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5 Stage, 50 V, 500 Hz, 50 μs MOSFET Based Design Of Unipolar Pulse Power Marx Generator

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Abstract: *The Marx Generator is a multistage pulse generator which is a prime source for generation of high voltage pulse by connecting number of stage capacitors in parallel and series for charging and discharging during ON and OFF period respectively. Marx Generator has wide applications in various field with different characteristics of high voltage output pulse for different requirements. This paper deals with design and simulation in Multisim software of five stage Unipolar solid state Marx Generator having 50 V of output pulse with 10% voltage droop with repetition frequency of 500 Hz and 50 μs maximum pulse width using MOSFET switch. The diodes are used to charge the capacitor at each stage. A 555 timer generates control pulses for the capacitors to charge in parallel during ON time. During OFF time of the pulses the capacitors are brought in series with the help of MOSFET switches. Hence the simulation results confirms the validity of simple multistage Marx Generator topology to generate pulses.*

Keywords: *Marx Generators, Unipolar, High Voltage Pulse, Inductor, MOSFET, IC 555timer.*

I. Introduction

Rapid discharge of stored energy in short interval as electrical pulses into a load produces big quantity of instant power [1]. An impulse generator is an electrical apparatus which produces very short rise time of high voltage or high current pulses. Marx Generator is a multistage high voltage impulse generator which was first proposed by Erwin Otto Marx in 1924 having wide application in fields like industrial, scientific, agricultural, environmental etc. Marx Generator working is based on charging the capacitors in parallel up to its input DC voltage applied. Those capacitors are then connected in series with the help of switching devices which is very important component. The switching device is a solid-state switch which have become more and more suitable for pulsed power application nowadays because of some of its advantages such as compactness, reliable, flexible, efficient, long life time, less losses and low costs as compared to spark gap mechanical switch which used in conventional Marx Generator. Both MOSFET or IGBT is utilized in place of spark gaps and gives variable pulse width. It can also generate a fast pulse rise time within a few ns across the load. The advantage of MOSFET is that switching loss is less as compared to IGBT as the switching time of MOSFET is much lesser than IGBT (typically:- 20 ns for a MOSFET, 200 ns for an IGBT) [2].

This paper deals with the design and simulation of Unipolar Marx Generator proposed topology having 5 stages but using MOSFET as a switch. This topology has replaced the charging resistors in conventional Marx with high voltage diodes and inductor based charging method is used to charge all the stage capacitors [3]. There are many new topologies based on different charging methods of solid state Marx Generators are proposed in literature. Yifan Wu has proposed repetitive and high voltage Marx Generator using solid-state devices with inductive based charging [4]. Drawback of this topology is that it limits the pulse frequency due to long charging time constant. A novel solid-state pulsed power modulator driving by magnetic ring transformers is introduced by Jian Qiu [5]. The charging power supply here is a full bridge resonant inverter. The limitation is that due to the use of magnetic rings, the stray parameters distort the output voltage waveforms.

II. Growth Of Pulsed Power Marx Generator

1.1 Conventional Marx Generator

In conventional Marx generator, bank of capacitors C_1, C_2, C_3 till C_n stage as shown in Fig.1.1 are charged in parallel by applying DC input voltage and then this stored energy in all the capacitors are discharged simultaneously by connecting them in series into the load capacitance or the tested object for producing several high kV of voltages. The wave shaping circuit is used for improvement of output pulse waveform obtained across test object. Normally capacitive load is used as it is large enough that the shape of the output waveform does not change to a large extent with changes in test capacitance. The discharge time constant will be very small as compared to charging time constant. If suppose single capacitor say C_1 is used then it will generate voltages up to 200 kV. To generate output voltage pulse beyond this voltage, single capacitor and its charging unit may be too costly and the size becomes very large at the rate of the square or cube of the voltage rating [6].

In conventional Marx generator the charging resistance is chosen to limit the charging current to about 50 to 100 mA, and the generator capacitance is chosen such that the product RC time constant is about 10 seconds to 1 minute. The gap spacing is chosen such that the breakdown voltage of the gap G is greater than the charging voltage [7]. As shown in Fig.1.1 during discharge time along with capacitor all the spark gap switches are also connected in series. The gaps are made to spark over at the same time by some external means. As seen spark gaps have many disadvantages such as low repetition rate, short life time, inefficiency, requirement of separate triggering circuit for the spark gaps to trigger so in order to solve these problems, some new Marx circuits are proposed with the use of semiconductor switches such as MOS-FETs or IGBTs.

