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Feasible Study Effect of Electric Energy Adjustment in High Frequency Ozonizers to Generate Ozone Gas

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Abstract

This paper presents the feasible study effect of electric energy adjustment in ozonizers to generate ozone gas based on high frequency corona discharge using high voltage high frequency in power inverter. This power inverter uses full bridge converter at switching frequency 25 kHz and controls its operation using pulse width modulation (PWM) techniques. Power MOSFETs#IRFP250 is controlled by IC#TL494. The highly non-uniform electric field ozone tube of two-level insulator cylindrical. The testing of ozonizers using 5 levels of electric energy adjustment are 0.5, 0.6, 0.7, 0.8 and 0.9 kWh, the ozone tube of which enables ozone gas generating capacity of 221, 315, 497, 536 and 623 mgO_3/hr respectively.

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Keywords: inverter, ozonizer, ozone gas, electric energy, ozone tube

1. Introduction

Nowadays, ozone gas is widely brought to use for living such as using ozone to clean the vegetables instead of manganese to kill diseases and reduce a quantity of chlorine in water. Bringing ozone to clean the air purely has some drawbacks. For examples, if it is used too much concentrated, it can irritate the body. It is useful to health if quantity is properly used and is applied to work suitably. This paper presents a study of the effect of energy adjustment to the ozone quantity. The high voltage high frequency is constructed by using a principle of switching AC power supply. A high voltage high frequency is supplied to the load, which are two-layer electrode in series, for producing ozone gas. The generating ozone gas is based on the principle of spreading molecules of oxygen. It will produce ozone gas from the equation of $O_2 + O = O_3$.

The ozone gas can withstand an energy level. Also, the heat affects to the quantity of the occurring ozone gas. Therefore, the quantity of voltage and the suitable frequency have to be controlled to generate ozone gas [1,2].

The ratio of using energy to produce ozone gas to chemicals is from 493 kJ/mol to 762.23 kJ/mol. Adapting unit has the necessary energy between 5.583 kWh/m^3 and 8.631 kWh/m^3. Since there is only 21% oxygen in the

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air, the necessary energy should be used from 1.172 kWh/m^3 to 1.620 kWh/m^3. It is enough to generate ozone gas in the gap of two-layer electrode in series [1,2].

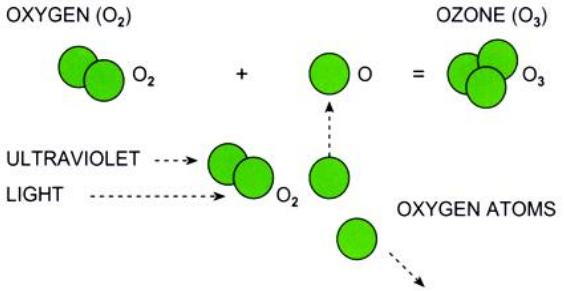


Fig. 1. The Process of Ozone Gas [6]

2. Theory of Ozone Gas

The main factor of air comprises 79% nitrogen (N_2) and 21% oxygen (O_2). The rest is inert gas and steam. Ozone gas is the gas, consisted of 3 atom oxygen, under unstable status, easy dispersion that is depended on the environment and density of the productive quantity. The procedure of production consists of the generating free oxygen atom process from oxygen molecule in the air. After that free oxygen atom is together with oxygen molecule to obtain ozone gas (O_3) which is brought to use in industrial cured system. The occurring ozone gas process forms from 2 processes – ionization process and dissociation process. The ionization, spreading of gas is the increment of electron avalanche leading to breaking down in insulator, which electric current is considered through the border line of insulator. The following occurrence is the heat because the current flows in insulator, which is from the occurred breaking down. This causes the low related energy of ozone gas disintegrated. Therefore, the ozone gas production should not make a break down. That is electron energy from electric field, having energy less than ionization energy but this energy is enough to separate the oxygen atoms [1,2].

3. Diagram Block of Ozonizer

Fig. 2. shows the diagram block of ozonizer, which is constructed from the ac high voltage high frequency switching power supply. The ac input voltage is 220 V, 50 Hz supplied to rectifier circuit in order to produce the dc voltage of 310 V. From the dc voltage to ac voltage, the inverter controlled by Pulse Width Modulation (PWM) is used to obtain the high frequency of 25 kHz. The low voltage of inverter from the primary side steps up to high voltage of the secondary side at 5 $kV_{p\text{-}p}$ in order to produce the High Frequency High Voltage (HF-HV) into the ozone tube. Then, it generates the ozone gas [1,2].

