Development of dielectric barrier discharging power supply

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Abstract. Due to the demand of a dielectric barrier discharge power supply, a high voltage and high frequency AC power supply was designed and implemented. Its output voltage is standard or approximate standard sine waveform with the frequency range of 1 kHz to 50 kHz. The output voltage and output frequency can be adjusted individually. The maximum output power of the power supply is 2 kW. It can be operated through local or remote control. The power supply has been used in the dielectric barrier discharging research under different conditions.

1. Introduction
Dielectric barrier discharging (DBD) is one of the important ways of obtaining low-temperature plasma. Many researches about DBD are carried out because of the wide application of low-temperature plasma in industrial and military fields. In order to study the influence factors of the low-temperature plasma produced by DBD, a flexible DBD power supply is needed.

![Figure 1. Four different DBD structures](image)

The discharging structure of DBD is various. Figure 1 shows four different DBD discharging structures. With the same discharging structure the material and thickness of dielectric layer or discharging electrode and the working gas can be different. They all influence the production of low-temperature plasma. Researchers often hope to find the optimal combination condition of generating low-temperature. In the study process, a versatile power supply that can meet the various demands is
essential. For an AC power supply, different material or structure DBD means different discharge voltage, different discharging output power. In addition, the output frequency is another influence factor of low-temperature generation. So the AC power supply should have adjustable output voltage and frequency, at the same time, its output power should be enough.

Considering of most DBD structure and control requirement, the specification of the AC power supply was designed and is showed in table 1.

| Specification of the AC power supply for DBD application. |
|----------------------------------------------------------|
| **Output voltage** | 0~30 kV peak |
| **Maximum output power** | 2 kW |
| **Output frequency** | 1 kHz~50kHz |
| **Control mode** | Local and remote(CAN bus, fiber, RS232 serial port) |

2. Design of the AC power supply

In this section, the design of the high voltage high frequency AC power supply is introduced.

2.1. Choice of topological structure

The AC power supply is achieved through inverter technology usually. Multilevel inverter technology can output more standard sine wave. It only needs a high-frequency filter circuit which is easy to be achieved. While an H-bridge inverter which can be called two-level inverter can output a square wave only. The square wave has abundant low-frequency and high-frequency harmonic. In order to get a sine wave, a filter or frequency selected circuit with a large-scale of low-frequency and high-frequency is needed which is hard to be achieved. But the output frequency of the AC power supply is 50 kHz. If the multilevel inverter topology is selected, higher switching frequency than 50 kHz should be used in the multilevel inverter. For a 2kW output power the switching devices of the inverter is hard to be chose. So the H-bridge inverter topology was selected. Figure 2 shows the principle diagram of the AC power supply. The key designs in the power supply are the high voltage transformer and the filter.

2.2. Transformer design

In the topology shows in figure 2, the adjustment of output voltage of the power supply is realized through an electric controlled voltage regulator, which can adjust the input AC power. The adjustment of output frequency is realized through the inverter which is controlled by the control system.

**Figure 2.** Circuit diagram of the AC power supply
The high voltage transformer is a key component because its distributed parameters influence the filter parameter and lead to output voltage wave distortion especially in high frequency output state. Figure 3 shows the high frequency transformer equivalent circuit.

For a high frequency and high voltage transformer, its secondary windings turns are more, so the distributed capacitance CDS and distributed inductance LLS are larger. When the CDS and LLS are converted to the primary of the transformer, the equivalent capacitance and inductance are larger because of the high ratio of the high voltage transformer. The distribute capacitance and inductance will influence the filter parameter especially at high frequency. When the distributed capacitor and inductance are larger than the filter parameter, none filter can realize the function and the frequency decided by the distributed capacitor and inductance will be the cut-off frequency of the sine wave outputted by the transformer. So the key of the high frequency transformer design is how to decrease the distribute capacitance and distribute inductance.

