

Booster Circuit for Harvesting Renewable Energy Based on Bioelectric Microbial Fuel Cells Whose Power Can Be Adjusted

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Abstract. Microbial fuel cells (MFCs) represent a promising technology that converts organic waste into electrical energy through bacterial activity. The process involves capturing a low voltage of approximately 0.4 V generated by the MFC using a small capacitor, which is then stored and transferred to a larger capacitor to increase the capacity. In order for this energy to be used for general AC-powered devices, an inverter is essential to convert the DC output to AC. This system, consisting of a series of capacitors and inverters, along with voltage dampers and rectifiers, forms a circuit that can potentially function as an efficient low-power generator. The effectiveness of this arrangement remains to be tested, which will determine its viability as a renewable energy storage solution.

1 Introduction

Microbial fuel cells (MFC) are microbial-based fuel cells (MFC) that can produce renewable energy from bacterial activity. Through the use of exoelectrogenic bacteria as a catalyst, this bio-electrochemical fuel cell is able to directly convert chemical energy to electrical energy. Electrons are transferred to the anode of MFCs through a range of extracellular electron transfer (EET) mechanisms, referred to as anodic respiration, by exoelectrogenic bacteria that exclusively extract electrons through oxidation. The generated electrons are subsequently transferred to the cathode where they are employed in the oxidized compound's reduction reaction (i.e. E. electricity (or, in the case of air-cathode MFCs, oxygen) [1]. Renewable energy production can be accomplished simultaneously by adding nutrients as an energy source. Thus, it is believed that MFC technology, which uses organic waste to create electricity, holds a lot of promise. However, the energy generated by a single MFC is practically useless due to its high internal resistance and low output voltage, which is the mainstream MFC technology (it cannot even directly activate low-power electronic devices

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such as LEDs and cell phone chargers). The required operating voltage of the device is at least between 2 and 5 V, and the power consumption can be up to 1.2 W [2].

A single air-cathode MFC has a maximum theoretical voltage of 1.14 V across its anode and cathode [3]. Activation polarization, concentration polarization, and Ohmic losses are examples of electrode potential losses that affect air cathode MFCs. These losses are dependent on the substrate, microorganisms, electrode overpotentials, internal resistance, and external resistance [4], [5]. As a result, the typical observed open circuit (OCV) of these devices falls between 0 and 5 V. An MFC can produce power densities ranging from 1 to 2000 mW m⁻². Consequently, for practical use, the MFC output voltage and power need to be increased. To get around problems with low voltage or power, some MFCs are currently only connected in series or parallel. However, even though sequentially stacked MFC units have the potential to produce higher voltages, doing so is frequently challenging and ineffective because of the individual MFC units' voltage reversal, which results in a sizable overall voltage decay. Important [6], [7]. By connecting individual MFC units with maximum power point tracking (MPPT) systems to charge stacked polarized capacitors, considerable efforts have recently been made to control and suppress the occurrence of voltage reversal [8], [9]. Nevertheless, the stacked voltage may rise as a result of this technical method only between two and three volts [10], [11].

A power management system (PMS) has been suggested as a way to store enough energy to power the electronic load and raise the MFC's low output voltage to the required voltage. Essentially, PMS uses supercapacitors to temporarily store electrical energy and direct current to direct current (DC/DC) converters to raise low MFC voltages to usable levels. To date, many kinds of individually created or commercially available PMSs have been proposed, and their effectiveness has been assessed, to link MFCs with electronic loads. But only up to 2 or 3 V can be increased in the stacked voltage using this technical method [12], [13].

The purpose of this work is to develop an energy amplifier circuit to boost the microbial fuel cells' (MFC) low electrical energy output. The circuit raises the voltage so that the MFC output can be used to charge batteries or power a variety of low-power devices. This makes the electricity generated by MFC more useful.

2 Materials and Methods

Within an anaerobic anode compartment, Microbial Fuel Cells (MFCs) employ living microorganisms as biocatalysts to produce bioelectricity [14]. In the early 1990s, MFC was considered a promising technology.

