The Effect of The Magnetic Field on an Ozone Generator FED by A Non-Sinusoidal Resonance Inverter

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Abstract: The performance of magnetic field-induced dielectric barrier discharge (DBD) as an ozone generator has been investigated. The effects of permanent magnet induced DBD position has also been varied using three approach models. Model 1 was by placing the ring permanent magnet under the ground electrode tied with Teflon, model 2 was by placing 2 (two) permanent magnet rings above the high voltage electrode and below the ground electrode, respectively which was limited by a Teflon solid material and the magnetic conditions were repelling each other, model 3 was by using 2 (two) pieces of ring permanent magnet placed above the high voltage electrode and below the ground electrode which was bounded by Teflon materials and these magnetic conditions were attracting each other. When the fly-back transformer terminal was connected to the high voltage and ground electrodes for model 1, the maximum measured voltages and discharge currents for model 1,2, and 3 were 13.8 kV and 690 mA, 12.5 kV and 973 mA, 11 kV and 800 mA, respectively. The ozone generator produced ozone gas at 110 ppm, 162 ppm, 207 ppm for model 1,2, and 3, respectively. Furthermore, the addition of permanent magnet beans as electrodes increased energy to produce plasma in the gap between the high voltage electrode and dielectric ceramic. It was shown that the permanent magnet beans enhanced the development of plasma in the gap. The effect of induction of ring permanent magnet with attractive conditions is new thing to improve the performance of ozone generators.

Keyword: DBD, magnetic field, non-sinusoidal inverter, plasma, Lissajous, ozone

1. Introduction

Dielectric barrier discharge (DBD) was first introduced by Siemens which was used as an ozone generator. Siemens began his experiment to examine the effect of dielectrics on the plasma produced and this plasma was used to react oxygen compounds to ozone gas [1]. The main components of this dielectric barrier discharge (DBD) are high voltages in kilovolts with system frequencies from Hz to kilo Hz, high voltage and ground electrodes and dielectrics made of ceramics, glass, mica, etc. The construction of the barrier discharge dielectric (DBD) is given in figure 1 below [2]. The dielectric barrier discharge (DBD) application has fulfilled various aspects of science such as ozone generators used for drinking water treatment, waste treatment, waste gas treatment, plasma medicine, surface treatment, etc [2-7].

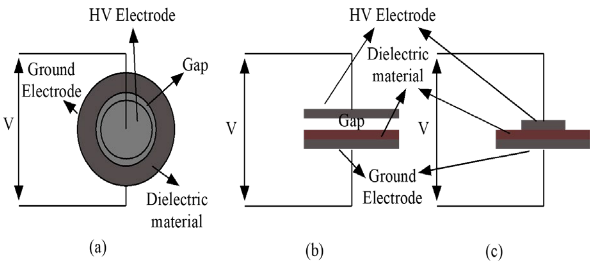

Figure 1. Dielectric barrier discharge arrangement. (a). Cylindrical DBD, (b) Planar DBD, (c) Surface DBD.

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The ozone formation reaction process which is more dominant when the high pressure on the gas is given in the following reaction as equation (1) [8].

$$O + O_2 + M \rightarrow O_3 + M \quad (1)$$

This chemical reaction does not always succeed in forming an ozone gas, but this reaction sometimes produces oxygen gas and molecular M as in the reaction equation (2) below.

$$O + O + M \rightarrow O_2 + M \quad (2)$$

At the case of discharge of electric charge in the air, molecule M is molecular oxygen or nitrogen. Ozone under certain conditions can react again with nitrogen given in equations (3) and (4).

$$NO_2 + O_3 \rightarrow NO_3 + O_2 \quad (3)$$

$$O + NO_3 \rightarrow O_2 + NO_2 \quad (4)$$

There are two-steps process of ozone generation in a non-equilibrium discharge in air at atmospheric pressure. First, oxygen atoms dissociate to an oxygen molecule with the threshold energies [9,10] for these processes as seen in Table 1:

Table 1. Threshold energy in the oxygen ionization

Process	Threshold energy (eV)
$O_2 + e \rightarrow O^- + O$	4.2
$O_2 + e \rightarrow O + O + e$	5.58
$O_2 + e \rightarrow O + O(^1D) + e$	8.4

Secondly, oxygen ion reacts with molecule O_2 and creates an ozone molecule that requires the presence of electrons with these energies.

Nowadays, many researchers conducted a dielectric barrier discharge (DBD) to be used as an ozone generator. Kamel examined surface dielectric barrier discharge (SDBD) and volume dielectric barrier discharge (VDBD) as an ozone generator with cylindrical geometry. This DBD has cooling media. This study showed the cooling media could improve the performance of ozone generators [11]. Some researchers also examined ozone generators using power supply impulses in order of nanosecond and managed to regulate spark discharge to produce the ozone well [12-15]. The mini impulse generator prototype was also successfully made by Waluyo which was used for high voltage purposes [16]. Murdiya uses a half-bridge resonance inverter power supply and was successfully combined with a dielectric barrier discharge (DBD) to produce high voltage plasma [17].

