Dielectric barrier discharge analysis from the point of view of supply voltage and reactor topology

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Abstract. This paper aims to provide a comprehensive analysis of the output of DBD reactors considering 2 different power supplies that provide rectangular command voltage with variable duty cycle and frequency. The experiments presented were performed with these power supplies considering four geometries of DBD reactor. At this stage the input parameters of the power supplies are: frequency of control pulses, duty cycle and high voltage level applied on the DBD reactors by choosing a certain number of turns for the primary windings of the high voltage coil. The parameters considered as outputs from the reactor-power supply assembly were: the high voltage output and the electric current from the primary induction coil.

1. Introduction

Dielectric-barrier discharges (DBDs), also referred to as barrier discharges or silent discharges have found a number of interesting industrial applications in addition to the historical ozone generation. The generation of powerful coherent infrared radiation in CO2 lasers and of incoherent ultraviolet (UV) or vacuum ultraviolet (VUV) excimer radiation in excimer lamps are examples of more recent developments. [1]

Typical electrode configurations of planar and cylindrical dielectric-barrier discharges are given in figure 1. DBDs are characterized by the presence of one or more insulating layers in the current path between metal electrodes in addition to the discharge gap(s).[1]

![Common dielectric-barrier discharge electrode configurations](image)

Figure 1. Common dielectric-barrier discharge electrode configurations.[1]
This paper focuses on the DBD discharge by analysing the electrical parameters using two different power supply topologies. The first power supply topology is half bridge topology and the command circuit is built around TL494 integrated circuit. The second power supply is a fly-back topology with the command circuit built with the help of UC/SG 2525 integrated circuit.

2. Experimental setup
The experiments performed with the power supplies considered all four geometries of DBD type reactors. The high voltage transformer secondary consists of 2500 windings placed on a ferrite core. At this stage the input parameters of the sources that were adjusted are:
- Frequency of control pulses - by means of potentiometers connected to the specific inputs of the command integrated circuits;
- Duty cycle - by means of potentiometers connected to the specific inputs of the command integrated circuits;
- The high voltage level applied on the DBD reactors was done by choosing a certain number of turns in the primary winding of the high voltage coil (18 and 22 windings), which allowed the modification of its transformation ratio.

The experimental setup block schematic is presented in figure 2. The supply voltage for the power section is 96V for the TL494 power supply and 48V for the SG2525. The command supply voltage used for TL494 was 12V because of the integrated circuit limitations. The SG2525 is more permissive from this point of view, thus the supply voltage for the command part used was 20V.

![Block schematic of the experimental setup](image)

2.1. Experimental adaptation for all 4 DBD discharge electrode configurations
The 4 DBD discharge topologies are presented in figure 3. The dimensions for reactor 1 to reactor 3 are: the inside diameter of the ground electrode of 10 mm, the outside diameter of the ground electrode of 16.6 mm, the diameter of the HV electrode of 7.8 mm. The dielectric material used was glass.

The first reactor presented is the one consisting of air-dielectric configuration. The dimensions for this reactor are: the discharge space (D1.1) = 2 mm, the thickness of the dielectric (D1.2) = 1.5 mm.

The second reactor presented is the one consisting of dielectric-air-dielectric configuration. The dimensions for this reactor are: the discharge space (D2.2) = 1 mm, the thickness of the dielectric (D2.1 and D2.3) = 1.5 mm.

The third reactor presented is the one consisting of air-dielectric-air configuration. The dimensions for this reactor are: the discharge space (D3.1 and D3.3) = 1 mm, the thickness of the dielectric (D2.2) = 1.5 mm.

The fourth and the last reactor presented has circular configuration. The dimensions for this reactor are: the inside diameter of the ground electrode of 7 mm, the outside diameter of the ground electrode
of 9 mm, the discharge space (D4.2) of 1.5 mm, the thickness of the dielectric (D4.3) of 1.5 mm, the diameter of the HV electrode (D4.1) of 1.7 mm and D4.4 = 17 mm.

Figure 3. Experimental setup representation of the common dielectric-barrier discharge topology configurations.

2.2. Schematic of the TL494 power supply
The circuit built around the integrated TL494 is versatile and can control a half bridge or full bridge of MOSFETs or IGBTs through a gate control transformer (GDT), see figure 4. This should make a driver who is able to control the flyback transformers found in CRT TVs and computer monitors.

Figure 4. Complete schematic of the power supply built with TL494.[2, 3]

TL494 uses a 5% dead time to ensure correct switching and at frequencies above 150 kHz, this minimum downtime is higher. The output control on pin 13 is set to a reference voltage of 5 Volts on pin 14, which makes the two outputs of transistors operate in push-pull mode, which will be used to drive each of their ICs inverted MOSFET driver.

2.3. Schematic of the SG2525 power supply
The SG2525 integrated circuit is used in the standard PWM generator / oscillator connection where the oscillation frequency is determined by C2, R7 and RV2. The RV2 potentiometer can be adjusted to obtain exact frequencies according to the required application specifications, see figure 5.

The frequency range for this source is from 6 kHz to 60 kHz, between the two outputs at pin 11 and pin 14. The two outputs oscillate alternately in push (totem) mode, driving the connected Mosfet transistor in the flyback configuration.
3. Experimental results

The parameters measured taken under the previously described conditions are presented in Table 1. Some examples of waveforms extracted from the oscilloscope are presented below.