2.1 MFC Structure

The general structure of microbial fuel cells is depicted in Figure 1. comprises cathode and anode chambers that are divided by a proton exchange membrane (PEM) [15]. At the anode, active biocatalysts oxidize organic substrates to release protons and electrons. Electrons are conducted via an external circuit, and protons are conducted to the cathode chamber via the PEM. In the cathode space, reduction of oxygen to water occurs in conjunction with proton and electron reactions [16]. Active biocatalysts in the anode compartment will oxidize the carbon source or substrate, and produce electrons and protons. Equation (1) illustrates the anodic reaction of acetic acid. Since the presence of oxygen in the anode chamber will prevent the production of electricity, practical systems must be built to keep bacteria and oxygen apart (anaerobic space for anodic reactions) [17].

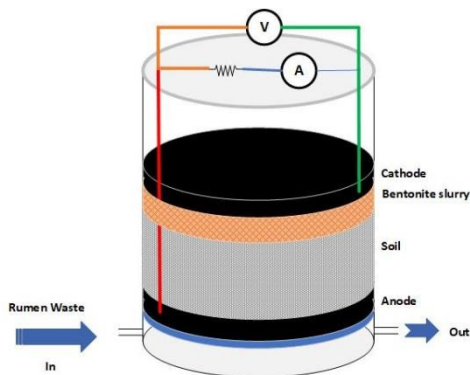


Fig. 1. The MFC system consists of anode and cathode compartments

By establishing a membrane that permits charge transfer between the electrode, the anode chamber—where bacteria grow—and the cathode chamber—where electrons react with oxygen—it is possible to isolate the biocatalyst from oxygen. Microorganisms in the anode chamber play an important role in producing electrons and protons. The resulting electrons are used to reduce the electron acceptor at the cathode after passing through the external circuit. The protons produced must enter the cathode through the proton exchange membrane. The anaerobic anode compartment is therefore one of the MFC's primary components. In the anode chamber, all necessary conditions are present for biomass degradation. Microorganisms, a mediator (if desired), a substrate, and an anode electrode acting as an electron acceptor are all contained in this compartment. Equation (3) illustrates the overall response within the anode chamber.

Microorganisms, a mediator (if desired), a substrate, and an anode electrode serving as an electron acceptor are all contained in this compartment. Equation (3) depicts the overall reaction in the anode chamber. The bacteria in the anode chamber function as catalysts needed for the reaction anodic [18]. As mentioned in the background, various factors influence MFC performance, namely electrode material, equipment configuration, and so on. Therefore, optimizing these factors will be very effective in improving performance in MFC energy harvesting. One of the most effective factors influencing MFC performance is the transfer of electrical energy from each MFC to utilize its electrical energy, through various methods including adding a booster circuit consisting of a storage and inverter circuit and optimizing the booster circuit design. In this case, it must also be added that the temporary storage of each MFC is an important part of the MFC to isolate the electrical system from the bacterial life system in the MFC medium [19]. Therefore, various circuit designs have been studied in different studies. Furthermore, the ideal booster circuit design must have the following characteristics: (i) can transfer electrical energy from the MFC without disturbing bacterial life; (ii) can transfer electrical energy from multiple MFCs; (iii) can increase stress; (iv) can change voltage polarity (dc to ac); and (v) the necessary electronic components are available on the market [20]. The material most often used for direct storage is batteries, because the voltage comes from the MFC, while batteries generally have a large voltage, so the voltage transfer process is difficult [21]. Modifying the transfer system using a difficult battery can be useful in improving MFC performance. To enable the transfer of electrical energy, a number of researchers have started modifying electrical energy transfer systems lately by employing different series of tiny capacitors. Apart from that, to change the polarity of the DC voltage to AC and increase the voltage, various methods of combining small capacitor storage circuits into large capacitors and then into batteries and these modification

methods have been tried [22]. The other showed that this booster modification can increase the transfer of electrical energy.

2.2 Design stage of small capacitor storage circuit

The capacitor used in this research is a small capacitor measuring 1 uF. Before being used as a storage material, small capacitors go through several stages. The small capacitor is first calibrated to the size of 1uF using a capacitance meter. Small capacitors are then connected to the MFC using wires to store each single MFC's energy [23]. After the stringing process is complete, the capacitor's voltage is then measured with a voltmeter until it reaches a voltage of 1-2 volts. The stringing process ends with all the MFCs being strung together.

