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Simulation of power supplies used for nonlinear electrical discharges

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Abstract. This work will present an analysis of the functionality of power supplies producing laboratory controlled electrical discharges using pulsed variation of voltage. The analysis is done on simulated electrical parameters using PROTEUS ISIS software. Furthermore in this paper there will also be presented a simulation of plasma discharge used with power supplies in order to assesstheparameters in functionality of these power supplies.

1. Introduction

Non-thermal plasma, also named cold plasma, can be produced by different types of electrical laboratory discharges, such as GlidArc, mini plasma torch and dielectric barrier (DBD) discharges.

Limiting the current to values below 1A does not allow the evolution of the electric discharge to an electric arc, which would mean the substantial increase of the temperature of the plasma particles, hence the name of cold or non-thermal plasma. This limitation can be done with passive elements like resistors, inductors or capacities, or by the construction of the power transformer, through the dispersion inductors.

For the production of cold plasma, direct current, alternating current, low, medium or high frequency or pulsed power supplies can be used.

2. Simulation setup of the power supplies

In this chapter the simulation of some power supplies are presented and analyzed. The analysis consists of viewing the command signals, comparing the power circuit for the analyzed circuits and also the comparison with a connection to a resistor and a connection to the discharge itself. The power supplies have a frequency of maximum 44 kHz due to the limitations of the real life high voltage transformer.

A discharge emulation circuit is used in order to test the connection to the discharge. This circuit is presented in figure 1.

The emulation circuit is designed using capacitors to emulate the gathering of energy before the discharge and a resistance that emulates the discharge resistance itself. The relay is used for emulating the charging of the capacitor and its discharge onto the resistor, thus emulating the electrical discharge between electrodes.

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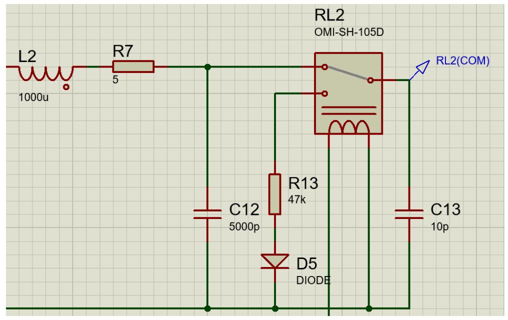
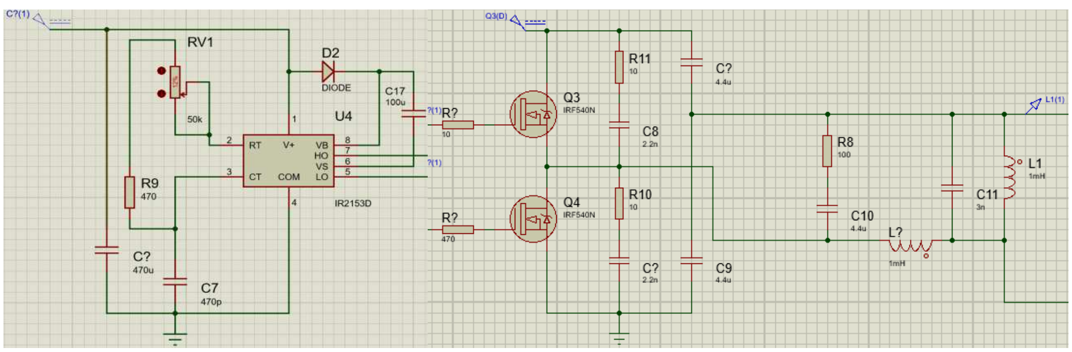


Figure 1. Discharge emulation circuit [1]

2.1. Power supply built with IR2153 circuit

This power supply has the command section built around the IR2153 circuit. It providesvariable frequency from 22kHz to 90 kHz. Due to the above mentioned limitation this power supply will only operate at maximum 44 kHz.

The power section is made up of IRFP540NMOSFET transistor, the circuit works based on an L-C oscillator circuit on the primary winding of the transformer.