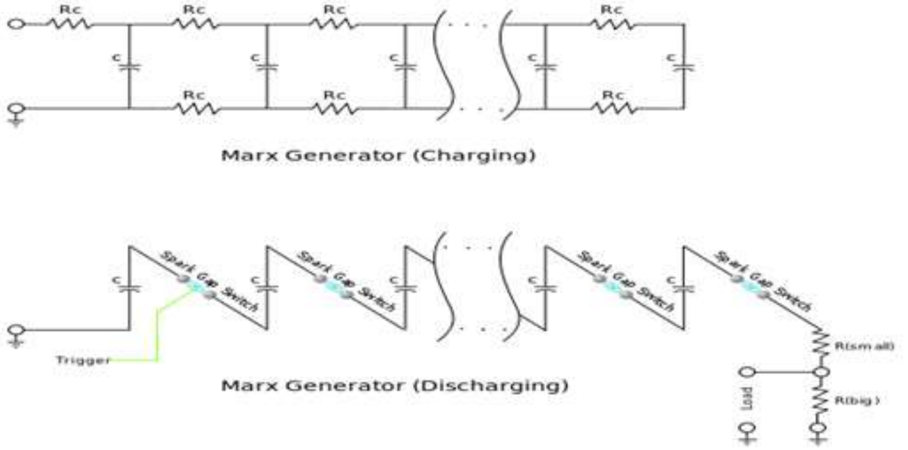

Fig.1.1 Charging and Discharging Circuit of Conventional Marx Generator.

1.2 Solid State Marx Generator

As the Conventional Marx generator had drawbacks such as low repetition rate, short life time, inefficiency which are now eliminated by modern Marx generator circuit as shown in Fig.1.2. With the advancement of semiconductor technology, solid-state devices like IGBT and MOSFET, BJT etc are becoming more and more appropriate for modern Marx generator topologies. These compact and efficient solid state devices have replaced the bulky, heavy, costly and inefficient gas and magnetic switching devices used. The voltage rating of these solid state switches restrict their use to few hundred volts, however several Marx Generators in the range of hundred kV have been designed and implemented using these switches. So solid state semiconductor switches i.e IGBT and MOSFET with high voltage blocking capabilities are developed. Both IGBT and MOSFET gives variable pulse width and can generate a fast pulse rise time within a few ns across the load. The switching time of MOSFET is much lesser than IGBT (typically:- 20 ns for a MOSFET, 200 ns for an IGBT).

IGBT are available at higher voltage ratings (up to 6500 V), where as the MOSFETs are limited to 1200 V [2].

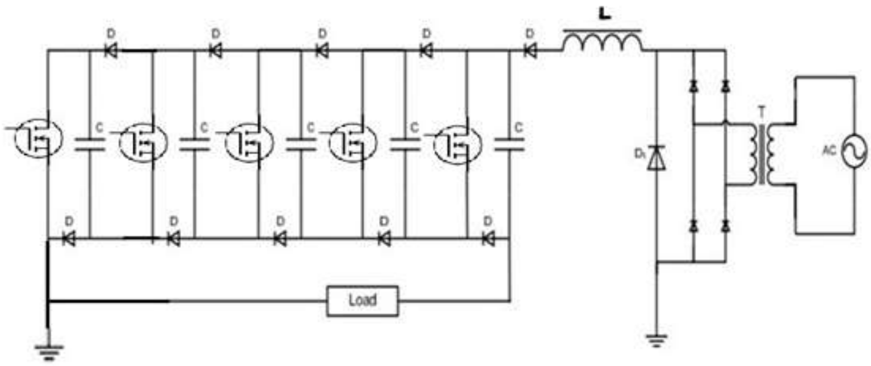

Fig.1.2 Solid-Sate Unipolar Marx Generator Circuit using MOSFET

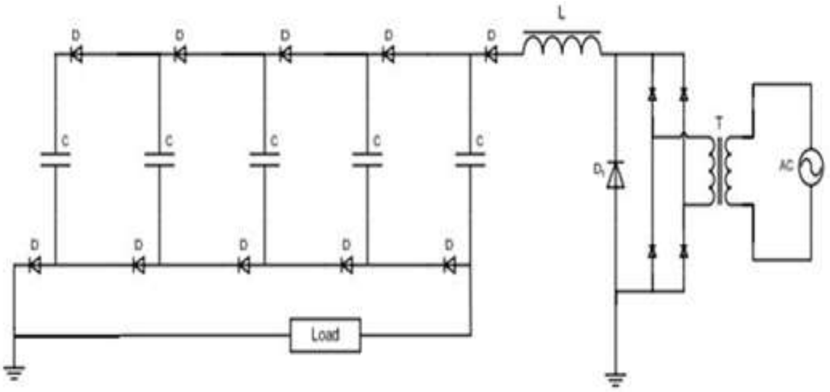

Fig.1.2.1 Marx Generator Circuit during Charging Mode

1.2.1 Charging Mode of Operation

In this mode, MOSFETs are at off-state. As shown in Figure 1.2.1, the Step down transformer T is used which steps down the 230 V from the AC supply mains to 10 V AC which is an input then given to the diode bridge rectifier circuit to convert it into 10 V DC. The large inductor acts as a current limiter and cause boost of the voltage of capacitors for charging in parallel from the input DC voltage applied.

