The Application of FPGA in PWM Controlled Resonant Converter for an Ozone Generator

By Tole Sutikno

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The Application of FPGA in PWM Controlled Resonant Converter for an Ozone Generator

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Article Info

ABSTRACT

Pulse Width Modulation (PWM) is a very common technique used in many different applications. The Conventional method its generation is the heart of the inverter system. This paper present methodology to generate Sinusoidal PWM (SPWM) signal for three-phase inverter based on EP20K200EFC484-2x Altera Field Programmable Gate Array (FPGA). Designing a PWM inverter drive using FPGA has several advantages, such as: it's quick, very modifiable, and very suitable for prototyping. In this paper, the PWM signal is used control switching action conducted by MOSFET as part of power electronics devices in resonant power converter which has 24 volt DC input voltage. As the result, by using resonant oscillation controlled by FPGA the high sinusoidal voltage until 1.0 kV peak-to peak has been generated in the load side.

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1.   INTRODUCTION

One of the well known methods to generate ozone in normal atmospheric environment is by using dielectric barrier discharge or sometimes referred to as silent discharge [1].The main elements of a silent discharge chamber are dielectric layer that covers at least one of both of the electrodes. To break the oxygen molecule to a single atom, high alternating voltage (ac) supply is connected across the electrodes. The ac voltage is normally obtained using the 50/60Hz utility supply that is stepped-up using a high voltage transformer [1, 2]. Such configuration requires the chamber to be operated at very high voltage i.e. near to the sparking potential; typically above 20 kV for a 1 mm discharge gap. With regard to safety, high voltage may not be suitable for certain household applications, such as domestic water and air treatment. In addition, low frequency transformer is generally large, has a large number of turns and less efficient.

Recently, it is recognized that high frequency ac power supply (in the range of tens to hundreds of kHz) allows for an increase in the discharge power to the dielectric barrier discharge (DBD) chamber [3-5]. In effect, the application of high frequency decrease of the required amplitude of the applied voltage[6]. The main advantage of having a lower applied voltage is the opportunity to build ozone generators using non-conventional dielectric materials which are known to have much lower dielectric breakdown voltage such as mica, alumina ceramic, and polymer. Furthermore, high frequency transformer requires much smaller footprint than the conventional 50/60Hz transformer.

The power delivered (P) in ozone chamber, as it is reported in reference [3, 7] can be obtained by approximated formula as follow:

$$P = \frac{1}{T} \int V(t) \cdot I(t) dt \qquad (1)$$

$$W = \int V(t) \cdot I(t) dt \qquad (2)$$

Where W is energy loss per cycle inside the chamber, V(t) is the voltage across the chamber, and I(t) the current flow through the ozone chamber

After having the energy lost per cycle, the power consumed by the silent discharge can be obtained by multiplied the energy lost per cycle with the frequency (*f*) of applied voltage. The equation (1) becomes:

$$P = W \cdot f \qquad (3)$$

Regarding the equation above (3), the use of supply frequencies above 50-60 Hz allow to increase the power density applied to the electrode surface inside chamber and increase ozone production for a given surface area, while decreasing the necessary peak voltage (the higher the frequency, the higher the power density and the lower the applied voltage). The use of switching converters based on fast power electronic devices such as metal oxide semiconductor field effect transistors (MOSFETs) or insulated gate bipolar transistor (IGBT) will give the possibility to increase the frequencies up to several kHz [8-11].

Among the different high frequency power supplies, resonant converters are known to be the most promising [4, 12-15]. Various methods are experimented using high frequency power converters for ozone generation. Nisoa et al in reference [16] is reported to use the full bridge resonant converter operated at resonant frequency of 88 kHz [15]. Although simple, the converter requires four MOSFET switches and is fed from an ac main. The voltage at the DC input is quite high is about 340 Volt. Alonso et. al. [17] proposed a resonant converter driving an ozone chamber filled with special discharge gas such as X_e, A_r, or N_e operated at certain pressure. The dielectric layer is constructed in borosilicate glass or quarzt with a conductive thin layer on the surface. Although the ozone yield is high, such chamber is considered complicated to construct.

