

High Density Ozone Generation System using Fuzzy Inference Engine

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Abstract. Ozone (O₃) is generated by voltage control inverter of single phase sinusoidal waveform different from current control inverter of three phase used in motor control. Ozone quantity is directly proportional to the frequency as well as the voltage of power supply. In this paper, we propose not only a voltage control inverter of 600Hz and step-up transformer from 220V to 12KV using IGBT, but also fuzzy inference engine using MADANI Min-Max composition so as to generate the high density ozone generation. We substantiate that the proposed Ozone generation system produces the double quantity of ozone and higher efficiency than conventional ozone system using the current control inverter through lots of real experiments on the developed ozone system.

Introduction

Ozone (O₃) is generated by Ozone generator using single phase inverter combined with step-up transformer to 12KV at 600Hz as well as Air Preparation System (APS). The inverter used in ozone generation is different from the three phase inverter used in motor control and the inductive load characteristics of the electric circuit.

The ozone generator has capacitive load characteristics because of the charging and discharging taken place between the two electrodes between discharging tubes arranged in parallel and steel contacts encompassing the tubes in high frequency alternatively, the tubes filled with pressurized air.

The conventional ozone generator controls the supplying current of the inverter output by adjusting not only the frequency, but also the voltage level of the PWM square waveform so as to maintain the current level. These cause the voltage waveform required in the ozone generation to be fluctuated so as to track the desired current levels continuously.

This current type inverter used in ozone generator has a short discharging period which is critical parameters of efficient ozone generation and the spikes caused by this impulse current destroys the discharging tubes at the rising and falling edge of square wave.

Because of these defects from the conventional current control inverter [CCI], in this paper, we proposes system for the high density concentration and high efficiency of ozone generation system [OGS]; the first, one phase PWM inverter with adjustable amplitude and frequency, the second, LC filter for smoothing PWM voltage of inverter into sinusoidal waveform as well as for compensating the power factor (PF). Finally, the fuzzy controller for the high density ozone generation using MAMDANI MAX-MIN fuzzy inference, where parameters such as ozone concentration as well as supplied voltage level and the supplying voltage as output are used as input and output of the proposed FIS, respectively.

Ozone Generation Technologies. The word "Ozone" is originated from the Greek word "Ozein" meaning a peculiar smell of fish, Schöbein used the word in 1840 for the first time. From then, the Ozone generation technologies have been advanced to a silent discharge through electrolysis, Opro-chemical combination, high frequency electric field and illumination of radiation.

However, the silent discharging technology is considered to be practical in industrial production. The glass (or ceramic) discharge tube is enclosed by metal electrode with a clearance of air gap. The air or oxygen are passed through hese electrodes of 6~18KVAC sinusoidal voltage of ceramic(anode contact) and metal (cathode contact) as shown in Fig.1(a).

Fig.1 (b) shows an industrialized ozone generation system with lots of ozone tubes in parallel expansion of lots of ozone tubes like in Fig.1 (a).

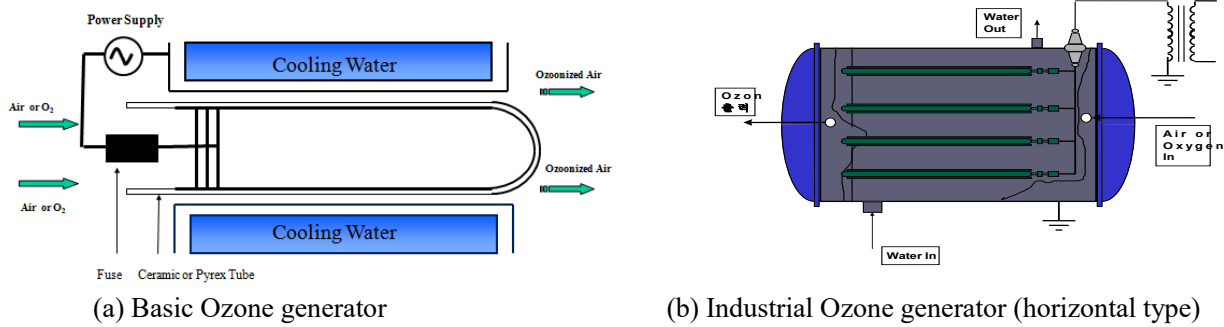


Fig.1 Silent discharging Ozone generator

High pressurized air (or oxygen) is blown into the inlet, and passed through the discharging air with gap of 3mm clearance, power supplying of 6000Vac~12000Vac,600Hz.

