High-Voltage Pulse Generator Based on Pulse Transformer and Marx Generator

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Abstract: The paper presents a novel high-voltage pulse generator system based on pulse transformer and Marx generator. This system comprises mainly a Marx generator, which is charged to a high voltage by a pulse transformer. To verify the viability of this technology routine, a generator system with 3-stage Marx generator charged by an air-core pulse transformer is designed. The output pulse is designed to be a 200-300 kV and 200 ns FWHM (Full Wave at Half Maximum) pulse signal on the load. The experiment platform is being set up. The simulation results are accordant with the design purpose. This novel system has the characteristics of quite high energy efficiency, accurate control, and the design with less number of spark switches is applicable for operating at repetition rate.

Keywords: High-voltage pulse, pulse transformer, compact Marx generator, thyristor, energy efficiency

1 Introduction

High pulse power technology is to compress the energy in time and volume [1]. The pulse power system with Pulse Forming Line (PFL) is commonly used. High voltage is charged to PFL, then PFL release the energy to the load in an extremely short time (10~100ns). Marx generator and Tesla transformer are always applied singly as the charging part for PFL. In recent years, a compact Marx generator without PFL has been applied to drive low impedance load [2]. A novel high-voltage pulse generator based on pulse transformer and Marx generator is designed. This system has the characteristics of quite high energy efficiency, accurate control, and the design with less number of spark switches is applicable for operating at repetition rate.

2 Principle of the System

The operating principle of the system is shown in Figure 1. The closing of primary loop of the pulse transformer is controlled by thyristors. The energy stored in the low-voltage capacitor banks is delivered to the capacitor banks of Marx generator by pulse transformer. The capacitors in each stage are charged to a considerably high voltage, which decreases the number of the Marx stages and the spark switches. The spark gaps of the Marx generator are closed when the voltage of the capacitor banks reaches to the threshold value. As all the stages are connected in series with extremely high voltage, the energy stored in the capacitor banks is transferred to the load.

The thyristors have good performances in accurate control, current passing capability and high repetitive frequency. The transformer is designed with high coupling coefficient, so high energy efficiency of the whole generator system could be gained association with thyristors and Marx generator. The design with less number of spark switches is applicable for operating at repetition rate

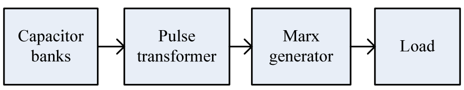


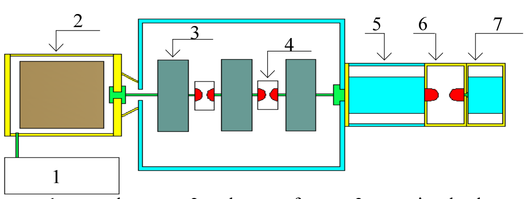
Figure 1.The principle of this novel system

To verify the viability of this technology routine, a generator system with 3-stage compact Marx generator charged by an air-core pulse transformer is designed. The output is designed to be a 200-300 kV and 200 ns FWHM (Full Wave at Half Maximum) pulse on the load.

3 Design of the System

3.1 General Layout

A scheme of the generator system is shown in Figure 2.The system consists mainly of a compact Marx generator, which is charged to a high voltage by an air-core pulse transformer. A peaking capacitor and a peaking gap are designed to reduce the rise time.



1. control system 2. pulse transformer 3. capacitor bank 4. spark gap 5. peaking transmission line 6. peaking switch 7. load

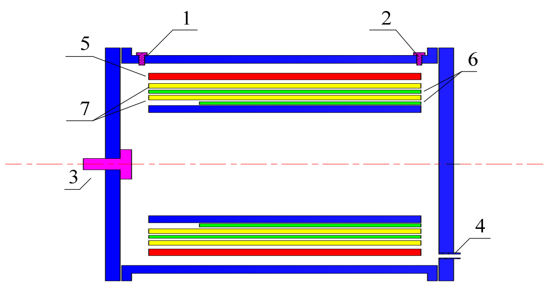
Figure 2.The scheme of the system

3.2 The Air-Core Transformer

3.2.1 Structure

An air-core pulse transformer with high coupling coefficient is designed and fabricated. This pulse transformer is used to charge for the Marx capacitors. The output voltage of the transformer is lower than that of common pulse transformer. As a result, compactness of this transformer could be improved for insulation, and the energy loss is reduced.

The overall diameter and length of the transformer are 40cm and 36cm respectively. Figure 3 shows the schematic design of the transformer. The primary coil is winded by copper-wire, and the secondary coil is winded by enamel insulated wire. The space between the windings is filled with electric insulation oil and insulation films. This structure has the advantage of reducing the probability of breakdown at some week points possibly existing in the films [3]. The transformer can bear the voltage of 140kV in theory.