The effect of the magnetic field on the high voltage plasma between the electrode and the dielectric has been investigated by Park [18]. Park used needle electrodes as high-voltage electrodes placed inside the gap between the electrode and dielectric [18]. Murdiya also examined the influence of magnetic fields on plasma produced by surface barrier discharge (SDBD) and showed things that were different from DBD without magnetic fields. It was shown that plasma with the influence of magnetic fields was denser than plasma without a magnetic field [19]. Pakarek also examined the effect of permanent magnets on the development of high voltage plasma in the gap between a needle and a dielectric, where the position of needle electrode was parallel to permanent magnet. The results of the study showed the effects of magnetic fields affected the movement of gas molecular ions [20]. Liu began the study by comparing plasma generation with magnetic field induction (not induced by magnetic fields). He also did the arrangement of plate electrodes and dielectrics in magnetic field and focused on the nanosecond power supply connected to a high-voltage electrode. This experiment results in fact is the plasma moving above the dielectric surface that is induced by magnetic fields and it is slightly different from the plasma without induction by magnetic fields [21]. Murdiya, et.al used a permanent magnet with an intensity of 315 mT in a dielectric barrier discharge (DBD) experiment as an ozone generator. Magnetic fields with magnetic induction of around 300 mT were also used in dielectric barrier discharge (DBD) for the wettability of polypropylene.

Pakarek used permanent magnets with 60 mT induction in dielectric barrier discharge (DBD) for ozone production [17, 22,23].

In this study, we attempted to examine the ozone generator with novel configuration of DBD. We also installed another power supply as known with non-sinusoidal inverter. Then, dielectric barrier discharge (DBD) which was induced by permanent magnetic fields for ozone production has been carried out in this research. The effect of a permanent magnet addition that induced a dielectric barrier discharge by placing two permanent magnet rings above and below the high voltage and ground electrodes were also investigated. Otherwise, ferrite permanent magnet beans were also used as additional electrodes and they were attached to the high voltage electrode surface. There were three models of permanent magnet ring positions were tested. First model was ,the permanent magnet ring was placed under the ground electrode, second model was by placing the permanent magnet ring above and below the high voltage and ground electrodes under the repulsion condition between the permanent magnet rings, and third model was the same as the second model with the difference in the condition of permanent magnets attracting each other. The power supply used was a non-sinusoidal inverter with a maximum voltage of 15kV. In this study, the characteristics of plasma, current and voltage characteristics, Lissajous diagrams and ozone concentrations produced from several models were examined.

2. Experimental procedures

A. High voltage generator circuit and experiment set up

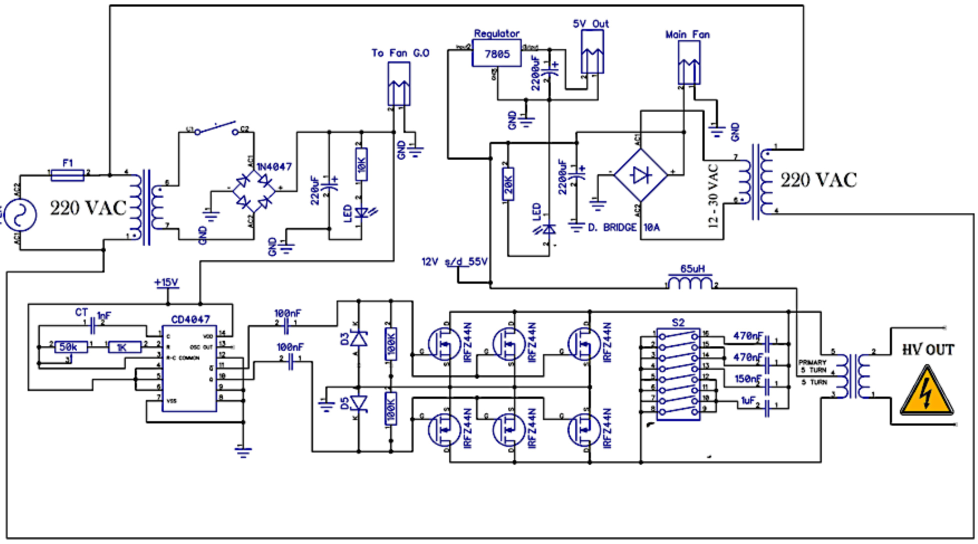


Figure 2. Complete electronic circuit of a nonsinusoidal half bridge resonance inverter

The complete electronic circuit of a non-sinusoidal inverter is given in figure 2. The inverter input was supplied from a direct current (dc) power supply with a voltage of 18 volts dc. For the MOSFET control circuit side on this inverter was equipped with IC CD4047 which was a PWM IC (pulse width modulation). In this electronic circuit, six MOSFETs that were connected in parallel and form a bridge circuit in order to enlarge the current into the LC resonance circuit. In order to produce oscillation currents, this circuit was equipped with an inductor of 65 micro Henry and was connected in series with capacitors with varying values of 470nF, 150nF, and 1uF, respectively. In this test, the selected capacitor was 150nF. The output of the resonance circuit was connected to the low voltage side of the fly-back transformer with the primary coil was a center tap with some turns 10/2. The high voltage side of the fly-back transformer was connected to the high voltage and ground electrodes as given in figure 3. The photograph of the complete ozone generator is depicted in figure 4. Non-sinusoidal high voltage generator fed by the resonance inverter circuit applying a voltage of 18 Vdc was connected to the primary side of the fly-back transformer. The high voltage side of the fly-back transformer was connected to the high voltage DBD terminal. The measurement of the output voltage of the fly-back transformers using a voltage divider with a ratio of 1,000: 1 (with the brand of SEW) was connected to the high voltage electrode terminal, and the output was also connected to a digital oscilloscope (Hantek 6204 BC). The discharge current in the DBD circuit was measured by using a current probe (Hantek CC65), and it was also connected to a digital oscilloscope. We also measured the Lissajous graph by detecting voltage of Cs of 0.01uF and high voltage probe. In this research, we practice how to produce ozone gas by injecting free air into the DBD with the help of a small fan. Ozone concentration data was recorded by an ozone meter HT-E-O3.