Ring transformer has least leakage inductance, but its insulation structure leads to the lower output voltage unless the diameter of the ring magnetic core is large enough. E-type or U-type transformer with coaxial structure has less leakage inductance, and its insulation voltage can be controlled through adjusting the distance of primary and secondary windings and the magnetic arm length of the E-type or U-type magnetic core. For a 30 kV output voltage, the U-type transformer with coaxial structure windings was selected. In order to increase the insulation voltage between the turns, the slot structure of high voltage winds is designed. In view of the limited magnetic arm length, the primary and secondary windings are divided into two equal pieces and fixed in the two magnetic arm of U-type magnetic core. The two primary and secondary windings are connected in series. Figure 4 shows the structure and winding connecting method of the transformer. The outside windings of the coaxial structure windings are the secondary windings. For a wide range output frequency, the ferrite core was selected.

2.3. Filter design
The output frequency of the power supply is from 1 kHz to 50 kHz, it is a wide frequency range. It is hard to design a filter without any gain or attenuation. So the whole output frequency is divided into eight subsection. Every subsection corresponds to a filter parameter or filter circuit. The correspondence of output frequency and filter circuit are showed in table 2.

| Output frequency | Filter circuit | Filter parameter |
|------------------|----------------|-----------------|
| 1~5 kHz          | L1=5.35 mH     | C1=1.32 uF      |
|                  | C2=0.5 uF      |                 |
| 4.9~7 kHz        | L1=5.35 mH     | C1=1.32 uF      |
| 6.1~7 kHz        | L1=3.13 mH     | C1=1.32 uF      |
| 7~14 kHz         | L1=2.28 mH     | C1=1.32 uF      |
| Frequency Range | L1 Value | C1 Value |
|-----------------|----------|----------|
| 10.5~15 kHz     | L1=925 uH | C1=1.32 uF |
| 14~24.5 kHz     | L1=413 uH | C1=1.32 uF |
| 15~25 kHz       | L1=104 uH | C1=1.32 uF |
| 25~50 kHz       | C1=1.32 uF |

The design rule of the filter circuit is to pass and gain the target frequency, so it can be design as a resonant circuit. The resonant frequency of filter is designed as the middle of the subsection frequency.

2.4. Control system design
The control system of the AC power supply fulfils the frequency adjustment and signal convert between the control computer and the AC power supply. So a digital signal processor (DSP) TMS320LF2407A was selected. Based on the function of TMS320LF2407A, a CAN bus interface and RS232 series port are designed. The RS232 series port has two output channels, one is the series port itself, and another is converted to a optical fiber interface through an electro-optic converter. In addition, based on a large number of I/O of TMS320LF2407A, a digital keyboard control channel is design which is installed on the front panel and fulfils the local control function. The remote control function is fulfilled through the CAN bus port and optical fiber interface. The RS232 series port was designed as a debug interface.

2.5. System assembly
The whole AC power has three parts of assembly. Figure 5 shows the photograph of the power supply cabinet. The top layer is the control system and inverter part; the middle layer is the band-pass filter part; the bottom layer is the high voltage transformer part.

![Figure 5. The AC power supply photograph](image)

3. Experimental verification
In order to verify the performance, the experimental was carried out on an insulating material in case of load breakdown. Figure 6 and figure 7 show the output voltage waveform respectively at 1 kHz and 50 kHz. Between 5~50 kHz, the amplitude of output voltage can reach 30kV. But between 1~5 kHz, the amplitude of output voltage is lower and lower with the decrease of the output frequency. At 1 kHz, the maximum output voltage is 6.8 kV. The reason is that resonant circuit hasn’t been design according to 1 kHz for the large volume of resonant induction. Figure 8 and figure 9 show the output voltage and discharge current waveforms at 5 mm air gap. Their output voltage is all 18 kV and output frequency is 7kHz and 14kHz respectively.
4. Conclusion
The AC power supply has used in the field of DBD and voltage withstand test of insulation materials at different frequency. The AC power supply is easy to operated and running well. For the distributed capacitance and inductance the cut-off frequency of the transformer is 55 kHz only. Based on the test analysis the coupled inductor between the primary and secondary windings is the reason probably. It needs further validation. In addition, the filter parameter design is according to the resonant frequency, it lead to the more frequency subsection, it should be optimization.

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