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ELECTRICAL EFFICIENCY OF EDM POWER SUPPLY

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ABSTRACT: In this paper the authors present for comparison the principal types of Pulse Generator for Electrical Discharge Machining. Some ways to improve electrical efficiency, based on development of electronic power devices, development of digital signal controllers and development of power converters topology are also presented. A resonant converter with series-parallel LCC circuit, for EDM applications, was analyzed by PSpice simulation. The performances of EDM Power Supply were improved by adding an electric circuit with double role: energy recovering and ignition voltage limiter. The ignition voltage slew rate was increased by adding a supplementary MOSFET Switch in parallel with the gap. Two, three and finally four converters were parallelized, in this way the output current increased. A bloc-schema was proposed for EDM experimental set up.
KEY WORDS: Pulse Generator, Current Limiting, Resonant Converters, Current Source, Digital Signal Controller

1. INTRODUCTION

In Electrical Discharge Machining an electric high voltage is applied between Electrode Tool (ET) and Work Piece (WP). Usually, the gap has dimensions between 5μm and 500μm and a dielectric liquid is present inside. After a delay time, (unknown, dependant of dielectric state, surface state etc.), an electric spark starts up between ET and WP. Voltage decreases at a low level (20-30V) and current increase to a level which depend on power circuit. Die Sinker Electrical Discharge Machining principle is graphical represented in figure 1, where:

1. is the electrode tool.
2. is the passive gap (with dielectric liquid).
3. work piece.
4. wearing crater.
5. active gap (with dielectric liquid).
6. erosion crater.

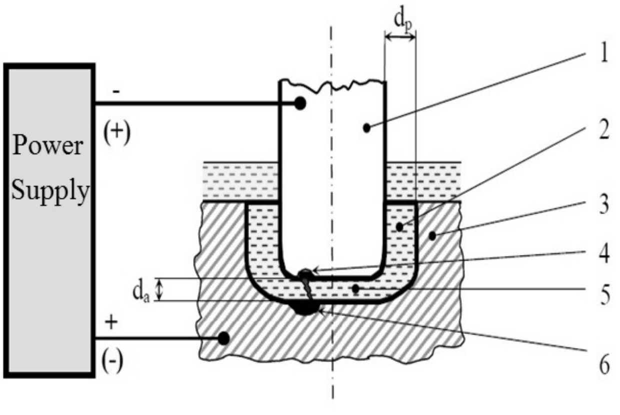

Figure 1. Die Sinker EDM Principle

A complex of phenomena determines to come in sight an erosion crater on the work piece and a wearing crater in the electrode tool. The debris appears in the gap and it must be eliminated. For this, it is necessary to stop the current through the gap for a short time period.

2. PULSE GENERATORS

The Pulse Generator applies the electrical voltage between Electrode Tool and Working Piece, necessary for Electrical Discharge Machining (EDM).

2.1 RC pulse generator

This type of pulse generator was used on the earlier EDM machines. When the gap is passive, the current trough the resistor R charges the capacitor at the high voltage. After the ignition is started, the capacitor is discharged trough the active gap.

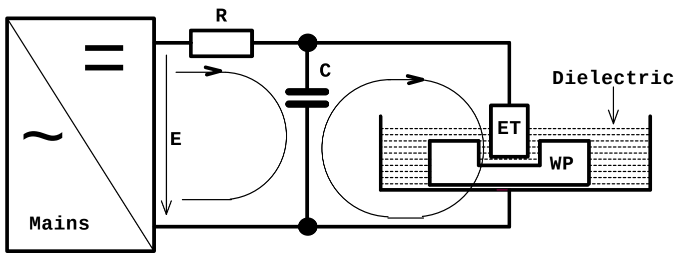

Figure 2. RC Pulse generator for EDM

The control of pulse parameters is not realized and electric efficiency is poor (20…40%). But the frequency of pulses can be high (above 1MHz) and this type of generator is actually used in micromachining [4].