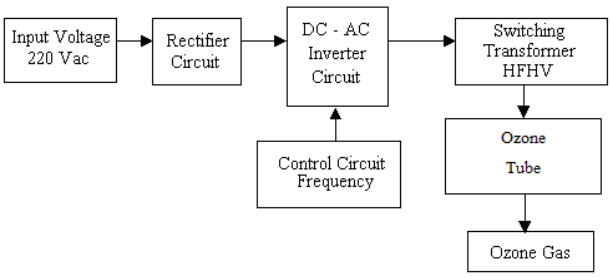


Fig. 2. Diagram block of ozonizer

3.1 The Designing of Ozone Tube

The principle of ozone tube designing is the ozone gas quantity will occur well under unsmooth electric field. Therefore, two-layer electric insulator is chosen for the electrode design as the difference permittivity (ε) of the electric insulator. It is suitable for nonuniform electric field to have the nearly ε of each layer in electric field stress. Therefore, two-layer co-core of cylinder ozone tube design is chosen under the followings as shown in Fig. 3.

- Silica is chosen for 1st layer electric insulator due to effecting to generate ozone gas. The permittivity ε_1 is 8, where the diameter is 2.9 cm. and length is 18 cm.
- Air is chosen for 2nd layer electric insulator which is the permittivity $\varepsilon_2 = 1$
- Cathode frilled aluminum in filament coil inside of the silica's electric insulator is used. The reason is aluminum has a high conductivity.
- Anode is the stainless steel cylinder with 3.3 cm. diameter and 18 cm. lengths.

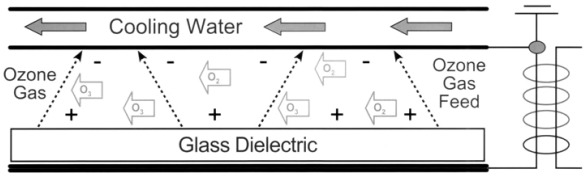


Fig. 3. Generate ozone gas by electric field of corona discharge for ozone tube [6]

3.1.1 Calculation of electric field (E) and voltage (V) of ozone tube [1,2].

From Fig.4, $r_1 = 1.3 cm., r_2 = 1.45 cm., r_3 = 1.65 cm., l = 18 cm.$

From the energy of 5.58 kWh/m^3 to 7.73 kWh/m^3, air is composed of 21% oxygen (O_2), so energy is 1.172 kWh/m^3 to 1.620 kWh/m^3 chosen [4,5].

$$\begin{aligned} \text{Air volume} &= \pi\left(r_3 - r_2\right)^2 \times l \\ &= \pi\left(1.65 - 1.45\right)^2 \times 18 \\ &= 2.262\ cm^3 \end{aligned} \tag{1}$$

Minimum energy per volume (W_{min}) of 1.172 kWh /m^3

$$\begin{aligned} W_{\min} &= 1.172 \times 10^3 \times 2.262 \times 10^{-6} \\ &= 0.00265\ Wh \end{aligned}$$

Maximum energy per volume (W_{max}) of 1.620 kWh /m^3

$$\begin{aligned} W_{\max} &= 1.620 \times 10^3 \times 2.262 \times 10^{-6} \\ &= 0.00366\ Wh \end{aligned}$$

From $$W = \frac{1}{2} \int_{Vol} \varepsilon E^2 dv \tag{2}$$

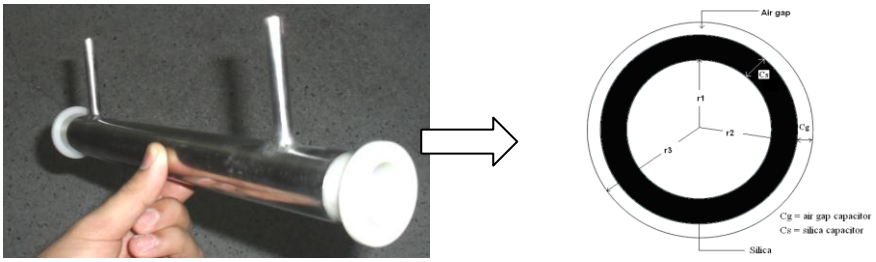


Fig. 4. The structure of ozone tube

From Eq. (2), E_{min} and E_{max} are given by :

