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Research Article

Controlled Voltage of Hot Snare Polypectomy Device in Electrosurgical Device

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The study aimed to understand the working procedure of the Olympus PSD-30 Electrosurgical Unit, in which a high-frequency alternating current measures the voltage and power output from the unit when used for a surgical operation to determine the extent of tissue damage. In examining this, power and voltage were analyzed using a stopwatch output; then with an Arduino time-based for 1, 2, and 3 seconds to understand the different modes of the cut and coagulation feedback with an RCC circuit used to mimic the human body. This shows a pattern in which the feedback power increases and the voltage decreases as the cut and coagulation mode increases. The percentage between the stopwatch and Arduino is 29% for the 1 and 2 seconds. With this information, Arduino Uno timing was used to experiment with the device for the different power settings for both the cut and coagulation modes from 2 W to 50 W at 5 W intervals. Based on each trial, the signal was measured for a magnitude of 1 Vpp, and the crest factor obtained was 1.5 with a voltage of 1.088 V and 1.0519 V for both the LabView and oscilloscope, respectively, for the electrosurgical unit of 350 kHz. The power control gives 0.4 W, 2.04 W, and 3.01 W for the power peak at 1, 2, and 3 seconds for the 50 W cut mode of the electrosurgical devices.

1. Introduction

The widely accepted method for screening and evaluating colorectal cancer and polyps is colonoscopy which is generally safe with an estimated rate of complication of 0.3%. The discovery of polyps leads to a process called polypectomy. The polypectomy discovery had a massive reduction in mortality from colorectal cancer. But this process comes with some complications, which are internal bleeding, coagulation syndrome, and perforation, which are the most severe to human health [1].

Based on different studies regarding the mortality rate and complications experienced, it is generally believed that the surgeon's experience plays a significant factor in the postpolypectomy difficulties and the patient's lives. To make the process safer by protecting the lives of patients and making the medical practitioners' work more accessible and secure, there is a need to assist in reducing the complication to the barest minimum. Then the need to improve the electrosurgical unit is essential by analyzing the processes and improving the existing process to lower the surgeon's experience and reduce the complications and mortality rate.

The main objective of this study is to analyze the design and construction of the feedback system, which will be used to control the voltage of the cut section of the electrosurgical unit. First, the circuit will be built to act as the human colon while the microcontroller will be used to control the foot switch pressed, which gives 5 V and, when unpressed, provides 0 V. Then, the cutting process should be able to stop when a certain voltage is reached based on the footswitch.

1.1. Modelling. There are three different ways to model the inside of a human colon, which can be done by living organisms' tissue sample, gel block, and an electric circuit which is a resistor-resistor-capacitor (RRC). The RRC will be deployed to act as the human body for the experimental procedure to understand the variation in the voltage and power of the electrosurgical unit.

Tissue has both the properties of conductors and dielectrics. The complexity that arises in the body entails both resistance and reactance. The resistance arises from both the extracellular water (ECW) and intracellular water (ICW), while the reactance arises from the cell membranes [2].

The resistance of the ICW is denoted by R_I, the resistance of the ECW is denoted by R_E, and the cell membrane is denoted by C_M, as shown in Figure 1.

This study focuses on monitoring the change in voltage during the operation of the ESU, which is not a new idea. Electrosurgical unit producers have this feature integrated into their devices which is mostly for the bipolar method with both sending and receiving electrodes for the current flow through the accessory. This study will use a hot snare using the monopolar method. This brings on additional complications in the accuracy of the measurements due to the length of the wire of the snare and grounding patch by integrating the patient's body, not just the polyp, into the measurements. In this case, the circuit would be the path the current takes from the ESU through the snare, then through the polyp and patient, and back to the ESU through the ground patch.

The cell membrane is composed of mainly proteins and lipids and determines how the current flows inside the cell. It is expected that the voltage will increase with increasing frequency, but tissue is not completely homogeneous or isotropic; it is anisotropic, meaning that the conductivity term is different if taken in different directions. With further analysis, additional variables such as temperature, electrode, tissue interface impedance, and even the type of electrode are all relevant factors because of these complex situations inside the cell, which makes numerical modeling difficult.

The model acts as a colon or rectum in the human body with parallel and series connection between capacitance and resistance. High frequencies of current move through the intracellular water while low frequencies move through the extracellular water.

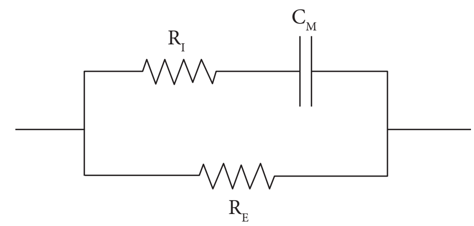


Figure 1: Human body equivalency circuit RRC [2].

2. Literature Review

Electrosurgical generator units (ESUs) work with therapeutic endoscopy by providing the high-frequency electrical flow needed to utilize numerous endoscopic embellishments. The term electrosurgical energy depicts the change of alternating electrical flow created by the ESU into thermal energy inside the tissue. In endoscopy, for example, polypectomy snares, forceps, and sphincterotomes fill in as conductors that convey electrical energy to the expected therapeutic site. The most presently accessible ESUs have refined chips and programming empowering them to create different electrosurgical waveforms that impact the final product of electrosurgical energy. ESUs have highlights that upgrade both patient security and usability.

Cancer is broadly known as a significant medical condition generally having a presence in every part of the world; about one-fourth of mortality results from cancer growth. Among a wide range of cancer growths, colorectal was the third most common cancer affecting people (male and female) in 2014. Also, around 136,830 cases and 50,310 mortalities were recorded, according to the American Cancer Society because of colorectal cancer growth in 2014 [3]. Colonoscopy is generally recognized as the ideal methodology used to screen for precancerous injuries and forestall colorectal cancer growth. Although there have been difficulties in the procedure, colonoscopy is yet thought to be, for the most part, a safe technique [4]. Importantly, both the experience of an endoscopist and the number of colonoscopy systems performed by an endoscopist influence the occurrence of complications experienced [5]. Additionally, the proof shows that the complex pace of an endoscopy methodology performed by an unpracticed endoscopist is nearly high when contrasted with those performed by an accomplished endoscopist [6]. That is, some unfavorable occasions might happen during or after the colonoscopy system because of inexperienced endoscopists. Consequently, it is important and doable to look for a way that assists unpracticed endoscopists with further developing their method of execution. Since some normal difficulties are almost certainly brought about by exorbitant tissue warm injury, like bleeding, perforation, and postpolypectomy consumption condition, the amount of warm tissue injury created by monopolar colonoscopy removal merits additional consideration by endoscopists [7].

Current polypectomy devices and procedures are insufficient to forestall all postpolypectomy bleeding, perforation, and postpolypectomy conditions, but adherence to specific standards can significantly lessen the danger of these confusions. The utilization of electrocautery can be limited in the resection of little colorectal polyps. The hot forceps method, whenever utilized by any means, ought to be bound to polyps lower or equivalent to 5 mm in size. Sessile polyps, something like 2 cm, ought to be eliminated piecemeal in many cases, and submucosal infusion ought to be thought about; however, is not needed for all cases. Submucosal infusion of epinephrine is compelling in forestalling prompt draining from the evacuation of enormous sessile or pedunculated polyps, and separable snares can be considered for all or chosen instances of pedunculated polyps for anticipation of both prompt and postponed bleeding. Clipping is not powerful yet is a sensible thought for the avoidance of bleeding in chosen patients, and the conclusion of polypectomy deformities could be anticipated to forestall perforation and may forestall bleeding in chosen cases. New advancements that could additionally lessen or dispense the bleeding and perforation after polypectomy are woefully required [8].