2.2 Controlled Pulse generators

These types of generators are very useful on numerical controlled machines. They use one or more electronic switch and their performances had improved especially by evolution of electronic power devices [4, 8]. One of most important requirements for these types of generators is current limiting. Resistive current limiting technique use in principle a resistor and a fixed voltage power supply, as is shown in figure 3.

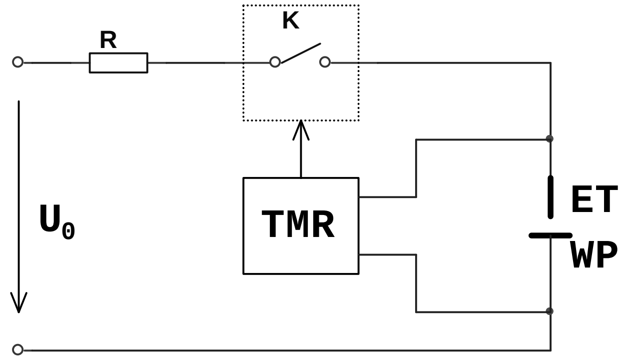

Figure 3. Resistive current limiting technique for EDM controlled pulse generator

The timer electronic bloc (TMR) imposes pulse duration and period of repetition. The typical diagram for normal discharge (roughing Die Sinker EDM Technology) is shown in figure 4, [8], where:

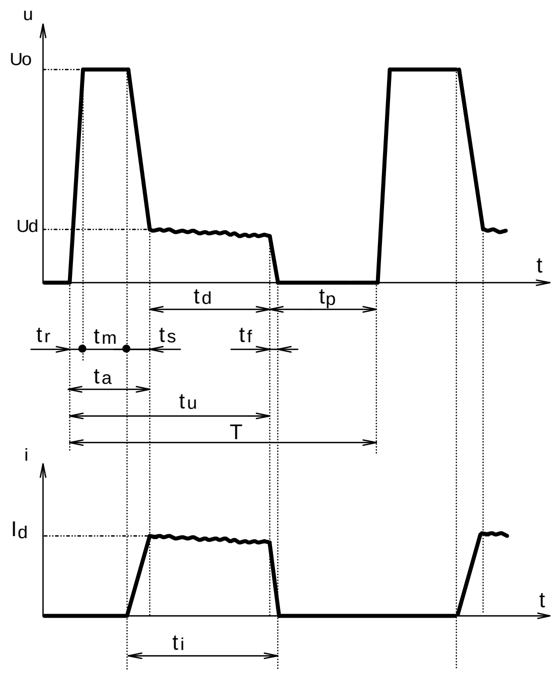

Figure 4. RC Pulse generator for EDM

- U_o is the breakdown voltage and his value is fixed by power supply. U_o have a value between 100V and 300V.
- U_d is the discharge voltage, and it has a little fall and radiofrequency noise. U_d have a value between 20V and 30V. The radiofrequency noise has maximum power spectrum in 50MHz – 90MHz range.
- I_d is the current value during the discharge (1A.....10A.......200A)
- t_r is the rise time of voltage pulse.
- t_m is the holding time of the ignition voltage.
- t_s is the starting discharge time.
- t_a is the ignition delay time.
- t_d is the discharge time.
- t_u is the voltage pulse width (1...3000μs)
- t_p is the pause time (1...3000μs).
- T is the period of the voltage pulses.
- t_i is the current pulse width.

The energy for one discharge is:

$$w_i = \int_0^{t_u} u(t)\cdot i(t)\cdot dt \qquad (1)$$

The amplitude of current pulse is:

$$i_d = \frac{U_0 - u_d}{R} \cong const \qquad (2)$$

Results:

$$w_i = u_d \cdot \frac{U_0 - u_d}{R} \cdot t_i \qquad (3)$$

where:

$$t_i \cong t_u - t_a \qquad (4)$$

Delay ignition time t_a is a stochastic variable, depending on the gap state. TMR command bloc defines control mode by imposing parameters t_u or t_i, which, in conjunction with amplitude of current pulse determine the energy pulse [4, 8]. The principals working mode are: isopulse mode, where t_i and implicit w_i is constant, and isofrequency mode, where t_u is constant. In the isopulse mode, the control of process is more accurate and technological results are better.

