and as high as 1 kHz have been successfully generated stably.

Finally, the point of view is taken from the food technology field. In this field, the studies are conducted to contribute to the production of food treatment technologies that do not use heat. Furthermore, this developed technology also provides benefits in understanding the response of microorganisms when exposed to a pulsed electric field which helps to develop further the mechanism of dielectric breakdown theory for better understanding. The ultimate result is to produce food that is high quality, fresh, and lasts longer for the good of universal humanity.

1.8 Thesis Organisation

Chapter 2 consists of a literature review related to the application of PEF, including microbial inactivation mechanisms, and critical factors. In addition, it also touches on PEF system components, various PEF generator techniques, and commercial electroporation instruments. Thus, it covers almost essential topics associated with PEF treatment technology.

Chapter 3 defines the development process of the compact high-voltage pulse generator based on the capacitor-discharge concept. Also, it explains in detail the suitable component used to develop the electroporator and proposed circuit design to ensure the reliability and stability of the output pulse.

Chapter 4 describes the results obtained through simulations and practical studies regarding the performance of the developed compact high-voltage pulse generator. For the actual experiment, raw goat's milk from Osman Goat Farm was treated via PEF. The results obtained were analysed to observe the effectiveness of the PEF technique in inactivating the inherent microorganisms.

Chapter 5 defines the possible future work that can be done to uplift and enhance the application of PEF technology especially in industrial sector. It discusses more on the improvement of the technology itself like changing in treatment chamber design and encouraging the application of nanosecond pulse.

REFERENCES

Agrawal, A.K. and Goyal, M.R. (2017). *Processing Technologies for Milk and Milk Products: Methods, Applications, and Energy Usage*, Apple Academic Press. Available at: https://books.google.com.my/books?id=n4U0DwAAQBAJ.

Alkhafaji, S.R. and Farid, M. (2007). An investigation on pulsed electric fields technology using new treatment chamber design. *Innovative Food Science & Emerging Technologies*. 8(2), 205–212. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1466856406000865.

Altunakar, B. (2007). *Food preservation by pulsed electric fields and selected antimicrobials*. Washington State University.

Arshad, R.N., Abdul-Malek, Z., Munir, A., Buntat, Z., Ahmad, M.H., Jusoh, Y.M.M., Bekhit, A.E.-D., Roobab, U., Manzoor, M.F. and Aadil, R.M. (2020). Electrical systems for pulsed electric field applications in the food industry: An engineering perspective. *Trends in Food Science & Technology*. 104, 1–13. Available at: http://www.sciencedirect.com/science/article/pii/S0924224420305379.

Astráin-Redín, L., Raso, J., Cebrián, G. and Álvarez, I. (2019). Potential of Pulsed Electric Fields for the preparation of Spanish dry-cured sausages. *Scientific Reports*.

Baker, R.J. and Johnson, B.P. (1993). Series operation of power MOSFETs for high-speed, high-voltage switching applications. *Review of Scientific Instruments*.

Barbosa-Canovas, G. V, Pothakamury, U.R., Gongora-Nieto, M.M. and Swanson, B.G. (1999). *Preservation of foods with pulsed electric fields*, Elsevier.

Barbosa-Canovas, G. V and Sepúlveda, D. (2005). Present status and the future of PEF technology. *Novel food processing technologies*., 1–44.

Barsotti, L., Merle, P. and Cheftel, J.C. (1999). Food processing by pulsed electric fields. I. Physical aspects. *Food Reviews International*. 15(2), 163–180.

Bendicho, S., Barbosa-Cánovas, G. V and Martín, O. (2003). Reduction of protease activity in simulated milk ultrafiltrate by continuous flow high intensity pulsed electric field treatments. *Journal of Food Science*. 68(3), 952–957.

Bintsis, T., Litopoulou-Tzanetaki, E. and Robinson, R.K. (2000). Existing and potential applications of ultraviolet light in the food industry - A critical review. *Journal of the Science of Food and Agriculture*. 80(6), 637–645.

Bird, R.B., Stewart, W.E., Lightfoot, E.N. and Spalding, D.B. (1961). Transport Phenomena. *Journal of Applied Mechanics*.

