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Design, Simulation and Prototype Construction of a Pulsed Power Source for Use in Electrostatic Precipitators

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Abstract
Among the common structures of filters, electrostatic filters have been very important in the industry due to their various advantages. Pollutant separation in these filters happens by charging them and absorbing them in the electric field. Using a high-amplitude dc voltage to create a strong field and as a result discharging the corona and charging the pollutant particles are the basis of this system. However, the use of pulsed voltages with high amplitude can bring better efficiency and lower energy consumption. For this reason, in this article, a pulsed voltage source for starting an electrostatic filter is investigated. The existing pulse structures have been investigated and by combining two of them, a new structure including the energy storage capacitor network and a magnetic switch to produce the required pulse has been presented. In this structure, a saturable inductor plays the role of a switch, which can overcome the voltage limitations of semiconductor switches and cover any voltage level. The proposed structure is analyzed and simulated for a specific example.

Keywords: Pulse Power, Saturable Inductors, Magnetic Switches, Pulse Magnetic Compressor, Electrostatic Filters.

1. INTRODUCTION

Energy plays a fundamental role in the life of the industrial economy, in other words, when energy is available in sufficient quantity and on time, economic development will be possible.

There are different forms of energy such as wind, water, and nuclear.

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An electrostatic precipitator (EPS) is a filtration system used to remove fine particles such as smoke and dust from a moving gas [1,2]. The basis of these filters is the force induced in the particles by using their electrostatic charge, so as to cause the least disturbance in the path of gas movement and not to apply a pressure drop to the gas [3,4]. Unlike filter systems such as wet scrubbers, which apply energy directly to the moving fluid, in ESPs, energy is applied only to the particles to be removed, and this results in significant energy savings [5,6].

The application of new structures for corona and plasma generation in an ESP has been investigated in [7] and the blocked dielectric discharge structure has been used for plasma generation in this system. The particle collection efficiency has been measured under different voltages and under a constant frequency of 100 Hz and a flow rate of 10 L/min. Experimental results have shown that the square-shaped voltage with a smoother surface can increase the ESP efficiency. Blocked dielectric discharge, which is a system for generating controlled unbalanced plasma under atmospheric pressure, is used to generate electrical discharge for pollution control.

To remove smoke and particles caused by burning wood and coal in closed environments such as home fireplaces, the use of an ESP is proposed in [8]. Small particles less than micrometers can easily affect the performance of the body's ventilation and blood supply systems, and on the other hand, due to their very small dimensions, they do not settle due to gravity and can remain floating in the air for a long time. Therefore, these particles can be separated from the air by using a precipitator. The converter used is a resonant half-bridge converter with ZVS capability, which operates under a switching frequency of 100 kHz and converts the dc voltage of 400 V to 30 kV using a step-up transformer.

In [9] the analysis of the unipolar ionization field in an ESP corona parameter has been investigated by combining an iterative calculation method based on FEM with charge simulation method. The computational model has also been compared with actual measurements of the flux density and electric field with data from an ESP.

An ESP needs a power supply with the ability to make high current and voltage pulses for optimal performance. Semiconductors usually can’t withstand this level of voltage and current, but a MPC circuit using a saturable inductor as a switching device can produce proper pulses for ESP. This paper uses a MPC circuit combined with a Marx generator as a multistage structure to increase output voltage level.. This structure has not been presented in papers so far. With this structure we can reach a higher level of voltage with a smaller structure.

In this paper, the design of the optimal pulsed power source for use in an ESP is presented. In the proposed converter, the combination of two structures of Marx generator and MPC circuit is used. In other words, in the proposed circuit, there is a three-stage Marx generator, where an MPC circuit is placed in each stage instead of a single capacitor. The advantage of this circuit over a normal Marx generator is the use of a magnetic switch instead of a spark gap or a semiconductor switch. In this case, the replaced switch has a longer lifespan than the spark gap and can withstand a higher voltage-current level than semiconductor switches.

2. SUGGESTED SOURCE STRUCTURE

Fig. 1 shows the structure of an MPC with a magnetic switch and a resistive load [5].

In this circuit, a MOSFET semiconductor switch is used as the primary switch, and it is connected in series with a fast diode so that when the current reaches zero, the switch is turned off and the capacitor C_0 is not charged again through the capacitor C_1 in the negative direction. A fast thyristor can be used instead of the combination of MOSFET and diode series, but since this type of thyristor is not easy to access, the series combination of the two mentioned switches is preferably used.