The generated ozone is expelled out through the Ozone outlet as shown in Fig.1 (a). The cooling water is circulated so as to ban the reduction of the generated ozone to Oxygen when Ozone is exposed in environment exceeding 40°C.

Fig.1 (b) shows an industrialized ozone generator with lots of ozone tubes in parallel like in Fig.1(a). Fig.2 shows ozone generation result according to changing of supplied frequency with supplying voltage fixed at 6000Vac and with the tank pressurized by 1.4bar of the air.

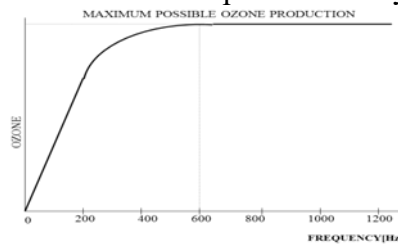


Fig.2 Ozone generation characteristics according to the frequency changes

The discharging electric circuit is constructed by the current flow from the inverter; the current is boosted up by using the step-up transformer and discharged from the Pyrex discharging electrode to the metal contact within the ozone tank, and then return to the ground of step-up transformer.

Table 1 shows the generated ozone quantity according to the supplying power frequency.

Table1 Classification of Ozone generation system

Classification	Freq. Range	Used Discharging Tube	Power Supply	Generated Ozone Quantity
Commercial Freq	60Hz	Pyrex Tube	Slidak	Low
Middle Freq.	60~1000hz	Pyrex Tube	Inverter and Boosting Transformer (Si Core)	High(40g/m ³ h per tube)
High Efficiency/Density Freq.	(1~15)KHz	Ceramic Tube	Inverter and Boosting Transformer (Ferrite Core)	High(120g/m ³ h 1tube)

Role of power supply in Ozone generation system. Ozone quantity is directly proportion to supplying voltage from 600 to 2KVac of the gas cell if the other parameters such as the relative humidity and pressurization of the air are well conditioned.

The governing equation of ozone generator is described by the following equation (1):

$$P=4fV_a[(V_o - V_a)C_d - V_aC_a] \quad (1)$$

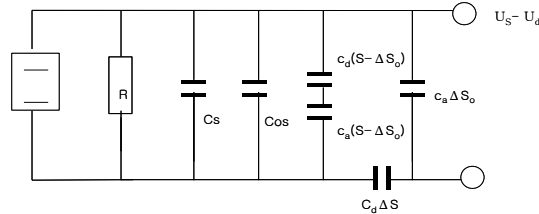
where f-input frequency, V_a -supply voltage at air gap, V_o -maximum value of supply voltage, C_d -dielectric capacitance, C_a -air capacitance at the air gap.

The ozone generation system has capacitive features because of capacitive loads of single phase high voltage electrically. Although the generated ozone quantity is proportional to the frequency and supplying voltage, in some case, the specific OGS takes advantage of the frequency adjustment to control the quantity and concentration while fixing the voltage control the frequency in a specific case.

Because the power factor (PF) in the OGS is very low (0.3~0.5) because of capacitive characteristics of ozone tubes, the matching transformer like a choke must be inserted between boosting transformer and ozone generator so as to improve power factor [PF] $\cos(\theta)$ to almost 1 so that the effective maximum energy might be transmitted to the OGS

Electrical characteristics of Ozone generation system

The equivalent electrical circuit of ozone generation system using silent discharging can be modeled in Fig 3.



R: resistance, C: Capacitance, c: Specific capacitance per surface areas, s: Electrode Surface Area, U: voltage
S: electrode surface, U: voltage

Fig. 3 Equivalent electric circuit of silent discharging [1]

Equivalent model in Fig.3 shows lots of capacitance are cascaded in parallel or in electrical network, which are the reason why the OGS has capacitive load characteristics.

Fig. 4 shows electrical phenomena within the discharging tube for one period of supplying voltage.