2.3 Design stage of a small capacitor storage circuit to a large capacitor

Large capacitors are used to collect energy from large capacitors measuring 1000 uF. Before being used as a storage material, large capacitors undergo several stages. The large capacitor is first calibrated to the size of 1000 uF using a capacitance meter. The large capacitor then functions as the main energy storage before being connected to a 6-volt battery via a booster. The stringing process ends after the voltage measurement reaches 6-volt.

2.4 Design stage of the large capacitor storage circuit to the booster before the battery

The booster circuit consists of a large DC to DC voltage converter. Before being used as a storage material, large capacitors undergo several stages. This circuit requires power that comes from the DC voltage of the previous circuit. The final storage before entering the inverter is a 6 V battery.

2.5 Inverter Design Stage

The inverter circuit consists of a DC-to-AC voltage converter measuring 220 volts. Before being used as a modifier, the circuit goes through several stages. This circuit requires measurements using a DC voltmeter and AC voltmeter. If the final measurement is around 220 Volt then the final solution is to use a PCB assembly. The description above is as shown in Figure 2.

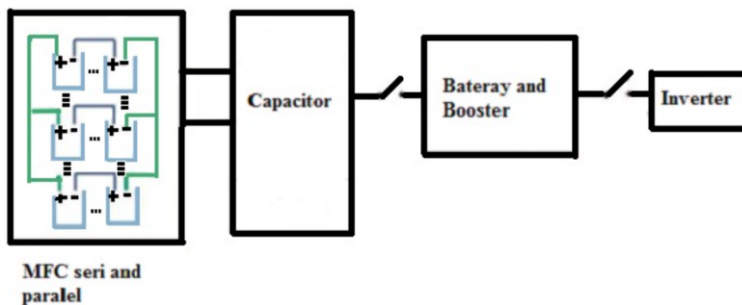


Fig. 2. Realization of the booster circuit in research

2.6 Electronic equipment

Table 1 displays the electronic parts that were utilized in the two voltage booster circuit designs.

Table 1. Electronic components used in the booster design

Element	Unit	Quantity
IC 4047		1
Capacitor	0,22 μ F	1
Resistance	100 Ω	2
Resistance	220 Ω	2
Resistance	350 Ω	2
Resistance	470 Ω	2
Potentiometer	22 k Ω	1
Transistor	IRF150	2
Transistor	IRF540	2
Transistor	IRFZ44	2
Transistor	BC337	2
Transistor	TIP 3055	2
Transformator	CT 5A	1
Transformator	CT 10A	1

3 Results and Discussion

3.1 MFC Structure

The MFC input voltage ranges from 0.3-0.4 volts, for 20 MFC (2 x 10 MFC), the minimum input voltage to the capacitor is 7 volts. The electrical measurement corresponds to the voltage and electric current produced by the Microbial Fuel Cell (MFC) system using ceramic PEM. This electrical measurement aimed to determine the effect of variations in substrate concentration and bacterial incubation time on the optimum power density produced through the Microbial Fuel Cell (MFC) system. The anode chamber in the Microbial Fuel Cell (MFC) system contains 100 grams of sediment and a cow rumen waste substrate sample with a volume of 200 mL [24], [25]. This measurement was carried out once every day at 14.00 WIB on 20 samples using two digital multimeters connected to a NiChrome wire. The 20 samples consisted of 1 control medium and 6 variations of substrate concentration, namely 0 times (without dilution), 2 times, 4 times, 6 times, 8 times, and 10 times which were repeated 3 times. In measuring the voltage and electric current strength, the polarization method is applied which is supplemented with varying resistors alternately for each sample. The aim of applying this polarization method is to determine the optimum power density produced through the Microbial Fuel Cell (MFC) system [26]. The power density was obtained from the average voltage and electric current strength of the seven samples with three repetitions.

3.2 Relationship between Optimum Power Density and Bacterial Incubation Time

To determine the effect of incubation time for cow rumen waste bacteria on the resulting power density value, it is necessary to measure the voltage and electric current strength in the microbial fuel cell (MFC) system. Based on the data obtained, the relationship between power density and time (day) can be seen as shown in Figure 3