The current flow should change between positive and negative at a frequency of more than 100,000 times each second (100,000 Hz) to stay away from the neuromuscular reactions and shocks that happen with a 60 Hz current wall socket. If the current is sufficiently high, cell water will heat quickly, bringing about bubbling of cell films. At the point when these blasting cells are adjusted along a wire, the outcome is portrayed as electrosurgical cutting. For regions farther from the wire, or when the applied energy is less extreme, the current is lower. Therefore, cells heat gradually, and coagulation results in cells shrinking without exploding and separating the tissue.

By controlling the variable effects of the tissues, the proportion of cells cut to those coagulated can be controlled, but cold snare polypectomy has no coagulation. Electrocautery uses a direct current-to-heat electrode, which can be applied to a tissue to produce coagulation with no cutting, but electrosurgery gives both cutting and coagulation simultaneously. Electrosurgery arises, hence, as the best innovation for delivering helpful coagulation, resection, and tissue removal in the body.

2.1. Previous Work. Bleeding after a forceps biopsy is extremely common and reasonable and shows an unnoticed coagulation problem. In addition, clinically, bleeding does not happen after cold forceps and snare resection of small (2–7 mm) polyps [9]. It is the hot forceps biopsy that is related to an expanded danger of postponed bleeding inferable from thermal-induced ulceration.

Postpolypectomy bleeding is considered intense or postponed and happens in roughly 1.5% and 2%, individually, of polypectomies [10]. Instant bleeding is believed to be identified with deficient use of electrosurgical coagulation during snare resection, given the untimely mechanical snare crosscut of the cutting versus coagulation parts of the electrosurgical current. Prompt bleeding is even more frequent in pure and blended cutting, but delayed bleeding is often experienced in coagulation current. A review investigation of pure against blend coagulation current for colonoscopic polypectomy has no critical contrasts, albeit a huge distinction was found in the bleeding time; most hemorrhages happened promptly in 12 hours when the blended current was utilized, and all were postponed (2–8 days) when pure coagulation current was used [11].

2.2. Parameter. The fundamental terminologies used in the electrosurgical device are the current, voltage, and resistance, which possess basic principles and units. The current is the progression of electrons during a timeframe and is estimated in amperes which move through a pathway called the circuit. The resistance acts as an obstacle to the flow of current for both direct and alternating and is estimated in ohms. This is like the impedance acting against current flow. Based on the resistance acting as an obstacle to current flow, a force is needed to push the current, and voltage acts in this capacity. Voltage fills in as the main impetus that pushes current flow forward. Higher voltages increase the profundity of the injury, which can work with the ideal endoscopic impact, yet can likewise damage the tissue zones. The relationship between terminologies is described by Ohm's law which states that voltage is directly proportional to the current, as in equation (1). Likewise, the power addresses how much energy moved in a period, while the temperature change is inspired when current flows. The power is given as in equation (2), while the temperature is governed by Joule's law given as in equation (3). Based on the laws, V is the voltage, I is the current, R is the resistance, P is the power, Q is the generated heat by current flow, and T is the time frame. Based on an improved electrosurgical unit device with predefined voltages levels and tissue impedance levels controlled by the processors, ending the output power by the electrosurgical unit is easier, possibly diminishing the accidental tissue injury. Neuromuscular and myocardial reactions are prominent when the frequency is low and can cause much damage or even death. This is why alternating current in the homes, which is 60 Hz, is not suitable for electrosurgical units. The electrosurgical unit operates at a higher frequency between 300 Hz and 1 MHz [12].

$$V = \mathrm{IR}, \tag{1}$$

$$P = \mathrm{VI}, \tag{2}$$

$$Q = I^2\mathrm{RT}. \tag{3}$$

In living tissue, the voltage increment should be higher than 200 Vpp before current can be sufficient to make electrosurgical cutting. Some ESUs have power yields that hold voltage continually beneath the 200 Vpp limit, thereby facilitating coagulation with no cutting, irrespective of the power setting. In monopolar circuits, these yields are regularly named Soft Coag, which is normal for bipolar applications. Voltages over 200 Vpp produce current densities that can deliver electrosurgical cutting utilization to supersede impedance and drive tissue coagulation [13].

2.3. Cut and Coagulation. The electrosurgical unit possesses two fundamental currents, coagulation and cut flows, which are contrasted principally in the rate and extent to which they instigate a temperature increment on the tissue. Ultimately, the coagulation flow gives slower expansion temperature in the cells with temperature ranges from 70 to 100°C and makes them dry out and shrivel without exploding. The outcome is tissue parching when the electrode is in direct contact with the tissue or tissue fulguration on the off chance that the cathode is not in direct contact with the tissue. While the cut flows, it causes faster hotness expansions on the tissue, which is over 100°C, making the cell water bubble and burst, prompting tissue cleavage [14].

2.4. Variables of Tissue Effect. ESUs are influenced by many variables that affect the electric circuit and the ideal tissue effect. The most significant of these is the current density, which decides the intensity of the impact accomplished during electrosurgery. Current density is characterized by how much current moves through a cross-sectional area of tissue. Current density can be expanded by either expanding the intensity of the current conveyed into a similar cross-part of tissue or by diminishing the cross-sectional area of tissue to which a current is being conveyed. The heat created in the tissue is relative to the power disseminated by the tissue. Applying current to a little region of a polyp causes excessively high hotness against a similar current applied to a bigger region of a similar polyp. Likewise, to produce how much hotness is expected to cut across a polyp with a bigger diameter, more current power is required [12].

The variable that can be controlled is the power output in which the power settings increase with current density. Numerous advanced ESUs have some type of chip that contrasts the power output and a proportion of the impedance of the tissue with the electrode. Impedance increases as the tissue becomes coagulated, which influences a decrease in current flow. These ESUs have a choice that endeavors to hold power steady as intently as conceivable to the chosen watts over a scope of impedances. The output power is particularly valuable during polypectomy and assists with lessening snare entrap by giving enough power during the whole resection.

The endocut is intended to change current due to changes in impedances and pulse to yield advanced control of the cut. The instant response in cut mode is intended to convey power rapidly when the impedance is low toward the beginning of the cut and keep the power constant, despite changes in impedance. ESU is intended to offer the user a few distinctive waveform modes with marks, like "Pure Cut," "Blend1 Cut," "Blend2 Cut," "Soft Coag," "Auto Stop Coag," and "Forced Coag."

A huge variable that is controlled totally by the user is time by the foot pedal. Power increased by time leads to heat energy conveyed (energy (joules) = power (watts) × time (seconds)). In any case, the clinical aftereffect of conveying 50 W of force for 2 s is different from that of conveying 20 W for 5 s, even though the total heat energy conveyed (100 J) is similar [15]. In addition, it is vital to note that if the time and power settings are similar, either the cut or coag waveform will convey similar energy yet with a different result. When the ideal waveform and power setting have been chosen, the time the foot pedal is pressed will generally decide the eventual outcome.

2.5. Monopolar or Bipolar Circuit. In endoscopy, both monopolar and bipolar circuits are used to make the circuit complete. During monopolar assembly, the circuit uses a grounding pad through a remote return electrode to be completed. Energy from the electrode moves at least resistance through the patient's body to be gathered at the grounding pad and returned to the generator to finish the circuit. As the whole circuit adds to the complete impedance, contrasts in the impacts of the power settings might be observable in patients based on changes in size and body. It must be ensured that the circuit is small by making sure the grounding pad is close to the treatment location.

A grounding pad is not required with bipolar because it possesses both the active and return electrodes at the probe tip [16].

2.6. Snare Polypectomy. Based on an overview of 189 US endoscopists, the current utilized for polypectomy changed and entailed "Pure Coagulation" for 46%, "Blend" for 46%, and "Pure Cut" for 3%. Four percent of responders differed from the current during polypectomy [16]. In a similar report, cold or hot biopsy forceps were mostly utilized for polyps 1–3 mm in size, while electrosurgical snare resection was used for polyps 7–9 mm in size ($P < 0.0001$).