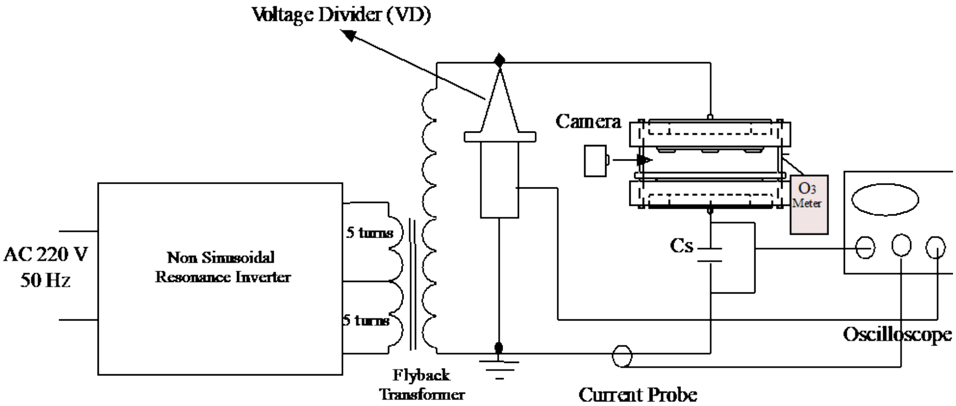


Figure 3. Experiment set up and collecting data

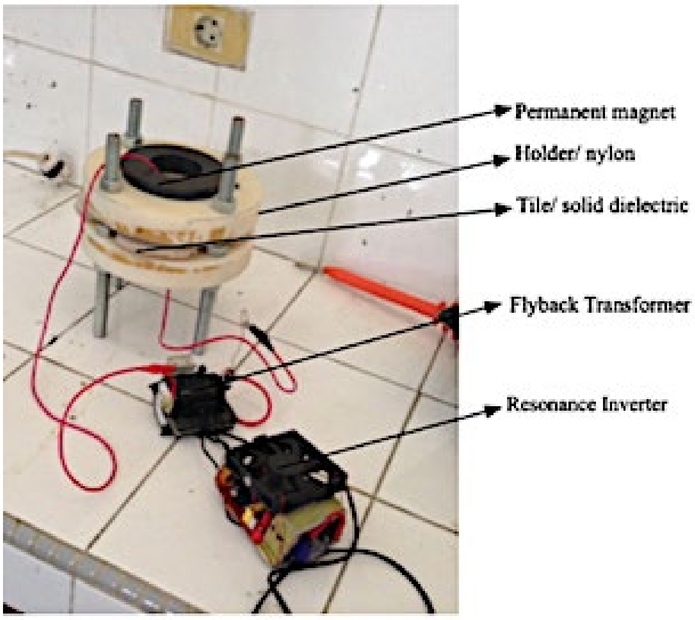
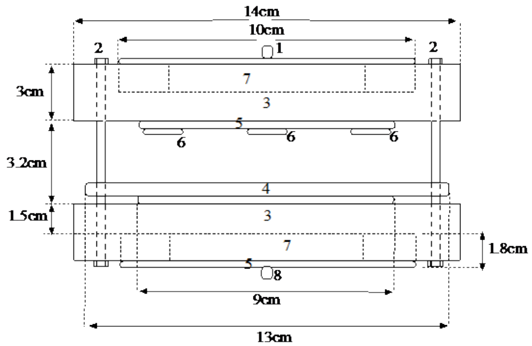


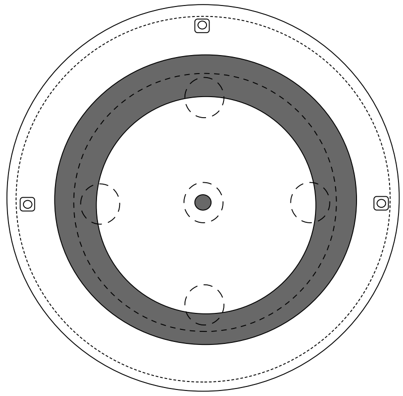
Figure 4. Complete arrangement of ozone generator

B. DBD Configurations

The dimensions of DBD can be seen in figure 5 below. We designed a Teflon as a holder of the permanent magnet ring with an outer diameter of 14 cm and the Teflon thickness of 3 cm, respectively. The distance between the holders (Teflon to Teflon) was 3.2 cm, while the outer diameter of the permanent magnet ring was 10 cm. The high voltage and ground electrodes used were made of stainless steel with a diameter of 9 cm. The dielectric used in this DBD was the floor tiles (Trademark Platinum), it was made in Indonesia. This ceramic had a diameter of 13 cm with a thickness of 0.7 cm. A high voltage electrode was attached to 5 (five) small permanent magnets which were useful for initiating a plasma in the gap between the high voltage electrode and ceramic dielectric as shown in figure 6. This ozone generator was also installed the permanent magnet rings (10cm Outer Diameter) with several models including model 1 was by placing the ring permanent magnet under the ground electrode tied with Teflon, model 2 was by placing 2 (two) permanent magnet rings above the high voltage electrode and below the ground electrode, respectively which was limited by a Teflon solid material and the magnetic conditions were repelling each other, model 3 was by using 2 (two) pieces of ring permanent magnet that placed above the high voltage electrode and below the ground electrode which was bounded by Teflon materials and these magnetic conditions were attracting each other.



a. Side view



b. Top view

1. HV Termination
2. Bolt and Nut 10M
3. Teflon/Holder
4. Solid dielectric/Tile (Trademark Platinum)
5. Electrode
6. Permanent Magnet Bean (Ferrite Magnet)
7. Circular Permanent Magnet (10 cm OD)
8. HV Termination