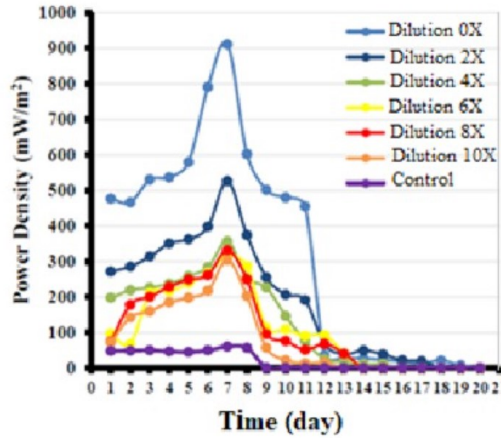


Fig. 3. Power density values producing

In Figure 4 it is shown that the power density values produced at each substrate concentration for the trend are relatively the same. In this study, the bacteria were in the lag phase (adaptation phase) which occurred from day 1 to day 2 where the bacteria adjusted to new environmental conditions. Then, the bacteria experience growth due to rapid and constant self-division causing reactions that produce electrons and protons thereby increasing the power density value significantly according to Figure 4. This phase is known as the Log or Exponential Growth Phase. In this study, this phase occurred on days 3 to 7. After the exponential growth phase, the points on the graph on days 8 to 12 show a decrease in the resulting power density value because the bacteria have entered the Stationary Phase. In this phase, dead bacteria are directly proportional to living bacteria due to reduced nutrient levels so that electricality decreases. This is also influenced by variations in the concentration of cow rumen waste substrate that have been determined. The performance of bacteria in the Microbial Fuel Cell (MFC) system will be optimal if the number of microorganisms is proportional to the substrate concentration. Then, in this study, the number of dead bacteria was greater than the live ones, shown on the 13th to the 20th day. This shows that the bacteria are in the Death or Logarithmic Decline Phase.

Based on Figure 3, it can be determined that on 3 days the bacteria produce optimum power density with the highest voltage and electric current strength, namely on the 6th day, 7th day, and 8th day. The bacteria in the Microbial Fuel Cell (MFC) system begin to work optimally to produce voltage and strong electric current or what is called optimum 1, namely on the 6th day. Then it produces the highest voltage and electric current or what is called optimum 2, namely on the 7th day. Then, it is at the optimum state of 3 on the 8th day.

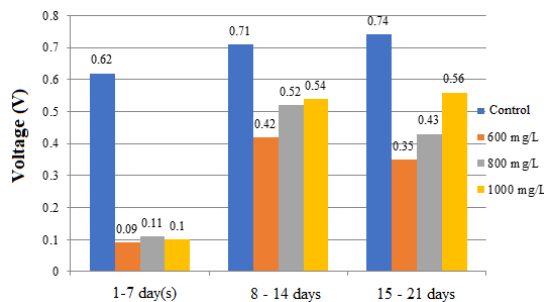


Fig. 4. Voltage generated for every MFC

3.3 Capacitor-Based Storage Circuit Design

The design for storing electrical energy originating from MFC is as follows. A circuit that transfers electrical energy to a small capacitor:

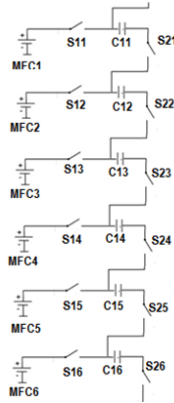


Fig. 5. Overview of the storage process in stages.

The small capacitor is C11- C16 using a size of 10 μF , 1 volt as shown in figure 5. Switches S11-S16 and S21-S26 use IC 4046.

Timing τ is determined using the equation

$$\tau = RC$$

With R = intrinsic resistance of the cable (0.40 Ω) and C capacitance of the installed capacitor (1000 μF). Because the energy contained in the capacitor comes from the MFC, the bioelectric process by bacteria is slow, so the timing τ is the minimum timing. Transferring electrical energy from a small capacitor to a large capacitor. The large capacitor is C21 circuited. The large capacitor is C21 using 100 μF , 10 volts, and the 100 μF capacitor is connected to a 6-volt battery.

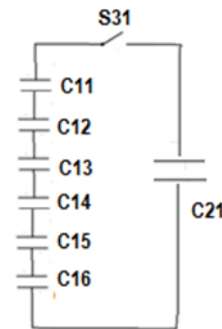


Fig. 6. The process of storing electricity from a small capacitor to a larger capacitor (C21).

3.4 Design Inverter

An inverter is a functioning power electronic circuit to convert DC electricity with adjustable voltage and frequency. A single-phase inverter circuit can be formed from IC 4047 as an oscillator, and two transistors as an electronic switch with a push-pull configuration as shown in figure 7.