Boussetta, N., Soichi, E., Lanoisellé, J.-L. and Vorobiev, E. (2014). Valorization of oilseed residues: extraction of polyphenols from flaxseed hulls by pulsed electric fields. *Industrial Crops and Products*. 52, 347–353.

Bradshaw, H.D., Parson, W.W., Sheffer, M., Lioubin, P.J., Mulvihill, E.R. and Gordon, M.P. (1987). Design, construction, and use of an electroporator for plant protoplasts and animal cells. *Analytical Biochemistry*.

Buckow, R., Ng, S. and Toepfl, S. (2013). Pulsed electric field processing of orange juice: A review on microbial, enzymatic, nutritional, and sensory quality and stability. *Comprehensive Reviews in Food Science and Food Safety*.

Buckow, R., Schroeder, S., Berres, P., Baumann, P. and Knoerzer, K. (2010). Simulation and evaluation of pilot-scale pulsed electric field (PEF) processing. *Journal of Food Engineering*.

Butz, P. and Tauscher, B. (2002). Emerging technologies: Chemical aspects. In *Food Research International*.

Campbell, D., Harper, J. and Natham, V. (2008). A compact high voltage nanosecond pulse generator. *Proc. ESA Annual* ...., 1–12. Available at: http://www.electrostatics.org/images/ESA_2008_H3.pdf.

Castro, A.J., Barbosa-CÁnovas, G. V. and Swanson, B.G. (1993). Microbial Inactivation of Foods by Pulsed Electric Fields. *Journal of Food Processing and Preservation*.

Chang, D.C. (1989). Cell poration and cell fusion using an oscillating electric field. *Biophysical Journal*.

Chang, D.C. and Reese, T.S. (1990). Changes in membrane structure induced by electroporation as revealed by rapid-freezing electron microscopy. *Biophysical Journal*.

Charles-Rodríguez, A. V., Nevárez-Moorillón, G. V., Zhang, Q.H. and Ortega-Rivas, E. (2007). Comparison of thermal processing and pulsed electric fields treatment in pasteurization of apple juice. *Food and Bioproducts Processing*.

Chauhan, O.P. and Unni, L.E. (2015). Pulsed electric field (PEF) processing of foods and its combination with electron beam processing. In *Electron Beam*

Pasteurization and Complementary Food Processing Technologies. pp.157–184.

Chen, X.D. (2006). Modeling thermal processing using computational fluid dynamics (CFD). *SUN, DW Thermal food processing: new technologies and quality issues. Boca Raton: CRC.*

COMSOL (2016). Multiphysics Cyclopedia. Available at: https://www.comsol.com/multiphysics/finite-element-method [Accessed December 19, 2022].

Coster, H.G.L. and Zimmermann, U. (1975). The mechanism of electrical breakdown in the membranes of Valonia utricularis. *The Journal of Membrane Biology*.

Doevenspeck, H. (1961). Influencing cells and cell walls by electrostatic impulses. *Fleischwirtschaft*. 13(12), 968–987.

Doevenspeck, H. (1960). Verfahren und Vorrichtung zur Gewinnung der einzelnen Phasen aus dispersen Systemen. *DE*. 1, 237–541.

Dunn, J. (2001). Pulsed electric field processing: an overview. *Pulsed electric fields in food processing: Fundamental aspects and applications*., 1–30.

Education, P. (2012). Microbial Growth (Part-2). *SlidePlayer*., 7. Available at: https://slideplayer.com/slide/16312496/ [Accessed January 7, 2021].

Evans, G. and Cox, D.N. (2006). Australian consumers' antecedents of attitudes towards foods produced by novel technologies. *British Food Journal*.

Evrendilek, G.A., Avsar, Y.K. and Evrendilek, F. (2016). Modelling stochastic variability and uncertainty in aroma active compounds of PEF-treated peach nectar as a function of physical and sensory properties, and treatment time. *Food Chemistry*. 190, 634–642.

Faridnia, F. (2015). The impact of pulsed electric field (PEF) processing on solid food materials. Available at: https://otago.ourarchive.ac.nz/handle/10523/5826.

Farkas, J. (1998). Irradiation as a method for decontaminating food: A review. In *International Journal of Food Microbiology*. pp.189–204.

