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A Study on Enhancement of Ozone Gas Concentration using Microcontroller based PWM Circuit

[*1]V. Lakshminaryanan and [2]P.A. Balakrishnan

[1]Dr. Mahalingam College of Engineering and Technology, Pollachi, TN, India.
[2]KCG College of Engineering and Technology, Chennai, TN, India
**Corresponding Author E-mail: vlnaarayan@gmail.com*

Abstract

A case study on changing the switching frequency and voltage in a converter circuit to generate high concentration ozone gas is studied. A higher ozone concentration in a single cell can be achieved at a high frequency with a discharge gap of 3mm and feeding gas flow rate of 10LPM by passing air or oxygen as feed gas compared to conventional fixed voltage, fixed frequency ozone generator. The idea is to improve the concentration by using Pulse Width Modulation (PWM) technique by varying frequency starting from 1.5 kHz to 5 kHz and with voltage 2.5kV or 3kV with constant feed gas flow rate. The conventional ozone generator uses 3 kHz, 3kV to produce constant ozone concentration with constant feed gas flow rate. A series of simulation studies has been carried out with proteus software to estimate the frequency and voltage parameters during the discharge. The experimental result shows fine increase in concentration with PWM technique compare to conventional method.

Keywords: Silent corona discharge, ozone generator, Dielectric material, PWM technique

Introduction

Ozone is one of the strong oxidants; it is employed for treatment of waste water and bad odors, disinfections and the removal of organic substances [1]. Moreover, the remaining ozone after treatment converts naturally to oxygen; so secondary environmental pollution does not occur. The most common method of ozone generation is to produce an alternative current corona discharge in a gap bounded by metallic electrodes and containing at least one solid dielectric barrier. This procedure was first proposed by Siemens in 1857 [2] and has been considerably studied [3] [4] [5] [6]. In practical application of ozonisers, the concentration and yield level is most important of merit for evaluation of the ozonisers performance. However these are not independent of each other and can't be consider separately. The selection must be made as to which one of these quantities should be maximized, depending upon the individual application encountered. Increasing the concentration of the ozone is important to reduce its cost.

The most common method of ozone generation is to produce an AC corona discharge in a gap bounded by metallic electrodes and containing at least one solid dielectric barrier. A typical arrangement is shown in Figure 1.

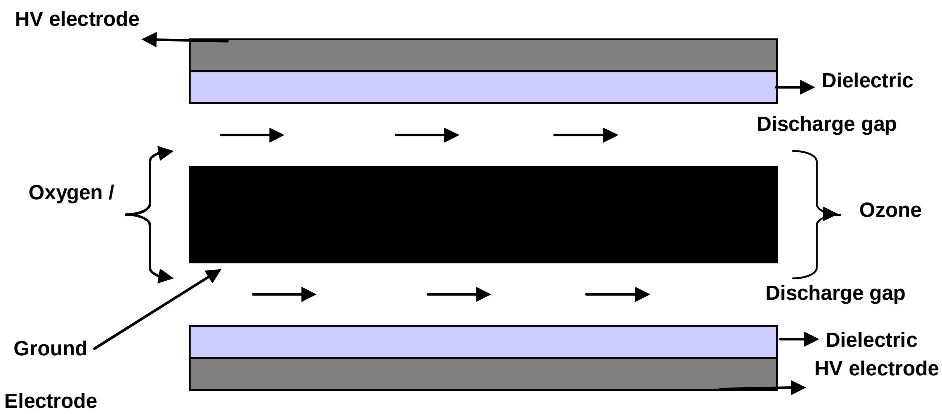

Figure 1: Cylindrical ozonisers cross section.