"Pure Coagulation" current has been utilized effectively for the resection of enormous polyps which are greater than 2 cm at variable power settings between 2 and 50 W and without snare entrapment [17]. In a preliminary study relating "Blend" current ($n = 758$) to that of "Continuous Coagulation" current ($n = 727$), the difficulty rate for snare polypectomy was comparable. In any case, a huge distinction in the circumstances of postpolypectomy bleeding was noted. Every single bleeding ($n = 8$) happened when blend current was utilized, though completely delayed postpolypectomy bleeds ($n = 6$) happened with the utilization of coagulation current [11]. In a review study including 4735 polyps resected with "Pure Cut" current at 40 W, the pace of postpolypectomy bleeding was generally low at 1.1%, albeit prophylactic measures; for example, clipping was embraced in 12% of the polypectomies to diminish the danger of bleeding [18]. In one more review study, polypectomy utilizing Endocut brought about a better histologic nature of the resected samples than polypectomy utilizing a "Blend" current at 30 W [19]. Yet, imminent investigations on the clinical results of polypectomy utilizing Endocut are justified. Generally, "Pure Cutting" current might prompt quick bleeding, while abuse of deep coagulation might lead to slow bleeding [7].

3. Materials and Methods

The Olympus PSD-30 electrosurgical unit has 295 mm (W) × 160 mm (H) × 420 mm (L) in dimension, a weight of 7.8 kg, a fundamental frequency of 350 kHz, open circuit output voltage of 900 V, outputting power range of 2 W to 50 W, voltage fluctuation within ±10%, fuse rating 3.15 A, 250 V, fuse size of 5.0 × 20 mm, as shown in Figure 2. Some components for its operation include a power cord, foot switch, P cord, S cord, spare fuse, and P plate. The nomenclature of the electrosurgical unit has different sections, which include the warning section (Refer to instructions, patient plate, S-cord, high-frequency output, and output timer), coagulation section (Soft, Auto stop, and Forced), cut section (Pure, Blend1, and Blend2), power switch (Power ON/OFF), front panel (Type CF applied part, Stand-By, and Program), connector section (Active, S-cord, Patient plate, Refer to instructions, connection for neutral electrode), and rear panel (potential equalization terminal, footswitch, fuse, and alternating current).

The electrical circuit has a frequency of (50/60 Hz) which is converted to the high frequency of the Electrosurgical Unit of 350 kHz with the ability to change the power settings from 2W–50 W in 5 W increments with power voltage at 220, 230, and 240 V.

The voltage amplitude and phase difference were measured using the Keysight DSOX1202G digital storage oscilloscope with a frequency of 100 MHz. The oscilloscope has three probes channel 1, channel 2, and the external trigger. The oscilloscope sample rate is at 2 GSa/s at a point of 2 M. The built-in oscilloscope generator is at 20 MHz.

Figure 2: Pictorial view of the electrosurgical unit [20].

The Arduino UNO microcontroller was used to manage the footswitch timing for different time series (1 s, 2 s, and 3 s). This microcontroller possesses 14 digital input/output pins and six analog input pins. There is a maximum DC of 20 mA per pin, and it runs at a clock speed of 16 MHz [21].

3.1. Modified Electrosurgical Unit. The modification was done for the electrosurgical unit with an RRC circuit of 1.2 k ohms resistor, 600 ohms resistors, and 1 n farad circuit to mimic the human body [2]. The 600 ohm resistors are connected in series with the capacitor, then in parallel with the 1.2 k ohm resistor. One end of the circuit is connected to a common ground with the PSD-30 ESU, while the other end is connected to the patient plate acting as the body. This can be seen in Figure 3.

This setup allows the reading of the power and voltage when the footswitch is pressed down to initiate the firing and a place to stop the ESU from firing by interrupting the signal sent to it. The footswitch setup works with two normal switches momentarily. One of the switches is used to control the cutting mode, while the other is used to manage the coagulation mode. The modification was performed with these two switches whereby the wires connecting to the switches were cut, and then in between, the microcontroller was used, which provides two inputs and outputs for the microcontroller. When a pedal is pressed, a 5 V signal passes, while when the pedal is depressed, the signal reads 0 V. This makes the microcontroller control the time for the pedal pressed, which is 1 second, 2 seconds, and 3 seconds. Based on this, the microcontroller is the intermediary between the ESU and the footswitch [22].

3.2. Modified Footswitch with Arduino. The footswitch was modified with the Arduino to manage the timing when pressed. The Arduino provides a better timing sequence for the footswitch. The footswitch has the cut+, coag+, cut−, coag−, +5 V, and GRND. The +5 V is connected to the V in on the Arduino, while the cut− or coag− is connected to the breadboard based on the mode power to be measured.

3.3. Oscilloscope. The oscilloscope used is the Keysight DSOX1202G Digital storage oscilloscope has 100 MHz, 2 GSa/s sample rate, 2 M points, Built-in 20 MHz function generator (standard). It is used to make professional measurements, including Bode plots (FRA), mask testing, math, FFT, and serial protocol analysis.

The oscilloscope was used in conjunction with the ADC to create the DAQ signal of the LabView stimulator to test the signal from the function generator experimentally. The output signal from the function generator was displayed on the oscilloscope as a waveform. The output signal waveform varied with time series and was displayed graphically on the oscilloscope screen. This is used to analyze the signal distribution based on the frequencies and the peak-to-peak voltage. The probes are polarized cable connectors that transfer electrical signals between the devices. They are used to connect a stimulator and the circuit under test. The probe acts in signal modification and reduces the noise effect.

3.4. Function Generator. An Agilent function generator 33220 A is a piece of electronic test instrument used to generate and deliver standard waveforms, typically sine and square waves, to a device under test. It can be used to test a design or confirm that a piece of electronic equipment is working as intended.

It is fully compliant with LXI Class C specifications and possesses 20 MHz sine and square waveforms for pulse, ramp, triangle, noise, and DC waveforms. It has 14-bit, 50 MSa/s, 64 k-point arbitrary waveforms with AM, FM, PM, FSK, and PWM modulation types of linear and logarithmic sweeps and burst operation from 10 mVpp to 10 Vpp amplitude range coupled with graph mode for visual verification of signal settings.

3.5. Measuring System. The measuring part entails both the voltage measurement from the oscilloscope and the DC power measurement. Firstly, the oscilloscope is used for the voltage measurement that will be read for both the cut and coagulation to understudy the pattern and control the amount used by ESU. Understanding the voltage pattern will assist in analyzing the time series for 1 second, 2 seconds, and 3 seconds.

The second part is the DC power measurement to understand the power consumption for each process involved in the cut and coagulation. Since the ESU has a power range from 2 W to 50 W, each power rating will be analyzed to understand the DC power supply to the ESU.

This second part of the feedback system will utilize the voltage measurement of the device under test (DUT), in which the model is the alternating current passing through. The measuring system will consist of multiple parts with different roles. First, the function generator will be used to send signals with frequencies in the oscilloscope range of 1 kHz to 500 kHz. The voltage peak-to-peak measurement will be set to 1 Vpp while the offset current will be at 1 Vdc for the DC-DC converter that supplies the oscilloscope and the ADC converter.

The basic idea is to measure the pure cut for the electrosurgical process but with the limitation, which is its high voltage. The voltage will be controlled by analyzing the voltage through the DC-DC converter to reduce the effect of the pure cut mode.

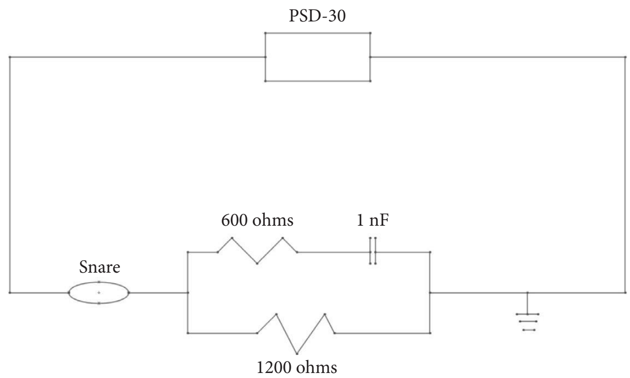


Figure 3: Schematic diagram of the built circuit [22].