Fellows, P.J. (2009). *Food processing technology: Principles and practice: Third edition*,

Ferreira, V.J., Arnal, Á.J., Royo, P., García-Armingol, T., López-Sabirón, A.M. and Ferreira, G. (2019). Energy and resource efficiency of electroporation-assisted extraction as an emerging technology towards a sustainable bio-economy in the agri-food sector. *Journal of Cleaner Production*.

Gášková, D., Sigler, K., Janderová, B. and Plášek, J. (1996). Effect of high-voltage electric pulses on yeast cells: Factors influencing the killing efficiency. *Bioelectrochemistry and Bioenergetics*.

Gerlach, D., Alleborn, N., Baars, A., Delgado, A., Moritz, J. and Knorr, D. (2008). Numerical simulations of pulsed electric fields for food preservation: A review. *Innovative Food Science and Emerging Technologies*.

Geveke, D.J., Gurtler, J. and Zhang, H.Q. (2009). Inactivation of Lactobacillus plantarum in apple cider, using radio frequency electric fields. *Journal of Food Protection*.

Góngora-Nieto, M.M., Sepúlveda, D.R., Pedrow, P., Barbosa-Cánovas, G. V. and Swanson, B.G. (2002). Food processing by pulsed electric fields: Treatment delivery, inactivation level, and regulatory aspects. *LWT - Food Science and Technology*.

Guerrero, A.F.G., Farfán, A.J.U., Hoyos, F.A.R. and Plata, E.A.C. (2013). Increased Power Capability in MOSFETs by Capacitive Coupling of Gate Signals. In *Simposio Internacional sobre la Calidad de la Energía Eléctrica-SICEL*.

Hamilton, W.A. and Sale, A.J.H. (1967). Effects of high electric fields on microorganisms. II. Mechanism of action of the lethal effect. *BBA - General Subjects*.

Heinz, V., Alvarez, I., Angersbach, A. and Knorr, D. (2001). Preservation of liquid foods by high intensity pulsed electric fields - Basic concepts for process design. *Trends in Food Science and Technology*.

Ho, S.Y. and Mittal, G.S. (1996). Electroporation of cell membranes: A review. *Critical Reviews in Biotechnology*.

Hoover, D.G., Metrick, C., Papineau, A.M., Farkas, D.F. and Knorr, D. (1989). Biological effects of high hydrostatic pressure on food microorganisms. *Food technology (USA)*.

Hülsheger, H., Potel, J. and Niemann, E.-G. (1981). Killing of bacteria with electric pulses of high field strength. *Radiation and Environmental Biophysics*. 20(1), 53–65.

Hülsheger, H., Potel, J. and Niemann, E.G. (1983). Electric field effects on bacteria and yeast cells. *Radiation and Environmental Biophysics*.

Jacob, H. -E, Förster, W. and Berg, H. (1981). Microbiological implications of electric field effects II. Inactivation of yeast cells and repair of their cell envelope. *Zeitschrift für allgemeine Mikrobiologie*.

Jambari, H. (2014). *Pulsed Electric Field By Cascaded H-Bridge Multilevel Inverter For Inactivation Of Saccharomyces Cerevisiae In Orange Juice*. Universiti Teknologi Malaysia.

Jambari, H., Azli, N.A. and Piah, M.A.M. (2010). Cascaded H-bridge multilevel inverter based pulsed power supply for liquid food sterilization. In *Power Engineering and Optimization Conference (PEOCO), 2010 4th International*. pp.154–158.

Jambari, H., Azli, N.A. and Piah, M.A.M. (2011). Comparison of pulsed electric field generation techniques for microbial inactivation application. *Journal of Theoretical and Applied Information Technology*.

Jayaram, S., Castle, G.S.P. and Margaritis, A. (1993). The effects of high field DC pulse and liquid medium conductivity on survivability of Lactobacillus brevis. *Applied Microbiology and Biotechnology*.

Jiang, W. (2007). Fast high voltage switching using stacked MOSFETs. In *IEEE Transactions on Dielectrics and Electrical Insulation*. pp.947–950.

Jordan, C.A., Neumann, E. and Sowers, A.E. (2013). *Electroporation and electrofusion in cell biology*, Springer Science & Business Media.

Kasri, N.F., Piah, M.A.M. and Adzis, Z. (2020). Compact High-Voltage Pulse Generator for Pulsed Electric Field Applications: Lab-Scale Development L. Maresca, ed. *Journal of Electrical and Computer Engineering*. 2020, 6525483. Available at: https://doi.org/10.1155/2020/6525483.