The use of class E shunt amplifier to generate high voltage and ozone product is first reported in reference [18]. However it appears that the paper lacked the information on how it is applied to an ozone chamber. Furthermore no result on ozone yield published and the performance of converter remains unknown.

Most of inverter with pulse width modulation control digitally is conducted by using microcontroller or Digital Signal Processing (DSP), but in other hand PWM implementation signal is possible to be conducted in hardware logic with is possible to offer better speed and shorter time. The implementation of digital operation in the hardware logic is possible to be done by using FPGA (*Field Programmable Gate Array*). FPGA is possible to be loaded by thousand logical gates. These logical gates will form a logical system that is possible to be implemented as high speed combinational or sequential with unlimited data bit bandwidth [18-22].

In this paper the PWM signal generated by using FPGA is implemented to trigger MOSFET as power electronics devices in resonant power converter. Usually the PWM signal for Class E resonant converter or Class E resonant inverter is generated by using PWM IC or microcontroller [23-24]. The input to a resonant power converter is a DC voltage or current source, and the output is a voltage or current resonant pulse. Power semiconductor devices perform the switching action, and the desired output is obtained by varying their turn-on and turn-off times. In this paper MOSFET is used as switching device. The switches of resonant converters are turned on to initiate resonant oscillations and are maintained in an on-state condition to complete the oscillations. The output waveform depends mainly on the circuit parameters and the input source. The on time and switching frequency of power devices must match the resonant frequency of the circuit [23-26].

2. PLANAR OZONE 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 1.
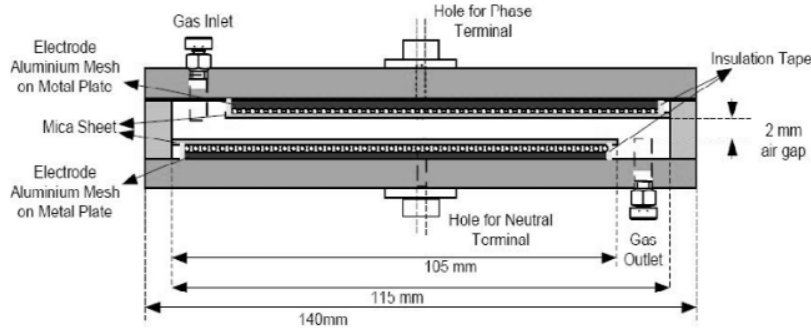
Figure 1. OZONIZER chamber

The proposed dielectric material is muscovite mica. Muscovite mica is tough, less flexible, and is known to have high abrasive resistance with excellent durability. It is possible to construct wide plane dielectric shape muscovite mica with 0.1 mm thick without a crack. The dielectric strength is more than 20 kV/mm with dielectric constant in range 6 to 7. The maximum operating temperature is about 500°C. The air gap inside the chamber is designed at 2 mm. The high voltage and ground electrode is constructed using aluminium mesh placed on a metal plate. The small wire of aluminium mesh forms a rough and non homogenous geometrical surface. The rough and non homogenous surface is known to assist the creation of electrostatic field emission to release electron from the electrode [27-29]. A high voltage insulation tape is wrapped around the edges sides of electrode to prevent the spark or arch to occur.

3. RESONANT POWER CONVERTER

The switching devices in converters with Pulse Width Modulation (PWM) control can be gated to synthesize the desired shape of output voltage or current. However, the devices are turned on and off at the load current with high $\dfrac{di}{dt}$ values. The switches are subjected to high voltage stress and the switching power loss of a devices increase linearly with the switching frequency. The turn on and turn off loss could be a significant portion of the total power loss. The Electromagnetic interference is also produced due to high $\dfrac{di}{dt}$ and $\dfrac{dv}{dt}$ in the converter waveforms. The disadvantages of PWM control can be eliminated or minimized if the switching devices turn on and off when the voltage across a devices or its current become zero [1]. The voltage and current are forced to pass through zero crossing by creating an LC resonant circuit, thereby called resonant pulse converter. Among the resonant converter Class E resonant converter is one of converter which uses only single power electronics switch and has low switching losses [7-8].