Analyzing the principia schema (figure 3) and the chronograms (figure 4), it results that difference between ignition voltage U_0 and gap voltage U_d is supported by R during the discharge time period (t_i). Considering ideal switch (K), dissipated power on the resistor is:

$$p_d = [(U_0 - u]_d)\cdot i_d \qquad (5)$$

The consumed power is:

$$P_c = U_0 \cdot i_d \qquad (6)$$

The utile power is:

$$p_u = u_d \cdot i_d \qquad (7)$$

It results the electric efficiency of Pulse Generator:

$$\eta = \frac{P_u}{P_c} = \frac{u_d}{U_0} \qquad (8)$$

For a small difference between ignition voltage U_0 and gap voltage U_d, the efficiency can be acceptable (eq. U_d=24V; U_0=60V, the efficiency is 40%). But for high ignition voltage the efficiency is very poor (eq. U_d=24V; U_0=300V, the efficiency is 8%). Using two power supplies, one having high voltage - low current for ignition, and another having low voltage - high current for sustaining the discharge process, like in figure 5, the efficiency can be acceptable. Driver block assures properly command for switches, TMR block imposes time duration for pulses, Threshold Detector (TD) senses the moment of discharge apparition for starting timers. The efficiency can grow around 50% (eq. for: U_d=24V; U_{01}=300V; U_{02}=45V).

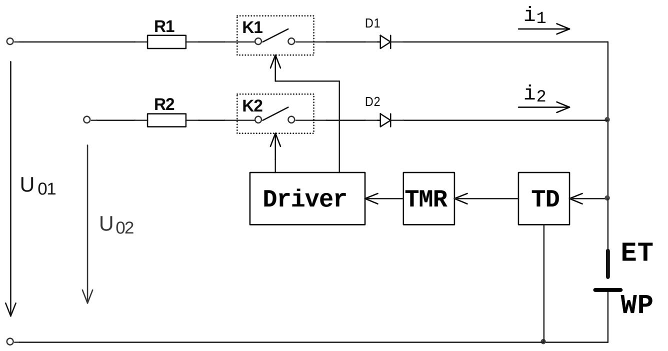

Figure 5. Two sources pulse generators for EDM

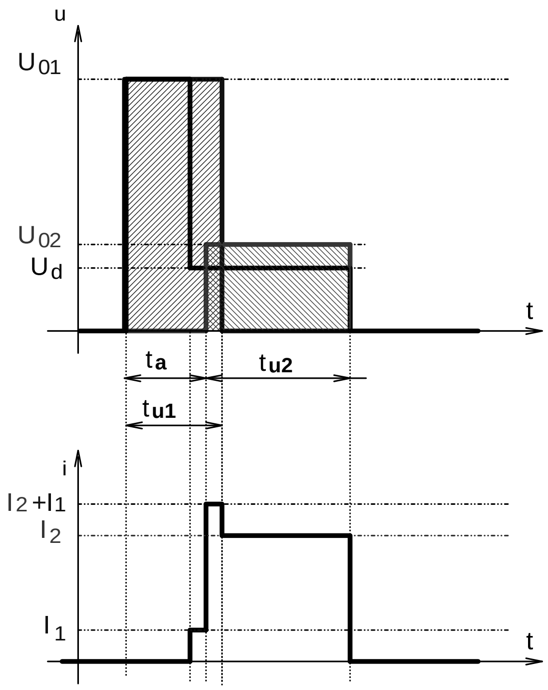

Figure 6. Chronograms for two sources pulse generators

2.3 Pulse generator with inductive current limiting

For increase the efficiency is necessary to replace the limiting current resistor R by a coil with inductance L and adopt the chopper technique for limiting the current. Step Down (Buck) Converter can be use in a closed loop to control the value of current intensity as it is shown in figure 7.