1. grounding 2. input voltage 3. output voltage 4. aspirating hole
5. primary coil 6. secondary coil 7. insulation films

Figure 3. The structure of the transformer

3.2.2 Measurement

Inductance values of the primary and the secondary coils of the transformer, and stray inductance of the circuit are measured by LCR meter, TH2821A, at the frequency of 1 kHz, as listed in Table 1.

Table 1. Parameters of the transformer

Parameters	Values
Primary coil inductance, L_{11} (secondary coil open)	21.5uH
Primary coil inductance, L_{1s} (secondary coil short)	3.3uH
Secondary coil inductance, L_{22} (primary coil open)	93.8mH
Secondary coil inductance, L_{2s} (primary coil short)	18.56mH

The coupling coefficient of the transformer, k, is estimated to be 0.91 by (1) [3]:

$$k = \sqrt{1-\left(L_{1S}/L_{11}\right)} = \sqrt{1-\left(L_{2S}/L_{22}\right)} \qquad (1)$$

According to reference [4], the first peak value is higher than the secondary peak value if the coupling coefficient is greater than 0.8. To increase the utilized voltage value and stabilize the spark gap, the first voltage peak is applied in this system.

3.3 The Marx Generator

3.3.1 Structure and operation principle

The Marx generator used in this system is composed of capacitor banks, spark gaps, charging inductance and grounding inductance, as shown in Figure 4.

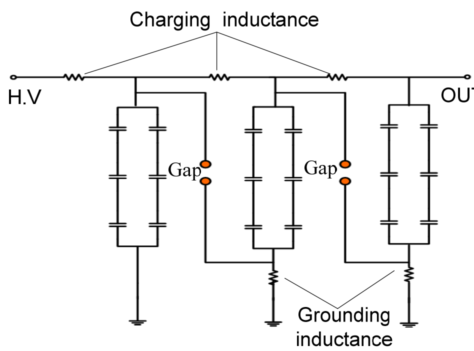


Figure 4.The scheme of the Marx part

The pulse capacitors (55nF/100kV) are connected in serial-parallel to increase the holding value of high voltage in each stage and the value of capacitance. The capacitors of each stage are charged via the charging inductances to a potential by the pulse transformer. The first switch is closed when the potential of the capacitor banks reaches to the breakdown value V, then the second switch will be over-volted to potential 2V and will also be closed. All stages will be connected in series, and a RLC circuit is created. The discharging course is so quick that the inductances will function as insulation parts.

The optimized RLC circuit is obtained in the matched case when $R = 2\sqrt{L/C}$, where L is the inductance value of the circuit, C is the capacitance value of the circuit , and R is the resistance value of the load. The values of peak voltage (V_{peak}) and FWHM (t_{peak}) are given by the following expressions:

$$V_{peak} = 0.73nV \qquad (2)$$

$$t_{pulse} = 0.8\pi\sqrt{LC} \qquad (3)$$

where n is the stage number.

The matched case or the near matched case is possible in practice, owing to the lower impedance of this

Marx circuit.

3.3.2 Spark gaps

The spark gaps with SF_6-gas are designed. The breakdown voltage of SF_6-gas [5] is given by (4) and (5):

$$V_b = 65 p^{0.73} d / f \tag{4}$$

$$f = E_{max} / E_{av} \tag{5}$$

where V_b (kV) is the breakdown voltage; p (0.1MPa) is the gas pressure; d (cm) is the distance between electrons; f is the uniformity coefficient of electric field; E_{max} is the maximum electric-field intensity; E_{av} is the average electric-field intensity.

In standard Marx generators, it is common practice for the first two or lowest gaps to be three-electrode devices. The Marx generator is then fired or "erected" by applying a strong trigger pulse to the trigger electrodes of these spark gaps. On the contrary, all the gaps are self-breakdown spark gaps in this Marx generator. The breakdown of the gaps is actually controlled by thyristors in the primary loop of the transformer.

It is important to point out that the former gap should breakdown earlier than the next stage gap. So the breakdown voltage of the former gap should be lower than the next. In addition, the breakdown voltage of the second gap should be less then 2V to ensure the closure of the second gap.

3.4 Peaking Part

As mentioned in reference [6], a combination of peaking capacitor and a peaking gap could be used in compact Marx system to reduce the rise time.

