ABSTRACT

This project presents the development of a Pulsed Electric Field (PEF)-based water purification system that utilizes a high-voltage pulse generator to achieve microbial inactivation in drinking water. With increasing demand for safe and sustainable water treatment technologies, this approach eliminates the need for chemical disinfectants by leveraging irreversible electroporation. The system integrates a low-voltage DC power source, a boost converter, and a Capacitor Diode Voltage Multiplier (CDVM) circuit to generate pulsed high-voltage outputs. An IGBT switch, controlled through a pulse generation mechanism, shapes the output into narrow electric pulses, which are then applied across the water sample using high-voltage electrodes. These electric pulses disrupt microbial cell membranes, effectively sterilizing the water. The design was validated through simulation in MATLAB and tested with a hardware prototype. The system demonstrated a stable high-voltage output (~3kV), consistent capacitor charging, and successful microbial reduction in experimental trials. This method is energy-efficient, cost-effective, and scalable, making it suitable for rural and urban deployment in decentralized water treatment systems.

INTRODUCTION

PURIFICATION NEED IN DRINKING WATER

Access to clean and safe drinking water is a fundamental necessity for human health and well-being. However, conventional water purification systems often face limitations in terms of efficiency, scalability, and environmental sustainability. With increasing urbanization, industrialization, and agricultural activities, drinking water sources have become vulnerable to contamination by a wide range of pathogens and chemical pollutants.

This has created a pressing need for innovative, energy-efficient, and chemical-free purification technologies. Traditional purification methods, such as chlorination and boiling, although effective, may not be suitable for all environments due to their dependency on continuous chemical supply or energy resources. Moreover, the use of chlorine can lead to the formation of harmful disinfection by-products like trihalomethanes (THMs), which pose additional health risks.

These limitations have driven research into alternative methods that can provide rapid, effective, and environmentally friendly water disinfection. One such advanced method is the application of Pulsed Electric Fields (PEF) for the inactivation of microbial contaminants. PEF is a non-thermal technique that applies high-voltage electric pulses across the water sample to disrupt the cell membranes of bacteria and other pathogens through a process known as irreversible electroporation.

The high electric field intensity—typically up to 50 kV/cm—creates pores in microbial cell membranes, leading to cell death without the need for heat or chemical additives. To generate these high-voltage pulses, a specialized circuit configuration is utilized, comprising a DC-DC boost converter and a capacitor-diode voltage multiplier (CDVM). The boost converter steps up the input DC voltage, and the CDVM further amplifies it to produce the desired high-voltage output. This output is then modulated using an IGBT-based switching mechanism to produce sharp pulses of controlled width and frequency.

These pulses are applied to water via high-voltage electrodes. Unlike continuous electric fields, which can lead to electrolysis and electrode degradation, PEF systems use intermittent pulses to minimize such effects, thereby enhancing electrode lifespan and system efficiency. Additionally, PEF systems can operate at relatively low power while delivering high energy density to the target pathogens, making them highly efficient. A key advantage of PEF-based purification systems is their modular and scalable design.

Such systems can be compact and lightweight, making them ideal for rural, remote, and off-grid communities where access to conventional water treatment infrastructure is limited. Moreover, by incorporating a closed-loop control system—typically implemented using a microcontroller like the Arduino Nano—it is possible to dynamically adjust parameters such as pulse frequency, voltage, and duty cycle in response to varying water quality conditions.

This ensures safe operation, improved energy management, and the potential for IoT integration for remote monitoring and diagnostics. In conclusion, the need for advanced purification solutions like PEF arises from the limitations of traditional water treatment methods. By leveraging the principles of high-voltage pulse generation using boost converters and voltage multipliers, and by integrating intelligent control systems, it is possible to develop a robust, cost-effective, and sustainable solution for ensuring access to clean drinking water, particularly in underserved regions.

METHODOLOGY

The methodology of this project is structured around the design, development, and testing of a Pulsed Electric Field (PEF) based water purification system that utilizes high-voltage electric pulses to inactivate harmful microorganisms in drinking water. The system operates on the principle of electroporation, where short-duration, high-intensity electric pulses disrupt microbial cell membranes, leading to their deactivation without the need for chemicals or high temperatures.

The project adopts a phase-wise approach, covering each critical component, including power circuit design, pulse generation, control implementation, and system validation. The initial phase begins with the design of the high-voltage pulse generation module, which comprises a DC-DC boost converter followed by a Capacitor Diode Voltage Multiplier (CDVM). A low-voltage DC supply is used as the primary input, typically sourced from a regulated adapter or a DC battery source.

The boost converter elevates the voltage to a desired intermediate level, and the CDVM further multiplies it to reach output voltage levels up to several kilovolts. This output voltage is essential for generating effective electric field intensities capable of disrupting microbial cells in water. The next step involves the design of the pulse modulation circuit, which uses an IGBT (Insulated Gate Bipolar Transistor) or high-speed MOSFET as a switch.

This switch chops the high DC voltage into sharp, high-voltage pulses of controlled duration and frequency. The pulse characteristics—such as width, amplitude, and repetition rate—are carefully selected based on literature guidelines to ensure effective microbial inactivation while minimizing energy consumption.

Typical pulse durations range from tens of nanoseconds to a few microseconds, with field intensities up to 50 kV/cm. Once the high-voltage pulses are generated, they are applied across a treatment chamber containing the water sample.

OBJECTIVES

- Design a high-voltage water purification system using the Pulsed Electric Field (PEF) method.
- Ensure energy-efficient and chemical-free purification suitable for rural and off-grid areas.
- Use high-voltage electric pulses to effectively kill bacteria and pathogens in water.
- Avoid using chemicals or heat, which can harm water quality or consume more energy.
- Develop a DC-DC boost converter combined with a Capacitor-Diode Voltage Multiplier (CDVM) to generate the required high voltage from a low-voltage source.
- Implement a high-speed switching system (like an IGBT) to generate short electric pulses of desired frequency and duration.
- Design water-safe electrodes that apply electric pulses directly to the contaminated water.
- Ensure the system is safe, reliable, and energy-efficient while maintaining the physical and chemical quality of water.