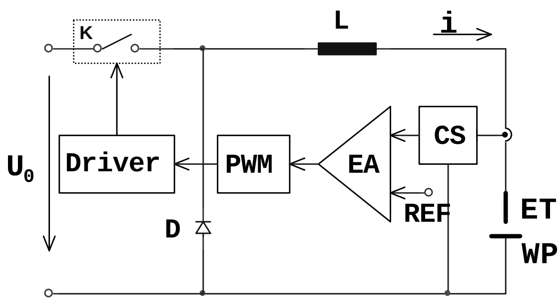

Figure 7. Buck Converter as a Current Source for EDM pulse generator

Current sensing block (CS) provides a voltage proportional with the current and this value is compared with reference. The error amplifier command Pulse Width Modulation (PWM) module and finally the switch K [9].

In Continuous Conduction Mode (CCM), there are two situation as shown in figure 8:

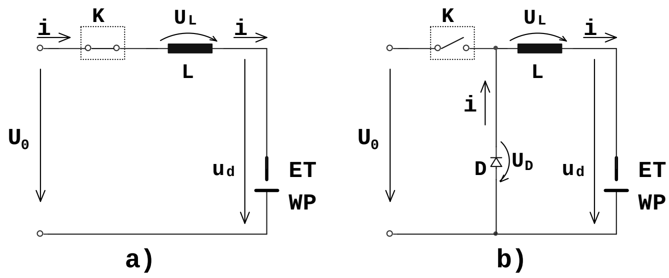

Figure 8. The states of Buck Converter in CCM mode

In figure 8a) the switch K is "ON", and, assume ideal circuit elements, it results:

$$U_L = U_0 - u_d \tag{9}$$

$$U_L = L\frac{di_L}{dt} \tag{10}$$

$$\frac{di_L}{dt} = \frac{U_0 - u_d}{L} \cong \frac{U_0}{L} \tag{11}$$

The current increases with high slope. In figure 8b) the switch K is "OFF" and results:

$$U_L = -U_D - u_d \tag{12}$$

$$\frac{di_L}{dt} = \frac{U_D - u_d}{L} \cong -\frac{u_d}{L} \tag{13}$$

The current decreases slowly. Because after the EDM pulse is finished current decreases too slowly, another switch is necessary. Electrical schema is shown in figure 9 [5] and chronograms in figure 10.

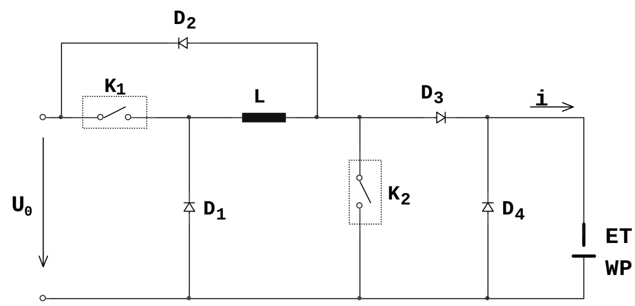

Figure 9. Buck Converter based EDM pulse generator

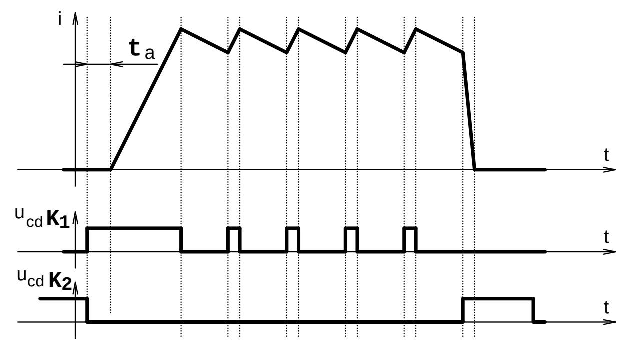

Figure 10. Chronograms for Buck Converter based EDM pulse generator

The supplementary diodes prevent undesirable phenomenon: D_2 prevents upper voltage, D_3 inverse current and D_4 inverse voltage. The authors have simulated the principia schema by emulating the principal states of gap (high resistor in parallel with small capacitor for pre-ignition state and switch in series with small resistor for discharge state). The efficiency increased to 70..75% for high input voltage U_0=300V. The most important power losses are during the switching time when an important voltage and current appears on the power electronic devices (especially for K_1 and D_1). The efficiency can be improved by decreasing U_0 at 100V, recovering the energy stored on the core's magnetic field and adopting interleaving technique [6, 7]]. We can increase the efficiency by adopting Synchronous Buck Converter With low R[on] switches. And, finally, we can use the novel silicon carbide transistors (SiC) e. g. C2M0080120D, MOSFET transistor which have: R[on] = 80mΩ and switching time much lower than silicon devices. These novel devices don't have yet Pspice model for simulation. An experimental setup is necessary for research and this will be treated in the future work.