Kinosita, K., Hibino, M., Itoh, H., Shigemori, M., Hirano, K., Kirino, Y. and Hayakawa, T. (2012). Events of Membrane Electroporation Visualized on a Time Scale from Microsecond to Seconds. In *Guide to Electroporation and Electrofusion*.

Kishore, N.K., Emani, S.S., Maiti, T.K. and Bisht, G.S. (2007). Studies on Pulsed Electric Field applications for food sterilization. In *2007 International Conference on Industrial and Information Systems*. IEEE, pp.497–502.

Knorr, D., Angersbach, A., Eshtiaghi, M.N., Heinz, V. and Lee, D.U. (2001). Processing concepts based on high intensity electric field pulses. *Trends in Food Science and Technology*.

Kumar, S., Agarwal, N. and Raghav, P.K. (2016). Pulsed electric field processing of foods-a review. *International Journal of Engineering Research and Modern*

Education. 1(1), 111–1118.

Kuo, F., Ricke, S.C. and Carey, J.B. (1997). Shell Egg Sanitation : UV Radiation and Egg Rotation to Effectively Reduce Populations of Aerobes , Yeasts , and Molds. *Journa of Food Protection*. 60(6), 694–697.

Lado, B.H. and Yousef, A.E. (2002). Alternative food-preservation technologies: Efficacy and mechanisms. *Microbes and Infection*. 4(4), 433–440.

Lindgren, M. (2001). Pulsed electric field processing—Modeling and equipment design implications. In *Proceedings of International Seminar on Electric Field Processing—The Potential to Make a Difference, Gloucestershire UK*.

López-Giral, N., González-Arenzana, L., González-Ferrero, C., López, R., Santamaría, P., López-Alfaro, I. and Garde-Cerdán, T. (2015). Pulsed electric field treatment to improve the phenolic compound extraction from Graciano, Tempranillo and Grenache grape varieties during two vintages. *Innovative Food Science & Emerging Technologies*. 28, 31–39.

Luengo, E., Condón-Abanto, S., Álvarez, I. and Raso, J. (2014). Effect of Pulsed Electric Field Treatments on Permeabilization and Extraction of Pigments from Chlorella vulgaris. *Journal of Membrane Biology*.

Luengo, E., Martínez, J.M., Bordetas, A., Álvarez, I. and Raso, J. (2015). Influence of the treatment medium temperature on lutein extraction assisted by pulsed electric fields from Chlorella vulgaris. *Innovative Food Science & Emerging Technologies*. 29, 15–22.

Madigan, M.T., Martinko, J.M., Dunlap, P. V and Clark, D.P. (2008). Brock biology of microorganisms 12th edn. *Int. Microbiol*. 11, 141–142.

Majumdar, P. (2005). *Computational methods for heat and mass transfer*, Taylor & Francis.

Mankowski, J. and Kristiansen, M. (2000). A review of short pulse generator technology. *IEEE Transactions on Plasma Science*.

Mannozzi, C., Rompoonpol, K., Fauster, T., Tylewicz, U., Romani, S., Rosa, M.D. and Jaeger, H. (2019). Influence of pulsed electric field and ohmic heating pretreatments on enzyme and antioxidant activity of fruit and vegetable juices. *Foods*.

Masood, H., Diao, Y., Cullen, P.J., Lee, N.A. and Trujillo, F.J. (2018). A comparative study on the performance of three treatment chamber designs for radio frequency electric field processing. *Computers and Chemical*

Engineering.

Mohamed, M. and Eissa, A. (2012). Pulsed Electric Fields for Food Processing Technology. *Structure and Function of Food Engineering*., 32. Available at: http://cdn.intechopen.com/pdfs/38363/InTech-Pulsed_electric_fields_for_food_processing_technology.pdf.

Muraji, M., Tatebe, W., Konishi, T., Fujii, T. and Berg, H. (1993). Effect of electrical energy on the electropermeabilization of yeast cells. *Bioelectrochemistry and Bioenergetics*. 31(1), 77–84. Available at: https://www.sciencedirect.com/science/article/pii/030245989386107C.

Neumann, E., Sprafke, A., Boldt, E. and Wolf, H. (2012). Biophysical Considerations of Membrane Electroporation. In *Guide to Electroporation and Electrofusion*.

