Solid state Bipolar Marx Generator Topologies: A Comparative study

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***Abstract*— Solid state Bipolar Marx Generator is drawing considerable attention due to the increased use of pulsed electric fields on food processing industry for extraction, medical field for sterilization, biological fields for water treatment, environmental field for control of air pollution. The bipolar pulses reduce the amount of pulse energy required for a specified application compared to unipolar pulse. This paper gives the overview and comparison of the various topologies used for generation of bipolar high voltage pulse. A comparative analysis based on number of switches used, polarity, number of capacitors required and working for five switched topology, six switched topology and high voltage source topology has been done. IGBTs have been recommended for these topologies as it has high power handling capability and less switching losses. The evolution of solid state Bipolar Marx Generator from conventional Marx Generator using spark gaps has been briefed.**

Index Terms*— Marx Generators, IGBTs, Bipolar, High voltage pulse.

I. INTRODUCTION

Marx Generator is the primary source in pulsed power applications. Various applications of Marx Generator are: Air pollution control, wastewater purification, food sterilization etc. Taking the merits of solid state switches in to consideration, conventional Marx Generator has been modified by replacing the huge spark gaps by solid state switches and the resistive isolators by diodes.

The conventional Marx Generator shown in figure 1 has been derived from Impulse Generator [1]. E.O. Marx was the first person to bring this concept in to picture. He included the additional stages in to Impulse Generator which was a single stage. This had several advantages and helped to get higher voltage. The capacitors are charged in parallel and the discharge of the capacitors was done in series by triggering the spark gaps. The spark gaps required an external circuit for its triggering and being a mechanical switch it required regular maintenance. Another additional circuit required in conventional Marx Generator was a wave shaping circuit which overall increased the complexity. The high voltage, high power pulse obtained just by the discharge of the capacitors are later replaced with PFN (Pulse Formation Network) through which we could get controlled pulse. Next modification made was that, these PFNs were used along with Thyratrons and pulse transformers to have more flat controlled pulse of high voltage and high power. PFN was limited to a fixed impedance load and a fixed pulse width [2].

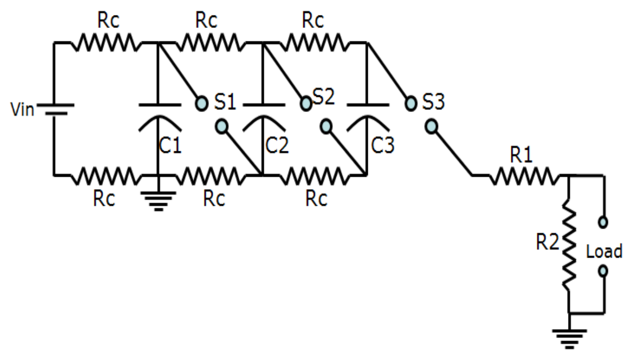

Fig 1. Conventional Marx Generator

The changes in the types of switches have actually led to the evolution. The basic switch used was the spark gaps which were later on replaced by PFNs and gas tubes.

The spark gaps used had limitations in repetition rate and lifetime, which made them impractical for many applications. Same with the Gas tubes, such as thyratrons and ignitrons. Even these switches had the limitations of the repetition rates and current limitations. Vacuum tubes can operate at high voltage but have limited current capability and have relatively high power loss. Then came the solid state switches. Today the solid state switches are the main switches used as they have several advantages over the traditional switches such as maintenance free, easier triggering methods etc. High voltage pulse power supplies operating at repetitive rates have wide applications in industries today. Traditional tyristors and Gate-turn-off tyristors can handle several kilo volts and kilo amperes but have low switching speed and PRF (Pulse Repetition Frequency).

For above mentioned tyristors, an additional step up transformer and multistage MPC (Magnetic Pulse Compression) circuits are required as they have low PRF for ON/OFF switching capability. Thus, to have higher PRF, we go for IGBT's and MOSFET's.

These devices are easy to drive and have short rise or fall time (rise time is 200 ns for IGBT and 20 ns for MOSFET). As we require a high voltage pulse, we usually go for IGBTs instead of a power MOSFET [3].

This paper is organized as follows. Brief description about the various topologies has been explained in section II. Section III gives the comparison between the topologies. Section IV concludes the paper with brief summary.

II. SOLID STATE BIPOLAR MARX GENERATOR

Solid state bipolar Marx Generator is capable of delivering repetitive bipolar high voltage pulses to the load. It has semiconductor ON-OFF switches. Here the switches used are that of IGBTs with anti-parallel diodes. Solid state Marx Generator was a Unipolar Marx Generator. The Bipolar Marx Generator is advanced to the unipolar as it adds value to the industrial processes as compared to that obtained from unipolar positive or negative pulses. Topologies of bipolar solid state Marx Generator have been explained.

A. Using Six Switches

The figure 2 represents a six switch topology of Bipolar Marx Generator in which six ON-OFF semiconductor switches are being used for each stage of voltage pulse generation [4].

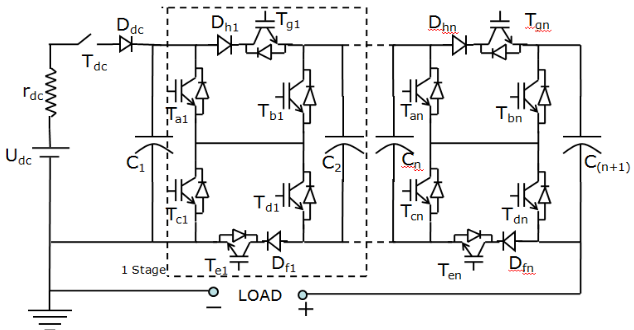

Fig. 2 Solid state Marx type Topology for bipolar pulse generation with six switches.

