Abstract—Ozone gas (O3) is widely used in deodorization, decolourization, disinfection, bleaching processes, gas/air treatment, chemical synthesis and recently in medical applications. Due the wide application of ozone then the ozone generator or ozonizer is urgently needed. A single switch resonant converter with ferrite transformer is proposed in this work. The prototype is constructed by two parts, first is ozone chamber and the second part is power converter with a single switch resonant converter and it supplied by photovoltaic simulator. The converter is successful to convert 12 volt from photovoltaic to 1.89 kVpp high frequency voltage to ozone chamber. The ozone gas produce with the proposed system is 450 ppm with oxygen as an input gas.

Keywords—resonant converter, ozonizer; photovoltaic simulator.

I. INTRODUCTION

Conservative ozone generation with 50 or 60 Hz high voltage power supply, the voltage injected was about 3 – 10 kVrms or 8.5 – 28 kV peak to peak [1-3]. However, in practical the injected voltage used for ozone chamber at atmospheric pressure and ambient temperature is considerable high and near to the sparking potential. The dimension of conventional power supply is in a large volume, due to the present of transformer. Regard to safety, high voltage may not be suitable for household applications.

Recently, ozone generation with 50 or 60 Hz high voltage power supply, the voltage injected was about 3 – 10 kVrms or 8.5 – 28 kV peak to peak [1, 4, 5]. This results give an increase in ozone production for a given surface area, while decreasing the require peak voltage.

The full bridge resonant converter operated at resonant frequency of 88 kHz was reported to generate ozone from 4 – 6 kV peak to peak [6]. The converter requires four MOSFET switches and high DC input voltage (340 Volt). A single hard switching converter driving an ozone chamber filled with special discharge gas such as Xe, Ar, or Ne, operated at certain pressure. The dielectric layer was constructed in borosilicate glass or quartz with a conductive thin layer on the surface. Although the voltage reduce to 1 kVrms or 2.8 kV peak to peak and the ozone yield was high, such chamber is considered complicated to construct. [4, 7].

Planar electrodes are made from metal with borosilicate glass as dielectric. This ozone chamber need to be operated at higher voltage (more than 7 kV) and frequencies from 5 - 7 kHz. [8-10]. Further more, the application of higher voltage result in filamentary effect inside the chamber [8, 11] and as a result a cooling system is necessary required.

A single switch resonant converter with ferrite transformer is proposed in this work. The prototype is constructed by two parts, first is ozone chamber and the second part is power converter with a single switch resonant converter and it supplied by photovoltaic simulator.

II. OZONIZER CHAMBER

The proposed ozone chamber is designed with simplicity and practically in mind. It is to be operated at atmospheric pressure and ambient temperature condition without the need to use special gas. In addition it requires no or water cooling. The geometrical configuration is a simple rectangular shape with a planar dielectric barrier, and the chamber is constructed in 70 x 140 mm square as shown in Figure 10. The chamber is constructed by aluminium mesh as electrode and metal tape with muscovite mica sheet as dielectric material are placed between the electrodes. The air gap inside chamber is 1.5 mm. Maximum operating temperature is about 500°C. A high voltage insulation tape is wrapped around the edges sides of electrode to prevent the spark or arch to occur [12].

The investigation to the characteristics of the chamber as it is supplied by high voltage high frequency gives Lissajous pattern. This pattern is shown in Figure 2. Due to this electrical characteristics, the equivalence circuit of the ozone chamber is represented in parallel capacitance and reactance [13] as it is shown in Figure 3.
III. DESIGN OF SIMPLE RESONANT CONVERTER

The basic configuration of class E resonant converter connected to RC load is shown in Figure 4. The load is designed to achieve resonance condition at certain switching frequency. To increase the voltage by, a high voltage high frequency transformer is added as shown in Figure 5. It is normally constructed using ferrite core. The secondary winding of transformer (L_o) is included as part of the resonance tank. The RC load in the circuit represents of equivalent circuit of ozone chamber.

The capacitors C_e will be charged and the switch voltage rises from zero to maximum and falls to zero again. When the switch voltage begins falling to zero, \( \frac{dv}{dt} \) normally will be negative. Thus, the switch voltage would tend to be negative. To limit this negative voltage, an anti parallel diode is connected in series with the switch (S_1). In practical this diode is already built in the switching component but in this purposed circuit, the switching device also has to withstand a high voltage.

A resonant circuit connected to simple resonant converter is similar with parallel loaded circuit in Figure 7. This resonant circuit is modeled from the secondary of transformer together with the equivalent model of ozonizer. This PLRC is able to deliver high voltage from lower voltage then the combination of this resonant circuit as AC part of single switch resonant converter.