LITERATURE REVIEW

Schoenbach et al. (1997) have investigated the impact of Pulsed Electric Fields (PEF) on biological cells and demonstrated that ultra-short, high-intensity electric pulses can effectively disrupt cell membranes. Their findings laid the groundwork for non-thermal microbial inactivation, highlighting PEF's potential in biomedical and water treatment applications.[10]

Qing et al. (2008) have proposed the use of Pulsed Electric Field (PEF) technology for effective water disinfection. Their study demonstrated that short, high-voltage electric pulses can inactivate microorganisms without the need for chemical additives or thermal treatment, making it a promising method for clean and energy-efficient water purification.[7]

Yang et al. (2010) have designed a high-voltage Pulsed Electric Field (PEF) generator aimed at sterilization applications. Their system efficiently delivered controlled high-voltage pulses to achieve effective microbial inactivation, demonstrating the feasibility of using PEF technology in compact and reliable sterilization systems.[14]

Redondo and Calado (2010) have presented an optimized design of Capacitor-Diode Voltage Multipliers (CDVM) for high-voltage power supply applications. Their work focused on enhancing voltage gain, efficiency, and compactness, making CDVMs highly suitable for integration into systems like PEF generators requiring high-voltage, low-ripple outputs.[8]

Elserougi et al. (2016) have developed a multi-module high-voltage generator integrating DC-DC boost converters and Cockcroft-Walton Voltage Multipliers (CDVMs) for drinking water purification. Their design enabled scalable voltage generation with enhanced efficiency and modularity, demonstrating the potential for effective PEF-based water treatment in decentralized and cost-sensitive environments.[3]

MATERIALS AND METHODS

ARDUINO UNO

The Arduino Uno in Fig 3.1 plays a crucial role in this project by serving as the central control unit for the Pulsed Electric Field (PEF) based water purification system. It is responsible for generating precise digital pulses to drive the MOSFETs that switch the high-voltage power supply, enabling the application of short, high-intensity electric fields across the electrodes through which water flows. These electric pulses disrupt the cell membranes of bacteria and other pathogens, effectively inactivating them without altering the chemical properties of the water. The Arduino also allows dynamic adjustment of the pulse width, frequency, and duty cycle, which are key parameters in ensuring effective microbial inactivation while optimizing energy efficiency.

ARDUINO UNO

N-CHANNEL MOSFET IRF540N

The N-Channel MOSFET IRF540N shown in Fig 3.2 serves as the core high-speed switching component in the Pulsed Electric Field (PEF) water purification system. Controlled by digital signals from the Arduino Uno [3.1], the IRF540N is used to switch a high-voltage DC source on and off in rapid pulses. These fast pulses are applied across the electrodes through which water flows, generating strong electric fields that effectively disrupt and inactivate microbial cell membranes. This switching action is vital to the core disinfection mechanism of the PEF process. The IRF540N is chosen for its high current handling, low on-resistance (R_{DS(on)}), and fast switching characteristics, which allow for efficient and precise control of high-voltage pulses.

N-CHANNEL MOSFET

BOOST CONVERTER

The DC-DC Boost Converter module in Fig 3.3 is a vital component in this system, designed to step up (boost) a lower DC input voltage to a higher DC output voltage, ensuring that connected loads receive the required operating voltage. This module works on the principle of high-frequency switching, where an inductor stores energy when the internal switch (typically a MOSFET) is on and releases it to the output through a diode when the switch is off. This controlled energy transfer increases the voltage level effectively. Operating at high frequencies (typically in the tens or hundreds of kHz), the boost converter offers a compact size, efficient performance, and faster response time compared to linear regulators. The module typically includes key components such as a high-speed switching transistor, fast-recovery diode, inductor, output capacitor, and a feedback control system for regulating the output voltage. The adjustable potentiometer on the module allows precise tuning of the output voltage, providing flexibility for a range of applications.

BOOST CONVERTER

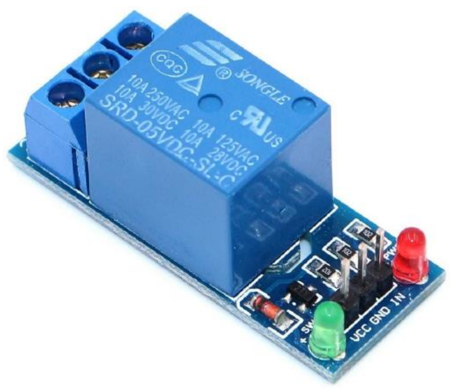
WATER PUMP

The 12V water pump illustrated in Fig 3.4 plays an essential role in facilitating fluid movement through the purification system. This compact and efficient diaphragm pump is powered by a 12V DC supply and is capable of delivering consistent flow rates suitable for small- to medium-scale water purification setups. It functions by drawing water from the source and pushing it through the Pulsed Electric Field (PEF) chamber, ensuring a continuous supply for treatment. The diaphragm mechanism within the pump allows it to handle liquids with minimal mechanical wear, reducing maintenance requirements and extending service life. Designed for low-voltage, energy-efficient operation, the pump offers quiet performance, low current consumption, and high reliability, making it ideal for portable or solar-powered purification systems. Its sealed construction ensures that the motor and electrical components are protected from water ingress, enhancing safety in wet environments. Additionally, the pump's anti-corrosive materials make it suitable for use with treated or untreated water, contributing to the durability of the overall purification unit.

WATER PUMP

RELAY

The 5V relay module depicted in Fig 3.5 is a vital electromechanical switching component that enables low-power control signals, such as those from an Arduino or microcontroller, to manage high-voltage or high-current loads safely and efficiently. In the context of this project, the relay acts as an intermediary switch, allowing the microcontroller to turn high-power devices—like the 12V water pump or the PEF chamber power supply—on and off without direct electrical connection. The module features a Songle SRD-05VDC-SL-C relay, capable of switching AC loads up to 250V at 10A and DC loads up to 30V at 10A. It includes opto-isolation circuitry to protect the control circuit from voltage spikes or electrical noise from the load side. The input side includes pins for VCC, GND, and IN (signal), with onboard indicator LEDs providing visual feedback on the relay's activation status (red LED for power, green LED for switching).This relay module ensures electrical isolation between the low-voltage control circuit and the high-voltage load, significantly enhancing safety and circuit stability.