The circuit is shown in Figure 2. It is normally used for low power applications requiring less than 100 W [6,8], particularly in high frequency electronic lamp ballast. The switching device has to withstand a high voltage. This inverter is normally is used for fixed output voltage. However, the output voltage can be varied by varying the switching frequency. The circuit operation can be divided into two modes: mode 1 and mode 2

Mode 1.

During this method MOSFET is turned on. The equivalent circuit is shown in Figure 3a. The switch current I_t consists of source I_S and load current I_o. To obtain an almost sinusoidal output current, the value of L and C are chosen to have a high quality factor, and low damping ratio. The switch is turned off at zero voltage. When the switch is turned off, its current is immediately diverted through capacitor C_e.

Mode 2.

During this mode, MOSFET is turned off. The equivalent circuit is shown in Figure 3b. The capacitor current I_C become the sum of I_s and I_o. The switch voltage rises from zero to maximum and falls to

zero again. When the switch voltage falls to zero, $I_e = C_e \dfrac{dv}{dt}$ will normally is negative. Thus, the switch voltage would tend to be negative. To limit this negative voltage, an anti parallel diode is connected and into MOSFET this diode is already built in.

Mode 3.

This mode exists only if the switch voltage falls to zero with a finite negative slope. The equivalent circuit is similar to that for mode 1, except the initial condition. The load current falls to zero at the end of mode 3. However, if the circuit parameters are such that the switch voltage falls to zero with a zero slop, there is no need for a diode and this mode would not exist. That is, v_T=0, and $\dfrac{dV_T}{dt} = 0$.
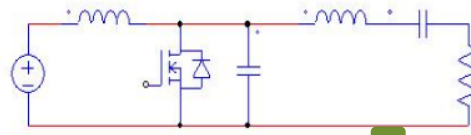

Figure 2. Circuit of Class E resonant converter

(a) mode I   (b) mode II
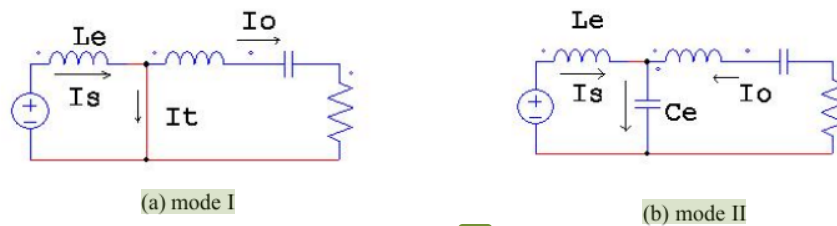
Figure 3. Switching modes for E-Class converter. (a) Model I , (b) mode II

4.   EXPERIMENT SETUP

The experiment is conducted by using FPGA EP20K200EFC484-2x. This FPGA has 200 generic gate, 8320 logic elements and 376 pins. To generate PWM signal, first the triangle signal and the threshold line is generated. The FPGA has provided pulse signal with frequency until 33.33MHz. This signal is adjusted by using frequency divider to generate desired clock. This clock is needed to trigger triangle generator. Look up table is used in triangle generator to generate triangle signal. This signal will be modulated or compared to threshold value to produce pulse width modulation. The sequential process is shown in Figure 4.
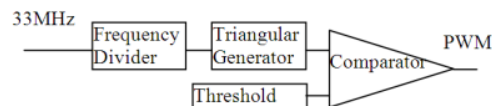
Figure 4. Schematic diagrams to create PWM in FPGA