Theoretically, the parallel loaded circuit will gives voltage attenuation as Equation (1):

\[
|G| = \frac{1}{\sqrt{(n^2 - 1)^2 + \left(\frac{n}{Q}\right)^2}}
\]  

where \( Q \) is quality factor, and \( n \) is the ratio between actual frequency and resonant frequency. Gain voltage as the function of frequency is illustrated in Figure 8. The maximum voltage is possible to achieve eight time of input voltage.
IV. PHOTOVOLTAIC MODULE SIMULATOR

The photovoltaic module simulator delivers power in the form of direct current according to the characteristic of photovoltaic which is programmed into the simulator. The characteristic of photovoltaic simulator is programmed to have 12 volt maximum power point ($V_{mpp}$) with 15.34 open circuit voltage ($V_{oc}$). The maximum short circuit current is 2.35 Ampere. The photovoltaic is possible to deliver maximum power at 25 Watt. Table 1 shows the characteristic of photovoltaic.

Table 1. The characteristic of photovoltaic

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power at mpp</td>
<td>25 Wattt</td>
</tr>
<tr>
<td>Voltage at mpp</td>
<td>12 Volt</td>
</tr>
<tr>
<td>Current at mpp</td>
<td>2.0833 Ampere</td>
</tr>
<tr>
<td>Field Factor</td>
<td>68 %</td>
</tr>
<tr>
<td>Real Field Factor</td>
<td>69.26 %</td>
</tr>
<tr>
<td>Temp. V</td>
<td>-0.005 1/°C</td>
</tr>
<tr>
<td>Temp. I</td>
<td>0.0006 1/°C</td>
</tr>
<tr>
<td>Series resistance</td>
<td>0.01 Per unit</td>
</tr>
<tr>
<td>Parallel resistance</td>
<td>100 Per unit</td>
</tr>
<tr>
<td>Open Circuit Volt.</td>
<td>15.34 Volt</td>
</tr>
<tr>
<td>Short Circuit Volt.</td>
<td>2.35 Ampere</td>
</tr>
</tbody>
</table>

As the parameters in Table 1 is plotted then the curve characteristic of photovoltaic is shown Figure 9.

V. EXPERIMENTAL SETUP

The experimental setup of the complete ozonizer with simple resonant converter supplied by photovoltaic is shown in Fig. 9. An input gas was injected at 1 liter per minute, then the high frequency power supply was switched on. There are several input gas used in this work i.e. natural air, dry air and oxygen. The output gas or ozone is measured by ozone monitor and before the ozone is release to the open air then is must be flowed to ozone destructor. The power supply is a single switch high frequency resonant converter. It is modified from class E resonant power converter. There is no parasitic capacitor at the high voltage side as in the conventional class E resonant converter because the chamber is already inherently capacitive. This inverter is operated in a frequency range of 27 kHz. To generate high frequency, a single MOSFET is controlled by pulse width modulation integrated circuit (PWM IC). The gate drive opto coupler is connected to the MOSFET and PWM IC to amplify the control signal and provide electrical isolation. The inverter is supplied by Photovoltaic Module Simulator. To increase the voltage a step up ferrite transformer is connected between the inverter and the ozone chamber. The advantages of this high frequency transformer is a small ferrite core size and much fewer windings.

VI. RESULT AND DISCUSSION

At resonant frequency 27 kHz, the sinusoidal output voltage was obtained up to 1.89 $kV_{pp}$ as shown in Figure 10 (a), meanwhile the voltage at low voltage side is shown in Figure 10 (b). At voltage output, the spikes are easily seen and they indicate the electric discharges. The control signal of converter turn on and off at zero voltage in Figure . This operation indicate that the resonant converter work with zero voltage switching.

The result also shows that the circuit gives maximum ozone concentration 450 ppm or at 1.5 $kV_{pp}$ as shown in Figure 11. The maximum ozone production is obtained when the input gas is oxygen.
CONCLUSION

Based on the experimental result produced by the proposed simple resonant converter to generate ozone, several conclusions can be summarized as follows:

1. The ozonizer developed by simple resonant converter is successfully operated at atmospheric pressure and ambient temperature and produce amount of ozone.
2. The proposed simple resonant converter is successful to convert the power from photovoltaic simulator to generate high frequency and voltage to the ozone chamber.
3. The use of simple resonant converter has been effectively magnify the dc input voltage 12 Volt from photovoltaic to 1.89 kV_p-p.
4. The ozone gas production with oxygen as an input gas has reach maximum result to deliver ozone in 450 ppm.

References