2.2.2 Discharge Mode of Operation:

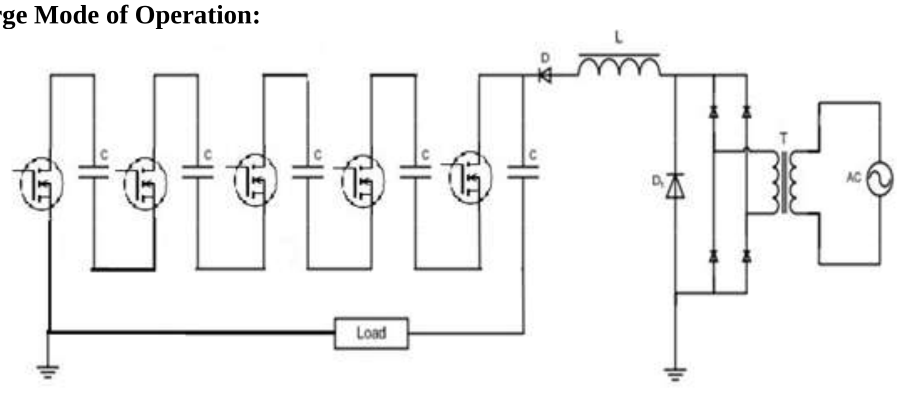

Fig.2.2.2 Marx Generator Circuit during Discharging Mode

In this mode the discharging of the capacitors are done in series to generate a high voltage pulse at the output across the load. The MOSFETs are turned on simultaneously and are used to discharge all the capacitors of the five stages of Marx Generator as shown in Fig 2.2.2. Thus, the load will come across a negative high voltage which is the sum of the voltage of all the capacitors. In this mode, also the inductor L isolates high output voltage generated across the load from the bridge rectifier via Freewheeling diode.

III. Design Of Mosfet Based 5 Stages Unipolar Pulse Marx Generator

2.1 Selection Of Inductor

This paper describes the proposed Marx Generator topology by using inductor based charging method. So this large inductor acts as a current limiter and cause boost up of the voltage for the capacitors to charge up to its maximum input voltage.

Load Current (I_L) is given by;

$$I_L = \frac{Vo}{R} = \frac{50}{1000} = 0.05 \text{ A} \qquad (2.1.1)$$

Inductor charging current ($I_{inductor}$) is given by;

$$I_{inductor} = \frac{Vin}{Deq} = \frac{10}{2.8} = 4.28 \text{ A} \qquad (2.1.2)$$

Now,

$$\Delta V \geq \frac{\Delta Q}{Cs} = \frac{(IL + Iinductor) \times \Delta t}{\frac{C}{n}} \qquad (2.1.3)$$

Where, 'I_L' is load current,

'$I_{inductor}$' is the inductor charging current,

'ΔT' is the maximum pulse width in µs,

'n' is number of stages in the circuit.

$$\text{Therefore, } \Delta V \geq \frac{(0.05+4.28)\times 50\times 10^{-6}}{5\times 10^{-6}} = 43.3 \text{ V} \qquad (2.1.4)$$

The Inductor L can be determine by;

$$\Delta I \geq \frac{\Delta V \times \Delta T}{L} \qquad (2.1.5)$$

$$L \geq \frac{43.3\times 50\times 10^{-6}}{(4.28 \ of \pm 5\%)} = 48.1 \text{ mH} \qquad (2.1.6)$$

2.2 Selection of Capacitor

Capacitor is designed based on the discharge time constant. The voltage droop of the output pulse is taken as 10 % of the peak voltage output i.e. 50 V. The value of equivalent capacitance at the time of discharge is given by;

$$Ceq = \frac{Vo \times \Delta T}{RL \times \Delta V} \qquad (2.1.7)$$

where, 'Δt' is the maximum pulse width,

'RL' is the load resistance,

'ΔV' is the voltage droop in output voltage pulse,

'Vo' is the output Pulse Voltage.

$$C_{eq} = \frac{Ci}{N} \qquad (2.1.8)$$

where, Ceq is the equivalent capacitance at the time of discharge. Since all the capacitors during discharge are connected in series, 'Ci' is the per stage capacitance and 'N' is the number of Stages.

$$\therefore Ceq = \frac{50V \times 50\mu S}{(10\% \ of 50V) \times 1000\Omega} = 5\mu\text{F} \qquad (2.1.9)$$

$$\therefore \text{Ci} = 5 \ \mu\text{F} \times 5 = 25 \ \mu\text{F} \qquad (2.1.10)$$

Hence each capacitor value designed for the Marx circuit is 25 µF.