3.6. PSD-30 System Identification. The experiment performed was used to include an autostop based on time settings in the electrosurgical unit. The process involves a preliminary stage of identifying the PSD-30 device and how its operation works, then an autostop setup to set the timing of the firing of the electrosurgical unit. Lastly, the firing management is done by using the LabView based on the timing series.

First, the RRC circuit designed to mimic a body was connected to the snare and earth of the electrosurgical unit. The footswitch is connected to the electrosurgical device, acting as the foot pedal for the firing sequence of the electrosurgical unit while the oscilloscope was connected to the positive end of the RRC circuit using the probe to read the signal from the electrosurgical unit. The oscilloscope was set to continue while the foot pedal was pressed to release 5 V while pressed and return to 0 v when released. This was performed with a stopwatch for 1, 2, and 3 seconds of pedal pressing with the cut and coagulation mode of the electrosurgical device. The measurements taken are the power output from the electrosurgical unit when fired and the unit's output voltage from the oscilloscope.

Then, to further improve the output voltage and power from the electrosurgical unit, an Arduino was developed to give an accurate timing for the firing of the electrosurgical unit through the foot switch. The foot switch was modified, with the footswitch having the cut+, coag+, cut−, coag−, +5 V, and GRND based on the cut and coagulation pedal of the foot switch. The +5 V is connected to the V in on the Arduino, while the cut- or coag-is connected to the breadboard based on the mode power to be measured. The measured output power and voltage are like the preliminary stage, and they were measured for both the cut and coagulation modes for a power range of 2 W to 50 W at an interval of 5 W.

Lastly, based on the crest factor, the electrosurgical unit used is PSD-30 with a frequency of 350 kHz. The frequency range from 1 kHz to 500 kHz was generated from the function generator for the sine and square signal to ensure the signals are similar for the oscilloscope and LabView. Generally, the oscilloscope result is the baseline, while the LabView signal is modified based on the frequency rate, read sample, terminal configuration, signal input range, and acquisition mode to ensure the signal obtained is the same as the oscilloscope signal [22].

Based on the crest factor (CF), which is the ratio of the voltage peak (V_p) to the root mean square (RMS) as in equation (4). The crest factor is used instead of the duty cycle to measure the signals because it gives a precise outcome for the voltage measured. For continuous motion, 100% of the duty cycle gives a 1.4 crest factor. Since the RMS constant for a sine wave is 0.7, and the CF constant for a sine wave is 1.4, if a crest greater than the CF constant is produced, it shows more hemostasis depth [12].

$$\frac{Vp}{\mathrm{RMS}} = \mathrm{CF}. \tag{4}$$

4. Result and Discussion

Majorly, the electrical circuit polarity switches between positive and negative at a frequency of 60 times per second (60 Hz). This can cause myocardial and neuromuscular responses, making the frequency unsuitable for electrosurgery. The PSD-30 used for this experiment generates 350 kHz frequency so that when in operation, it will eliminate these complications. The experiment was performed using the electrosurgical unit (ESU), which conducts the surgical process, an oscilloscope and ADC converter for measuring the voltage and signals, and a circuit with two resistors and a capacitor to mimic the human colon of the body. The ESU has power ranges from 2 W to 50 W for both the cut and coagulation mode, as shown in Figure 4.

The circuit was built using the RRC with 600 ohms and 1200 ohms resistors and one nano farad. The 600 ohms were connected in series with the capacitance acting as the intracellular water, then with a parallel connection to the 1.2 k ohms working as the extracellular water. The capacitor end was connected to the ground on the electrosurgical unit, while the 600 ohms end was connected to the snare of the electrosurgical unit. This gives a close loop circuit between the electrosurgical unit and the circuit. This circuit is used to mimic the human body's colon [2].

The signal was read using the oscilloscope with the probe connected to the RRC circuit. The footswitch is connected to the electrosurgical unit in which, for every second, the pedal is pressed, and there are corresponding changes in the power used by the electrosurgical unit with changes in the voltage from the oscilloscope. On pedal press, a 5 V is released to the electrosurgical unit.

The electrosurgical unit converts the standard electrical frequency between 50 and 60 Hz to 350 kHz. The footswitch has a cut and coagulation pedal to initiate an active connector on the unit. The footswitch pressed activates the voltage increase while the unpressed returns to zero.

4.1. Preliminary Results. The power range for the cut mode used to test the electrosurgical unit was from 2 W to 50 W. The overall upward trend can be seen in Figure 5. The minimum power was found at 2 W cut mode power with a corresponding measurement of 2.066 W at 1 second and 16.933 W at 2 seconds pedal pressed. While the maximum capacity obtained was at 50 W cut mode power with a power

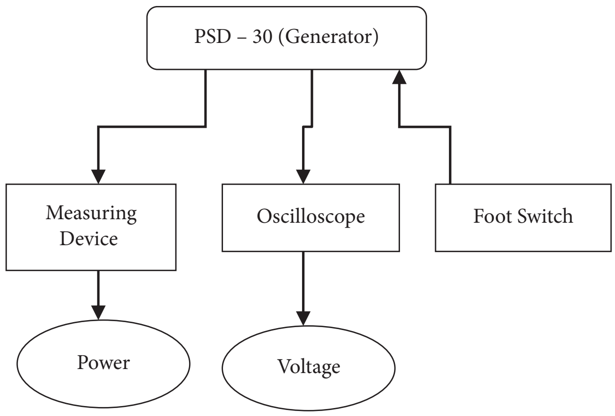


FIGURE 4: Schematic diagram for electrosurgical unit measurement [22].

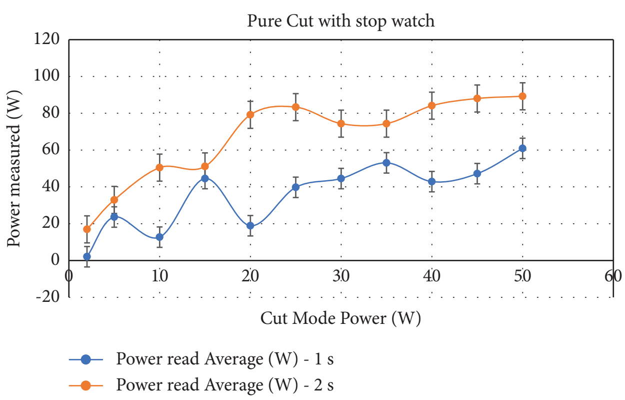


FIGURE 5: Power read to cut mode power.

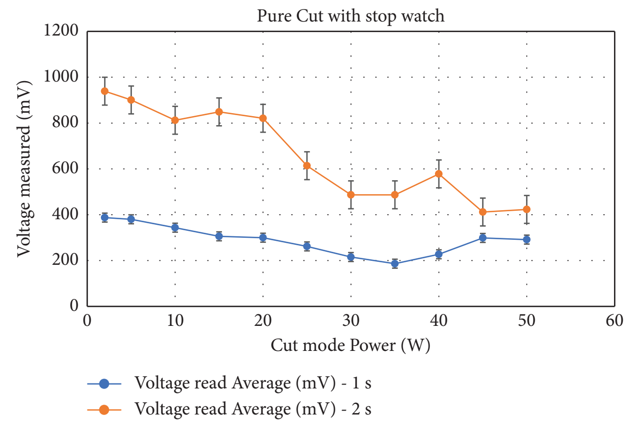


FIGURE 6: Voltage read to cut mode power.

output of 60.933 W at 1 second and 89.233 W at 2 seconds footswitch. The dips noticed in the graphs are due to the manual measurement with the stopwatch which is due to operator bias. This was improved with the introduction of Arduino.