When switch S is connected, energy is transferred to capacitor C1 through this switch and inductor L in resonance. At the end of the transfer half cycle, the current is zero and diode D is cut off. On the other hand, at this moment, the IS magnetic switch is also saturated and shorted. In this case, the energy of the capacitor C_1 has been transferred to the load and the capacitor is discharged exponentially in the resistive load.

In the above circuit, switch S limits the load voltage, because the load voltage is equal to the charging voltage of capacitor C_0, and this capacitor can store voltage as much as switch S can handle. If the above circuit is connected in several floors according to the structure of the Marx generator, a higher voltage range can be reached on the load using the same switch. For this purpose, the circuit of fig. 2 is suggested. Fig. 1 is a common structure of a MPC circuit [1,5,10]. Fig. 2 is the presented structure and parameters of Table 1 come from designing formula for the presented structure.

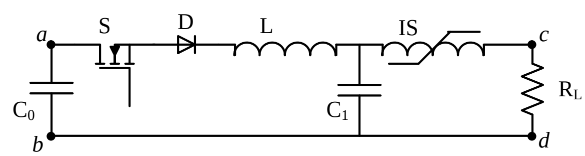

Fig. 1. MPC circuit structure with a magnetic switch [5].

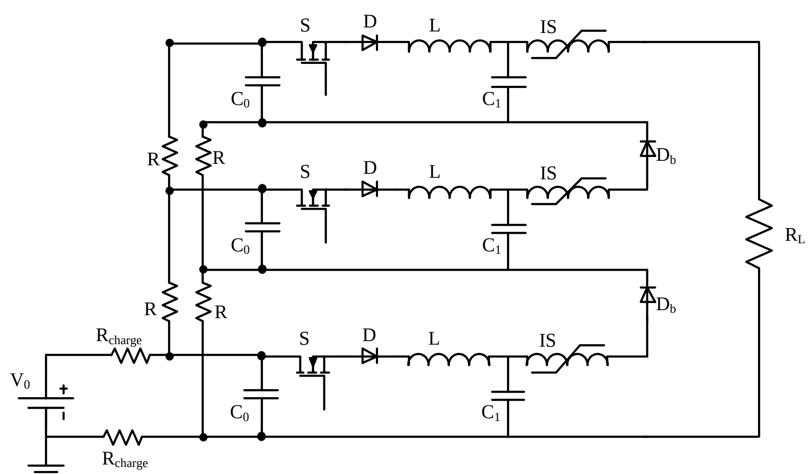

Fig. 2. The proposed circuit is a combination of MPC and Marx generator.