2.4 EDM Pulse Generator based on LCC resonant Converter

The efficiency can be improved for a high value by minimizing the switching stress for power electronic devices. The resonant and quasi-resonant converters ensure commutation on low voltage (ZVS-Zero Voltage Switching) or on low current (ZCS-Zero Current Switching), but not for all load conditions. In EDM process, the equivalent load resistance for power supply has different values, dependant on the gap state (open-circuit in pre-ignition state, low resistance on normal discharge (dependant on the programmed current) and very low resistance on short-circuit conditions). The resonant circuit which have two capacitors, one in parallel with load (or equivalent resistance load) and one in series, presents an interesting property to be an AC current source at ω_0 resonant frequency, [1, 2, 5] where:

$$\omega_0 = \sqrt{\frac{1}{L \cdot \frac{C_S \cdot C_P}{C_S + C_P}}} \tag{14}$$

In figure 11, it is presented circuit used for Pspice AC simulation:

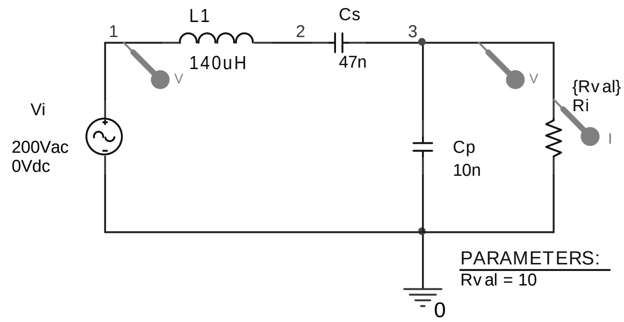

Figure 11. Series-parallel LCC resonant circuit for AC analyze

In figure 12 is shown the results of simulation, where you can see the frequency f_0=148KHz that circuit has current source behavior.