But the voltage measured shows a drastic decline in the cut mode power of the electrosurgical unit. The lowest voltage was seen at the 35 W cut mode power of the PSD-30 at 186.433 mV at 1 second and 486.766 mV at 2 seconds from the oscilloscope, as shown in Figure 6. The voltage declines as the cut mode power increases.

4.2. Pure, Blend1, and Blend2 Cut. The result shows a consistent increment in the cut power rating from the electrosurgical unit to the power read from the measuring device, as shown in Figures 7 and 8. The lower the time for the footswitch to be pressed, the lower the power output of the ESU.

Likewise, there is a constant increment of the power measured for all the time series (1 second, 2 seconds, and 3 seconds). It shows the downward fluctuation in the representation for voltage and power read for the pure, blend1, and blend2 cutting mode. The pedal timing for 1 second shows better consistency for both the power and voltage when compared to 2 and 3 seconds. But there is fluctuation in the power and voltage pattern, which increases as the timing of the footswitch increases.

The maximum voltage was experienced for Blend1 cut at 2 W cut power for 3 seconds which is 1375 mV while the lowest voltage was Blend1 cut at 10 W cut power for a second which is 61.5. While the maximum power was for Blend2 cut for 3 seconds at 118 W and the lowest power was for pure cut for a second at 7.5 W.

The power and voltage average shows an inversely propositional attributes in which as the time increases, the power increases, and the voltage decreases.

4.3. Soft, AutoStop, and Forced Coagulation. Figure 9 for the power read for the coagulation modes shows an incremental pattern like the cutting modes. There is a drastic increment between the coagulation power rating for all three different time series (1 s, 2 s, and 3 s) for the power read.

The representation for Figure 10 shows a drastic decline in the voltage read between 2 W and 5 W for the coagulation power rating. This is noticed for all the three different time series for 1, 2, and 3 seconds respectively. But in general, the pattern for all the time series is similar.

The highest power was at AutoStop coagulation for 3 seconds at 119.7 W while the lowest power was at forced coagulation for a second at 6.3 W. The voltage read after the 5 W coagulation power for maximum was at forced coagulation for 3 seconds was 36.2 mV while for minimum was at AutoStop coagulation for a second at 0.5 mV.

As the measurement is shown in Figure 11, based on the footswitch firing with the Arduino for the RRC circuit, we can identify the series pattern which shows the power increase for the cut mode power of the electrosurgical unit. The increase in time leads to more output power from the electrosurgical unit as the cut mode power increases.

The coagulation (soft, autostop, and forced) shows a voltage below the cutting volts of 200 V, which propagates the tissue coagulation properties.

4.4. Crest Factor Signal. The crest factor is used instead of the duty cycle to measure the signals because it gives a precise outcome for the voltage measured. For a continuous signal,

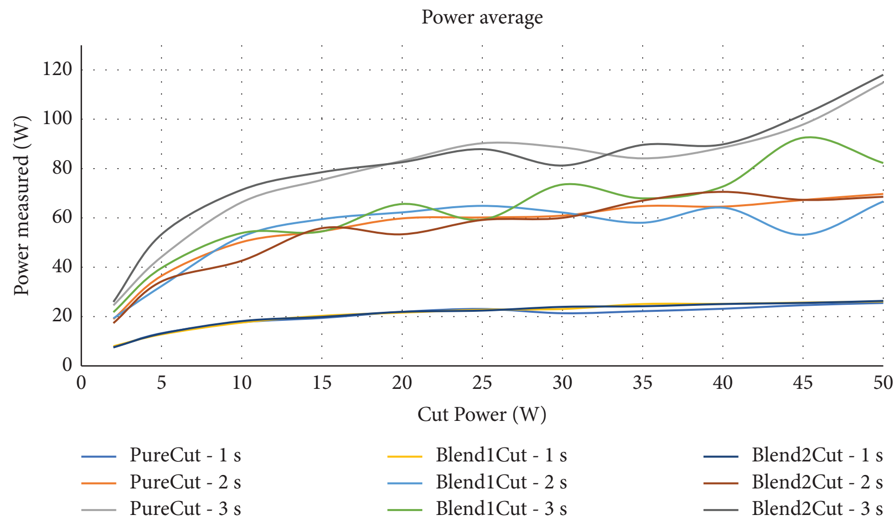


Figure 7: Power read to cut power rating for cutting mode.

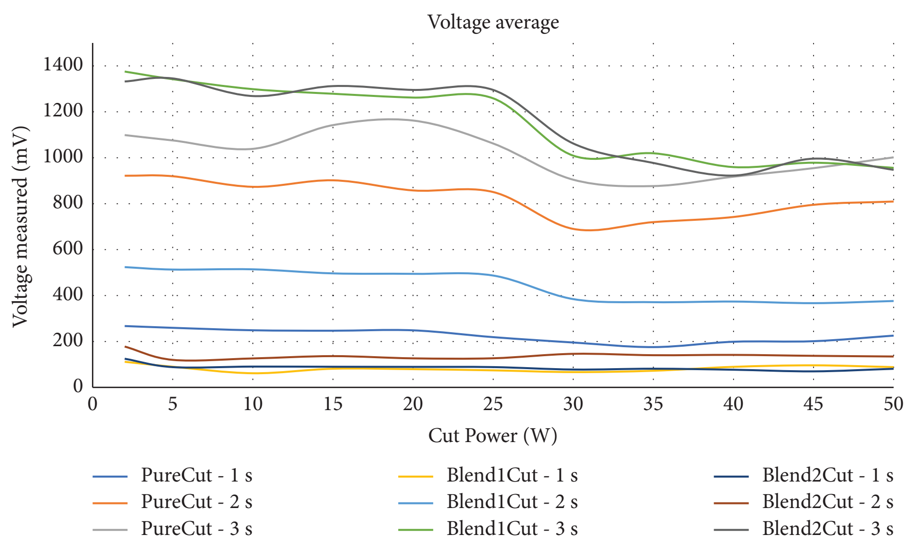


Figure 8: Voltage read to cut power rating for cutting mode.

100% of the duty cycle gives a 1.4 crest factor [23]. The function generator was used to generate the signal to be read by the oscilloscope and LabView. The function generator gives a sine and square signal with frequencies ranging from 1 kHz to 500 kHz with the PSD-30 fundamental frequency at 350 kHz. The signal magnitude is set at 1 Vpp while the offset is at 1 Vdc.

Crest factors (CFs) are the measure of peak and average voltage, as well as the frequency of the modulation. The CF is the ratio of the voltage peak to root mean square. The root mean square for a sine wave is a constant of 0.7, and the CF of the pure sine wave is a constant of 1.4.

For the electrosurgical device at 350 kHz, the CF for the sine wave is 1.5 for the oscilloscope and 1.55 for LabView. This shows that the value is close to the CF constant.

The electrosurgical unit fundamental frequency of a 350 kHz signal shows a difference of 0.036 V between the LabView and oscilloscope sine signal. The voltage peak-to-peak experienced by both the LabView and oscilloscope were 1.088 V and 1.0519 V, respectively, as shown in Figure 12.

