

Fast Trigger Generator for High Coulomb Spark Gap Switching Synchronisation

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ABSTRACT: Design and implementation of a 10kV subnanosecond pulse generator using Trigatron type spark gap as a switch. Straightforward and compact trigger generator using pulse shaping network which produces a trigger pulse of subnanosecond rise time. A pulse power system requires delivering a high voltage, high coulomb in short rise time. This is achieved by using pulse shaping network comprises of parallel combinations of capacitors and inductor. Spark gap switches are used to switch the energy from capacitive source to inductive load. The pulse hence generated can be used for synchronization of two or more spark gap. Because of the fast rise time and the high output voltage, the reliability of the synchronization is increased. The analytical calculations, simulation, have been carried out to select the circuit parameters. Simulation results using MATLAB/SIMULINK have been implemented in the experimental setup and sub-nanoseconds output waveforms have been obtained.

KEYWORDS: Fast trigger generator, spark gap switch, rise time, jitter.

I. INTRODUCTION

Pulse power activities have raised its importance due to its application in strategic and industrial sectors. High voltage and high current or combination of both are used in many applications such as breakdown experiments, high power radar system, simulation of electromagnetic interference, laser technologies, spark gap synchronization, material processing and high-speed photography. The pulsed power systems for these applications are typically large machines and are operated in a single-shot mode or at a low repetition rate. To meet the demand in pulse power system, multiple switchbased technologies is used. It is required to have synchronization of these multiple switches. Simultaneous synchronization of these switches is required to pass high coulomb energy through them for the various applications. When all modules of the capacitor bank are charging, if any one module pre-fires then it lifts the load end of another switch in equipotential condition, so they are not able to switch; whereas on the other hand when the voltage swing to negative value, capacitors are overvolted which may result either in their destruction or insulation failure between terminals. In order to prevent these conditions, it is necessary that all the switches should be triggered simultaneously before the opposite electrode comes at equipotential state [1]. There are various types of switches used in pulsed power technology such as magnetic switches, semiconductors switches, spark gap switches, etc. Spark gap switch is mostly used the switch in pulse power system. The main advantages of spark gap switches are a high hold-off voltage, large conducting current, high energy efficiency, fast switching, low cost. The switching speed and the spark resistance of spark gap switches depend on many factors such as voltage, current, gap distance, gas species, pressure, etc. When they are used in air, a typical rise time of 20-30 ns can be realized. Very fast switching, with switching times on the order of several ns or less than one ns, can be obtained when pressured gas, water, or a gas with a light molecular weight (e.g. H₂) is used as switching medium or when multiple gaps are adopted .

TABLE I. COMPARISON OF DIFFERENT SWITCHES[3]

Requirements	Magnetic Switches	Semiconductor Switches	Spark Gap Switches
High hold off voltage	++	+	+++
Large conducting current	++	+	+++
Fast switching	+	+	+++
Low impedance	+	+++	+++
High overload	+++	-	+++
Repetition Rate	++	+++	++
Efficiency	-	+++	+++
Cost	+	+	+++
Life Time	++	+++	+

(Excellent = +++, Good = ++, Satisfactory = +)

II. RELATED WORK

For proper and controlled synchronization trigger circuit is designed to fire the multiple spark gap switches. There are various topology for trigger generator which produces trigger pulses and results in simultaneous breakdown of spark gap within short time such as

1. Marx Generator
2. Pulse Transformer
3. Transmission Line Transformer
4. Spiral Generator
5. Pulse shaping network

Storing large amount of energy in the form of voltage and current, guiding it through proper path, efficient management of stray capacitance and lead inductance, and development of proper trigger circuit for synchronization of multiple spark gap switches is the challenge. Higher the accuracy in synchronization of trigger pulses, lower will be the isolation requirement i.e. if trigger pulses for entire parallel spark causes its breakdown within T sec, for that time period of T sec isolation of all spark gaps from each other are required for simultaneous breakdown.

1. HirenCanacsinhal[9] uses Marx generator as trigger circuit to generate pulsed power. The Marx modulator concept is a widely used technique to generate transient high-voltage pulses from relatively low d-c voltage sources. The basic Marx generator is comprised of a number of discrete stages, typically 6–20, with each stage comprised of a capacitor and a spark gap. Voltage multiplication is achieved by charging the capacitors in parallel via high value resistors and then discharging them in series through the stage spark gaps. Mostly they are used for high voltage applications. Recent technological upgrade in the mature Marx generator concept lead to the intensive use of semiconductor switches, replacing the passive elements and contributing to the compactness of the Marx modulators, capability to generate square pulse shapes, possibility to control the number of pulses, pulsewidth, frequency, and the ability to deal with different load conditions.
2. Adam Lindblom[5] discussed the Transmission Line Transformer; plays an important role in synchronizing the multiple switches and in transferring the energy from the capacitors to the load .To ensure the synchronization and to prevent the discharging of the high-voltage capacitors during the synchronization process, the secondary mode impedance of the TLT must be much larger than the characteristic impedance of the coaxial lines multiple switches are interconnected via a transmission line transformer, in such a way that all switches can be synchronized automatically and no special external synchronization trigger circuit is required. It can produce either exponential or square pulses, with various voltage and current gains and with a high degree of freedom in choosing output impedances. At the input side of the TLT, two identical capacitors are interconnected to the TLT via two switches. At the output side, all stages of the TLT are put in parallel to produce a large current. The TLT is made from coaxial cables. Magnetic cores are placed around the cables to increase the secondary mode impedance, which is defined as the wave impedance between two adjacent stages of the TLT.