Figure 5. View of Dielectric Barrier Discharge (DBD) Chamber

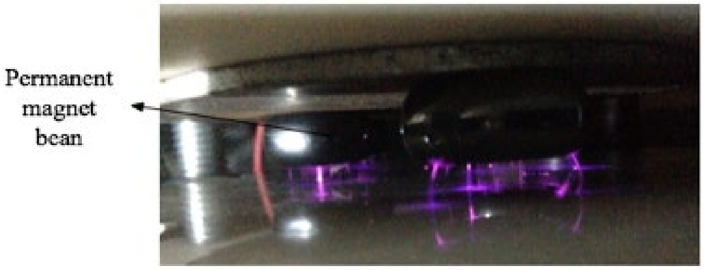


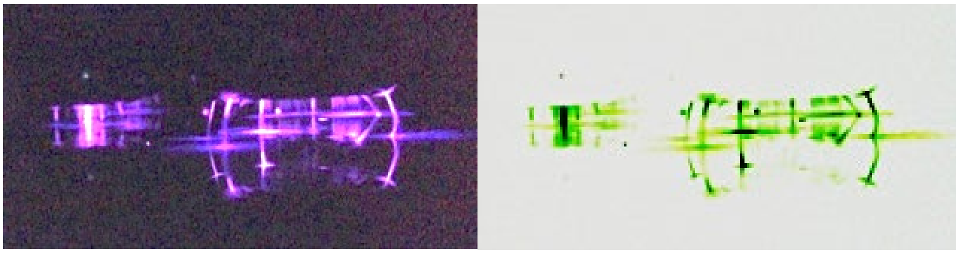
Figure 6. The arrangement of small permanent magnets on the high voltage electrode.

3. Results and discussion

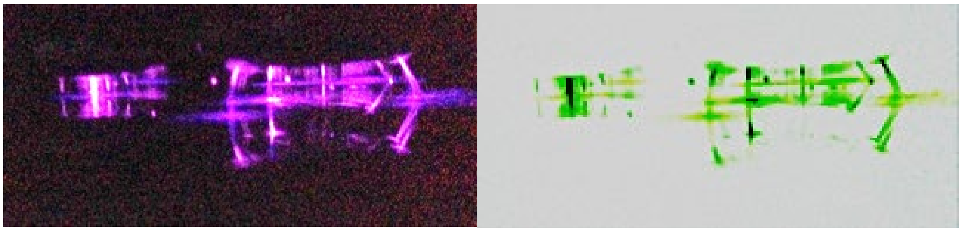
A. Plasma Photographs

From this experiment, model 1 is designed by placing a permanent magnet ring under the ground electrode, and plasma is initiated by adding some permanent magnet beans attached on the high voltage electrode, while model 2 and 3 are designed by equipping two permanent magnet rings above high voltage electrode and under ground electrode. These models also initiate a plasma in the gap by equipped some permanent magnet beans under the surface of the high voltage electrode. The condition of model 2 is making repulsion between permanent magnet rings while model 3 is attraction condition between permanent magnet rings. The plasma pictures that occur in the gap between the high voltage electrode and ceramic dielectric are given in figure 7 below. The light intensity on model 1 is higher than models 2 and 3 as seen in the left photo of figures 7a, 7b, and 7c. This is also supported by the right photo of the images in figures 7a, 7b and 7c which are the results of the invert color. In this condition, it can be seen in figure 7a which has a more extensive black color which is a higher light intensity when compared to figures 7b and 7c. There is some black area in all pictures, and it is indicated that the plasmas produce high-intensity energy. The black area in model 1 is more and more significant than model 2 and model 3.

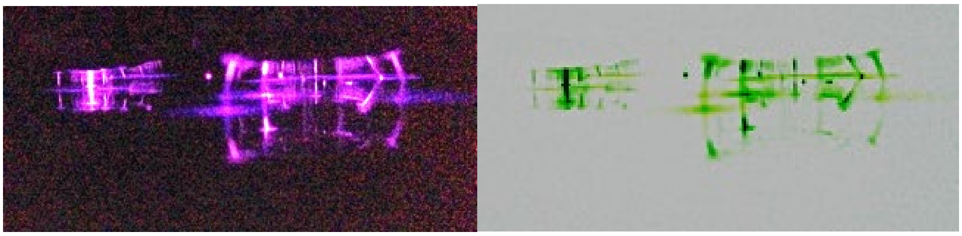
By adding some permanent magnet beans under the surface of the high voltage electrode, this method is successful for producing plasma in all the models. These permanent magnet beans are able to initiate plasma with the accumulation of electric and magnetic fields. Plasma appeared on the edge of the permanent magnet beans, and they developed on the surface of the ceramic. These plasmas are non-homogenous plasmas that form non-dense beam between them. Plasmas which have a high light intensity marked in black on the invert color condition energized with high discharge energy. The plasma produced in model 3 is denser than plasma in models 1 and 2. Then, plasma in model 2 is also denser than that of model 1. It can be seen that a permanent magnet is placed between two electrodes with attraction condition, it can make plasma more tight than model 1 and 2. Furthermore, by adding permanent magnet beans as electrodes, it will increase energy to produce plasma in the gap between the high voltage electrode and dielectric ceramic. It is shown that the permanent magnet beans enhance the development of plasma in the gap. This plasma can also cause erosion on the ceramic/dielectric surface. Model 1 is also found that the solid dielectric (ceramics) is more accessible to erode gradually than models 2 and 3. If an area of ceramic dielectric has a point of erosion, plasma tends to be concentrated in the area of the erosion point. This centralized plasma will glow the dark yellow light. The stages of plasma development on the erosion point are given in figure 8. It can be concluded that this erosion point has decreased its isolation resistance and the electric field is centrally located at that point. The plasma will continue to erode the point until finally, the solid dielectric can conduct the electricity. It is this phenomenon that always occurs in the event of an electrical breakdown in insulation materials which can be explained in theory, the plasma that occurred for all models under conditions of the air pressure of 1 atm. Noise produced by model 1 is also noisier than models 2 and 3.