A transmission line with proper parameter could also be applied as a peaking capacitor with a high holding voltage [7]. A transmission line is fabricated. The peaking transmission line is 130 mm long, 410 mm by external diameter, 280 mm by inner diameter, filled with glycerin with high dielectric constant. The capacitance of the transmission line is 0.53nF.

4 Simulation of Electric Circuit

An electric procedure is simulated with the code of PSPICE.

As shown in Figure 5, energy storage capacitor (C_P) is charged to a low voltage in advance. The primary loop of the pulse transformer is closed when thyristor is triggered, then the energy in C_P is transferred to the secondary loop, and the capacitor banks of Marx (C_{M1}, C_{M2}, and C_{M3}) are charged to a high voltage. When the voltage of the capacitor banks reaches to the threshold value, the self-breakdown switches (Gap_1 and Gap_2) breakdown, then the energy stored in the capacitor banks is transferred to the load.

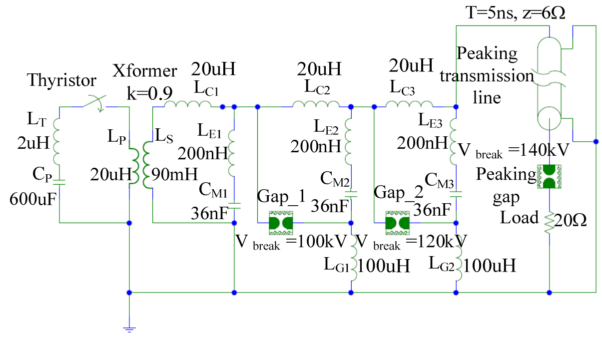


Figure 5. Circuit schematic

It is stressed that, the primary circuit is opened by thyristor after the closure of Gap_1 and Gap_2, and the reverse voltage with considerable value on C_P could be reused with the help of extra circuit.

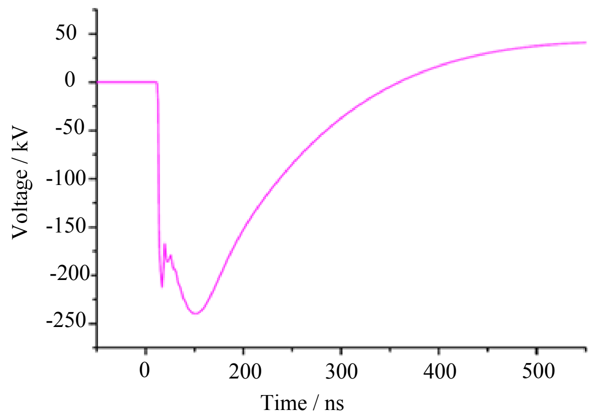


Figure 6.Voltage waveform on the load

With the parameters in Figure 5, the voltage waveform on load is shown in Figure 6. The generator delivers a high voltage pulse with amplitude of 240kV, rise-time of 40ns and FWHM of about 200ns. The simulation results are accordant with the design purpose.

5 Summary

This paper introduces a novel high-voltage pulse generator system based on pulse transformer and Marx generator. To verify the viability of this technology routine, a generator system with 3-stage Marx generator charged by an air-core pulse transformer is designed. The experiment platform is being set up. The simulation results are accordant with the design purpose. This generator system has the characteristic of quite high energy efficiency, accurate control, and the design with less quantity of spark switches is applicable for operating at repetition rate. Further study will be done on the experiment platform.

References

[1] Liu X S.High pulsed power technology [M]. Beijing: National Defense Industry press, 2005: 29.
[2] Neuber A. A., Chen Y. J., Dickens J. C. et al. A Compact, Repetitive, 500kV, 500J, Marx Generator [C]. 15th IEEE International Pulse Power Conference, 2005: 1203-1206.
[3] Jaimin Lee, Cheon H. Kim, Jeong H. Kuk, et al. Design of a compact epoxy molded pulsed transformer [C]. 15th IEEE International Pulse Power Conference, 2005: 477-480.
[4] MA Xun, DENG Jian-jun. Design of an Air Core Spiral Strip Transformer [J]. Power Supply Technologies and Application, 2008, (11)5: P57-59.
[5] Yan Z, Zhu D H. High voltage and insulation technology [M]. Xi`an: Electric Power Press, 2002:139-149.
[6] Sudararajan R., Nagabhushana G. R., Kishore N. K., et al. Influence of Peaking Capacitors in Reducing Rising Times of High Voltage Nanoseconds Pulse[J]. IEEE Transactions on Industry Applications, 2005, 41(3): P690-697.
[7] Feng Chang-shun. Preliminary Investigation of a Compact and Long-Pulse Marx Generator [D]. National University of Defense Technology, 2009:40-41.