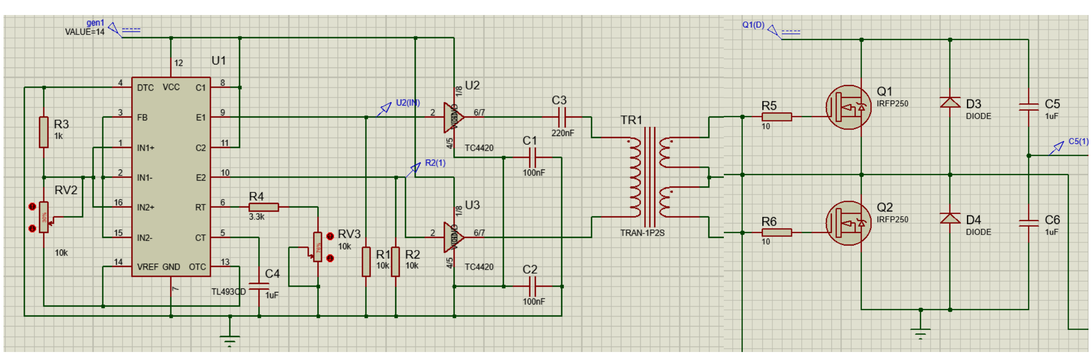


(a) (b)

Figure 2. Command schematics (a) and power schematics (b) of the IR2153 power supply

2.2. Power supply built with TL494 circuit

This power supply has the command section built around the TL494 circuit. It provides variable frequency from 38kHz to 150 kHz and variable pulse modulation.



(a) (b)

Figure 3.Command schematics (a) and power schematics (b) of the IR2153 power supply

The power section is made up of IRFP250N MOSFET transistor, the circuit works based directly connected to the primary winding of the transformer.

2.3. Power supply built with ATMEGA328P microcontroller

This power supply is built around the ATMEGA328Pmicrocontroller. The software provides 6 outputs that work in parallel at a frequency of 40kHz with a filling factor of 9%.

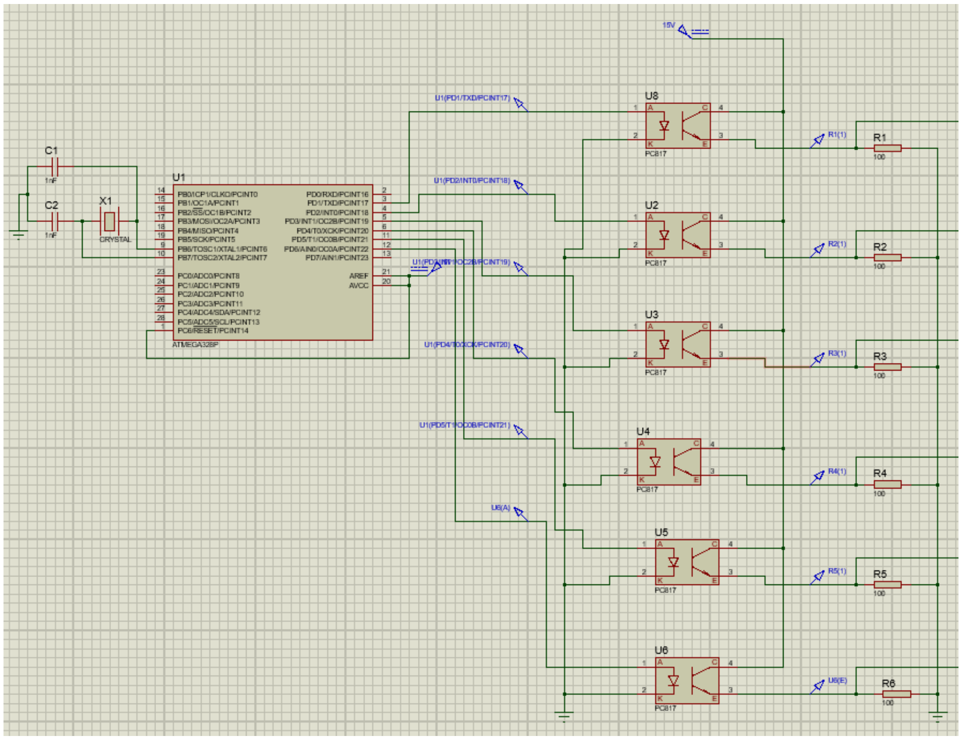


Figure 4 Command schematics built around the ATMEGA328P microcontroller

The power section is made up of 6 IRFP250N MOSFET transistors connected via diodes in order to prevent reverse current circulation. For this setup the classic fly-back topology was used thus increasing the frequency from a maximum of 44kHz to 240kHz.