a. Model 1

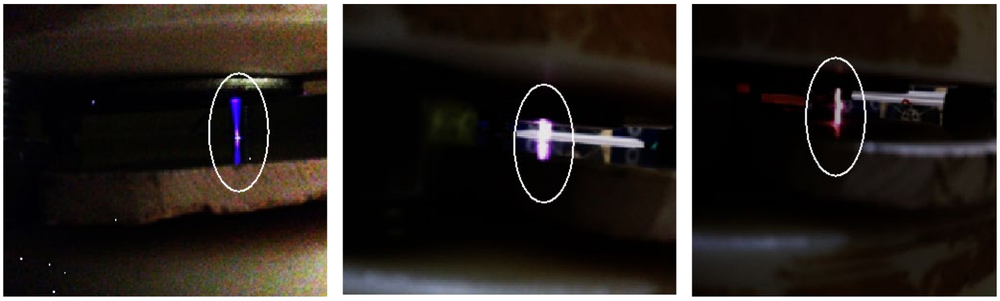


b. Model 2



c. Model 3

Figure 7. The results of plasma shooting for various permanent magnet conditions



First step Second Step Third step

Figure 8. Plasma at an erosive dielectric point (plasma picture in circle line)

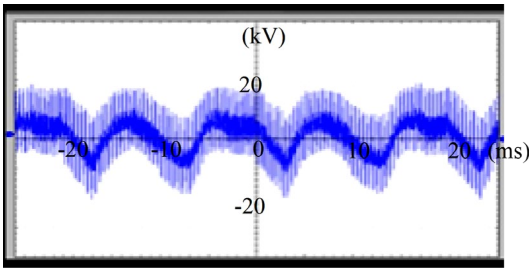
B. The voltages and displacement currents

The high voltage side of the fly-back transformer in a no-load state produced a non-sinusoidal wave with a maximum voltage of 17.3 kV that was measured by using a voltage probe with a ratio of 1: 1000 and it is given in figure 9a. When the fly-back transformer terminal is connected to the high voltage and ground electrodes for model 1, the results of current and voltage measurements are given in figure 9b. The maximum measured voltage is 13.8 kV and the maximum current pulse measured is 690 mA. The results of current and voltage measurements for model 2 show that the maximum voltage is 12.5 kV and the maximum current pulse is 973 mA. For model 3, the maximum current pulse measured is 800 mA and the maximum voltage measured is 11 kV. For all models produce current pulses which indicate micro discharge occurs in the gap between the high voltage electrode and ceramic dielectric. Of all the models, it appears that the most current pulses are in model 3, which also indicates that this model 3 produces more micro discharge than models 1 and 2. This is also characterized by current pulses of model 2 which are more than models 1. This current pulse occurs when the maximum voltage for all models. From figure 9 it can also be concluded that the maximum voltage and maximum current pulse at discharge for all models are different. When there is a discharge of current suddenly reaches its maximum value for all models. This discharge causes an increase of current in the test circuit.

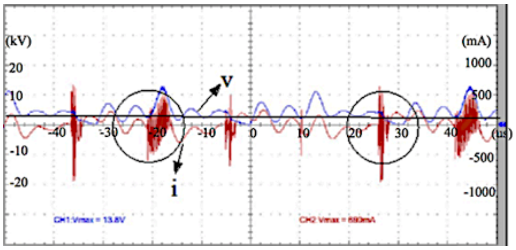
The discharge current in model 1 is depicted in figure 9b. Partial discharge occurs during positive cycles and negative cycles. Partial discharge occurs in a positive cycle that is at zero voltage and up to maximum voltage and then it decreases to zero. Next, it also occurs during a negative cycle of voltage. The current pulse in the positive cycle is more than the negative cycle. The current pulses in model 1 take place intermittently. The pulse amplitude of discharge current in the negative cycle is higher than the positive cycle. The discharge current is shown in figure 9c shows that partial discharge occurs during a positive cycle and a negative cycle as well. During a positive cycle, the partial discharge occurs starting from zero voltage until the voltage reaches the maximum value. The current pulse in the positive cycle appears for 2 us and then reappears in the negative cycle after 6 us of the positive cycle. In a negative cycle, it starts from zero voltage until the voltage approaches the minimum. The current pulse during the positive cycle is more than the current pulse in the negative cycle. This ozone generator model shows that the amplitude of discharge current is greater in the negative cycle than the amplitude of the current in the positive cycle. The ozone generator from model 3 (figure 9d) experiences a discharge of charge every period of 20 us.

The release of this charge occurs for every 15 us. This discharge is initiated when the equipment voltage reaches its maximum value of 11 kV, and it will take place even though the voltage value decreases to the minimum value. The electrical discharge in model 3 occurs when the voltage value is zero until reaching the maximum voltage, and it is continued until the voltage goes to the minimum and it returns to zero. After the discharge event, the voltage drops and an electrical discharge is not easy to redischarge for period of 20 us. When discharge occurs, the discharge current pulse rises to a maximum value of 800 mA. The release of this charge indicates that the ozone generator for model 3 is suffering micro discharge which reacts oxygen to form ozone gas. From the results of this current measurement, it can be seen that the plasma developed is not continuous which follows the release of the charge from this ozone generator.