Neumann, E., Sprafke, A., Boldt, E. and Wolf, H. (1992). Biophysical Considerations of Membrane Electroporation. In *Guide to Electroporation and Electrofusion*.

Novickij, V. (2018). *Development of High Power Square Wave Electroporators*,

Othman, N.S.B., Jindo, T., Yamada, M., Tsuyama, M. and Nakano, H. (2014). Fast high voltage solid state switch using insulated gate bipolar transistor for discharge-pumped lasers. *World Acad. Sci., Eng. Technol., Int. J. Elect., Comput., Energetic, Electron. Commun. Eng.* 8(12), 1869–1872.

Pedrow, P.D., Zhang, Q. and Barbosa-C¡novas, G. V. (1994). Inactivation of microorganisms by pulsed electric fields of different voltage waveforms. *IEEE Transactions on Dielectrics and Electrical Insulation*. 1(6), 1047–1057.

Pizzichemi, M. (2007). Application of pulsed electric fields to food treatment. *Nuclear Physics B (Proceedings Supplements)*. (172), 314–316.

Puc, M., Čorović, S., Flisar, K., Petkovšek, M., Nastran, J. and Miklavčič, D. (2004). Techniques of signal generation required for electropermeabilization: Survey of electropermeabilization devices. *Bioelectrochemistry*. 64(2), 113–124.

Qin, B.-L. (1995). Food pasteurization using high-intensity pulsed electric fields. *Food Technol.* 49(12), 55–60.

Qin, B.L., Barbosa-Canovas, G. V., Swanson, B.G., Pedrow, P.D. and Olsen, R.G. (1998). Inactivating microorganisms using a pulsed electric field continuous treatment system. *IEEE Transactions on Industry Applications*.

Qin, B.L., Pothakamury, U.R., Barbosa-Cánovas, G. V. and Swanson, B.G. (1996).

Nonthermal Pasteurization of Liquid Foods Using High-Intensity Pulsed Electric Fields. *Critical Reviews in Food Science and Nutrition*. 36(6), 603–627.

Ramaswamy, R., Jin, T., Balasubramaniam, V.M. and Zhang, H. (2005). Pulsed electric field processing: fact sheet for food processors. *Ohio State University Extension Factsheet*. 22.

Raso, J., Frey, W., Ferrari, G., Pataro, G., Knorr, D., Teissie, J. and Miklavčič, D. (2016). Recommendations guidelines on the key information to be reported in studies of application of PEF technology in food and biotechnological processes. *Innovative Food Science and Emerging Technologies*.

Ray, B. (2005). *Fundamental Food Microbiology*,

Reberšek, M., Faurie, C., Kandušer, M., Korović, S., Teissié, J., Rols, M.P. and Miklavčič, D. (2007). Electroporator with automatic change of electric field direction improves gene electrotransfer in-vitro. *BioMedical Engineering Online*. 6.

Reberšek, M. and Miklavčič, D. (2011)(a). Advantages and disadvantages of different concepts of electroporation pulse generation. *Automatika: časopis za automatiku, mjerenje, elektroniku, računarstvo i komunikacije*. 52(1), 12–19.

Reberšek, M. and Miklavčič, D. (2011)(b). Advantages and Disadvantages of Different Concepts of Electroporation Pulse Generation. *Automatika*.

Resurreccion, A.V.A., Galvez, F.C.F., Fletcher, S.M. and Misra, S.K. (1995). Consumer attitudes toward irradiated food: results of a new study. *Journal of Food Protection*. 58(2), 193–196.

Robinson, R.K. (2014). *Encyclopedia of food microbiology*, Academic press.

Roodenburg, B., Morren, J., Berg, H.E. (Iekje) and de Haan, S.W.H. (2005). Metal release in a stainless steel Pulsed Electric Field (PEF) system. *Innovative Food Science & Emerging Technologies*.

Saldaña, G., Cebrián, G., Abenoza, M., Sánchez-Gimeno, C., Álvarez, I. and Raso, J. (2017). Assessing the efficacy of PEF treatments for improving polyphenol extraction during red wine vinifications. *Innovative Food Science and Emerging Technologies*.