Figure 13 is based on the voltage measurement which shows an increase in intensity as the timing increases. The power measurement for the time series also shows the intensity increment with the timing. From the power output as in equation (5), R_T is the total resistance of the 600 Ω and 1.2 kΩ connection in parallel. (a) At 1 second firing, the signal experienced two signals intensity, with the first at approximately 50% at a power output of 0.2 W while the second which is 100% at 0.4 W. (b) and (c) At the firing, the signal experienced different intensities, with the highest cumulated power at 2.19 W and 4.14 W for 100% power percent for 2 and 3 seconds, respectively.

$$P = \frac{V^2}{R_T}. \quad (5)$$

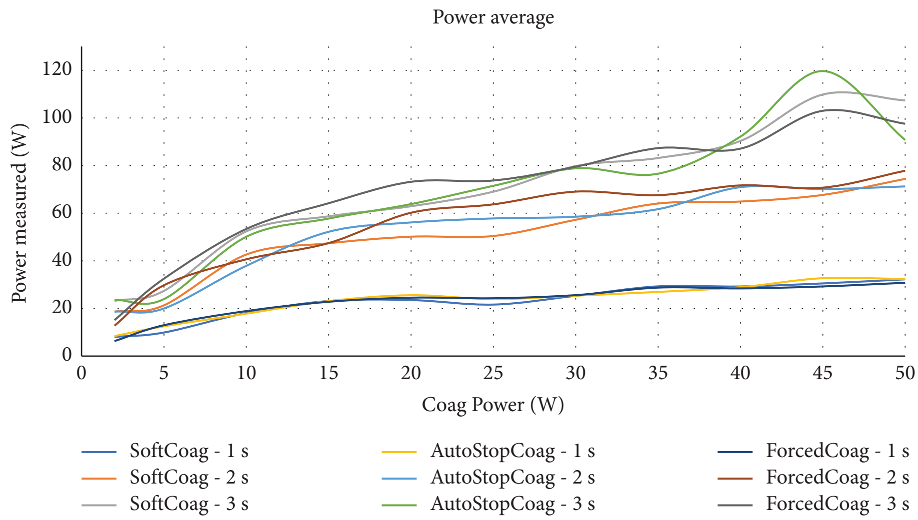


Figure 9: Power read to cut power rating for coagulation mode.

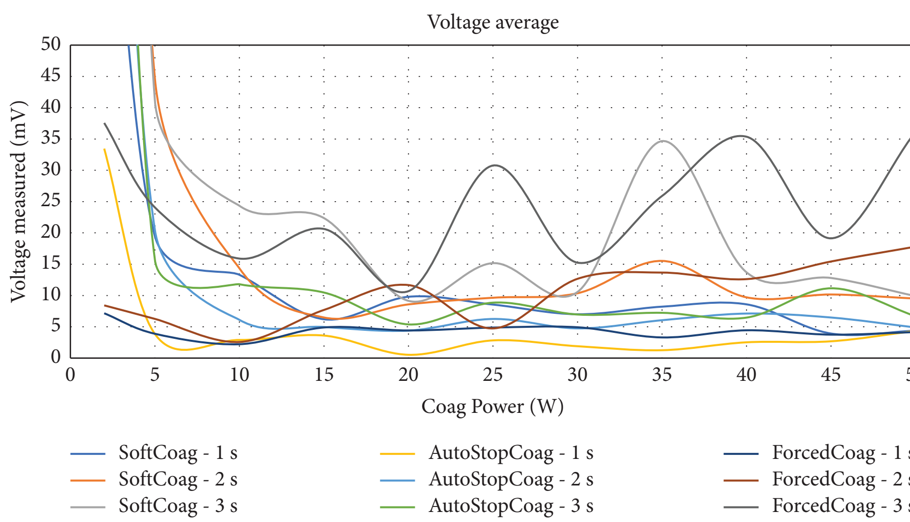


Figure 10: Voltage read to cut power rating for coagulation mode.

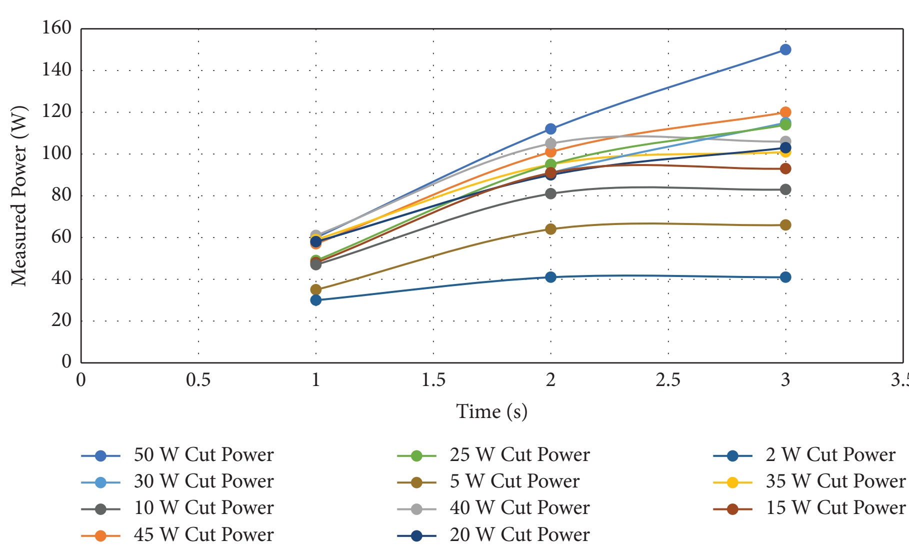


Figure 11: Electrosurgical unit power output with time series.

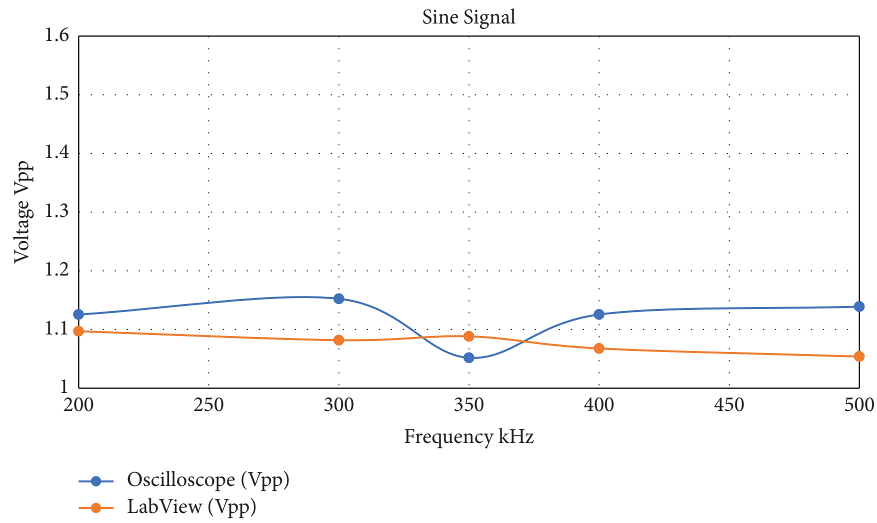
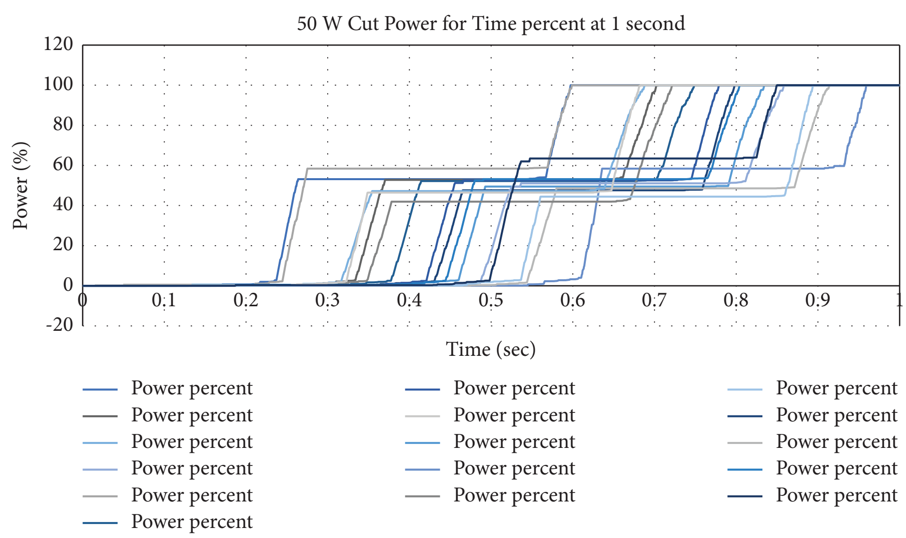


FIGURE 12: Electrosurgical unit fundamental frequency signal at 350 kHz.



(a)

FIGURE 13: Continued.