The gas gap is usually around 3 millimeters and the feed gas, air or oxygen, is passed longitudinally along the gap. A typical ozone generator, in which the gas gap and dielectric layer are both around 1.5 mm and the dielectric material, often made of glass, and may have a relative permittivity of 3. For an applied voltage of say 5 kV, an electric field of 2.5 kV mm^{-1} in the gas gap and 0.85 kV mm^{-1} in the dielectric is established. The above analysis which represents a simple capacitive division is perfectly valid provided there is no electrical discharge activity in the air gap. If the applied voltage V is increased then when the electric field in the gas gap achieves the breakdown field (around 3 kV mm^{-1} for air or oxygen), discharge in the gas will occur. These are often referred to as 'silent' or 'barrier' discharge and each has a channel diameter of 200-500 μm and involves a total charge of around 10^{-10} C. These discharge deposit electric charge on to the surface of the dielectric which is of the same polarity as that of the electrode on the other side of the gas gap. Thus, if the voltage in figure were positive, then when discharge commenced, positive charge would be deposited on to the surface of the dielectric in contact with the gas. The mobility of charge on most dielectric surfaces is low and thus for practical purposes, during the time scale associated with even low-frequency voltage applications (power frequency), the charges may be considered trapped and totally immobile. The charge sets up an electric field which opposes the field in the gas gap and, clearly, discharging in the gas gap at any position will continue until such time as the gas gap filed at that position has been reduced back to just below the breakdown value. Complete cessation of discharging will occur when the entire dielectric surface is covered with the required density of charge. Ozone is generated in an electrical discharge by firstly dissociation of O_2 to form atomic oxygen (O) and then later three-body collision recombination of atoms and molecular oxygen to form ozone[7]. This dissociation stage is caused by collisions of energetic electrons with molecular oxygen and thus it is reasonable to assume that the number of ozone molecules produced in any time interval will be directly related of the number of electrons generated in the discharge during that time interval. If one considers a ramp voltage applied to an electrode setup as that described, then, as the applied voltage is increased, no discharging takes place until the breakdown filed is created in the gas gap. With further increase in the applied voltage, discharging takes place but at all times is self regulating the effect of the charge accumulation on the dielectric surface. Thus the electric field in the gas gap is limited to the breakdown field and the total number of ozone molecules generated up to any time t corresponding to a voltage V. Obviously the difference between the applied voltage and the voltage across the gas gap is the voltage impressed upon the dielectric layer. This represents a practical limitation to any ozone generator since the dielectric will fall if stressed too highly.

It is important to recognize that discharging in the gas gap takes place only when the applied voltage is increasing. If the applied voltage ceases to increase, then discharging ceases and the generation of ozone ceases. Considering now what occurs when the applied voltage is in the form of an alternating sinusoid, the same argument holds and ozone will be generated while the voltage is increasing. Again the field in the gas gap will be limited to the breakdown field and discharging will cease when the voltage ceases to increase (i.e. at voltage peak). When the applied voltage then starts to decrease, the charge on the dielectric surface produced by the earlier discharges persists and the field in the gas gap is reduced at all stages by this constant field. When discharging commences in the opposite direction, the charge on the dielectric surface is rapidly neutralized and replaced with charge of the opposite sign and the process described above is repeated. The ozone generation rate varies with variation in all the generator and supply voltage characteristics. It shows, for example, that the generation rate may be varied by variation of the frequency of the supply voltage and this method is indeed adopted in some medium- and high-frequency generator [8]. When the supply frequency is constrained to power frequency however, the method of control is to vary the applied voltage.

Methods and Materials

Dust-free air enters an air-compressor at 1 atm pressure and is sent to the air-drying system. A two-column, cyclic regenerated adsorptive dryer with activated aluminum oxide is part of this drying system. A pressure regulator to control input pressure to ozone generator is connected at output of air dryer system. Dew point temperature is about 213^0K (-60^0C). A classical dielectric single pair tubular ozone cell generator

(Dielectrics borosilicate glass thickness 1.85 ± 0.1 mm; length 20 cm; gap 3.0 mm; residence time at nominal regime 4.8 sec) with electronic pulse control circuit to produce 3kV at 5 kHz is used. The Ozone generator was feed with industrial grade oxygen/clean dry air. An online ozone monitor (make: PCI-Wedeco, USA) was used for measuring ozone concentration. A five liter glass column was used for experiments and connected to the ozone generator as shown in Figure 2. The spent gas was sent through ozone destruct unit before releasing it to atmosphere.