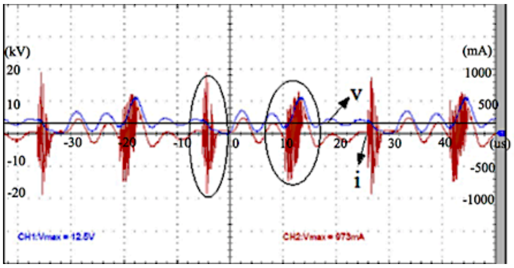
The measurements shown in the Lissajous diagram (figure 10) were carried out using the Sawyer-Tower circuit with a capacitor value of 0.01uF. The voltage versus electric charge graph gives different areas of the Lissajous area. On a 1-minute discharge condition, it appears that the Lissajous area for all models is slightly different. The area of Lissajous in model 3 is slightly more significant when compared to the area in models 1 and 2. The area of the Lissajous model 2 is the smallest area compared to other models. However, after a 5-minute discharge, the Lissajous area for all models expanded. The area of the Lissajous model 3 is slightly smaller than the models 1 and 2. The area of Lissajous in model 2 is the largest area compared to models 1 and 3. It is seen that the effect of the position of the permanent magnet parallel to the high voltage and ground electrodes on the area of the Lissajous (discharge energy) is not very significant. For further research, it is necessary to place a permanent magnet perpendicular to the high voltage and ground electrodes. The accumulation of electric and magnetic fields is predicted to have a different impact on the dielectric barrier discharge.



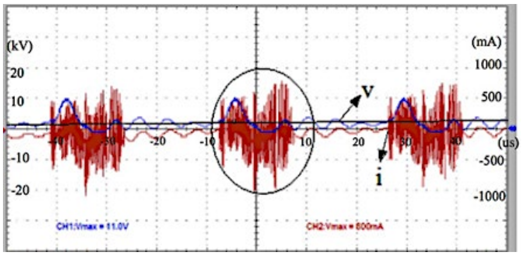
a. High volatge power supply in open circuit



b. Model 1



c. Model 2



d. Model 3

Figure 9. Voltage and discharge current for all models

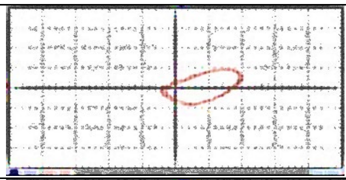
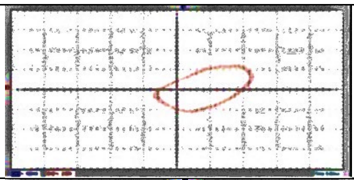
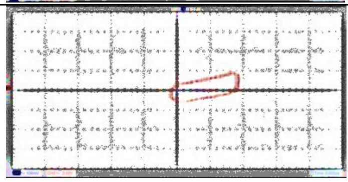
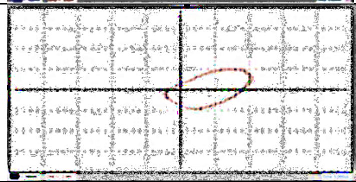
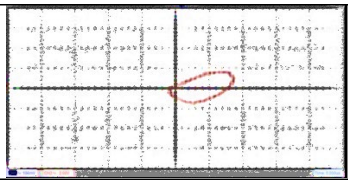
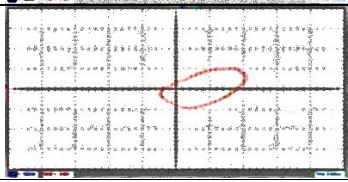
Model 1		
Model 2		
Model 3		
Time	First Minute	Fifth minute

Figure 10. Lissajous diagram for all models of DBD

In the generator ozon with DBD induced by magnetic field, the direction of electric field is perpendicular to magnetic field that is known as the Lorentz force:

$$\boldsymbol{F} = e\boldsymbol{v} \times \boldsymbol{B} \tag{5}$$

$$\boldsymbol{F}_{total} = n\boldsymbol{F}_{e} + n\boldsymbol{F}_{m}$$
$$= qn\boldsymbol{E} + qn(\boldsymbol{v} \times \boldsymbol{B}) = qn\boldsymbol{E} + \boldsymbol{j} \times \boldsymbol{B} \tag{6}$$

where n is the charge density, $\boldsymbol{F}_e$ the electric force, $\boldsymbol{F}_m$ the magnetic force, q the charge, $\boldsymbol{v}$ the charge velocity, $\boldsymbol{E}$ the electric field strength , $\boldsymbol{j}$ the current density and $\boldsymbol{B}$ the magnetic flux density. The Lorentz force will act on the charge in channels and it affects the micro discharge channels dimension and interaction between the micro channels, which can expand these channels on the surface of barrier. It also lead to ionize the oxygen gas to form the ozone molecule.