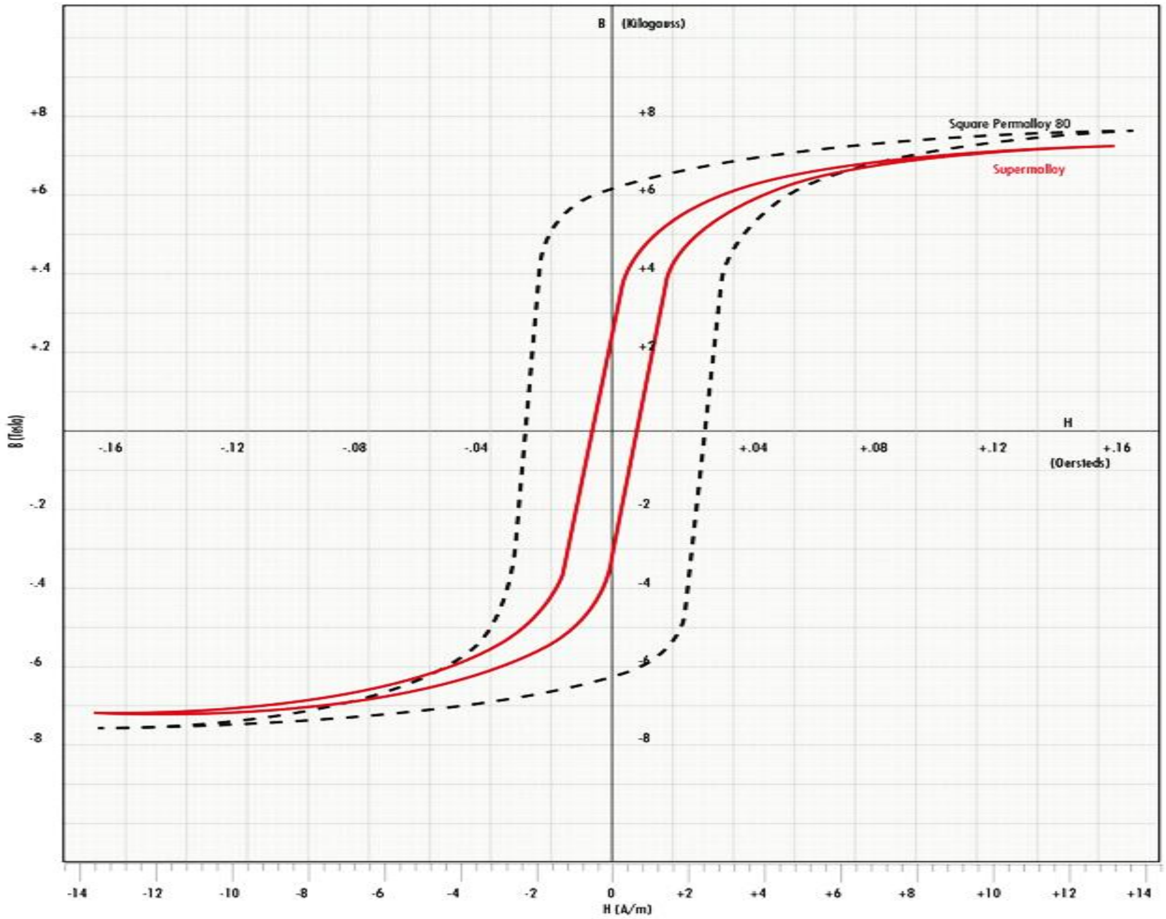

Fig. 3. Common Permalloy and square Permalloy hysteresis loop.

In the proposed circuit, three MPC circuits are placed based on the Marx generator structure, although the number of floors can be increased based on the needs and requirements of the system. The input capacitors of the layers are charged under the input voltage V_0 and through the resistors R and R_{charge}, which $R>R_{charge}$ and this helps all three layers to be charged almost at the same time. Although in practice, the floors closer to the source are charged a little earlier, you can wait until each floor is fully charged, and then make the switch. After charging the input capacitors of each floor, using a MOSFET drive circuit with three simultaneous outputs, it is possible to turn on the S MOSFETs of each floor, so that the operation of the MPC circuit begins.

3. SIMULATION OF THE SOURCE UNDER STUDY

Matlab/Simulink software has been used to simulate the studied circuit [11-15]. The magnetic switch model is the three-winding nonlinear transformer model available in Simulink, whose winding resistance and inductance values are chosen to be small, so as not to affect the system performance. The magnetic characteristic of the core is also based on the characteristic provided by the manufacturer for the square Permalloy material which is shown in Fig. 3 [16].

The simulation parameters are listed in Table (1) for the studied circuit. In fig. 4, the voltage of capacitor C_0 is displayed. This capacitor is charged to a voltage of 600 V and at the moment of 3ms when the switch S is connected, it starts to discharge through the inductor L in the capacitor C_1. The discharge must be completely formed and the voltage of the capacitor C_0 is completely transferred to C_1. However, since the charging resistances are not very large, the source effect causes the voltage of the capacitor C_0 not to be exactly zero.

Table 1. *Circuit parameters studied for simulation.*

Parameter	Value
Initial charge voltage V0	600 V
Main charging resistance (R_{charge})	250 Ω
Class charge resistance (R)	100 Ω
Capacitors C_0 and C_1	116 nF
Inductance L	700 µH
Load resistance (R_L)	50 Ω
Number of IS winding turns	20
Core cross section IS	4 cm^2
The length of the magnetic path of the core IS	0.22 cm
The saturation density of the core IS	0.75 T
MOSFET S	FQPF7N80
Diode D	BYT08-800
Diode Db	MBR20-150