RELAY

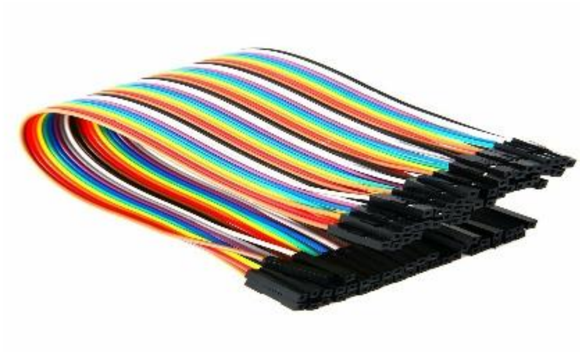
12VDC ADAPTER

The 12V DC 2A power adapter shown in Fig 3.6 is a regulated switching power supply unit that provides a stable 12-volt output with a maximum current capacity of 2 amps. This adapter is essential for supplying consistent and reliable power to various components in the project, such as the Arduino controller, relay modules, and 12V mini water pump. It converts standard AC mains voltage (100–240V AC, 50/60 Hz) into a low-voltage DC output, making it ideal for low-power embedded systems and electronic devices. The adapter features a barrel jack connector, which allows for easy and secure connection to common DC input jacks on microcontroller boards and peripheral devices. This power adapter is designed with built-in protection mechanisms, including over-voltage, over-current, and short-circuit protection, ensuring safe operation and extending the lifespan of connected components. Its compact and lightweight design also makes it well-suited for both lab testing and field deployment of the water purification system. In this project, the 12V DC adapter plays a crucial role in powering the pulsed electric field generation circuit, the water pump, and the control system, ensuring stable operation and consistent performance throughout the purification cycle.

12VDC ADAPTER

JUMPER WIRES

The jumper wires shown in Fig 3.7 are essential components used for creating electrical connections in a circuit without the need for soldering. These wires are commonly used in breadboarding, prototyping, and connecting various modules, sensors, and microcontroller boards like Arduino. They are available in three types: male-to-male, female-to-female, and male-to-female, each suited for different interconnections depending on the pin configuration of the components. The jumper wires are typically made of multi-stranded copper wire for flexibility and durability and are insulated with PVC to prevent short circuits. Each wire is color-coded, which helps in organizing and identifying connections easily during complex circuit development. The connectors at the ends ensure a firm grip on headers, sockets, or pins, allowing for secure and reusable connections.



JUMPER WIRES

LED

The LEDs shown in Fig 3.8 are fundamental components widely used in electronic circuits for visual indication and illumination. LEDs (Light Emitting Diodes) are semiconductors that emit light when an electric current passes through them. They are popular in breadboarding, prototyping, and final electronic products due to their low power consumption, long life, and high efficiency. LEDs come in various colors—such as red, green, blue, yellow, and white—each corresponding to different forward voltage requirements. The two terminals of an LED are the anode (positive) and the cathode (negative), which must be connected with the correct polarity in a circuit for proper operation. To prevent damage from excessive current, LEDs are typically used in series with a current-limiting resistor. These components are also available in different sizes (e.g., 3mm, 5mm) and package types for compatibility with a range of applications. Their compact design and low heat generation make them ideal for use in indicators, displays, and signaling in embedded systems like Arduino-based projects.

LED

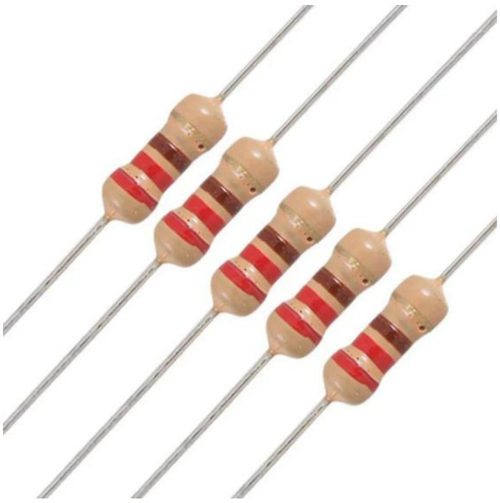
HW BATTERY

The HW battery shown in Fig 3.9 is a crucial power source component used to provide portable DC voltage for electronic circuits and projects. Commonly used in breadboarding, prototyping, and embedded system applications like Arduino, these batteries typically supply 9V, which can be regulated to power various components and modules. HW batteries are compact, lightweight, and ideal for powering low-current circuits where a stable voltage supply is required without relying on a wired power source. They are often connected using a battery clip with color-coded wires (usually red for positive and black for negative) that make it easy to identify polarity during circuit development. The battery clips usually come with either bare wire ends or standard connectors, allowing for seamless integration into breadboards or power jacks. The battery's reliable energy output makes it suitable for testing sensors, driving small loads like LEDs or motors, and enabling mobile operation of microcontroller-based systems.

HW BATTERY

RESISTOR

The 220kΩ resistor shown in Fig 3.10 is a passive electronic component used to limit current flow, divide voltages, and protect sensitive components in a circuit. It plays a vital role in breadboarding, prototyping, and building stable electronic circuits, including those involving microcontrollers like Arduino. A resistor with a resistance value of 220 kilo-ohms (kΩ) offers high resistance, making it suitable for applications such as pull-up or pull-down configurations, biasing transistors, and setting time constants in RC (resistor-capacitor) circuits. It helps in controlling the amount of current passing through other components, thereby ensuring safe and reliable operation. Resistors are typically made from carbon film or metal film material, ensuring durability and consistent performance. The 220kΩ resistor is identified by its color bands—red, red, yellow, and gold—which indicate its resistance value and tolerance as per the resistor color code.



220KOHM RESISTOR

EXPERIMENTAL SETUP AND PROCEDURE

THE EXISITING SYSTEM

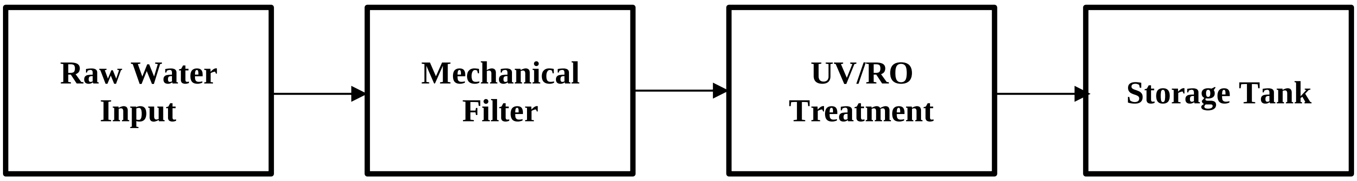
The existing system in Fig 4.1 for drinking water disinfection using a Pulsed Electric Field (PEF) operates from a stable DC power supply, typically derived from rectified and filtered AC mains. In this configuration, a high-voltage pulse generator is used to process the DC input and convert it into high-intensity, short-duration electrical pulses that are applied across electrodes submerged in the water chamber.

The system consists of a DC-DC converter stage for stepping up the input voltage, a high-voltage switch (such as a MOSFET or IGBT) for chopping the DC into pulses, and treatment electrodes positioned to expose the flowing water to the electric field. These pulsed fields cause irreversible electroporation of microbial cell membranes, leading to the effective inactivation of bacteria and viruses in the water.