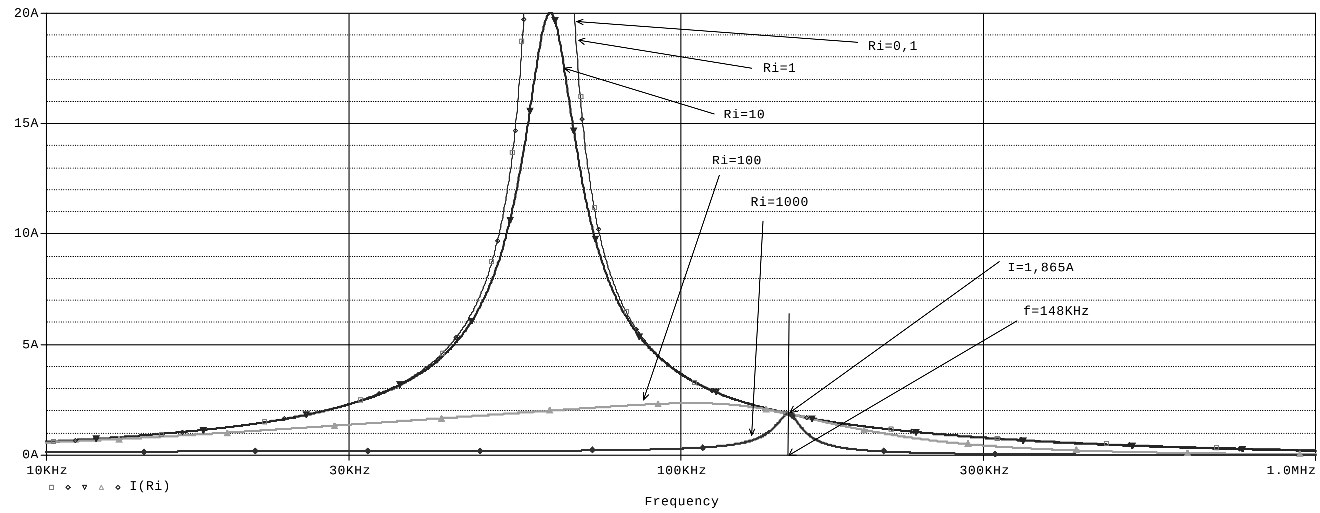

Figure 12. The frequency behavior of series parallel LCC resonant circuit

The complete schema for EDM pulse generator simulation is shown in figure 13. The independent sources V1A and V1B assure command sequences for both diagonals of MOSFET bridge. The source V6 permits or inhibits command for bridge's transistors and determines EDM pulse durations t_u and t_p. The voltage dependent sources EG1...EG4 command transistors X1...X4 between gate (G) and source (S). The source V5 commands switch transistor X5 and determines duration t_i. The resonant inverter has load high frequency transformers (U1), which have a null point rectifier with diodes D5 and D6 in secondary. Because we use an ideal model for transformer, magnetizing inductance L_M is added in exterior and also a leakage inductance L_{lk} . For 3F3 ferrite core type the working frequency in 100KHz… 200KHz is ideal for a good volume-losses performances, we used 150KHz frequency command for resonant LCC bridge inverter. In figure 14, it is shown the results of simulation; the ignition voltage is not applied very fast. For eliminate this inconvenient the switch X7 is ON during t_p duration and remains ON in the first microseconds in that we apply command for bridge switches. The current through the L resonant tank increased and the energy stored in magnetic field will be capable to increase rapidly the voltage applied to the gap when X7 becomes OFF. In figure 15, it is shown the results of simulation for two interleaved LCC resonant Converters with X7 action. Also X7 in ON state solves the problem of slow decreasing gap current when the EDM pulse is in t_p time interval. The discharge current has a shape near to ideal "DC" shape when the number of interleaved converters increased. In figure 16 we have conceived a schema for the future experimental set-up. A digital signal controller assures the commands for all the converters and stepper motor drive and has implemented software control strategy.

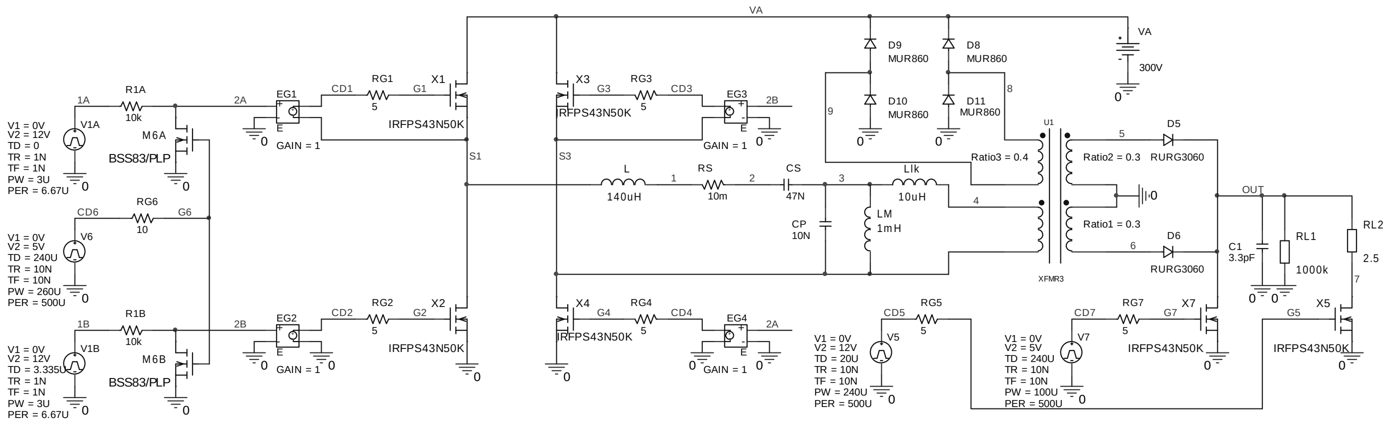

Figure 13. Electrical schema used in PSpice simulation of EDM-LCC Pulse Generator