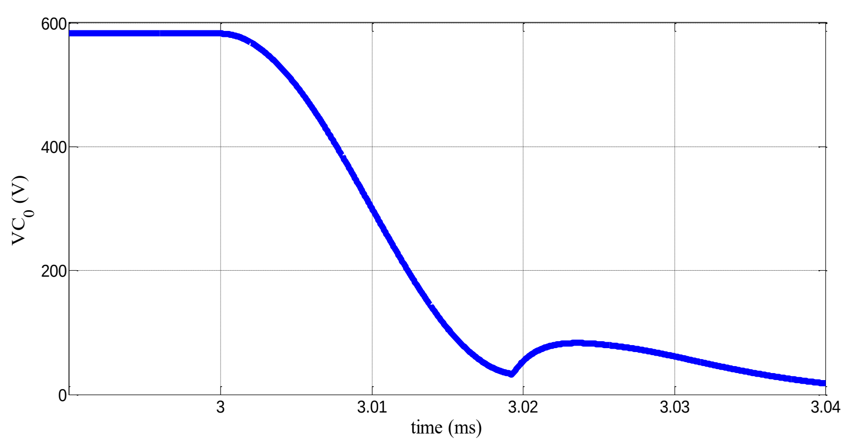

Fig. 4. Voltage waveform of capacitor C0 in mpc circuit.

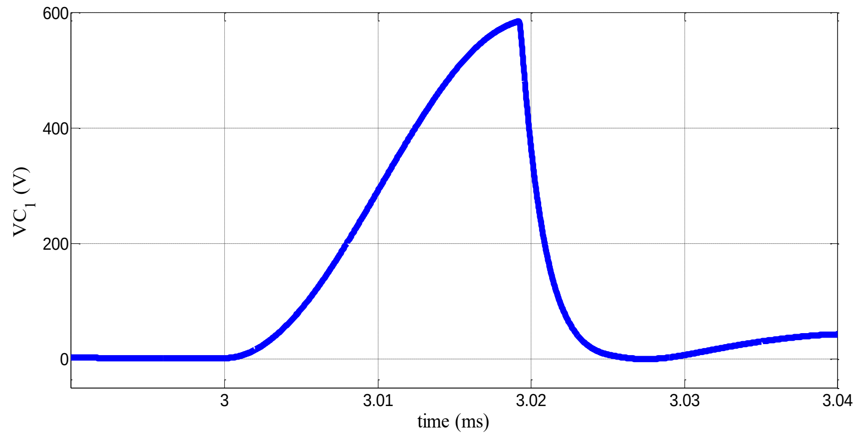

Fig. 5. Voltage waveform of capacitor C_1 in MPC circuit.

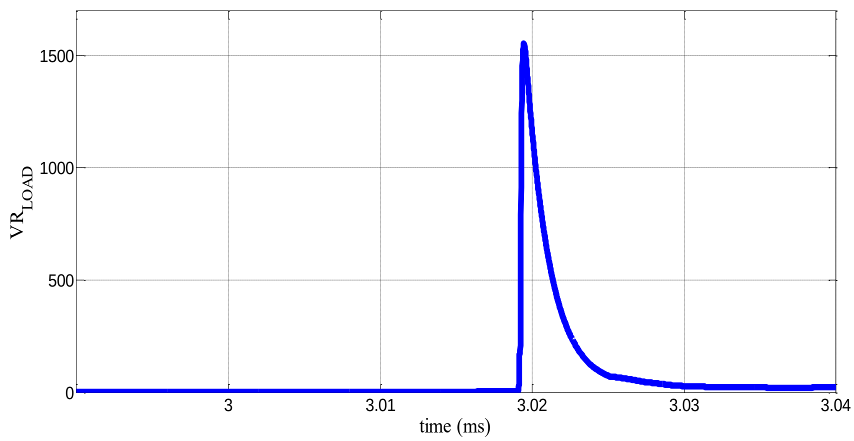

Fig. 6. The output voltage waveform of two resistive load ends.

Fig. 5 shows the voltage of capacitor C_1. This capacitor starts charging when the switch S is connected at the moment of 3 ms through the C_0-L-C_1 resonance circuit. The magnetic switch is designed in such a way that as soon as the capacitor C1 is fully charged, the magnetic switch goes into saturation and plays the role of the on switch. For this reason, this capacitor starts to discharge in a resistive load in approximately 1.5 ms when it is almost completely charged, and its voltage decreases almost exponentially.

Fig. 6 shows the output voltage of two resistive load ends. As it can be seen, the voltage has dropped rapidly at both ends of the load when the magnetic switch is connected, and then it starts to decrease exponentially in the load. According to the shape of the pulse width at half its amplitude is about 2 μs and its amplitude is about1600 volts, which is almost three times the source voltage.