Sale, a J.H. and Hamilton, W. a (1967). Effects of high electric fields on microorganisms: I. Killing of bacteria and yeasts. *Biochimica et Biophysica Acta (BBA) - General Subjects*.

Sale, A.J.H. and Hamilton, W.A. (1968). Effects of high electric fields on micro-organisms. III. Lysis of erythrocytes and protoplasts. *BBA - Biomembranes*.

Sarkar, A., Mitra, B., Shastry, A., Wadia, S., Mulherkar, R. and Lal, R. (2004). A low voltage single cell electroporator with a microfabricated sense-porate aperture. In *Proceedings of the IEEE International Conference on Micro Electro Mechanical Systems (MEMS)*.

Saulis, G. (2010). Electroporation of cell membranes: The fundamental effects of pulsed electric fields in food processing. *Food Engineering Reviews*.

Schoenbach, K.H., Joshi, R.P., Stark, R.H., Dobbs, F.C. and Beebe, S.J. (2000)(a). Bacterial decontamination of liquids with pulsed electric fields. *IEEE Transactions on Dielectrics and Electrical Insulation*.

Schoenbach, K.H., Joshi, R.P., Stark, R.H., Dobbs, F.C. and Beebe, S.J. (2000)(b). Bacterial decontamination of liquids with pulsed electric fields. *IEEE Transactions on Dielectrics and Electrical Insulation*. 7(5), 637–645.

Sepulveda, D.R. and Barbosa-Cánovas, G. V. (2005). Present status and the future of PEF technology. In *Novel Food Processing Technologies*.

Shirriff, K. (2020). Secrets of Arduino PWM. *Ken Shirriff's blog*. Available at: http://www.righto.com/2009/07/secrets-of-arduino-pwm.html.

Smelt, J.P.P.. (1998). Recent advances in the microbiology of high pressure processing. *Trends in Food Science & Technology*. 9(4), 152–158.

Stankevič, V., Novickij, V., Balevičius, S., Žurauskiene, N., Baškys, A., Dervinis, A. and Bleizgys, V. (2013). Electroporation system generating wide range square-wave pulses for biological applications. In *2013 IEEE Biomedical Circuits and Systems Conference, BioCAS 2013*.

Starodubtseva, G.P., Livinskiy, S.A., Gabriyelyan, S.Z., Lubaya, S.I. and Afanacev, M.A. (2018). Process control of pre-sowing seed treatment by pulsed electric field. *Acta Technologica Agriculturae*. 21(1), 28–32.

Sun, J. and Wang, P. (2014). A CMOS short pulse generator with a high-voltage stacked MOSFET switch. In *Midwest Symposium on Circuits and Systems*.

Sundararajan, R., Shao, J., Soundarajan, E., Gonzales, J. and Chaney, A. (2004). Performance of solid-state high-voltage pulsers for biological applications-a preliminary study. *IEEE Transactions on plasma science*. 32(5), 2017–2025.

Tatebe, W., Muraji, M., Fujii, T. and Berg, H. (1995). Re-examination of electropermeabilization on yeast cells: dependence on growth phase and ion concentration. *Bioelectrochemistry and bioenergetics*. 38(1), 149–152.

Tewari, G. and Juneja, V. (2008). *Advances in thermal and non-thermal food preservation*, John Wiley & Sons.

Thomas, P., Mujawar, M.M., Sekhar, A.C. and Upreti, R. (2014). Physical impaction injury effects on bacterial cells during spread plating influenced by cell characteristics of the organisms. *Journal of applied microbiology*. 116(4), 911–922.

Thomas, P., Sekhar, A.C. and Mujawar, M.M. (2012). Nonrecovery of varying proportions of viable bacteria during spread plating governed by the extent of spreader usage and proposal for an alternate spotting-spreading approach to maximize the CFU. *Journal of applied microbiology*. 113(2), 339–350.

Toepfl, S. (2011). Pulsed Electric Field food treatment - scale up from lab to industrial scale. *Procedia Food Science*.

Toepfl, S., Heinz, V. and Knorr, D. (2006). Applications of pulsed electric fields technology for the food industry. In *Food Engineering Series*.

Toshiba (2020). What is the difference between MOSFETs and IGBTs? *Toshiba Electronic Devices & Storage Corporation*. Available at: https://toshiba.semicon-storage.com/ap-en/design-support/faq/mosfet_igbt/igbt-002.html.