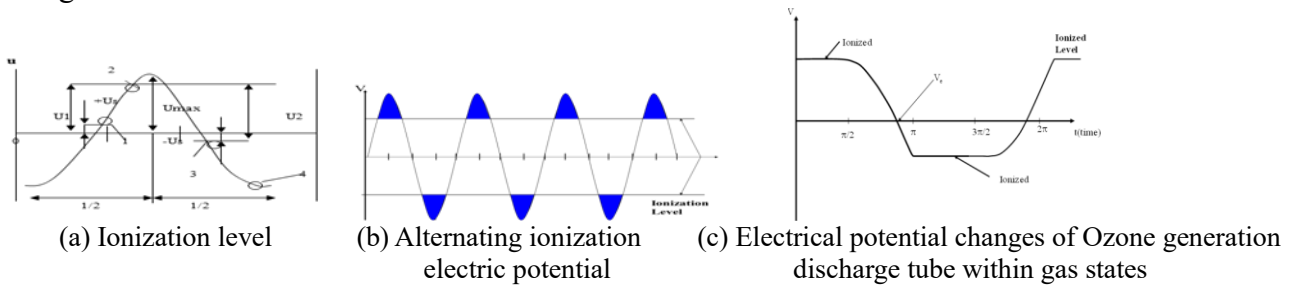


Fig. 4. Discharging condition according to the supplying voltage waveform [2] [3]

Owing to the changing of electrical characteristics, the ionization potential also changes alternatively as in Fig.2 (b).

The silent discharging takes place over all tubes when the supplying voltage of ΔU at the unit discharging surface ΔS_o exceed $+U_s$ and $|-U_s|$ as shown in Fig.7. The discharging current becomes as follows:

$$I = C_d \frac{dU}{dt} = \omega C_d U_{\max} \cos \omega t$$

$$I_m = 2 \left(\frac{\omega}{\pi} \right) \omega C_d U_{\max}$$

$$U_{\text{eff}} = \frac{U_{\max}}{\sqrt{2}}$$
(2)

where, U , I_m and U_{eff} represent input power, instantaneous maximum current and effective voltage.

The mean discharge current can be written as Eq.(3)

$$I = I_c + I_d = \frac{\omega}{c_d} S + \frac{C_o}{U_{\max}} \cos \omega t$$
(3)

where C_o represents summing capacitance in parallel discharging tubes Instantaneous current I_m can be rewritten as Eq.(4)

$$I_m = 4\sqrt{2}fC_d U_{\text{eff}}, \quad \text{if } U_{\text{eff}} < \frac{U_2}{2}$$

$$I_m = 4\sqrt{2}U_{\text{eff}} - 2fC_d S U_2, \quad \text{if } U_{\text{max}} \geq \frac{U_2}{2}; U_{\text{eff}} \geq \frac{U_2}{2\sqrt{2}} \quad (4)$$

The gases exist as an ionized state partly and then dropped below than the ionized potential. Waveform of electric potential the gas is shown as Fig.4 (c) The ionization voltage in ozone generation system V_i is proportional to the gas pressure and applied voltage between electrodes as Eq (5).

$$V_i \propto pg \quad (5)$$

where p-gas pressure, g-applied pressure.

Fig 5 shows a series of ozone generation dynamic sequences according to the electric potential variation within the air passing space.

The boxed areas denotes the ionized periods explained as in Fig.4 (b), take placed alternatively along the periodical sinusoidal waveform which are ionized time. Lots of Oxygen (O^{-2}) are combined with a single oxygen in ionized Oxygen ($O^{-1} + O^{-1}$) and becomes Ozone (O_3)

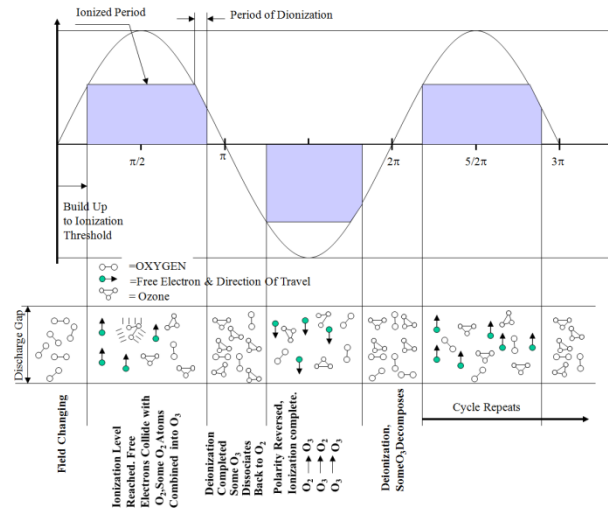


Fig.5 Ozone generation mechanism at air gap[4]