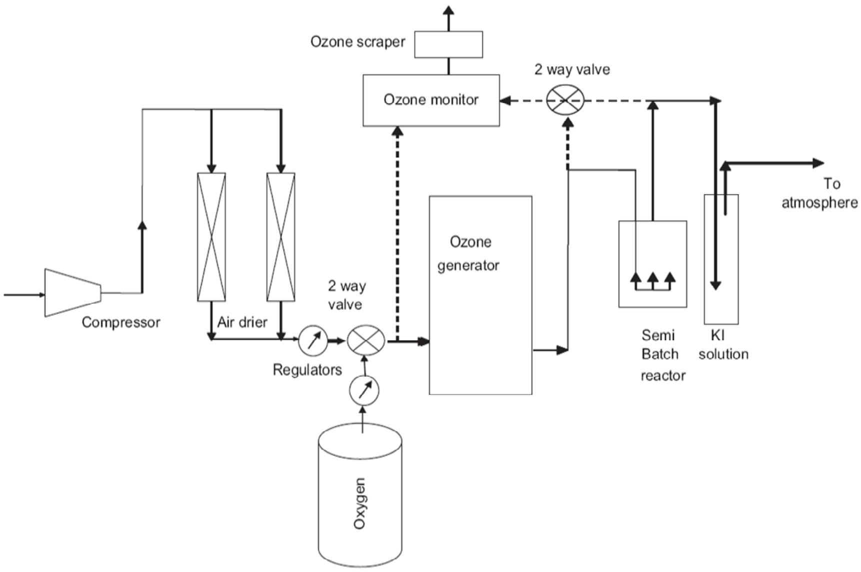

Figure 2: Experimental setup.

A single cell conventional ozonator with fixed voltage and fixed frequency control circuit is shown in figure 3.

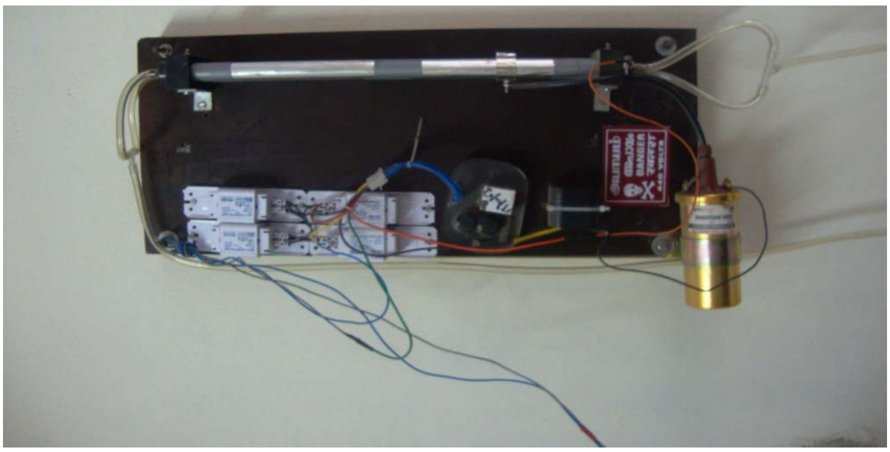

Figure 3: Conventional single cell ozonator.

HF-HV Switching Power Supply

The high-frequency, high-voltage, (HF-HV) switching power supply of high-ripple voltage is controlled by IC LM555. Switching devices, power MOSFETs IRFP460, are used in the converter controlled by the PWM strategy from IC LM555. The switching frequencies range from 1.5 kHz to 5 kHz. The energy from the converter is transferred through the HF-HV transformer to produce the HF-HV high-ripple voltage supplying the electrode tube. The structure and the circuit of this supply are shown in Figure 4 and 5. The PROMATE II is Microchip microcontroller device programmer. Through interchangeable programming socket modules, PROMATE II enables you to quickly and easily program the entire line of Microchip PICmicro microcontroller devices and many of the Microchip memory parts.PROMATE II may be used with MPLAB IDE running under supported Windows OS's, with the command-line controller PROCMD or as a stand-alone programmer. A program written in the high level language called C; which will be converted into PICmicro MCU machine code by a compiler. Machine code is suitable for use by a PICmicro MCU or Microchip development system product like MPLAB IDE.