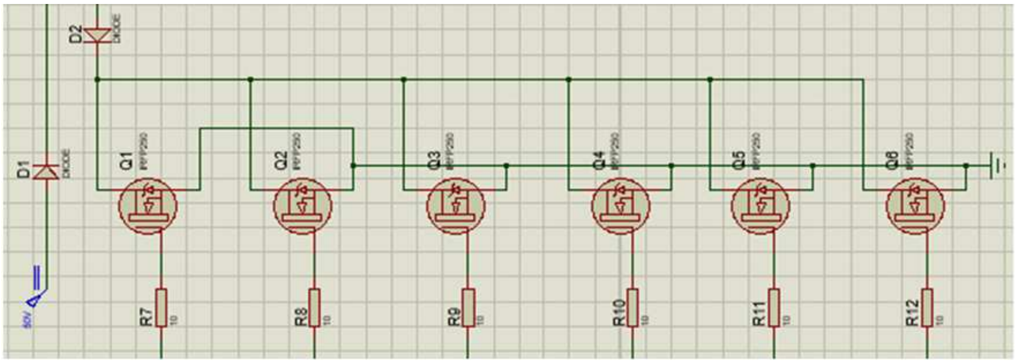


Figure 5 Power Schematics composed of 6 levels of fly-back topology with power MOSFET transistors

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3. Simulation results and interpretation

The simulation results from the above mentioned power supplies is presented and interpreted in this chapter.

3.1. Power supply built with IR2153 circuit

The simulation results for this power supply rely mostly on the command signals provided by the power supply command circuit and the L-C circuit.

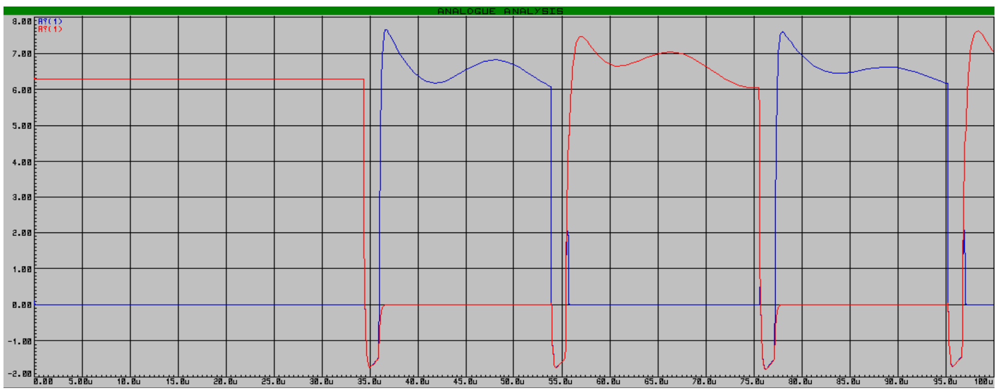
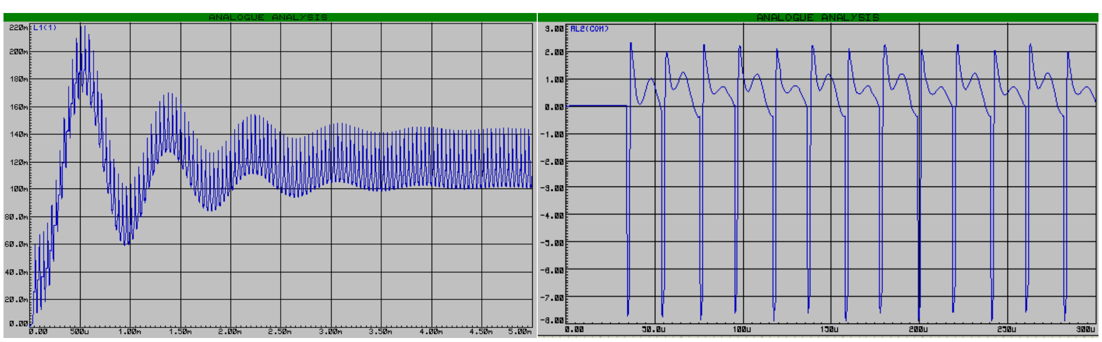