2.3 Selection of Switch

During discharging mode of operation, discharge current flows to load via switch. The load current should be lower than maximum current rating of the switch. The voltage blocking capacity across the switch should be more than the input dc voltage as all the switches are connected in parallel to it. The MOSFET switch is selected because the pulse frequency designed for the Marx circuit here is of high frequency. IRF450 is taken for simulation in Multisim 13.0 software.

2.4 Selection of Diodes

The peak inverse voltage of diode should be more than the maximum input DC voltage. The diode selected for the simulation is IN4007.

IV. Simulation Results

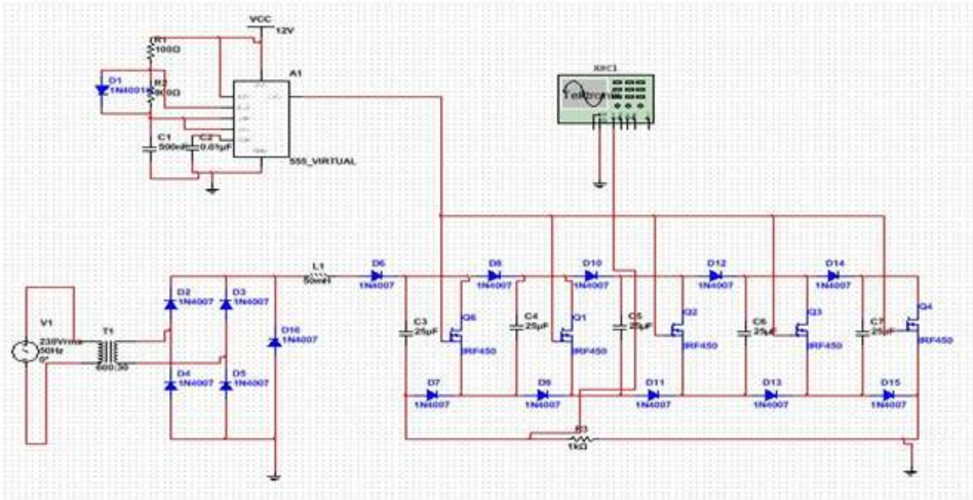

Fig.3.1 Five Stages Unipolar MOSFET based Marx Generator Circuit for Simulation

As shown in Fig.3.1, the five stages MOSFET based triggering Unipolar Marx Generator simulation Circuit. In this the input charging voltage is 10V. So for five stage maximum voltage of 46.8V has been obtained across the resistive load of 1 kΩ. IC 555 Timer based circuit is used for generation of constant control pulse for the MOSFET switch to trigger during the discharging mode.

Fig.3.2 Five Stages Output Voltage Pulse across the Load

Above Fig.3.2 shows the five stage output voltage pulse of the Marx Generator circuit. The output voltage obtained across the 1 kΩ resistive load through simulation in MULTISIM software is about 46.8 V for 5 stages as the input DC voltage given is 10 V. 10% voltage droop is noticed of the maximum peak output voltage pulse. The pulse width is about 50 µs. The pulse width of the output pulse is dependent on how much time the MOSFET switch will be ON during discharging mode in order to discharge very rapidly and completely all the energy stored in the capacitors.

V. Conclusion

solid state Marx Generator is more compact, offer simplicity in controlling the pulse width and repetition frequency as compared to conventional spark gap switch. Marx Generator has wide applications in various field such as industrial, medical, agricultural, environmental etc.

In this paper solid state Marx type circuits which achieve unipolar voltage pulse using MOSFET switch with inductor based charging method is described. This paper explains the design and simulation of unipolar Marx circuit of five stage, 50 V, 500 Hz repetition frequency, 10 % voltage droop in the output voltage pulse with 50 µs maximum pulse width. The input voltage given to the Marx circuit is 10V to charge all the capacitors in parallel through inductor which acts as a current limiter at the time of pulse generation. Drawback of this topology is that it limits the pulse frequency due to long charging time constant. The 555 IC timer circuit is used to generate the gate control pulse for the MOSFET switch to trigger during the fast discharge time of all the capacitors connected in series. The simulation result obtained in Multisim software of voltage pulse on resistive load of 1 kΩ indicate that it can easily generate repetitive high voltage almost square pulses with low voltage power source with longer life.

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