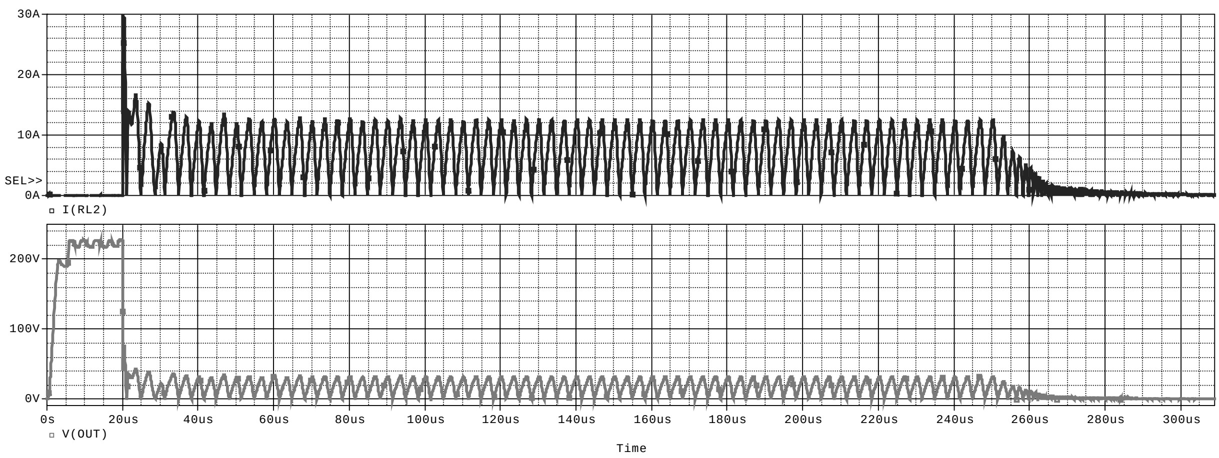

Figure 14. The EDM pulse for one stage of LLC converter without action of X7

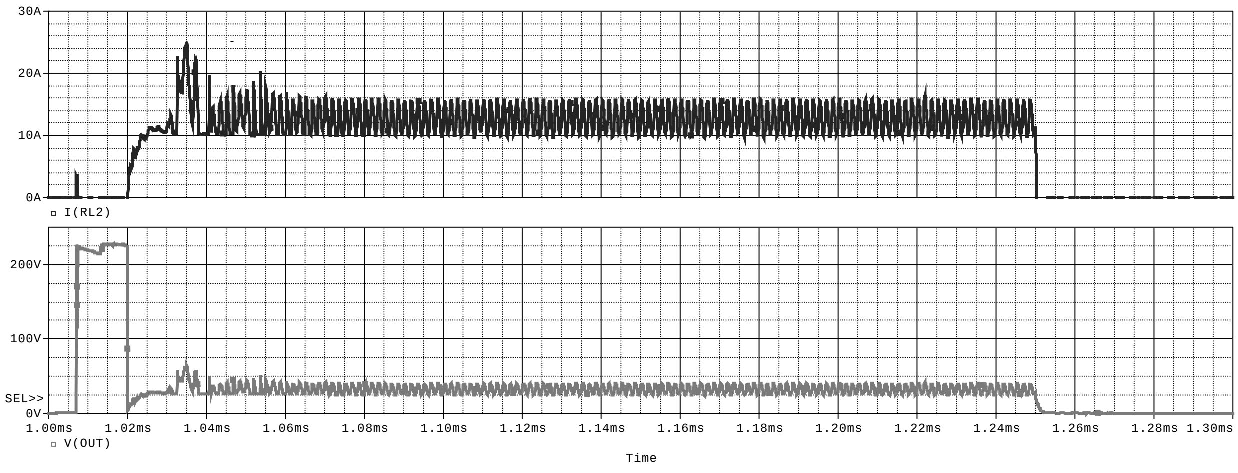

Figure 15. The EDM pulse for two interleaved stage of LLC converter with the action of X7