3. P.C. Sarojet. al. [1] designs a trigger circuit using pulse transformer with IGBT. IGBT is used to discharge the capacitor into primary winding of a step up pulse transformer. For triggering IGBT a gate driver circuit is used which is optically isolated from operator. The charging time depends on leakage inductance and capacitors used on primary and secondary sides of transformer. It is important to reduce the leakage inductance of pulse transformer to shorter the charging time.
4. M.F.ROSE et. al. discussed the spiral generator as trigger circuit[10]. The spiral generator is similar to a spiral wound transformer. The main difference is that the energy used to drive a spiral wound transformer is stored in external capacitor, while in spiral generator, it is stored in the spiral itself which make the spiral generator extremely compact. The energy per unit volume is hard to obtain with other pulse generating networks. The spiral generator experiences several losses during its operation which drastically reduces its efficiency. The losses of spiral generator also causes only 30% performance of the theoretical multiplication in practice.

III. DESIGN OF TRIGGER CIRCUIT

Trigger Circuit consists of pulse shaping network, IGBT, DC supply generated from voltage multiplier and doubler. The various components required for generation of trigger pulse is explained and shown in fig. 1.

A voltage multiplier converts AC electrical power from a lower voltage to a higher DC voltage, using a network of capacitors and diodes. Here Cockroft Walton Voltage Multiplier is used giving output voltage(V_0) as four times the input voltage (V_{in}) as shown in fig 2.

Pulse shaping network displayed in fig. [3] is used for generation of pulses where the rise time needs to be short. The output of the voltage multiplier is fed to the input of the pulse shaping network. It consists of RLC series circuit with Triggered spark gap as a switch which is called as auxiliary spark gap; causes discharge of the capacitor through the inductive load.

This auxiliary spark gap is triggered spark gap which is triggered by IGBT. The transient behavior of circuit produces damped sinusoidal trigger pulse for the load. The trigger pulse should be capable of maintaining the arc of the switch which causes its breakdown and should have low jitter for simultaneous synchronization of the load which is parallel connected triggered spark gap. Jitter is shot to shot variation in time.

A DC coupling capacitor is connected in series with the load to decouple the DC voltage from the supply. For triggering of IGBT, a gate driver circuit is used. Gate driver is optically isolated from the operator. Optical signal generated by handheld unit by operator triggers the IGBT through gate driver. A voltage pulse of IGBT is given to the pulse transformer. On the firing of IGBT, a 8 KV pulse is generated across secondary of the transformer. The pulse produced by IGBT is fed to the trigger electrode of the trigger spark gap of pulse shaping network. Pulse transformer also provides isolation between high voltage stage (i.e. pulse shaping circuit) and low voltage stage. Voltage doubler block provides voltage to the IGBT circuit. It doubles the supply voltage and also rectifies it.

PSIM/ MATLAB software is used to verify the closed form solution for trigger voltage and circuit parameters are designed for 10 KV sub-nanosecond(ns) rise time using standard equation for series L C network. Fig.4 shows the expected trigger voltage waveform with designed values of capacitances and inductances. Selected values of inductances and capacitances are as $L = 2\mu H$, $C = 6nF$, L_s is approximately 50 nH.

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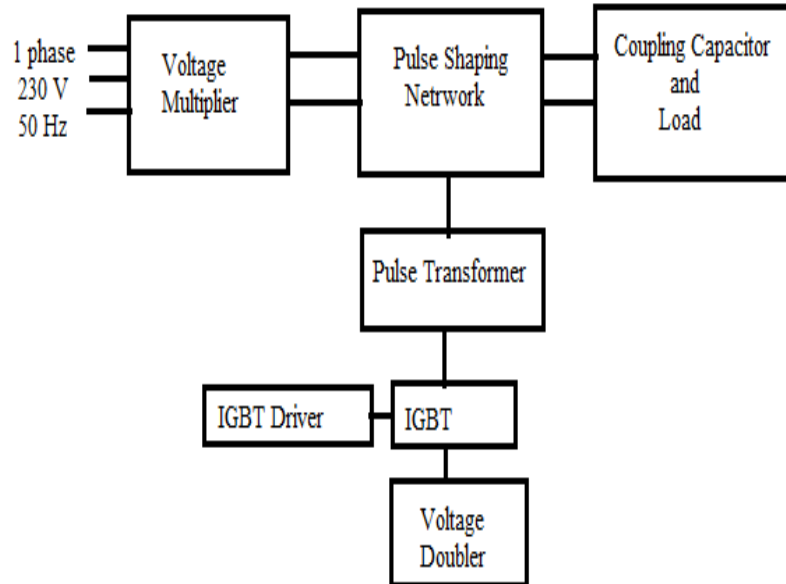