C. Ozone Production

Ozone measurement using a gas analyzer is shown in figure 11 below. The results of the comparison of ozone concentrations produced for all models are given in figure 12. When the ozone generator starts operating in a range of 1 minute, all models suffer a significant increase to generate ozone gas. It can be seen in figure 12, model 1 produces ozone at 98.3 ppm and model 2 produces ozone gas at 135 ppm and model 3 produces ozone to 111 ppm. For this period, it is seen that the generator ozone for model 2 is higher than models 1 and 3. And also the generator ozone for model 3 produces ozone gas higher than model 2. In the period from 1^{st} minute to 5^{th} minute, ozone generator for model 1 is more likely to remain stable in producing ozone gas until the gas concentration value reaches 110ppm. However, the generator ozone for model 2 is gradually up to a value of 162 ppm. Furthermore, the generator ozone for model 3 generates ozone gas which rises sharply until its concentration reaches 207 ppm. Ozone production speed for model 1, 2,and 3 was 22, 32.4 and 41.4 in ppm/minutes, respectively. Here, it can be seen that the ozone concentration produced from model 3 is higher than that of models 2 and 1. Model 2 also produces higher ozone concentrations than model 1. By looking at the maximum current pattern at discharge, it can be concluded that model 3 occurs current pulses more than models 2 and 1 which is indicated that there is a more ionic discharge that can increase the ionization process on oxygen which further it will produce more ozone gas than model 1 and 2. The effect of induction of ring permanent magnet with attractive conditions is the new thing to improve the performance of ozone generators. The generator ozone with dielectric barrier discharge induced by permanent magnets promotes the effect of ozone production by the ionization process on oxygen molecules. The presence of a magnetic field in dielectric barrier discharge broadens the path of free electrons in the ionization region (i.e. Larmor precession), and it bring down the mean energy of electrons to reach a high voltage electrode which will increase gradually by the collision with gas molecules [24, 25]. If the number of collisions with oxygen molecules increases, more ozone atoms will be formed.

Figure 11. Ozone measurement with a gas analyzer.

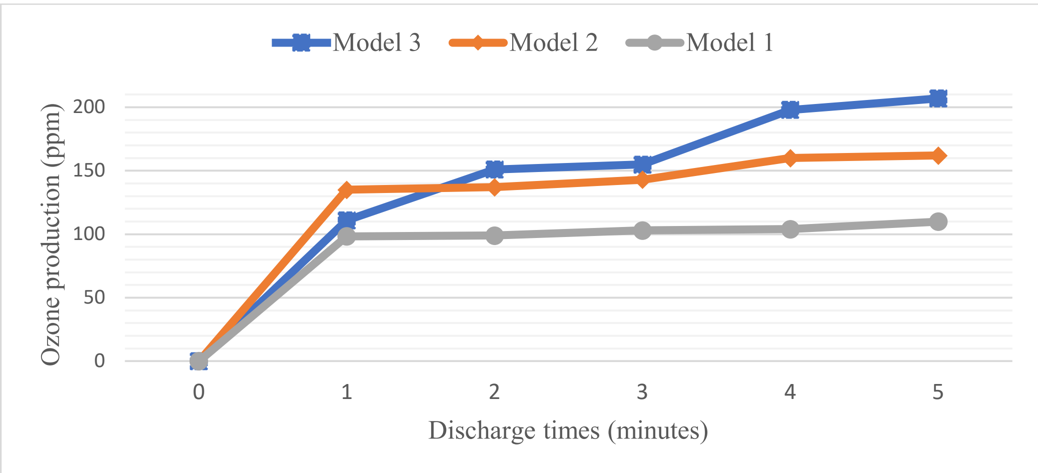


Figure 12. Comparison of ozone concentrations produced for all models

Model 3 has the velocity to produce ozone at an average of 41.4 ppm per minute. While models 1 and 2 produce ozone with an average of 22 ppm per minute and 32.4 ppm per minute, respectively. It is seen that model 3 is faster than models 1 and 2 in producing ozone. While the model 1 is the slowest in producing ozone.

4. Conclusions

This study has succeeded in showing the performance of an ozone generator by using permanent magnet beans as a high voltage electrode and induced with a permanent magnet ring with three models of the position of the permanent magnet. From the experiments, it can be concluded that model 3 with the position of the permanent magnet ring above the high voltage electrode and under the ground electrode with attracting each other produced more ozone in a 5 minutes period compared to models 1 and 2, respectively. The maximum measured voltage is 13.8 kV and the maximum current pulse measured is 690 mA. The results of current and voltage measurements for model 2 show that the maximum voltage is 12.5 kV and the maximum current pulse is 973 mA. For model 3, the maximum current pulse measured is 800 mA and the maximum voltage measured is 11 kV. The ozone generator generated ozone gas at 110 ppm, 162 ppm, 207 ppm for model 1,2, and 3, respectively. The model 3 was faster than model 1 and 2 to generate the ozone gas with a value of 41.4 ppm per minute. Model 3 inflowed many discharge current pulses which was indicated that there was a lot of electrical discharge in the gap to convert oxygen atoms to ozone gas. From the results of plasma shots that occurred in the gap between electrode and dielectric, it could be seen that model 3 produced a plasma with a lower light intensity than models 1 and 2. This could be proven by plasma images of inverted images that model 3 had fewer black areas compared to models 1 and 2. The effect of the position of the permanent magnet was clearly visible in the performance of the ozone generator under attractive condition, where it produced more ozone gas. The addition of permanent magnet beans as high voltage electrodes is new in the study of high voltage plasma.

5. Acknowledgment

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6. References

[1]. W. Siemens, "Ueber die elektrostatische Induction und die erzögerung des Stroms in Flaschendrähten," Poggendorffs Ann. Phys. Chem., vol. 102, pp. 66-122, 1857 (in German).

[2]. U. Kogelshatz, "Dielectric-barrier Discharges: Their History, Discharge Physics, and Industrial Applications," Plasma Chem. Plasma Process, vol. 33, pp. 1-46, 2003.

[3]. Y. Nomoto, O. Toshikazu, K. Seiji and A. Takayoshi," improvement of ozone yield by a silentsurface hybrid discharge ozonizer," *IEEE. Trans. Ind. Appl*., vol. 31, pp. 1458-1462, 1995.