Figure 6 Command signals from both output channels of the IR2153 circuit

The power section is made up of IRFP250N MOSFET transistor, the circuit works based on an L-C oscillator circuit on the primary winding of the high voltage transformer. The oscillation circuit is dependent to both the internal resistance of the circuit as well as the power supply’s internal resistance. It is important for both these internal resistances to match each other in order for the circuit to function properly. The graph shown in Figure 7 present the moment when the resonance takes place. The phenomenon repeats itself with each new iteration.



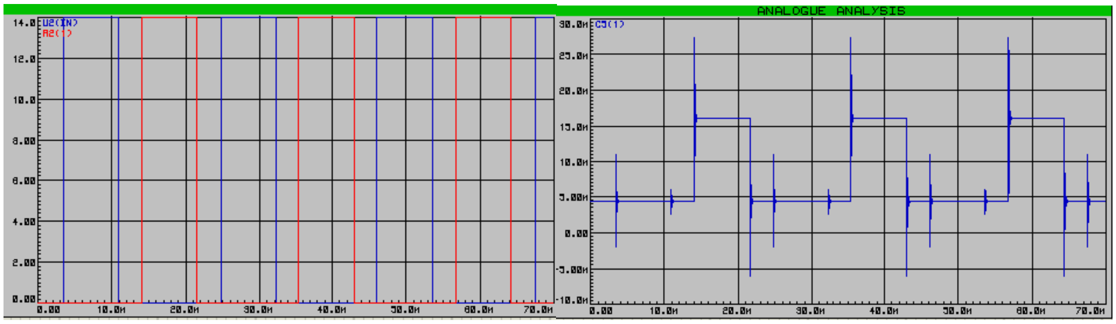
(a) (b)

Figure 7 Power output signal simulation (a) for the electrical discharge and (b) primary winding emulation

3.2. Power supply built with TL494 circuit

The power supply built using the TL494 circuit uses a PWM command signal that provides variable filling factor and frequency. The power circuit provides square wave signals to the primary winding of the HV transformer.

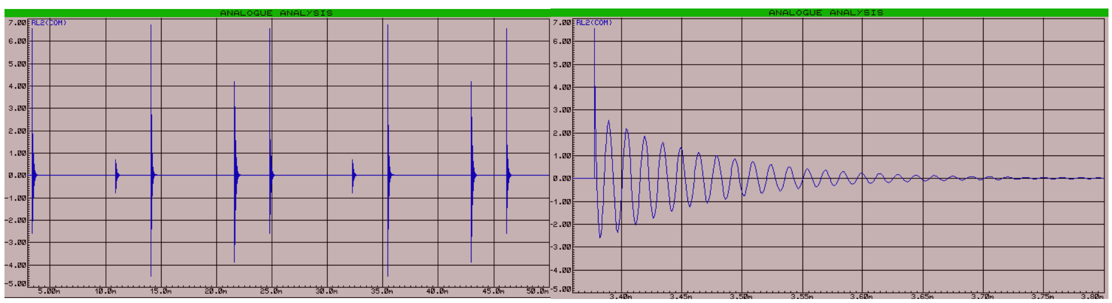
As it can be noticed in figure 8, the voltage spikes are a result of the primary winding inductance.



(a) (b)

Figure 8 Command circuit output (a) and power circuit output (b)

The simulation shows the multiple discharges that take place in an electrical discharge (figure 9a) and the oscillation of one discharge in particular (figure 9 b) .The discharges that take place also rely on oscillations provided by the capacitor and the primary winding of the capacitor.