In the absence of dynamic water quality monitoring, the pulse parameters—such as voltage, frequency, and pulse width—are typically set based on empirical values. This fixed-operation model simplifies the circuit design but limits the system's adaptability to varying water conditions. The high-voltage switch is controlled by a basic timing circuit or pulse generator, producing a repetitive pulse train at predefined intervals.

The energy from each pulse is transferred directly to the electrodes, with the strength and duration calibrated to ensure effective disinfection while minimizing electrolysis or thermal damage to the water. Since the input voltage remains relatively constant, the system can operate without the need for closed-loop control. However, the absence of feedback mechanisms, real-time sensors, or programmable control limits the system’s efficiency and protection features.

BLOCK DIAGRAM OF THE EXISTING SYSTEM



BLOCK DIAGRAM OF EXISTING SYSTEM

The block diagram illustrates a multi-stage water purification system designed to convert raw water into clean, potable water suitable for storage and consumption. The process begins with the Raw Water Input, where untreated water—potentially containing sediments, microorganisms, and dissolved contaminants—is introduced into the system. This water first passes through a Mechanical Filter, which removes larger physical impurities such as dirt, sand, and rust particles using coarse filtration media like sand, gravel, or mesh. This step protects downstream components and improves overall efficiency. The partially filtered water then enters the UV/RO Treatment unit. In this stage, Ultraviolet (UV) light is used to disinfect the water by inactivating harmful microorganisms such as bacteria and viruses through DNA disruption. Concurrently or alternatively, Reverse Osmosis (RO) is employed to remove dissolved salts, heavy metals, and other minute impurities by forcing water through a semi-permeable membrane under pressure. The final output—purified and disinfected water—is then directed into a Storage Tank, where it is safely held for later use. This tank may be equipped with features to preserve water quality, such as airtight seals or level sensors. Overall, the system integrates physical, biological, and chemical treatment methods to ensure the delivery of safe and clean water.

THE PROPOSED SYSTEM

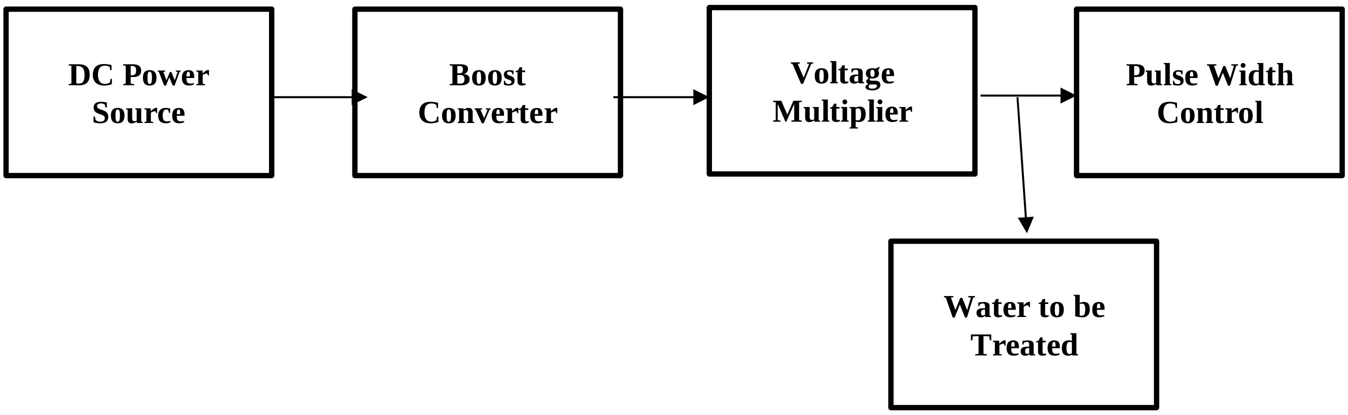
The proposed system in Fig 4.2 introduces a water purification architecture based on pulsed electric fields (PEF), integrating a DC-DC boost converter, capacitor diode voltage multipliers (CDVM), and a closed-loop control strategy. The primary goal is to generate high-voltage electric pulses capable of disrupting microbial cell membranes, thereby achieving effective sterilization of drinking water.

The system begins with a low-voltage DC source, which serves as the initial input for the boost converter. This converter steps up the voltage to an intermediate level and regulates it via a Proportional-Integral (PI) controller for maintaining output stability. At the heart of the pulse generator lies the CDVM circuit.

The regulated voltage from the boost converter is further amplified through multiple CDVM stages to achieve the high voltage levels required for PEF treatment. The number of multiplier stages can be selected based on the desired output voltage and system efficiency. A high-voltage IGBT-based switching unit is then employed to chop the amplified voltage, creating pulses of precise width and frequency. These high-voltage pulses are applied across a pair of electrodes submerged in water.

The resulting electric field causes irreversible electroporation of microbial cell membranes, ensuring the destruction of bacteria and pathogens without chemical additives. This method is energy-efficient, chemical-free, and ideal for rural or off-grid areas where clean water is a necessity. The system supports closed-loop feedback for voltage regulation, and its simulation confirms the viability of the design for real-time water treatment applications.

BLOCK DIAGRAM OF THE PROPOSED SYSTEM



BLOCK DIAGRAM OF PROPOSED SYSTEM

The block diagram represents the working principle of a Pulsed Electric Field (PEF)-based water purification system designed to disinfect drinking water using short bursts of high-voltage electric pulses. The process begins with a DC power source, which serves as the primary input to the system, typically derived from a regulated DC adapter or a renewable source like a battery or solar panel. This low-voltage input is fed into a DC-DC boost converter that steps up the voltage to a higher intermediate level using high-frequency switching. The boosted voltage is then passed into a voltage multiplier circuit, specifically a Capacitor-Diode Voltage Multiplier (CDVM), which further amplifies the DC voltage to several kilovolts required for PEF treatment. The high-voltage output from the multiplier is sent to the pulse width control unit, where a switching device such as an IGBT or MOSFET is used to generate short-duration, high-intensity electric pulses.