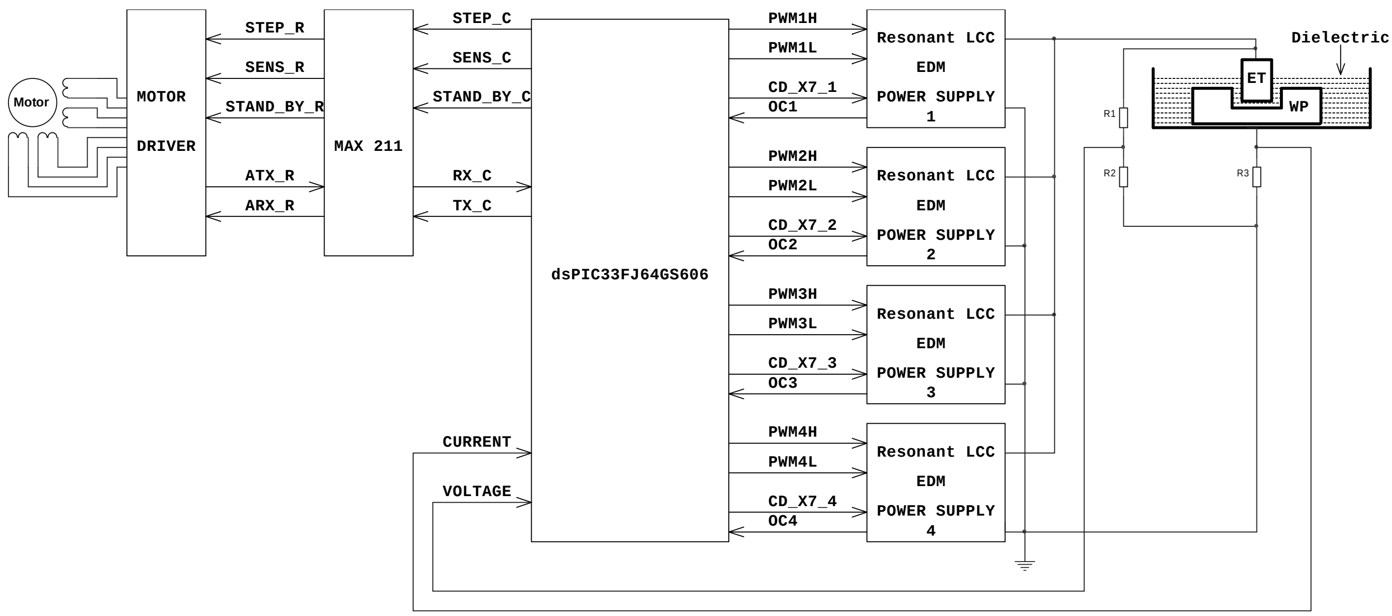

Figure 16. The conceived experimental set-up bloc schema.

3. CONCLUSIONS

The RC pulse generators are actually used in micromachining, where the amplitude of current is several amperes, working at a repetitive frequency above 1MHz, but the efficiency is poor (20..40%).

The controlled pulse generators with resistive limiting current offers a good control of pulses shape, but electrical efficiency is poor (20...50%).

The inductive limiting current by chopping technique increases efficiency at 70…75%.

The novel silicon carbide devices: diodes, JFET and MOSFET transistors which have switching time much lower than silicon devices minimize the switching losses and increase the electrical efficiency of EDM Power Supply based on Buck Converters.

The resonant LCC converter with energy recovering circuit, used for EDM pulse generator increases efficiency at 80..85%. Parallelizing two or more LCC interleaved convertors, the current will be stepping increased and the harmonics will be diminished. Supplementary switches can configure the shape of EDM voltage and current pulses.

4. REFERENCES

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