The complete circuit inside FPGA programming is shown in Figure 5. After the complete circuit for generating PWM signal has been accomplished in FPG programming, the program should be compiling and ready to down loan into FPGA board. The compilation report is shown in Figure 6.
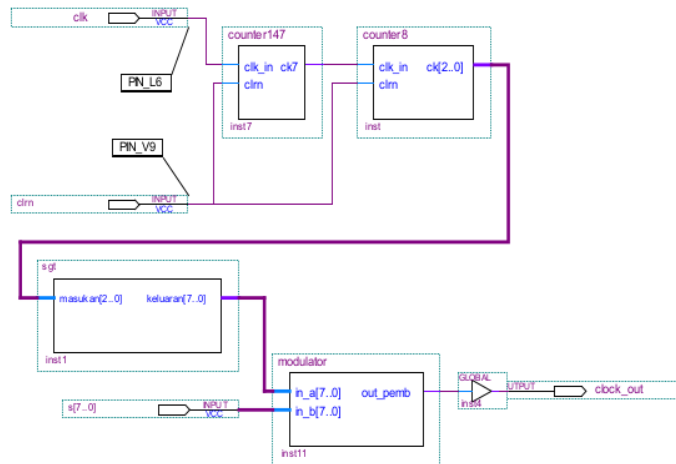
Figure 5. Complete circuits to create PWM in FPGA Programming
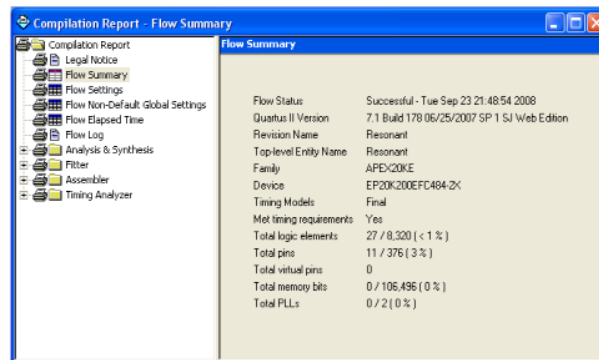
Figure 6. Compilation Report

During the laboratory experiment the E class converter consists of single MOSFET IRF640 and it is controlled by pulse width modulation signal produced by FPGA EP20K200EFC484-2x. This MOSFET is connected to the Agilent A3120 as opto coupler to separate the power circuit and control circuit. Inside opto coupler the pair of MOSFET in totem pole configuration has been embedded as driver as well. The experimental circuit is shown in Figure 7.

Figure 7. Experimental circuit

5.   RESULTS AND DISCUSSION

Before download the program into FPGA board, the PWM signal can be simulated first to recheck whether the generated PWM has been match with desired duty cycle and frequency to trigger MOSFET. The simulated PWM signal is shown in Figure 8.

Figure 8. Simulated PWM signal

At the resonant frequency, the E-Class resonant converter will give sinusoid voltage wave at terminal of the load as it s shown in Figure 9.

Figure 9. Voltage at resonant frequency of E Class resonant power converter

During the experiment, there are three probe used. Two probes without attenuation are used to measure voltage shape at the output terminal of FPGA board and the output of opto coupler. One high voltage high frequency probe is used to mea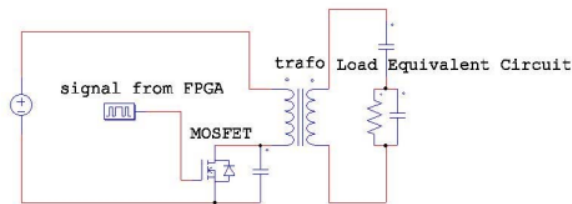sure voltage at load terminal. As it is shown in Figure 9, the PWM signal generated at resonant frequency is 28.34 kHz and the voltage at output opto coupler is 15.4 volt. The terminal voltage at load side is 1.01kV peak to peak or 337 volt rms. During the experiment E-Class resonance is supplied by 24 Volt dc as voltage input.

6.   CONCLUSION

The application of FPGA to generate PWM signal for control switching action of MOSFET in Class E resonant power converter has been made to generate high voltage at load side. The power converter has been work properly to generate sinusoidal voltage until 1.01kV peak to peak from 24 volt DC at resonant frequency. There is more possibility improvement on power converter side to produce efficient power consumption by using several modifications in PWM control strategy generated by FPGA.

ACKNOWLEDGMENT

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