The voltage waveforms of capacitor C_0, capacitor C_1, and the output for several cycles are shown in Fig. 7. Considering that the C_0

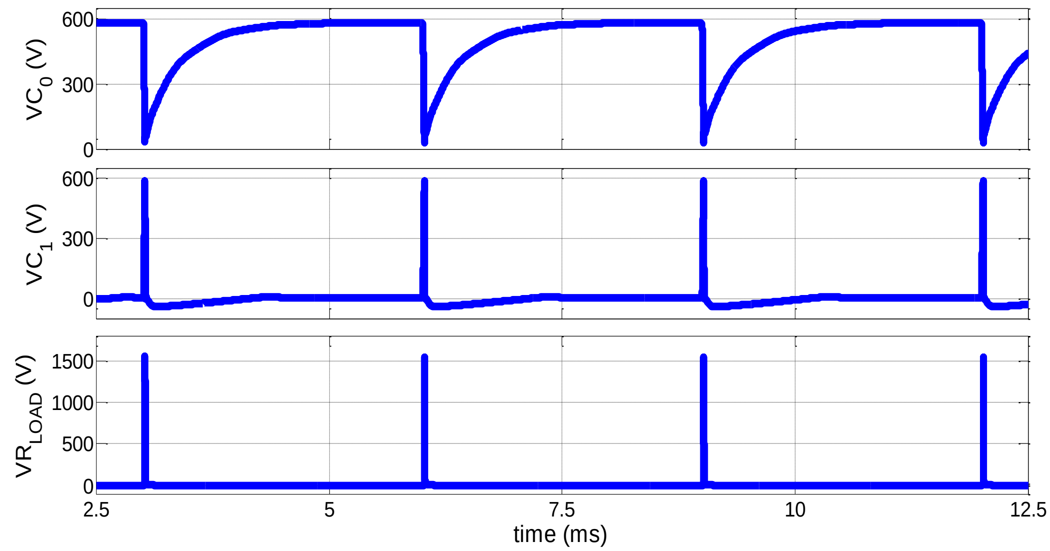

Fig. 7. Voltage waveform of capacitor C_0, capacitor C_1, and output (in order from top to bottom).

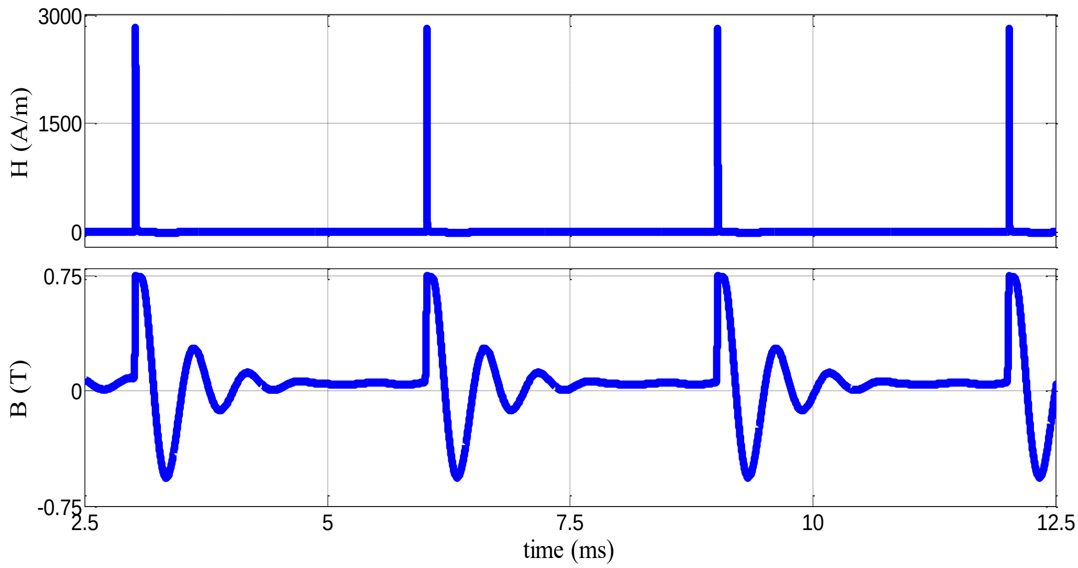

Fig. 8. Field intensity wave and magnetic flux density inside MPC core.

capacitor needs approximately 3 ms of time to charge, the same amount of time has been considered between each switching of the S key. The charging time of capacitor C_1 is about 19 µs and the width of the output pulse is about 2 µs. Therefore, they are shown as needles in the figure.