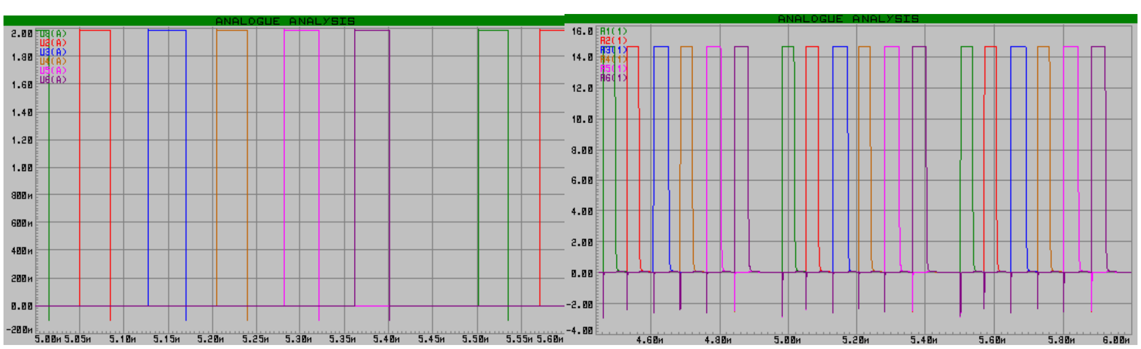


(a) (b)

Figure 9 Power circuit output of the entire signal (a) and power circuit output oscillation (b)

3.3. Power supply built with ATMEGA328P microcontroller

The power supply built around the ATMEGA328P microcontrollerprovides 6 paralleled outputs as it can be seen in figure 10 (a).Theoptocoupler provide the galvanic isolation between the microcontroller and the power MOSFETs. The signals for the MOSFETs can be seen in figure 10 (b), the ripple than you can notice is due to the inductance of the emulation of the electrical discharge.



(a) (b)

Figure 10.Command circuit output (a) and power circuit output (b)

Due to the increase in frequency, the oscillations end more abruptly and start again thus the discharge signals don't get to the full oscillation end. The increase in frequency also increases the recombination time of the ions thus the plasma has a higher density.

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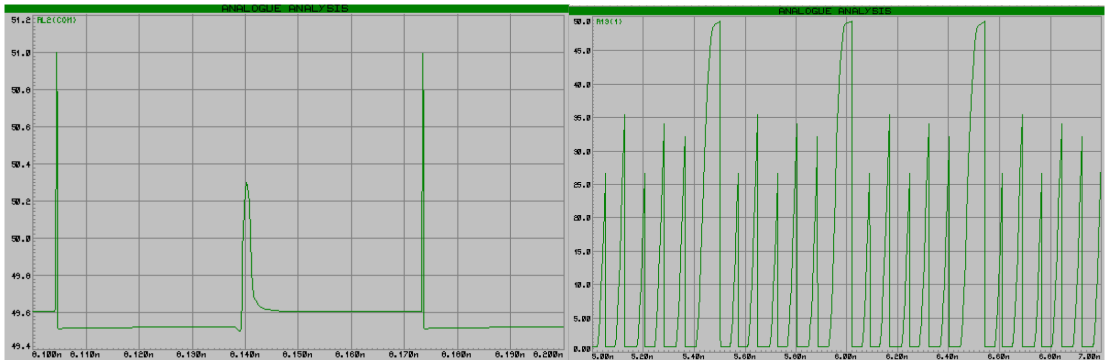

(a) (b)

Figure 11.Power circuit output of the entire signal (a) and power circuit output oscillation (b)

4. Conclusion

The electrical circuit used to simulate the evolution of the discharge voltage allows only one change to the circuit structure for the study of the transient regime. The oscillations on this frequency are produced during the non-zero values of the spark electrical current. The behaviour of the discharge is equivalent to that of a diode D placed on the same circuit branch with a low value resistance R, which constitutes the element of the dissipation for the accumulated energy. In operation, the value of the overall capacitance will increase considering a value corresponding to a memory capacity which takes into account any charged particles remaining in the gas after previous sparks.

The power supplies provide an understanding regarding the output circuit types that work with variable frequencies. The use for these power supplies is especially useful for DBD type electrical discharges, which due to multiple plasma channels and the fact that the discharge is extinguished quickly it requires a high frequency for maintaining them. In addition, at medium and high frequencies, a higher homogeneity of the produced plasma is obtained.

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