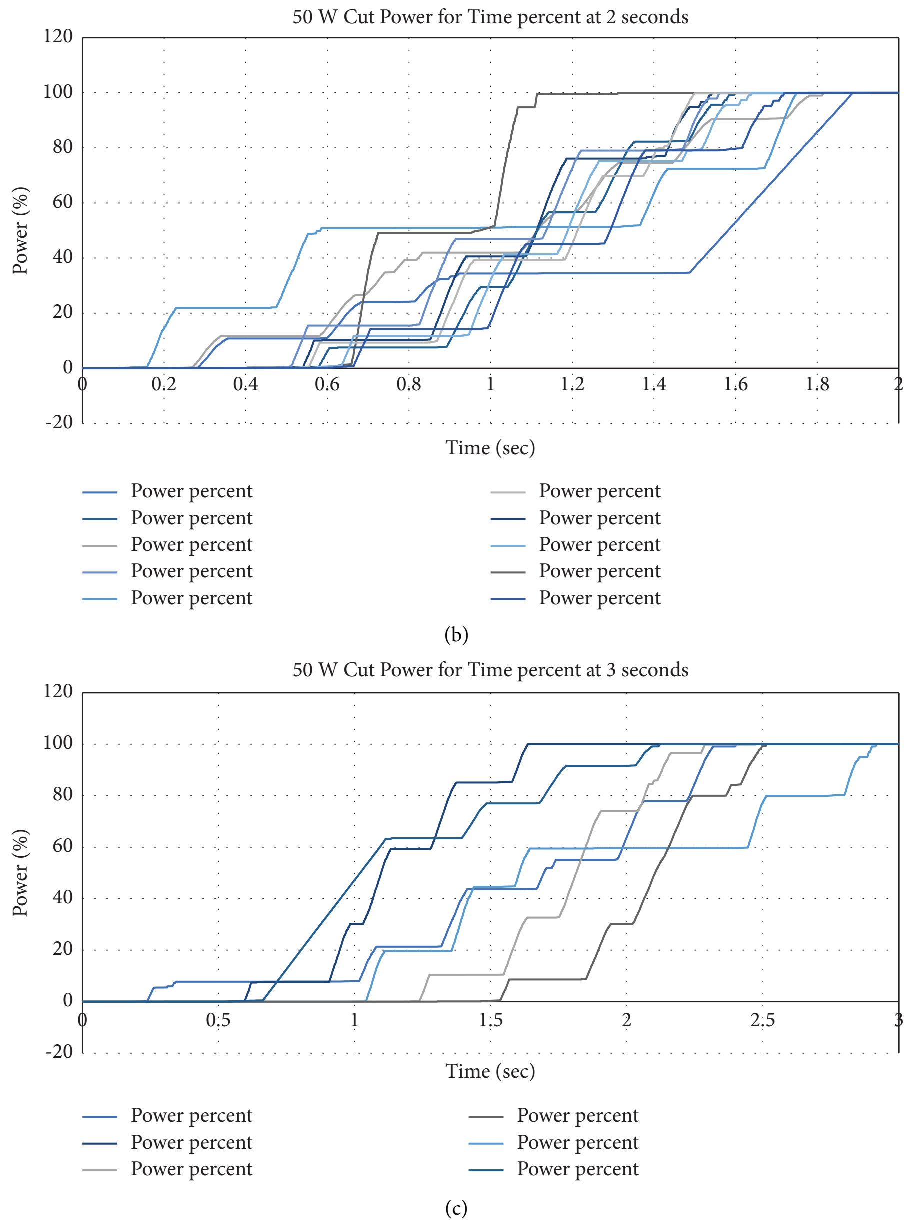


Figure 13: Signal intensity for time percent at 1, 2, and 3 seconds.

The intensities experienced by 1-, 2-, and 3-seconds voltage measurement are 2, 3, and 4 signal peaks, respectively. This shows an increase in intensity as the timing increases. The individual signals show similar intensity for the 1-, 2-, and 3-seconds time. Based on the firing, the power signal of the individual time series shows a similar pattern, as seen in Figure 13.

4.5. Power Control. Power control is based on getting the correct power output from the electrosurgical device so that it can be controlled to prevent patient complications and enhance the operator's judgment. The firing is done with the timing series from the Arduino for 1, 2, and 3 seconds. The response was obtained from the LabView based on the amplitude (voltage). The power calculation was based on the RRC circuit, which mimics the human body. The cumulative signal of power output shows the power intensity experienced based on the duty cycles and was obtained for the different firing times. Then, the power control was identified with the comparison method based on different percentages of power output on the polyps and largely dependent on the firing time of the electrosurgical devices.

The feedback signal of the voltage shows 1.05 V with a cumulative power of 0.4 W (100%) for a second 50 W cut mode which shows that the firing interception is at 0.2 W (50%).

The power measured for 2 seconds shows different power controls of 60%, 70%, 80%, and 90% at 1.31 W, 1.49 W, 1.70 W, and 1.95 W, respectively. This shows an increase in the intensity of the power cumulated based on the power control. The average power is 2.19 W, as shown in Figure 14.

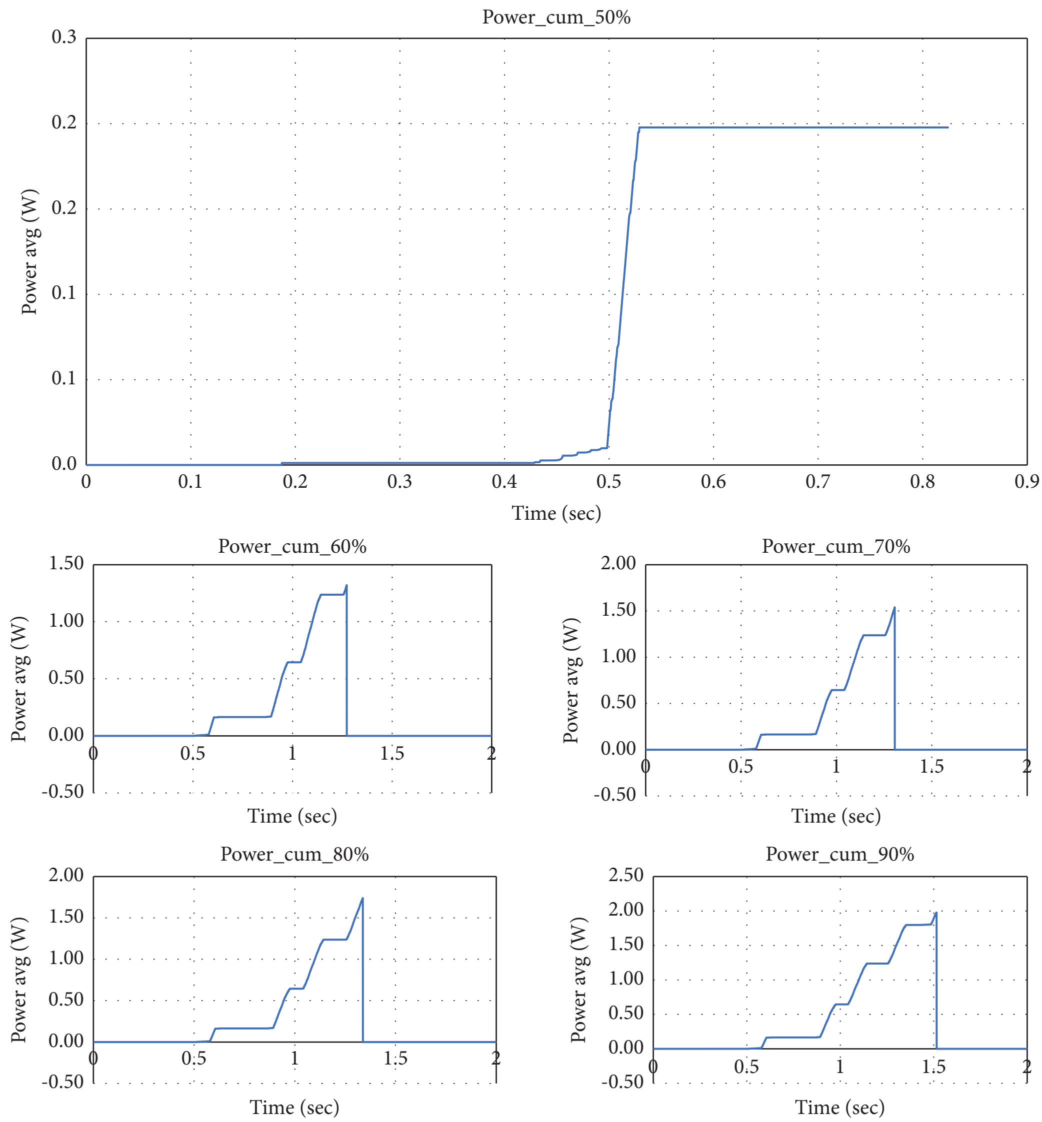


Figure 14: Power control for 1 and 2 seconds at 50 W cut mode.