WORKING OF PEF CIRCUIT

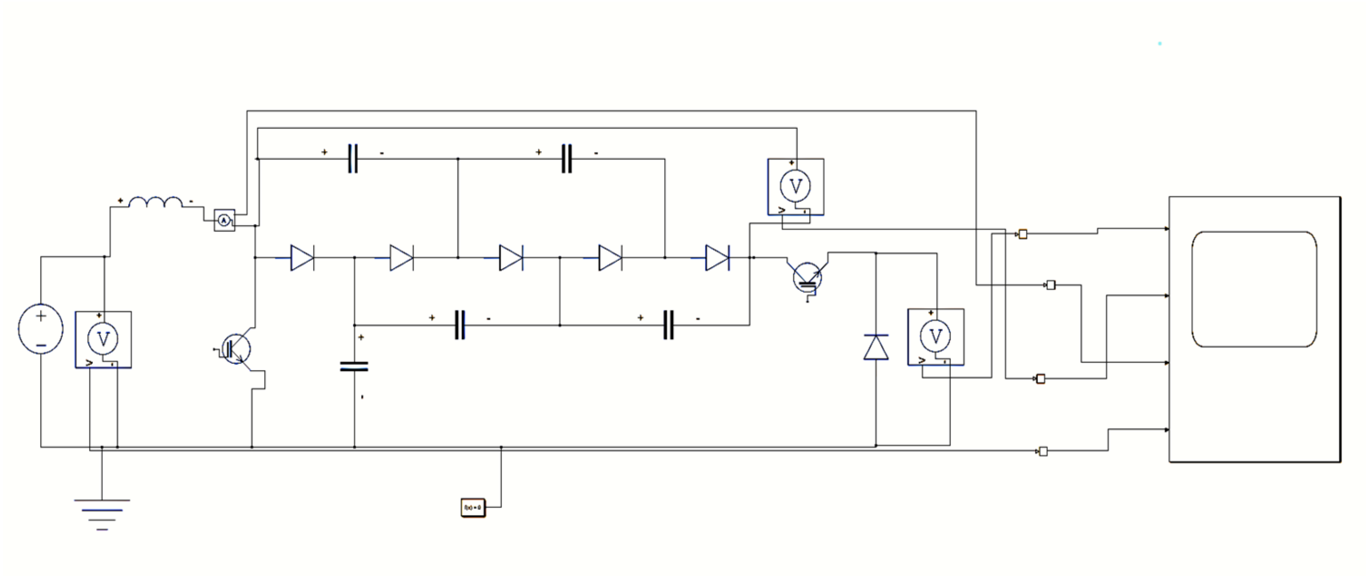
The working principle of the proposed high voltage electric pulse generator for water purification involves generating pulsed electric fields (PEF) using a combination of a boost converter, capacitor diode voltage multipliers (CDVM), and controlled pulse modulation. The system begins with a low-voltage DC source that provides the input power to the boost converter. This converter steps up the voltage to an intermediate regulated DC level through a controlled switching process.

The boost converter operates in closed-loop mode where its output voltage is continuously compared with a reference value. The resulting error signal is processed using a Proportional-Integral (PI) controller which dynamically adjusts the duty cycle of the converter. The adjusted duty cycle is compared with a high-frequency triangular waveform to generate gate pulses for the controlled power switch, typically an IGBT. The regulated output from the boost converter is then supplied to the CDVM circuit. This voltage multiplier section consists of multiple diode-capacitor stages arranged in a half-wave parallel configuration.

Each stage contributes to a proportional increase in voltage, resulting in a high-voltage DC output. The number of stages determines the final output voltage, and this relationship is carefully selected to ensure efficient voltage gain while maintaining a moderate boost converter duty cycle. Once the high voltage DC output is available, an IGBT is used to chop this output into pulses with controlled width and frequency.

These pulsed outputs form the high voltage electric pulses required for water purification. The switching frequency and pulse duration are governed by the gate pulse timing of the IGBT, which ensures that the pulses are short enough to avoid electrolysis but strong enough to induce irreversible permeabilization of microbial cell membranes. The generated high-voltage pulses are then applied across a pair of electrodes submerged in the water sample.

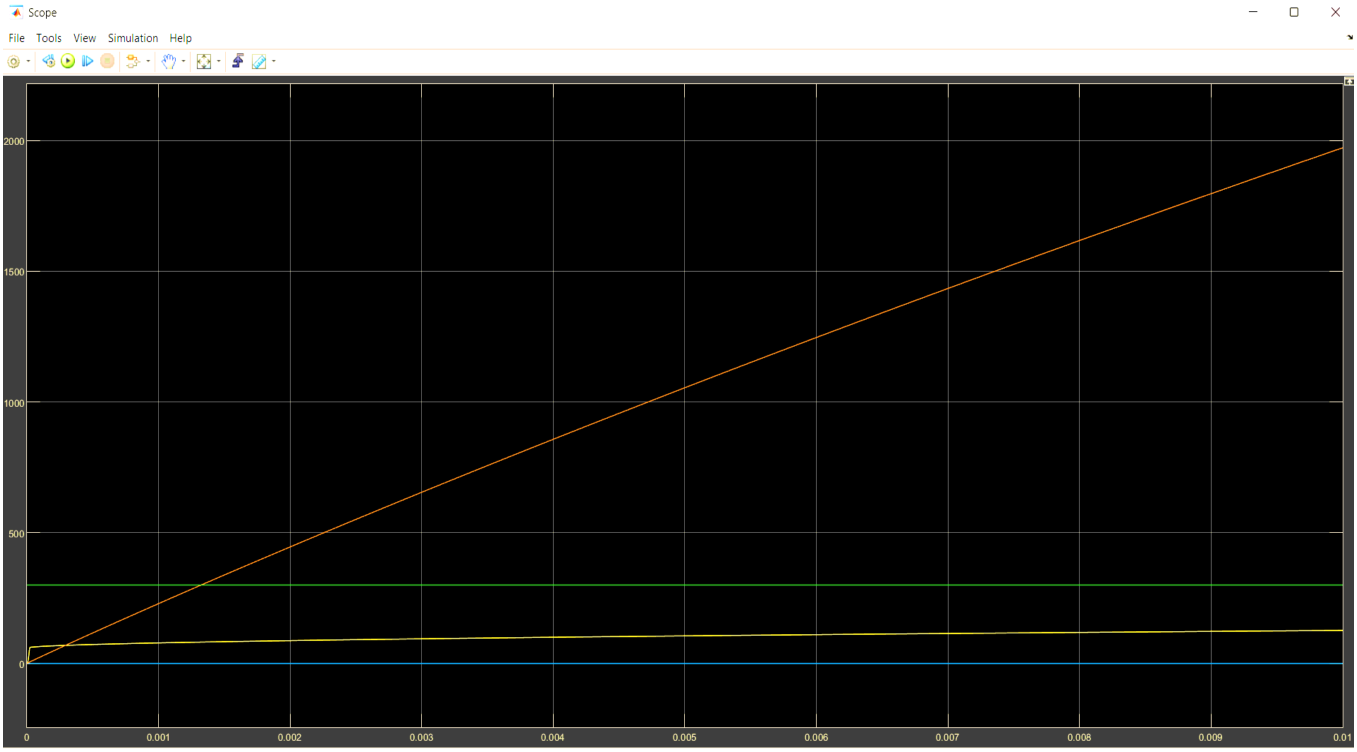
MATLAB SIMULATION



SIMULATION DIAGRAM OF THE PROJECT

The above simulation diagram represents a Pulsed Electric Field (PEF)-based Water Purification System modelled in MATLAB Simulink. The system begins with a DC voltage source, which is stepped up using a DC-DC boost converter comprising an inductor, a high-speed switch (IGBT/MOSFET), and a diode to produce a regulated intermediate voltage. This intermediate voltage is fed into a Capacitor Diode Voltage Multiplier (CDVM) circuit, composed of multiple stages of capacitors and diodes. Each stage successively increases the voltage, enabling the generation of a high-voltage DC suitable for PEF treatment.