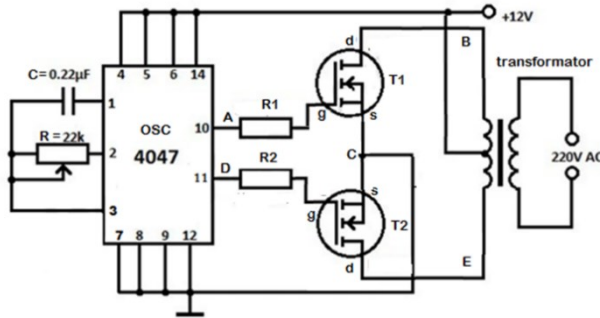


Fig. 7. Inverter using IC4047, terminals A, B, and C are filled with the following circuit point D, C, and E are filled with the following circuit.

Here, we use the transistor in a common emitter configuration. In a common emitter configuration, the transistor provides a 180° phase shift between input and output. Because of this 180° phase shift, the transistor can produce a high (maximum) signal at the output when the given input is low, and can produce a low (minimum) signal at the output when the given input is high. In this way, the transistor works like an inverter and produces an inverted value at its output. As we know, the transistor can function as a switch, namely the ON switch is in a saturated state and the OFF switch is in a disconnected state. Due to the characteristics of this transistor, we can use it as a switch to perform inversion operations. The input to the two transistors is obtained from IC 4047 (via outputs number 10 and number 11), which functions as an oscillator with an adjustable frequency (Figure 8).

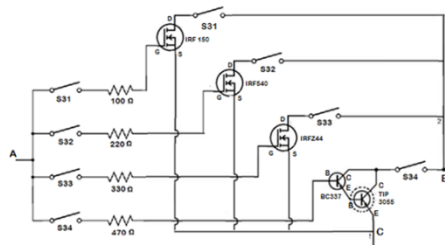


Fig. 8. The first part of the push-pull circuit using a transistor

Frequency setting is through the addition of additional components R and C which are installed via legs 1, 2, and 3 of IC 4047. The frequency chosen is 50 Hz according to what is happening in Indonesia. Because transistors have a limited ability to operate current, in this study 4 options have been provided (when the maximum power is 5W, 10W, 15W, and 20W). The available power comes from the MFC system which is available by the system. This transistor selection setting is based on the power available in the system, arranged using a switch and Arduino (Figure 9 and 10). The switches used are S31 (paired S31'), S32 (paired S32'), S33 (paired S33'), and S34 (paired S34).

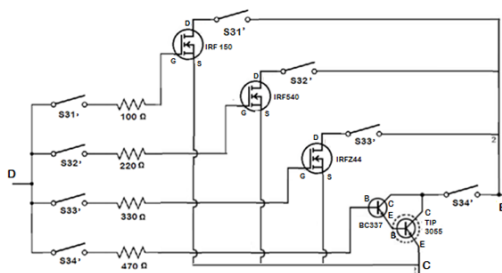


Fig. 9. The first part of the push-pull circuit using a transistor

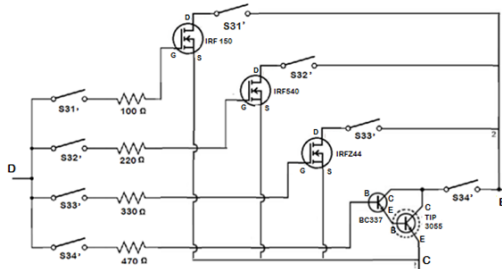


Figure 10 The first part of the push-pull circuit using a transistor

R is set using VR1 and C is C1. For example, if $R = 10 \text{ k}\Omega$, to get a frequency of 50 Hz then C must be equal to $4.55 \times 10^{-7} \mu\text{F}$ or $455 \mu\text{F}$ and to get a frequency of 60 Hz then C must be equal to $3.788 \times 10^{-7} \mu\text{F}$ or $379 \mu\text{F}$. The timing is set to a minimum of τ to give the bacteria time to produce bioelectric energy. Then the voltage enters the $4700 \mu\text{F}$ capacitor, and finally to the battery storage (6 volts). The inverter circuit was chosen to produce 220 volts effective voltage, with a frequency of 50 Hz. The electrical power is selected based on the charged power in the battery storage, and then the selection of push-pull transistors is chosen according to the power level, as in Table 3.