Ozone Generation System

Fig.6 shows PWM inverter used in the OGS. Three phase line voltage is converted to DC voltage after rectification by bridge circuit and the DC voltage is used in IGBT PWM inverter. The basic waveform of the PWM inverter has sinusoidal waveform of PWM inverter as shown in Fig.6(b)

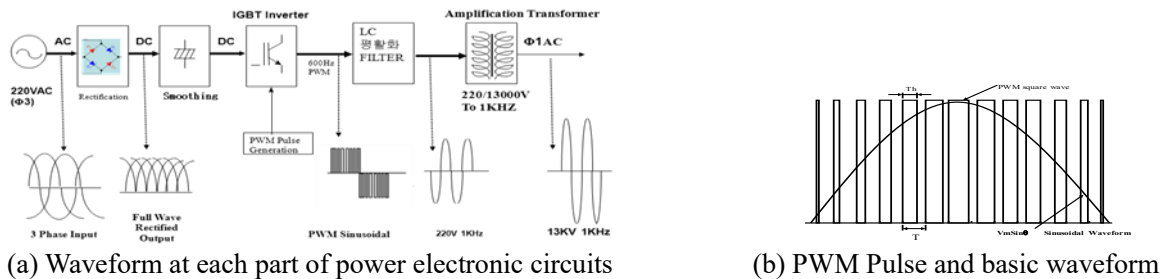
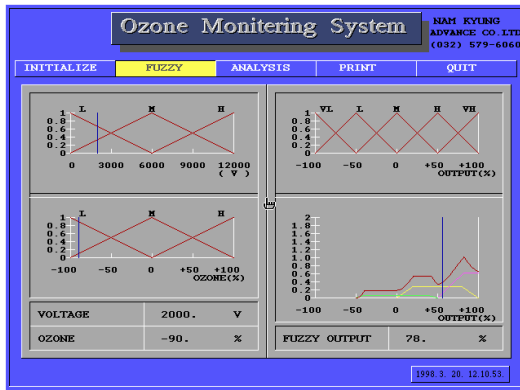


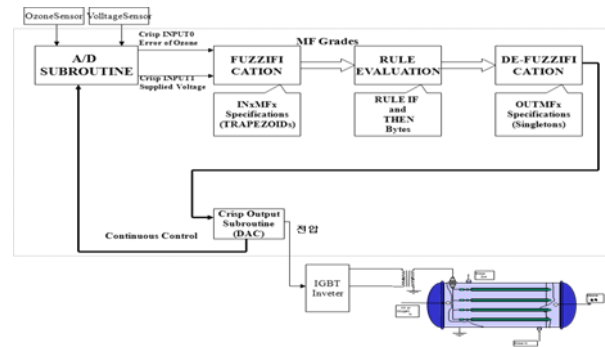
Fig.6 Configuration of PWM inverter and their basic waveform

We take advantage of MANDANI Min-Max composition in Fuzzy inference, where voltage amplitude and generated Ozone concentration per hour are used as input parameter and output amplitude of PWM inverter is used as crisp out put of Fuzzy Inference Engine [FIE].

Fig.7 (a),(b) shows FIE used in this developed OGS and triangular membership function[TMF] of ozone concentration. Fig.7 (b) shows the screen of PC based main controller implementing FIS while monitoring all states of the OGS. We can see the fired crisp result by Min-Max composition of FIS in Fig.7 (b)



(a) Configuration of FIS



(b) TMF of ozone concentration

Fig.7 Fuzzy inference engine in ozone generation system

Fig.8 shows configuration of the proposed OGS in this paper, where PC supervises all functions of the OGS, plays a part as master controller and monitors concentration of generated ozone from the OGS, calculates the output voltage from the FIE.

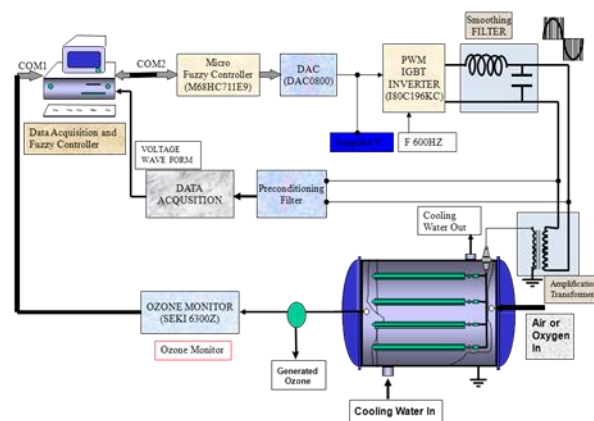


Fig.8 Configuration of Ozone generator including Fuzzy Inference Engine [6]

Experimental results

In this paper, we pretest the ozone concentration to examine the capability of the proposed OGS while changing input frequency with other conditions such as air pressure and supplying voltage fixed at 6000Vac and 1.3Bar, respectively. The test result is shown in Fig. 9. Comparing this result with Fig. 2 of ozone generation characteristics, we conclude that the proposed OGS has the same characteristics as explained in Fig.2 for the ozone generation.