SIMULATION OUTPUT OF THE PROJECT



SIMULATION OUTPUT OF THE PROJECT

This output waveform represents the voltage evolution at various stages of the Pulsed Electric Field (PEF) Water Purification System, simulated in MATLAB Simulink. The different colored traces illustrate the behavior of the boost converter output, individual CDVM stage voltages, and the final high-voltage output across the electrodes .The orange waveform indicates a steadily increasing high-voltage output, showing the successful voltage multiplication through the CDVM stages. The flatter traces represent stabilized voltages across the intermediate multiplier capacitors and regulated boost output.

CODE USED

```
#define pulsePin 8      // PEF pulse control (MOSFET gate)
#define pumpPin 3       // Relay to control pump
#define redLED 6        // Red LED: PEF active
#define greenLED 5      // Green LED: Pump active

const unsigned long pulseDuration = 10000; // 10 seconds for pulses
const unsigned long pumpDuration = 10000;   // 10 seconds for pump

void setup() {
  pinMode(pulsePin, OUTPUT);
  pinMode(pumpPin, OUTPUT);
  pinMode(redLED, OUTPUT);
  pinMode(greenLED, OUTPUT);

  // Initialize all outputs to LOW
  digitalWrite(pulsePin, LOW);
  digitalWrite(pumpPin, LOW);
  digitalWrite(redLED, LOW);
  digitalWrite(greenLED, LOW);
}

void loop() {
  // STEP 1: Apply PEF pulses for 10 seconds
  digitalWrite(redLED, HIGH); // Turn ON red LED
  unsigned long startTime = millis();

  while (millis() - startTime < pulseDuration) {
    digitalWrite(pulsePin, HIGH);
    delayMicroseconds(20);     // Pulse width
    digitalWrite(pulsePin, LOW);
```

```
    delay(1);                  // 1 kHz frequency
  }
  digitalWrite(redLED, LOW);   // Turn OFF red LED
  digitalWrite(pulsePin, LOW); // Ensure MOSFET is OFF

  // STEP 2: Turn on pump to move treated water
  digitalWrite(greenLED, HIGH); // Turn ON green LED
  digitalWrite(pumpPin, HIGH);  // Turn ON pump
  delay(pumpDuration);          // Run pump for 5 seconds
  digitalWrite(pumpPin, LOW);   // Turn OFF pump
  digitalWrite(greenLED, LOW);  // Turn OFF green LED

  // STOP or restart cycle
  while (true); // System halts (remove this if you want repeat)
}
```

DESIGN OF THE CIRCUIT

The design of the PEF-based high voltage pulse generator circuit is centered around a combination of a DC-DC boost converter, a Capacitor Diode Voltage Multiplier (CDVM), and a pulse shaping unit. This architecture is optimized to produce short, high-voltage electric pulses capable of disrupting microbial cell membranes, enabling chemical-free water sterilization.

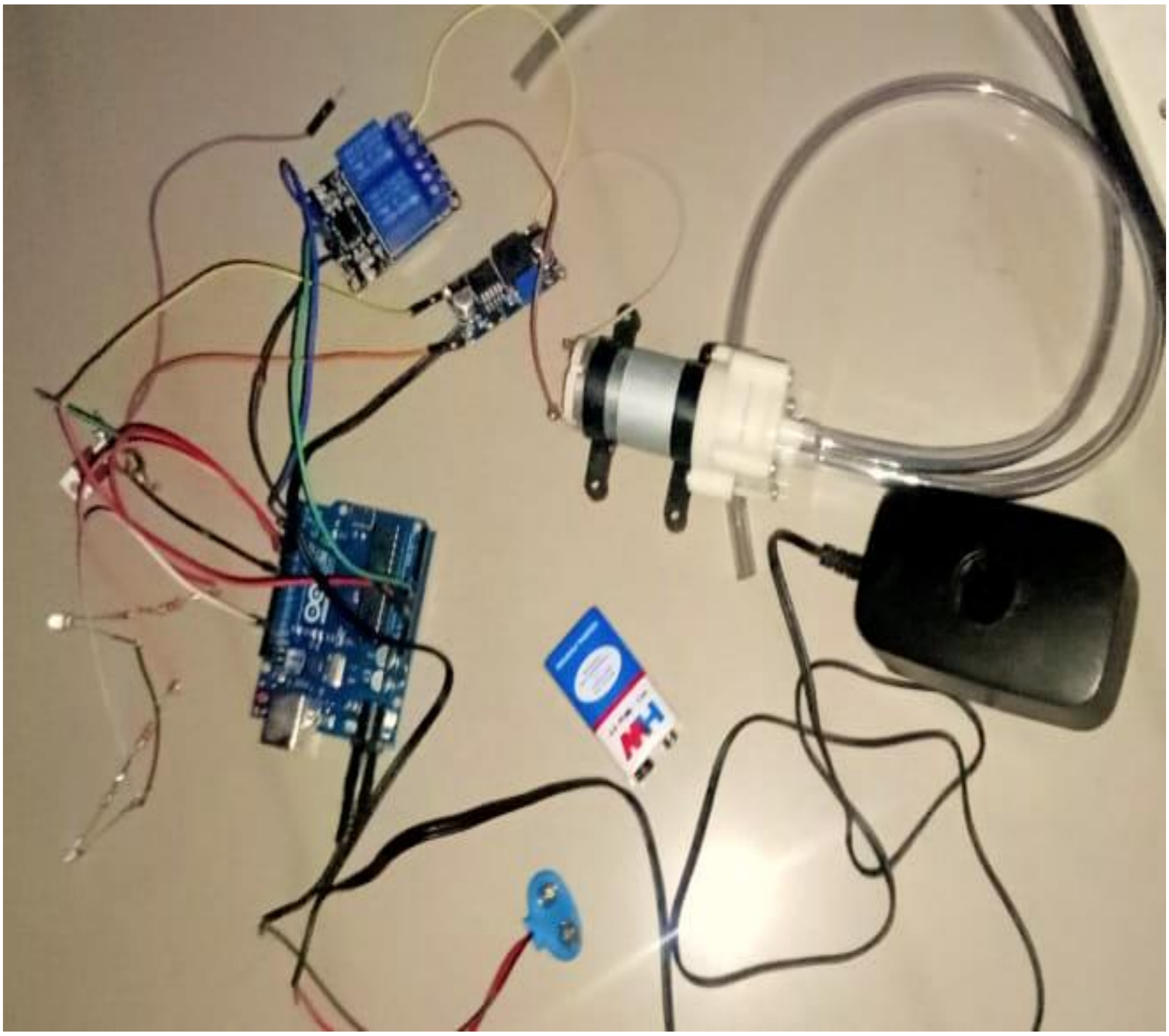
The system begins with a low-voltage DC input—typically from a regulated power supply or renewable energy source such as solar PV. This DC voltage is first fed into a boost converter, comprising a high-frequency inductor, a switching transistor (e.g., IGBT or MOSFET), and a fast recovery diode.