Tsong, T.Y. (1991). Electroporation of cell membranes. *Biophysical Journal*.

Vega-Mercado, H., Martín-Belloso, O., Chang, F.J., Barbosa-Ccanovas, G. V. and Swanson, B.G. (1996). Inactivation of Escherichia coli and Bacillus subtilis suspended in pea soup using pulsed electric fields. *Journal of Food Processing and Preservation*.

Vega-Mercado, H., Martin-Belloso, O., Qin, B.-L., Chang, F.J., Góngora-Nieto, M.M., Barbosa-Canovas, G. V and Swanson, B.G. (1997). Non-thermal food preservation: pulsed electric fields. *Trends in Food Science & Technology*. 8(5), 151–157.

Weaver, J.C. and Chizmadzhev, Y.A. (1996). Theory of electroporation: a review. *Bioelectrochemistry and bioenergetics*. 41(2), 135–160.

Xie, F., Varghese, F., Pakhomov, A.G., Semenov, I., Xiao, S., Philpott, J. and Zemlin, C. (2015). Ablation of myocardial tissue with nanosecond pulsed electric fields. *PLoS ONE*.

Žgalin, M.K., Hodžić, D., Reberšek, M. and Kandušer, M. (2012). Combination of

Microsecond and Nanosecond Pulsed Electric Field Treatments for Inactivation of Escherichia coli in Water Samples. *The Journal of Membrane Biology*. 245(10), 643–650.

Zhang, Q., Barbosa-Cánovas, G. V. and Swanson, B.G. (1995). Engineering aspects of pulsed electric field pasteurization. *Journal of Food Engineering*. 25(2), 261–281.

Zhang, Qinghua, MONSALVE-GONZÁLEZ, A., QIN, B. -L, BARBOSA-CÁNOVAS, G. V. and SWANSON, B.G. (1994). Inactivation of Saccharomyces Cerevisiae In Apple Juice By Square-Wave And Exponential-Decay Pulsed Electric Fields. *Journal of Food Process Engineering*.

Zhang, Q., Mosalve-Gonzalez, A., Barbosa-Canovas, G. V. and Swanson, B.G. (1994). Inactivation of E.coli and S.cerevisiae by pulsed electric fields under controlled temperature conditions. *Transactions of the American Society of Agricultural Engineers*.

Zhao, W., Yang, R., Liang, Q., Zhang, W., Hua, X. and Tang, Y. (2012). Electrochemical reaction and oxidation of lecithin under pulsed electric fields (PEF) processing. *Journal of agricultural and food chemistry*. 60(49), 12204–12209.

Zimmermann, U. (1986). Electrical breakdown, electropermeabilization and electrofusion. In *Reviews of Physiology, Biochemistry and Pharmacology, Volume 105*. Springer, pp.175–256.

Zimmermann, U., Pilwat, G., Beckers, F. and Riemann, F. (1976). Effects of external electrical fields on cell membranes. *Bioelectrochemistry and Bioenergetics*.

Zimmermann, U., Pilwat, G. and Riemann, F. (1974). Dielectric Breakdown of Cell Membranes. *Biophysical Journal*.

LIST OF PUBLICATIONS

1. Temperature Distribution Analysis in Parallel Plate Treatment Chamber for Pulsed Electric Field Processing: Numerical Study
   NF Kasri, MAM Piah, A Hamzah, Z Adzis
   ASEAN Engineering Journal, 12(3), pp.63-69.
2. Microcontroller-based pulse signal controller development for compact high voltage pulse generator: Practical development in food treatment technology
   NF Kasri, MAM Piah, A Hamzah, Z Adzis
   Journal of Food Processing and Preservation, 45(6), p.e15531
3. Compact high-voltage pulse generator for pulsed electric field applications: Lab-scale development
   NF Kasri, MAM Piah, Z Adzis
   Journal of Electrical and Computer Engineering 2020
4. Development of compact pulse generator with adjustable pulse width for pulse electric field treatment technology
   NF Kasri, MAM Piah
   International Journal of Power Electronics and Drive Systems 9 (2), 889
5. A compact and reliable pulse generator using dual 555-timer IC to produce PWM method
   NF Kasri, MAM Piah
   2017 IEEE Conference on Energy Conversion (CENCON), 100-104