The air-cathode MFC was operated continuously at 3640 ppm cow rumen nutrition. MFC power generation varies due to less stable microbial conditions of 18.50 mA m^{-3} and power density of 3.50 W m^{-3} respectively. The average output voltage of the MFC during the entire experimental period was $0.37 \pm 0.02 \text{ V}$. A total of 20 MFCs connected in series produced a voltage of approximately 7 volts. The 7 Volt voltage is stored in a 6 Volt battery. The same MFC circuit connected to the second battery produces 6 volts too. The two batteries, each 6 volts, are then connected in series to produce a voltage of 12 volts DC and fed to the multivibrator to be converted to AC voltage at a frequency of 50 Hz as shown in Table 2. The AC voltage formed has the equation

$$V = 12,2 \text{ Sin } 100 \pi t \text{ (volt)}$$

Table 2. Switch and transistor selection

Transistor $T_1 = T_2$	Resistor $R_1 = R_2$	Power	Transformator	Switch
IRF150	100 Ω	5 W	9-0-9, 1 A	S31 dan S31'
IRF540	220 Ω	10 W	9-0-9, 5 A	S32 dan S32'
IRFZ44	330 Ω	15 W	9-0-9, 5 A	S33 dan S33'
BC337 and TIP 3055	470 Ω	20 W	9-0-9, 10 A	S34 dan S3'

The voltage frequency depends on the settings of VR1 and C1, following the formula

$$f = \frac{1}{T}$$

$$T = 4.40 RC$$

Table 3. The 12 V voltage is subsequently transformed to AC voltage using a multivibrator circuit.

Parameter	Quantity
Voltage input	12 VDC
Voltage output	12,2 VAC
Frequency	50 Hz
Power	21 W
Current	1,9 A

Next, this AC voltage is passed to a step-up transformer (12V-0-12V to 220 V) to produce a voltage of 220 AV as shown in Table 3. The MFC works for 37 hours to charge the first 6 Volt battery, then the second 20 MFCs charge the second 6 Volt battery. During charging before the battery, each MFC is connected to a 470 μF (10-volt) capacitor. Each charge to the switch timing capacitor is made every 1 minute period. One minute later it is disconnected to open the connection to the 4700 μF (25-volt) capacitor. A total of 20 470 μF (10 volt) capacitors are connected to a 4700 μF (25 volt) capacitor which produces a voltage of 7 volts to charge a 6-volt DC battery. The total time to charge two batteries is 2 x 37 days = 72 days. The total power on the two batteries is 21 watts. Meanwhile, the power transmitted to the transformer to produce a voltage of 220 is 20 watts as shown in table 3. The installed transistor circuit is used for selection when the collected power is 10W, 20W, 30 W, and 40W. Power selection uses Arduino, the selection is based on the power stored in the battery.

Table 4. AC voltage output produces by the transformer.

Parameter	Quantity
Voltage input	12,2 VAC
Voltage output	220 VAC
Frequency	50 Hz
Power	20 W
Current	1,6 A

This research shows a new energy collection circuit system from MFC generation, based on DC-DC converters. Another boost converter is implemented, which takes advantage of the voltage generated by the MFC, to allow the influx of electrical energy. Through the arrangement of the transistors used it is possible to adjust the power to the power coming from the MFC. Research makes it possible to activate indicators (LEDs) via the MFC. The hope is to recreate the same system on a larger power scale to supply a larger power source, for example for home lighting.

The use of capacitors does not produce much high continuous power but allows internal power distribution. An inverter is a power electronic circuit that is used to convert direct voltage (DC) to alternating voltage (AC). Transistors (MOSFETs) can be utilized or used to make inverters, these MOSFETs in the inverter circuit function as switching to change DC voltage waves into sine waves or AC voltage waves.

4 Conclusion

Collecting electrical energy can be done with MFCs connected in series and parallel. Storing electrical energy from MFC can be done with capacitors and batteries (Accu). Converting direct voltage (DC) to alternating voltage (AC) can be done using an inverter consisting of an oscillator (multivibrator) circuit using transistors, with a frequency that can be adjusted by adding variable resistance and capacitors. Using a transformer, we can raise the voltage.

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