[4]. N. Zouzou, C. Agbangla, E. Moreau, and G. Touchard, "Diesel Particle Treatment Using a Surface Dielectric Barrier Discharge." *IEEE Trans. Plasma Sci*., vol. 36, pp. 1354–1365, 2008.

[5]. Nasruddin, Indri Kartika Putri, Sodiq Kamal,Heni Setyowati Esti, Rahayu, Heni Lutfiyati, Prasojo Pribadi, Tiara Mega Kusuma, Zaenul Muhlisin, Muhammad Nur, Laela Hayu Nurani, BudiSantosa, Tatsuo Ishijima, Toshio Nakatani, "Evaluation the effectiveness of combinative treatment of cold plasma jet, Indonesian honey, and micro-well dressing to accelerate wound healing", Clinical Plasma Medicine, Volumes 5–6,Pages 14-25, June 2017,

[6]. N. Osawa, T. Suetomi, Y. Hafuka, T, Shuha, Y. Yoshioka, R. Hanaoka, "Investigation on reactor configuration of non-thermal plasma catalityc hybrid method for NOx removal of diesel engine exhaust", *International Journal of Plasma and Enviromental Science and Technology*, Vol.6, No.2, September 2012.

[7]. K. Shimizu, S. Muramatsu, T. Sonoda, and M. Blajan, "Water treatment by low voltage discharge in water", *International Journal of Plasma and Enviromental Science and Technology*, Vol.4, No.1, March 2010.

[8]. S. Pekárek "Non-Thermal Plasma Ozone Generation ", Acta Polytechnica Vol. 43 No. 6/2003

[9]. V. Golota, B. Kadolin, V. Karas, I. Paschenko, S. Pugach, A. Yakovlev, Proc. 16th Int. Symp. on Plasma Chemistry (Italy, 2003)
[10]. S. Peka´rek" DC corona discharge ozone production enhanced by magnetic field", Eur. Phys. J. D 56, 91–98 (2010) DOI: 10.1140/epjd/e2009-00276-4.
[11]. K. Nassour *et al*., "Comparative experimental analysis of ozone generation between surface and volume DBD generators," in *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 25, no. 2, pp. 428-434, April 2018. doi: 10.1109/TDEI.2017.006600
[12]. Y. Nakata, R. Mabuchi, K. Teranishi and N. Shimomura, "Effect of small-diameter coaxial reactors on ozone production using nanosecond pulsed power," in *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 20, no. 4, pp. 1146-1152, August 2013. doi: 10.1109/TDEI.2013.6571429
[13]. I. Chalmers, L. Zanella, S. J. MacGregor, and I. A. Wray, "Ozone generation by pulsed corona discharge in a wire cylinder arrangement", *IEEE Colloquium Digest*, Vol.29, pp.1-4, 1994.
[14]. H. Akiyama, Y. Miyahara, J. Samaranayake, and S. Katsuki, "Ozonizer using pulsed power: Recent Development of ozonizer", *J. Plasma and Fusion Research,* Vol. 74, No. 10, pp. 1139-1143, 1998
[15]. K. Takaki, I. Yagi, T. Fujiwara and T. Go, "Influence of circuit parameter on ozone synthesis using inductive energy storage system pulsed power generator," in *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 18, no. 5, pp. 1752-1758, October 2011. doi: 10.1109/TDEI.2011.6032847
[16]. Waluyo, Syahrial, Sigit Nugraha, and Yudhi Permana JR" Prototype Design and Analysis of Miniature Pulse Discharge Current Generator on Various Burdens", *International Journal on Electrical Engineering and Informatics* - Volume 8, Number 3, September 2016
[17]. Fri Murdiya, Febrizal Febrizal, Amun Amri," The performance of surface barrier discharge in magnetic field driven by half bridge series resonance converter", *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, Vol.8, No.2, pp.95-102, Dec. 2017.
[18]. J.Y Park, G. H. Kim , J. D. Kim , H.S. Koh, D.C. Lee" NOx Removal Using DC Corona Discharge with Magnetic Field" Combustion Science and Technology, Vol. 133 Issue 1-3, pp. 65-77, Taylor & Francis, 1998
[19]. Fri Murdiya, Febrizal, "The performance surface barrier discharge in magnetic field driven by series resonance converter", *2017 6th International Conference on Electrical Engineering and Informatics (ICEEI)*, Langkawi Malaysia,25-27 Nov. 2017.
[20]. Stanislav Peka´rek "Experimental Study of Nitrogen Oxides and Ozone Generation by Corona-Like Dielectric Barrier Discharge with Airflow in a Magnetic Field" Plasma Chem Plasma Process, vol. 37, pp. 1313–1330, Springer, 2017.
[21]. Y. Liu, H. Qi, Z. Fan, C.S. Ren, "The impacts of magnetic field on repetitive nanosecond pulsed dielectric
[22]. Jodzis S, Patkowski W (2017) J Electrostat 85:43–51. https://doi.org/10.1016/j.elstat.2016.12.009
[23]. Stanislav Pekárek, "Experimental Study of Pulse Polarity and Magnetic Field on Ozone Production of the Dielectric Barrier Discharge in Air", Plasma Chemistry and Plasma Processing, Volume 38, Issue 5, pp 1081–1093, September 2018https://doi.org/10.1007/s11090-018-9914-2.
[24]. C. L. Wadhwa, High Voltage Engineering, New Age International, 2007.
[25]. Mohammed K. Khalaf, Sabri J. Mohammed, Muataz A. Majeed and Hanaa E. Jasim, "Effect of the Longitudinal Magnetic Field on the Electrical Breakdown in Argon and Nitrogen Plasma Discharges", World Scientific News, Vol. 55, pp. 114-125, 2016.

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