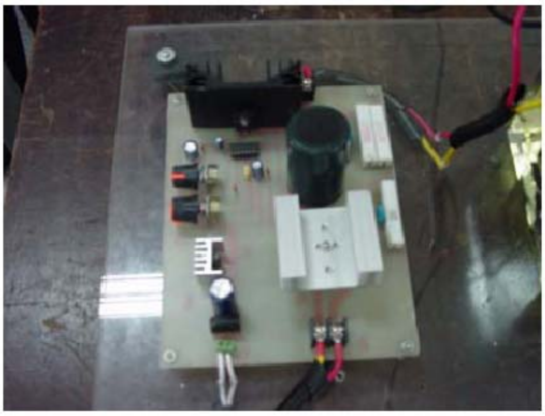

Figure 4: High-frequency, high-voltage, (HF-HV) converter circuit.

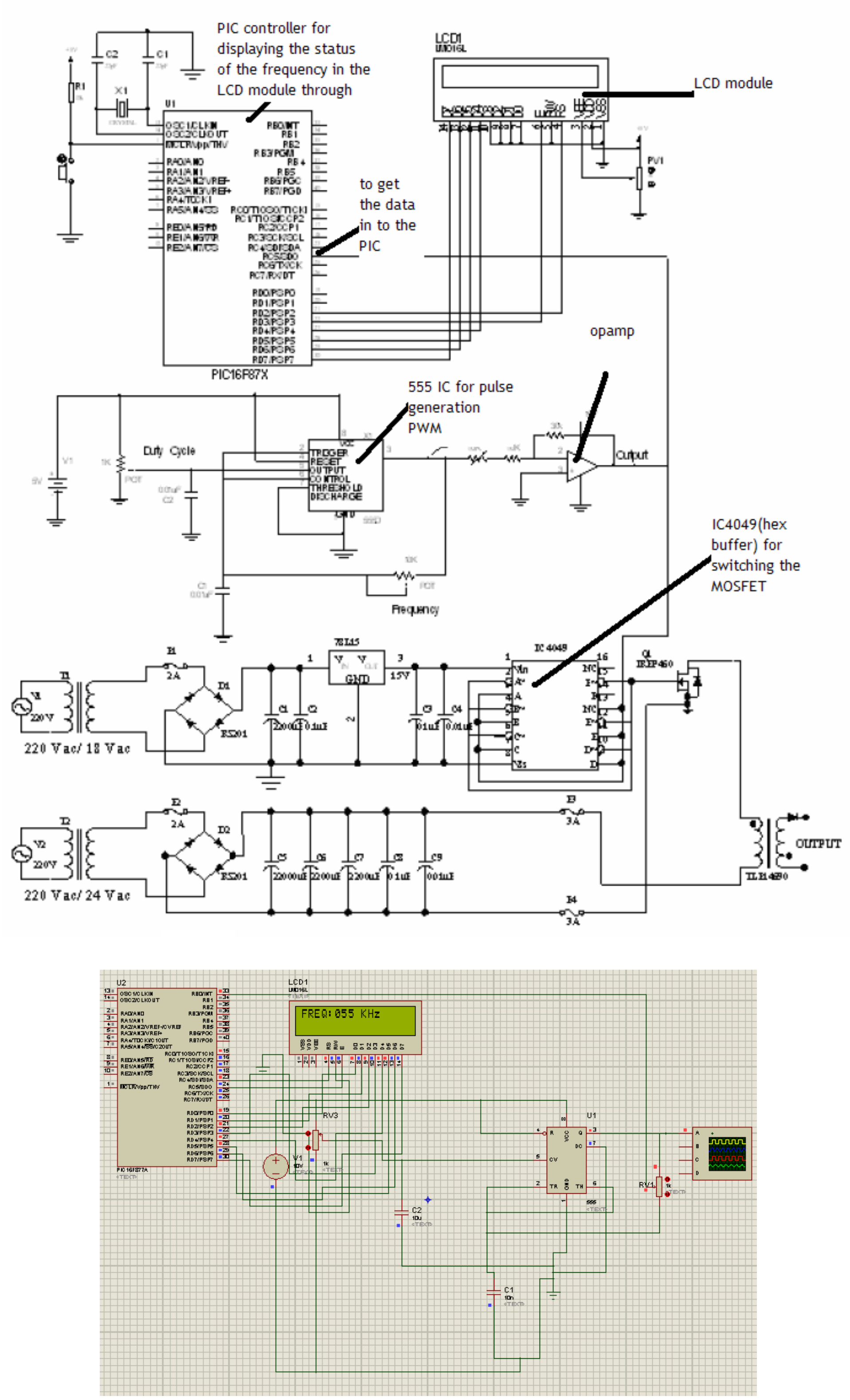

Figure 5: The Structure of HF-HV Converter Circuit.

Results and Discussions

Effect of frequency

The effect of frequency on ozone concentration is shown in figure 5. The tests are conducted at 3 kV constant voltages. With increase in frequency, the concentration rate has increased compared to conventional system. Although higher frequency is desirable for conventional high capacity generator, the operating frequency is limited by the heating of electrodes and control circuit chokes.

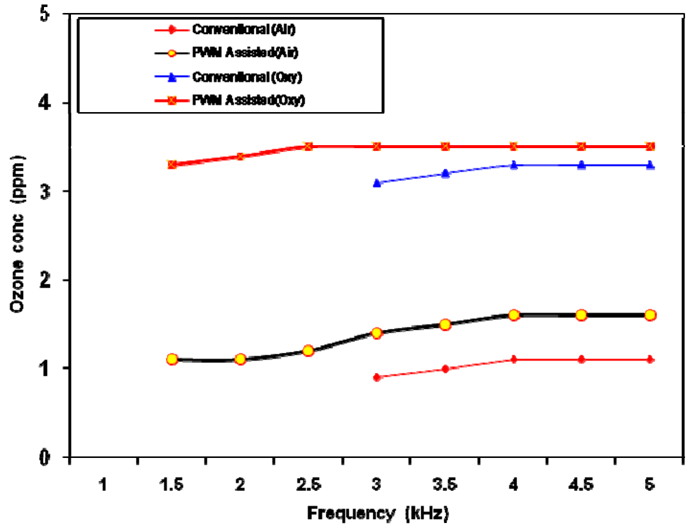

Figure 5: Ozone concentration Vs frequency.

From the study of the effect of changing the switching frequency, one can evaluate the process of ozone gas concentration. The experimental results in figure 5 demonstrate the relationship between the switching frequency and the quantity of concentration ozone gas. With the increase of the switching frequency, increased concentration of ozone gas are generated because the shifting of the frequency level in the converter circuit has an effect on the production resonance at the ozone tube. The operation of the ozone generator with the high-frequency fly back source allowed an increase in the efficiency and a reduction in the prototype size. This results in the reduction of the costs of ozonation system totally. These advantages considerably facilitate the design of an appropriate HF power supply for DBD applications. Thus, the model allows one to both predict with accuracy the discharge behavior using the experimental parameters and verify the condition.

Conclusions

A variable ozone gas concentration is obtained by designing and constructing the control circuit using PWM technique is verified compared to conventional fixed frequency, fixed voltage circuit.

In an application that needs ozone concentration below 1 ppm, the conventional system is recommended due to its lower cost. For an application that needs variable concentration of ozone gas above 1 ppm, the choice of high voltage with high frequency power supply is much more attractive configuration due to operation feasibility.

Further research work is taken to see the effect of varying high voltage with fixed frequency circuit.

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