$$E_{\min} = \sqrt{\frac{2 \times W_{\min}}{\varepsilon \, vol}}$$
$$= \sqrt{\frac{2 \times 0.00265}{(8.854 \times 10^{-12})(2.262)}}$$
$$= 16.273 \; kV/cm$$

$$E_{\max} = \sqrt{\frac{2 \times W_{\max}}{\varepsilon \, vol}}$$
$$= \sqrt{\frac{2 \times 0.00366}{(8.854 \times 10^{-12})(2.262)}}$$
$$= 19.129 \; kV/cm$$

Silica has a permittivity $\varepsilon_1 = 8$ and air has a permittivity $\varepsilon_2 = 1$
The voltage (V) of ozone tube is given in Eq. (3) :

$$V = \frac{E \, . \, r_2 \, . \varepsilon_2 \left(\varepsilon_1 \ln\left(\frac{r_3}{r_2}\right) + \varepsilon_2 \ln\left(\frac{r_2}{r_1}\right) \right)}{\varepsilon_1 \times \varepsilon_2} \qquad (3)$$

$$V_{\min} = \frac{16.273 \, . \, 1.45 \, . \, 1 \left(8 \ln\left(\frac{1.65}{1.45}\right) + 1 \ln\left(\frac{1.45}{1.3}\right) \right)}{8 \times 1}$$
$$= 3.37 \; kV$$
$$\approx 3 \text{ kV}$$

$$V_{\max} = \frac{19.129 \, . \, 1.45 \, . \, 1 \left(8 \ln\left(\frac{1.65}{1.45}\right) + 1 \ln\left(\frac{1.45}{1.3}\right) \right)}{8 \times 1}$$
$$= 3.963 kV$$
$$\approx 4 \text{ kV}$$

Where V_{min} and V_{max} are the minimum and maximum voltage of the electrode set in order to produce ozone gas, respectively.

3.2 Design of High Frequency High Voltage (HF-HV) AC inverter

The high frequency high voltage AC inverter is controlled by IC#TL494 [3]. Switching devices, Power MOSFET#IRFP250, are used in the full bridge inverter controlled by the PWM strategy from IC#TL494. The switching frequency is 25 kHz. The energy from inverter can transfer through a switching transformer to produce high frequency high voltage supplying the ozone tube [4] as shown in Fig. 5.

4. Experimental Results

The experiment results of ozone gas generator can be divided into 2 steps of experiments. The first experiment results are from circuit parts making switching frequency that can be adapted 25 kHz to drive Power MOSFETs in the full-bridge inverter and transfer energy to transformer. Fig. 6 shows the duty cycle of PWM control at 0.4 and the switching frequency is 25 kHz.

The other experimental results shown in Table 1 are the measurement of the used energy of 0.5 kWh to 0.9 kWh and ozone gas quantity (mgO_3/hr) which are derived from the secondary (output) voltage of a HF-HV transformer. It supplies to ozone tube at 5 $kV_{P\text{-}P}$, 25 kHz constant.