Fig. 1. Block diagram of the trigger circuit.

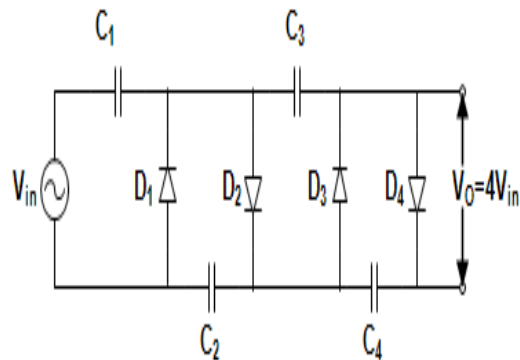


Fig. 2. Voltage multiplier circuit.

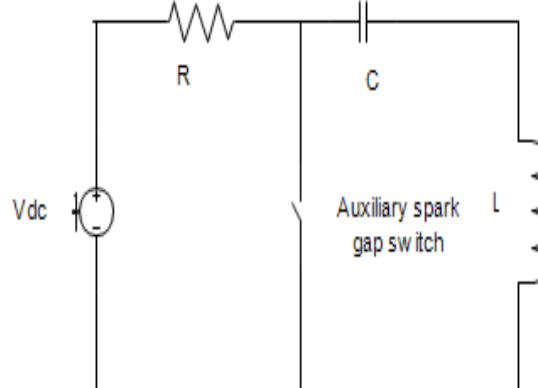


Fig. 3. Pulse shaping circuit

IV. EXPERIMENTAL RESULTS

Fig. 5 and 6 shows the experimental setup of the complete system with pulse shaping network as trigger circuit



Fig. 5. Hardware implementation of the system

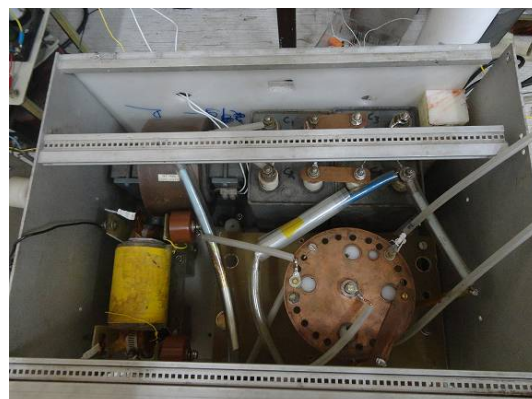


Fig. 6. Hardware of trigger circuit

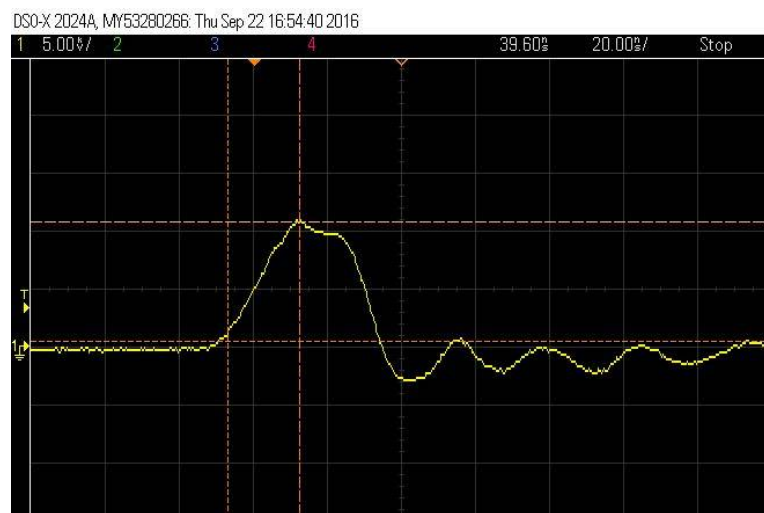


Fig. 7. Waveform of trigger circuit

IV. CONCLUSION

The simple and compact trigger circuit of 10kV with sub-nanoseconds rise time is successfully implemented and tested. The simulation results and experimental results are closely matching. The present prototype system gives rise time 54 nanoseconds.

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