Table 1. Experimental values ($V_{\text{rms}}$ and $I_{\text{rms}}$) extracted from the data collected.

| Reactor No. | Reactor 1 | Reactor 2 | Reactor 3 | Reactor 4 |
|-------------|-----------|-----------|-----------|-----------|
| No. of Measured parameters | TL 494 Power Supply | SG 2525 Power Supply | TL 494 Power Supply | SG 2525 Power Supply |
| $V_{\text{rms}}$ | 2717.569 | 2717.569 | 2960.316 | 3858.57 |
| $I_{\text{rms}}$ | 4.071 | 2.396 | 4.24546 | 3.43 |
| $V_{\text{rms}}$ | 2727.58 | 2553.1022 | 3001.958 | 4062.65 |
| $I_{\text{rms}}$ | 4.804 | 3.296 | 4.174517 | 3.39011 |
| $V_{\text{rms}}$ | 1162.284 | 1252.2647 | 1424.688 | 2070.7 |
| $I_{\text{rms}}$ | 2.4018 | 1.988655 | 4.289 | 2.011816 |
| $V_{\text{rms}}$ | 1159.388 | 1249.340786 | 1424.688 | 2073.4893 |
| $I_{\text{rms}}$ | 2.9111 | 0.981465 | 5.6561 | 3.88648 |
| $V_{\text{rms}}$ | 4553.109 | 558.5887 | 4416.59 | 4855.165 |
| $I_{\text{rms}}$ | 4.45934 | 2.012173 | 3.88648 | 2.88520 |
| $V_{\text{rms}}$ | 7536.677 | 5752.63 | 3500.722 | 2074.972 |
| $I_{\text{rms}}$ | 4.20724 | 6765.545 | 4.85383 | 4.0823 |

Figure 5. Complete schematic of the power supply built with SG2525.[2, 3]
3.1. Experimental results for TL494 power supply

The measured discharge parameters from the TL494 power supply are more stable compared to the SG2525 power supply. The power section uses a DC voltage of 96V and a half bridge topology which provides a +/- output, see figures 6-11.

**Figure 6.** Measured electrical parameters using the TL494 power supply, input voltage from a 4 ohm resistor (a), output voltage (b), DBD reactor 1, 22 primary windings, Frequency 60kHz, PWM 20%.

**Figure 7.** Measured electrical parameters using the TL494 power supply, input voltage from a 4 ohm resistor (a), output voltage (b), DBD reactor 2, 18 primary windings, Frequency 60kHz, PWM 20%.

**Figure 8.** Measured electrical parameters using the TL494 power supply, input voltage from a 4 ohm resistor (a), output voltage (b), DBD reactor 2, 22 primary windings, Frequency 60kHz, PWM 50%.
Figure 9. Measured electrical parameters using the TL494 power supply, input voltage from a 4 ohm resistor (a), output voltage (b), DBD reactor 4, 18 primary windings, Frequency 60kHz, PWM 20%.

Figure 10. Measured electrical parameters using the TL494 power supply, input voltage from a 4 ohm resistor (a), output voltage (b), DBD reactor 4, 18 primary windings, Frequency 60kHz, PWM 50%.

Figure 11. Measured electrical parameters using the TL494 power supply, input voltage from a 4 ohm resistor (a), output voltage (b), DBD reactor 4, 22 primary windings, Frequency 60kHz, PWM 20%.
3.2. Experimental results for SG2525 power supply
The SG2525 power supply uses a DC voltage of 48V and a flyback topology. The output is not as regular as the TL494 power supply also the discharge is not regular either, see figures 12 - 14.

**Figure 12.** Measured electrical parameters using the SG2525 power supply, input voltage from a 4 ohm resistor (a), output voltage (b), DBD reactor 1, 22 primary windings, Frequency 30kHz, PWM 20%.

**Figure 13.** Measured electrical parameters using the SG2525 power supply, input voltage from a 4 ohm resistor (a), output voltage (b), DBD reactor 4, 18 primary windings, Frequency 30kHz, PWM 50%.

**Figure 14.** Measured electrical parameters using the SG2525 power supply, input voltage from a 4 ohm resistor (a), output voltage (b), DBD reactor 4, 22 primary windings, Frequency 30kHz, PWM 20%.
It was observed that the current values in the primary of the high voltage coil are in the range of 1 A - 8 A, and the voltage values measured in the secondary of the high voltage coil are in the range 1.1 kV - 8 kV.

When using the source with TL494 the differences of the electric current values between a PWM of 20% and a PWM of 50% are insignificant. When using the SG2525 power supply there are important differences between the current values for the two PWM factors.

4. Conclusions
Power supplies provide an understanding of the types of output circuits that operate with different types of electric discharges reactors. As can be seen in the previous figures, the presence of the dielectric limits the electric current of a DBD discharge. Thus, the reactor configuration dielectric - air - dielectric had the weakest DBD discharge.

The best display of the DBD discharge (the more intense electric discharge) took place in the tubular reactor, mainly due to the use of the internal copper electrode and the external aluminium electrode which ensured a good emissivity of the electrons.

DBD electrical discharges, due to many simultaneously plasma channels and the fact that the discharge goes out quickly, require a high frequency for their maintenance. On the other hand during the experimental part, the frequency had to be limited due to ferrite saturation and MOSFET limitation.

Since both power supplies operate at close frequencies and the same width factor, also considering that each operates at different supply voltages for the power section, the difference in amplitude is due to the difference between the half bridge topology and the flyback topology.

5. References
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