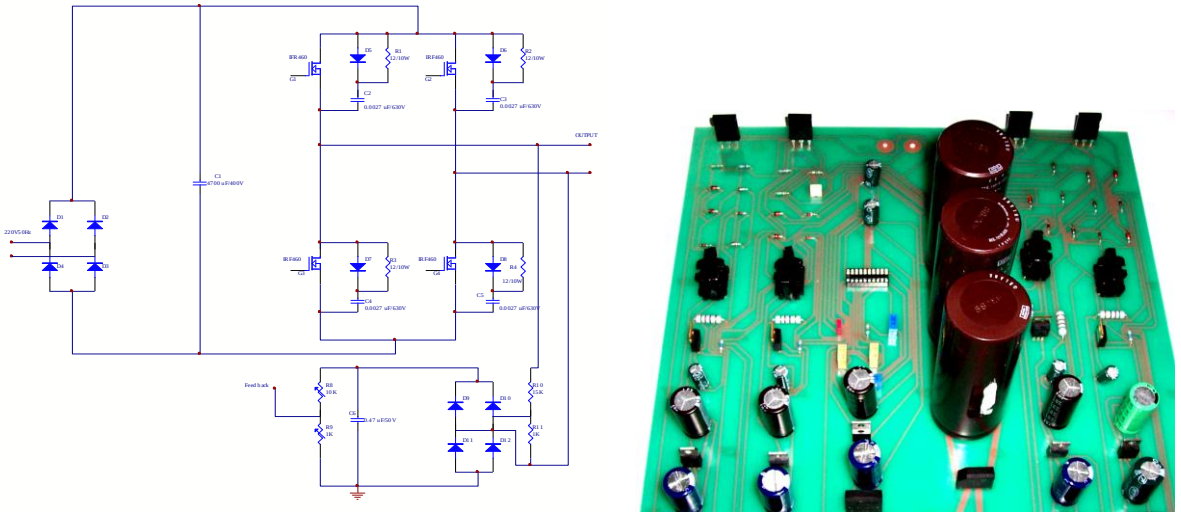
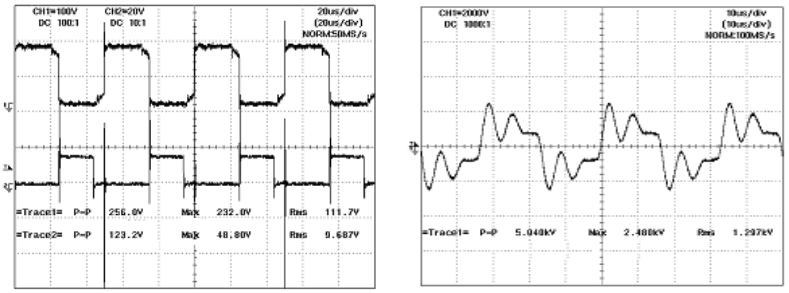


Fig. 5. Full Bridge Inverter (Power Inverter)

4.1 The results of measurement of V_{DS} signal of Power MOSFET and primary voltage and secondary voltage of switching transformer



(a) (b)

Fig. 6. (a) V_{DS} signal of Power MOSFET and primary voltage of switching transformer and (b) secondary voltage of switching transformer at 5 kV_{P-P}

Fig. 7. The chemical element in testing and ozone gas quantity

4.2 The relationship between the energy in full bridge inverter and ozone gas quantity

Table 1. The relationship between the energy and ozone gas quantity

Energy (kWh)	Frequency (kHz)	V_{OUT} (kV_{P-P})	Ozone quantity (mgO_3/hr)
0.5	25	5	221
0.6	25	5	315
0.7	25	5	497
0.8	25	5	536
0.9	25	5	623

Where parameters of Table 1 are :

- frequency (kHz) is a frequency of inverter
- Energy (kWh) is the energy of inverter
- V_{OUT} (kV_{P-P}) is output voltage of inverter
- Ozone gas quantity (mgO_3/hr) is ozone gas of ozone tube

Ozone gas quantity analysis [1-2,4]

Fig. 7 shows the quantity of ozone gas occurred by using chemicals for testing. The chemicals in this figure use Potassium Iodine (KI). Ozone gas is put into KI. This effects the change of solution color from transparent to yellow. Strach liquid pours into this solution that makes this solution change color again. The color will be dark blue. Then, sodium thiosulphate is used in tritratation in order to change dark blue to transparent again. This method can obtain and check the ozone gas quantity.

5. Conclusion

The result of experiment, the feasible study of electric energy adjustment of ozonizer in full bridge inverter, there is the effect towards the ozone gas generation. The experimental results are the relationship between electric energy and the quantity of generated ozone gas. That is the more electric energy increases, (also more ionization in ozone tube), the more quantity of ozone gas is generated, while testing at a frequency of 25 kHz and a high voltage on 5 kV_{p-p} constant.

In the future, the quantity of generated ozone can solve other ways such as the smell treatment and environmental problems. In addition, it can use a lot of other usefulness.

Acknowledgement

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