A Proportional-Integral (PI) controller regulates the duty cycle of the switch, ensuring a stable intermediate DC output voltage regardless of input variations.The regulated output from the boost converter is then passed through a multi-stage CDVM, which consists of alternating diodes and capacitors arranged in ladder topology.

Each stage incrementally boosts the voltage, and the number of stages is chosen based on the required final voltage and the intermediate level from the boost stage. The use of fast-switching diodes and high-voltage, low-ESR capacitors ensures minimal loss and efficient voltage multiplication. At the final stage, the amplified DC voltage is directed through a high-voltage IGBT-based pulse generator.

This switching stage chops the high DC voltage into short-duration pulses (typically in the microsecond range) with controlled pulse width and frequency, usually around 5 kHz. These pulses are then applied across a pair of electrodes immersed in the water sample, creating a high-intensity pulsed electric field (PEF).

The circuit design emphasizes precise pulse control, high-voltage insulation, and component reliability. The switching frequency and duty cycle are chosen to ensure proper electroporation without damaging water quality or overloading components.



CIRCUIT OF THE PROJECT

RESULTS AND DISCUSSION

EVALUATED RESULTS

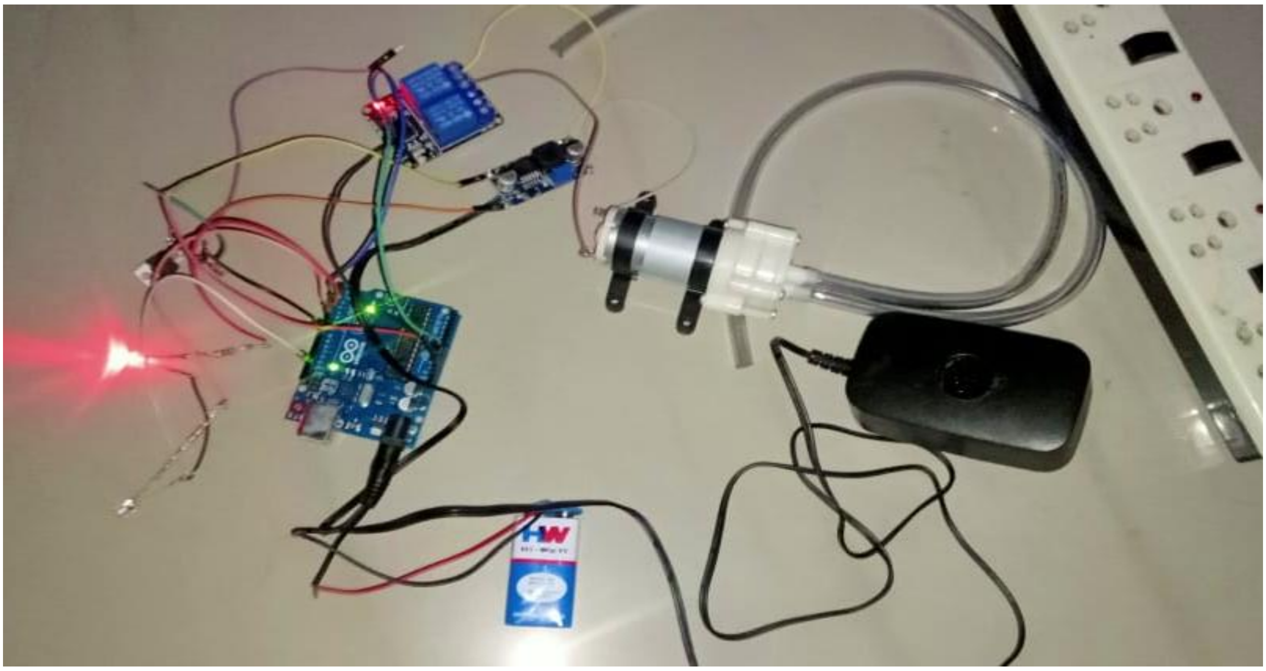
The proposed Pulsed Electric Field (PEF)-based water purification system was evaluated through MATLAB simulation and hardware testing to assess its effectiveness in generating high-voltage electric pulses for microbial inactivation. The focus was on timing precision, voltage stability, energy efficiency, and system improvements over conventional methods.