Fig. 8 shows the intensity of the magnetic field H(A/m) and the flux density B(T) inside the magnetic core. At the times when the core is saturated (T 0.75), the switch is connected and a large current flow through it, which causes the field strength to be high. After that, the switch goes back to the off position and

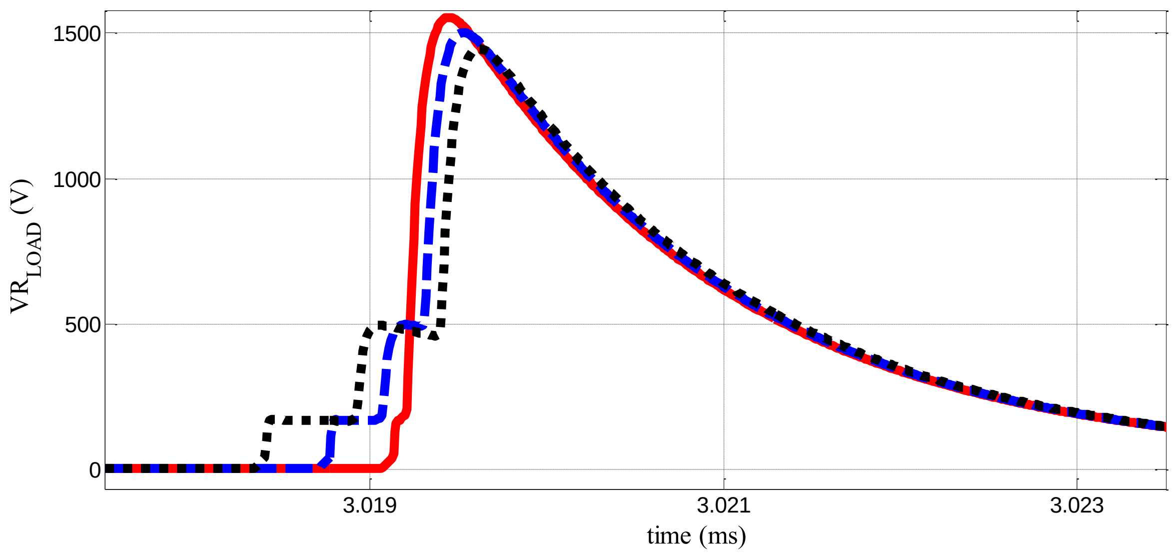

Fig. 9. Output voltage waveform for three cases, ideal (continuous line), with 5% difference in inductor values (dashed line) and with 10% difference (dotted line).

the flux density swings back to zero, ready for the next pulse. If the design of the magnetic switch is such that the intensity of the field is large enough during saturation, it ensures that the permeability of the core remains at the lowest value during this period.

One of the problems that arises during the construction of the source is the discussion of uncertainty in the values of the elements and not being equal in different classes [17,18]. This is especially true for the L inductor in different classes, because this inductor must be made by the designer and its ready-made element is not available in the market. For this reason, the effect of the element values that are not the same on the output waveform should be investigated. Since this problem can easily affect the timing of MPC circuits of different classes, it can be concluded that this problem causes the saturation of switches of different classes to be unsynchronized, it can increase the pulse width and decrease its range. In fig. 9, this state is shown for the L values of different classes differ by 5% and 10%. As can be seen, the output voltage range becomes smaller in the non-ideal state. Also, the rise time is reduced at the beginning of the pulse.

4. CONCLUTION

Industrial filters have been one of the most important parts of various industries, which are generally used to increase the quality of output products or to prevent the release of polluting particles in the air.

The followings are the advantages of circuits with MPC structure that are used to compress pulses in pulsed power systems.

- They can switch high voltage and current levels.
- They have a long lifespan.
- They have high reliability and do not break down or burn.

- They have a high pulse repetition rate.

But there are also weak points in these switches, which can be mentioned as follows:

- If the magnetic material used does not have a square characteristic, it will not have a good switching performance, and in other words, they will not be connected suddenly, but gradually connected and produce a lot of leakage current.
- A high pulse repetition rate can only be achieved using the reset circuit, which, in addition to the complexity of the reset circuit, also adds problems such as energy return to the circuit, which can overshadow the switching timing.
- The design of a magnetic switch is done only for one application and cannot be used for another application with a different voltage level and pulse width, and in general, the switch is not of general use like semiconductor switches.

By comparing the advantages and disadvantages of this switch with other switches, you can choose the right switch for a specific application. In this paper, a pulsed voltage source for setting up an electrostatic filter has been analyzed and a simulation has been done for a specific example. In the proposed structure, a saturable inductor plays the role of a switch, which can overcome the voltage limitations of semiconductor switches and cover up to any voltage level.

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