Fig.10 shows another test result while only changing the air flow into the ozone generation tubes with other parameters such as frequency at 600Hz and voltage at 6000Vac fixed with a view to compare the ozone concentration.

We analyze the efficiency of the OGS comparing with conventional current control inverter [CCI]. The proposed OGS has a characteristic of increased Ozone quantity according to the increased air flow. Finally, Table2 represents the comparison results of the proposed OGS using FIS and PWM sinusoidal inverter with the conventional CCI of square waveform without any feedback control

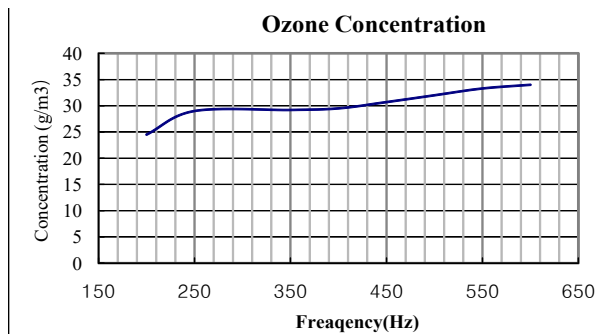


Fig.9 Ozone generation according to the only frequency changes

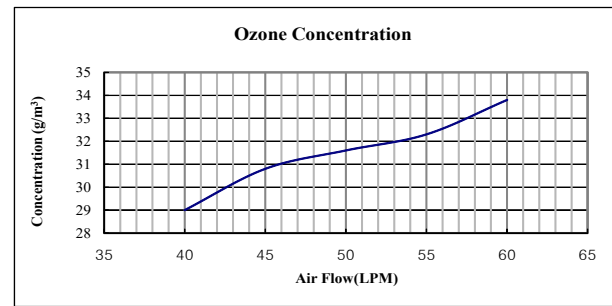


Fig.10 Test results while maintain frequency at 600Hz and the supplying voltage at 6000VAc

Conclusion

We proposed the OGS using not only voltage control inverter with PWM sinusoidal waveform generation, but also FIS for control the optimal ozone generation. The PWM square waveform from the proposed inverter is filtered for converting the square into analog sinusoidal waveform before inserted in step-up transformer. The FIS plays parts in controlling the ozone concentration by adjusting frequency as well as voltage into ozone tubes.

We can find that the proposed OGS generates more ozone concentration and less consumes the energy than conventional Ozone generator using a current control inverter by lots of real experiment.

Main reasons of these results are

- (1) Using the sinusoidal wave form instead of square wave PWM in the conventional CCI; (2) Optimal control by the FIS; (3) Adoption of chokes to transmit the maximum power to the ozone tubes with capacitive load characteristics by the PF correction.

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Table2 Comparison results: conventional current control inverter [CCS] and proposed OGS

Items	CCS	Proposed OGS	Remarks
Primary voltage at Tr[V]	440V	130	
Primary current at Tr[A]	6	18	
Line Frequency[Hz]	60	60	
Secondary Voltage at Tr[V]	9,380	11,800	
Secondary current at Tr[A]	0.1418	5.04	
Supplying Frequency[Hz]	819.5	600	Supplied at Ozone Tube
Total generated Ozone[Kg/H]	107.4	122.4	Monitored by Ozone monitor
Ozone quantity per tube [kg/HEa]	21.48	34	More Ozone generation
Power supplying into ozonation tube [Kw]	2.64	2.34	Power Supplied at Ozone Tube
Power per each tube [Kw/EA]	0.78	0.585	Less energy consume
Ozone generation per 1KW power [g/hr]	40.68	52.3	More Ozone generation
Pressure at tank [kgf/cm ²]	0.8	1.2	More pressurized
Air flow rate [LPM]	50	60	More air flow