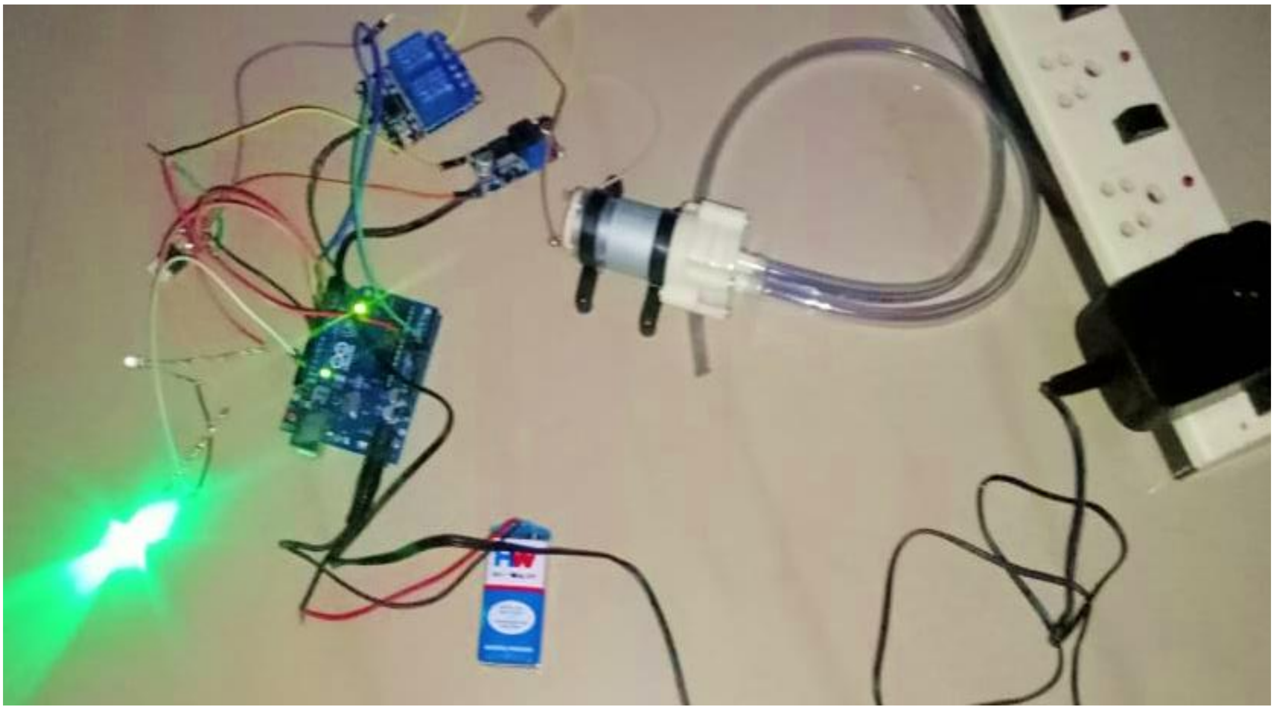
The system's control logic was programmed using an Arduino microcontroller, which executed two key phases: a 10-second PEF pulse phase (indicated by a red LED) followed by a 10-second water transfer phase (indicated by a green LED). The transitions were smooth and precisely timed, confirming the reliability of the automation.

Simulation results showed a stable intermediate voltage of ~400V from the boost converter, further amplified to ~3kV using a Capacitor Diode Voltage Multiplier (CDVM). This output was consistent with hardware performance, with no overshoot or instability. The generated pulses (~20 μs at 1 kHz) were accurately triggered via an IGBT/MOSFET.

Compared to traditional UV/RO systems, the PEF setup demonstrated significant advantages: rapid treatment (under 30 seconds per cycle), chemical-free operation, portability, and low cost. It also supports IoT integration through Arduino for future enhancements.

Overall, the system proved to be a reliable, energy-efficient, and scalable solution for decentralized water purification, particularly suited for rural and resource-constrained environments.





OUTPUT OF THE PROJECT

LIMITATION AND CHALLENGES

While the proposed high voltage electric pulse generator for water purification presents a promising method for achieving disinfection using pulsed electric fields (PEF), there are several limitations that warrant further investigation.

A primary concern is the requirement for precise synchronization between the boost converter and the capacitor-diode voltage multiplier (CDVM) to maintain stable output voltage.

Any deviation in duty cycle or component parameters due to switching losses, thermal drift, or aging may lead to inconsistent output, thereby reducing the effectiveness of microbial inactivation.

Moreover, the design heavily depends on maintaining continuous conduction mode with minimal ripple current, which necessitates precise inductor and capacitor selection. Variations in inductance or capacitance, especially under high-frequency switching conditions, can compromise pulse shape and amplitude, directly affecting disinfection performance.

Another challenge arises from the high voltage nature of the system, which demands careful insulation and robust safety mechanisms to prevent arcing or component failure, particularly in moist or contaminated environments where dielectric breakdown risk is elevated.

Additionally, scaling the system for large-volume water treatment may pose spatial and cost-related constraints due to the number of CDVM stages required for higher voltages. Hence, while simulation results validate the viability of the approach, practical implementation would benefit from advanced control strategies, fault detection mechanisms, and long-term reliability assessments before large-scale deployment.

CONCLUSION

The successful completion of this project has demonstrated the feasibility of using a high voltage electric pulse generator for the purpose of water purification. The system was designed using a DC-DC boost converter in combination with a capacitor-diode voltage multiplier (CDVM) to generate pulsed electric fields (PEF) capable of inactivating harmful microorganisms in water.

Through detailed theoretical design and simulation, the project achieved its objective of producing a high-voltage pulsed output from a low-voltage DC source. One of the key takeaways from this project was the importance of precise control in power electronic systems. By implementing a closed-loop PI controller, the output voltage was successfully regulated to meet the required pulse characteristics for effective water treatment.

The simulation results validated the design, showing stable voltage levels, continuous inductor current, and predictable behavior of capacitors and diodes. From a practical standpoint, this project provided valuable hands-on experience in areas such as high voltage design, component selection, system modeling, and control strategy implementation. It also highlighted real-world challenges such as ensuring system stability, managing component ratings, and designing for safety in high voltage environments.

Overall, the project has laid a strong foundation for further research and development. With additional work, including hardware implementation and testing on actual water samples, the system could be optimized for real-world use. It also has the potential to be extended for portable water purification units, especially in rural areas or during emergency situations. Thus, this project not only fulfilled its academic objectives but also contributes to the broader goal of developing sustainable and innovative solutions for public health.

FUTURE SCOPE

The proposed high voltage electric pulse generator demonstrates a viable solution for water purification using Pulsed Electric Fields (PEF), yet there remains significant potential for further enhancement and real-world application. One major area for future research is the integration of adaptive control algorithms that can dynamically adjust duty cycles and switching frequencies based on load variations and water conductivity.

This would improve system robustness and efficiency under varying operating conditions. Additionally, replacing conventional silicon-based switching components with wide bandgap devices such as SiC or GaN could enable higher switching frequencies and reduce thermal losses, thereby enhancing overall system performance. Future designs may also focus on developing modular, scalable architectures suitable for rural or remote locations with limited access to clean water.

Incorporating renewable energy sources such as solar panels with appropriate energy storage could make the system self-sustaining and eco-friendly. Another promising direction is the experimental validation of the system for a variety of water types with different microbial loads, pH levels, and impurities to establish broader applicability and compliance with health standards.

Furthermore, miniaturization of the circuit and optimization for compact, portable deployment could allow for point-of-use disinfection devices, especially useful in disaster relief and military applications. Advanced diagnostic systems for real-time monitoring of output pulse quality and water sterilization levels can also be explored. This would facilitate predictive maintenance and ensure consistent disinfection performance.

Overall, continued innovation in power electronics, control strategies, and materials will be key to realizing a reliable, efficient, and widely deployable PEF-based water purification technology.

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