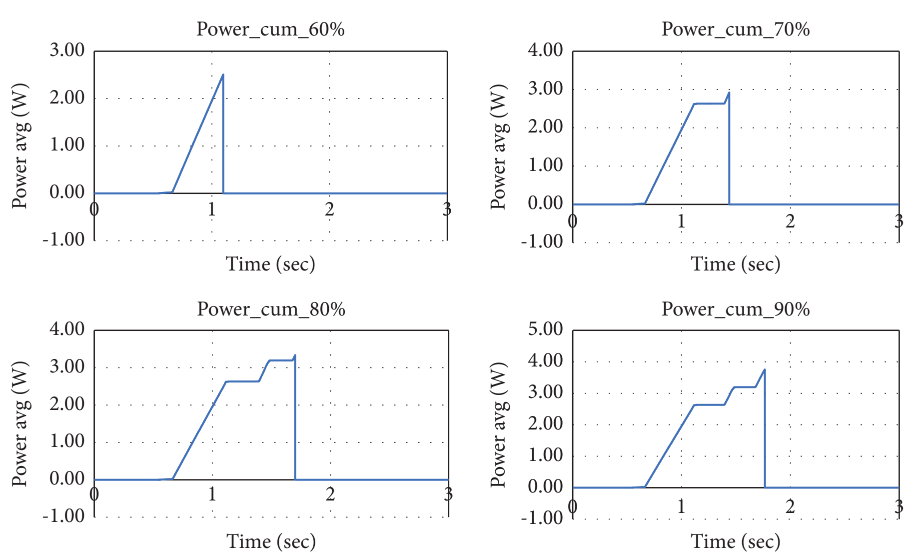


Figure 15: Power control for 3 seconds at 50 W cut mode.

Table 1: The average power for the 50 W cut mode of ESU [22].

	1 sec	2 sec	3 sec
Power average (W)	0.393947	2.04385	2.745558
Power standard dev (W)	0.065388	0.845216	1.001436
Power max (W)	0.492668	3.57434	4.147378
Power min (W)	0.273431	0.73457	1.850638

Figure 15 shows the power measured for the 3 seconds with control at 60%, 70%, 80%, and 90% with 1.56 W, 1.82 W, 2.08 W, and 2.34 W. The average power is 2.74 W experienced at 50 W cut power for 3 seconds. This shows that the increase in polyps will determine the power control of the electrosurgical unit.

Table 1 shows the average power for the 50 W cut mode of ESU. The type of power output released by the electrosurgical unit is very important to the surgeon, with the controlled variables increasing with the mode power setting from the PSD-30. The standard deviation at 1 sec was 0.065388 which is very low but as the time increases, the standard deviation increases which affects the intensities. As time increases, the area covered increases which in effect affects the standard deviation value.

There are different electrosurgical units with several waveform modes for the cutting and coagulation modes. But there is no standardized method; it depends on the manufacturers. For this experiment, the PSD-30 Olympus was used for the experiment. The same experiment applies to other devices with different waveforms to be achieved for the cut and coagulation modes.

5. Conclusion

The experiment was performed in three different methods to compare the results and confirm the signal effect for the electrosurgical unit for the cut mode (pure, blend1, and blend2) and the coagulation mode (soft, autostop, and forced).

The first trial performed was the setup where the electrosurgical unit was fired using a stopwatch for the time series of 1, 2, and 3 seconds. The measurement was obtained using an oscilloscope to measure the voltage and an output power device to measure the power from the electrosurgical device. There is a significant increase in the power output from the electrosurgical device which is dependent on the timing of the footswitch. The output power increases as the cut mode power and timing increase. The signal shows fluctuation in the output power obtained which is due to the limited control on the external stopwatch creating certain inconsistencies in the measurement.

Due to the uncertainty in the first trial, an improvement was made to remove the uncertainty and better the power output and voltage results. This led to the second trial, where an Arduino was developed to control the timing of the footswitch to improve the accuracy of the signal. The firing was performed using the Arduino Uno designed to manage the timing of the sequence for 3 different times (1, 2, and 3 seconds). This was performed for the cut and coagulation mode while measuring the output power and voltage with the power measuring device and oscilloscope, respectively.

It was observed that the pure cutting mode shows a high voltage between 877 mV and 1099 mV, which shows the reason it is used for quick cutting. The blend2 shows the highest voltage range between 956 mV and 1375 mV, which explains why it can cut and coagulate. While for the coagulation mode (Soft, AutoStop, and Forced), the three coagulation modes experience high voltage at the 2 W coagulation mode power, which explained that the setting for coagulation should be set at a minimum of 5 W coagulation mode power to avoid the high current since soft coagulation is recommended for stopping light bleeding. Likewise, the soft and autostop show similar traits in terms of limited fluctuation when compared with forced.

The experiment is to modulate the waveform by halting the current flow in which tissue gets an opportunity to cool and the part of cells that desiccate without detonating. By adjusting the duty cycle with voltage increases, the waveform will anticipate tissue impacts which lead to coagulation depth, thereby leading to hemostasis. A constant wave has a 100 percent obligation cycle and is frequently called a cut. On the other hand, a current of a fraction of the time and rest with off time has a 50% duty cycle. At the same time, a 20–80% duty cycle refers to a blend cut. The crest factor is used in this analysis because it gives better results and an understanding of the process. The power control was performed for the cut mode at 50 W to understand the firing time concerning the power output in which at 1 second, the power output is 0.4 W. While 2.19 W and 4.14 W for 2 and 3 seconds for the 50 W cut mode of the electrosurgical devices. This provides a limit for the operator in better understanding the operation of the device, which is also typically dependent on the polyps' size, which is not considered in this research.

Every manufacturer has suggested settings for the power mode, but it is noticeable that the selected watt may differ from the output signal given by the electrosurgical units, and adjustment relies on the experience and preferences of the operator.

The operator has a lot of influence on the accessory type, settings of the power mode, and the time series to be used, which determine the current flow. The time is the only variable controlled by the operator which determines the amount of heat generated.

The limitation of the experiment is the fluctuation experienced in the power output device of the electrosurgical unit, which is due to the electrical point on the wall socket. If this can be managed or the fluctuation reduced to the barest, then the output power will be stable. For future work, improve on the measuring methods and device while verifying with an organ, especially the coagulation mode, which shows drastic voltage drop. Likewise, the polyp size was not considered in this research.

This research will assist the operator in managing the cutting and coagulation modes of the PSD-30 electrosurgical unit with a view to the time of operation in tandem with the polyp's purpose. This provides operating procedures, irrespective of the experiences of the operator. This review looks for a technique to help unpracticed endoscopists in working on their presentation during colonoscopy methods by diminishing the event of exorbitant tissue warm injury. It offers an overall foundation for colonoscopy.

The part of this research paper is referred from the electronic thesis and dissertation [22].

Data Availability

The experimental data will be available from the first author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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