Figure 3 given below shows the charging mode in the six switch topology of bipolar Marx Generator.

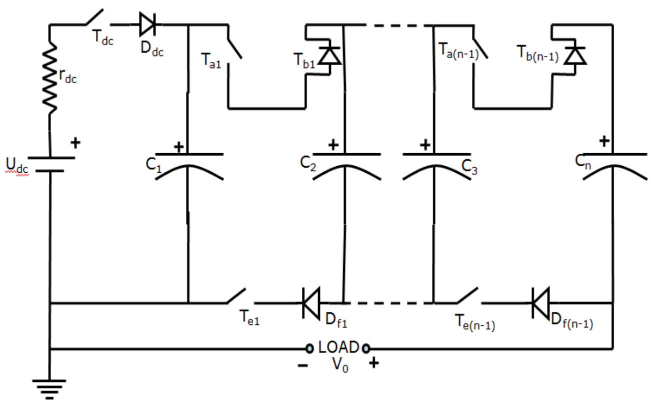

Fig. 3 Charging mode for the bipolar topology

The six switch topology works on the same principle as that of the conventional Marx Generator. The capacitors are being charged in parallel at the source voltage and are discharged in series to get the required pulse. The operating mode depends on the type of application, type of pulse required (positive or negative) and the required output in the load. The charging mode may follow three different paths based on the switches triggered (Fig. 2).

- T_{dc} - D_{dc} - D_{hi} - T_{gi} - D_{fi} - T_{ei}
- T_{dc} - D_{dc} - T_{ai} - anti parallel diode of T_{bi} - D_{fi} - T_{ei}
- T_{dc} - D_{dc}- D_{hi} - T_{gi} - anti parallel diode of T_{di} - T_{ci}

In above three paths i = 1,2,3,…n. These various paths have been provided so that the switches are relieved from the over stress which may in turn increase the required power ratings of the switches. For reference the second path T_{dc} - D_{dc} - T_{ai} - anti parallel diode of T_{bi} - D_{fi} - T_{ei} is shown in figure 3. The capacitors C_i are being charged from the DC source. To protect the switches from initial transients, the supply is being increased slowly.

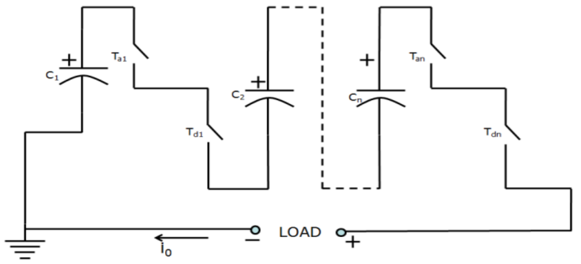

Fig. 4 Positive Voltage Pulse mode

For positive pulse, the switches T_{ai} and T_{di} are on and all the remaining are off as shown in figure 4. The capacitors C_i are in series except the (n+1)th capacitor in figure 2 which is not used in this mode and the voltage applied to the load is given by,

$$V_o = +nU_{dc} \qquad (1)$$

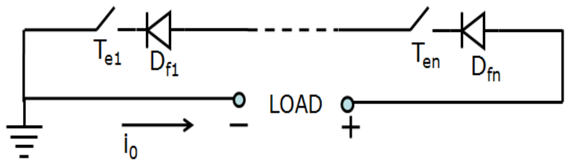

Fig. 5 Discharge of positive charged load capacitances

Figure 5 shows the discharge path for the positively charged load capacitance.

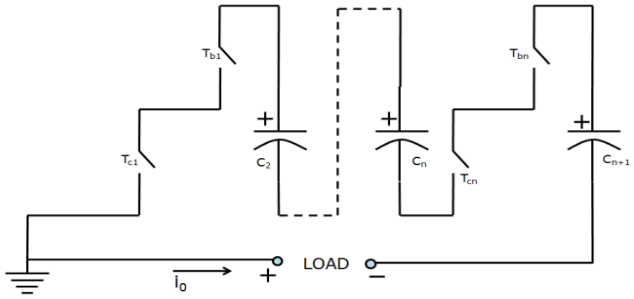

Fig. 6 Negative Voltage Pulse mode

As shown in figure 6, for negative pulse the switches T_{bi} and T_{ci} are on and rest all other switches are off. Again all the charging capacitors are in series except C_1 which is not used in this mode. The voltage applied to the load is given by,

$$V_o = -nU_{dc} \qquad (2)$$

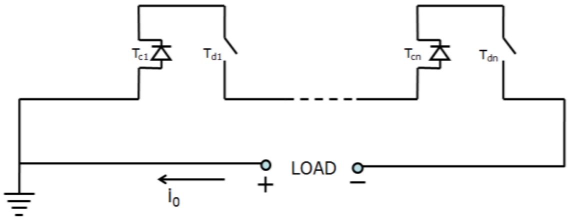

Fig. 7 Discharge of negative charged load capacitances

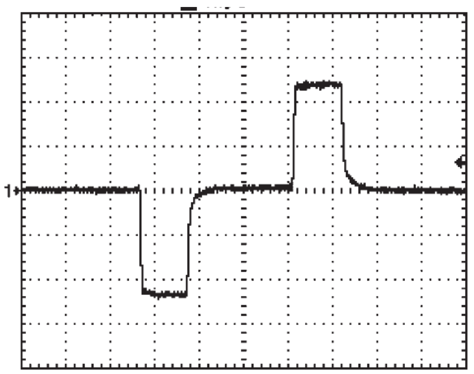

Fig. 8 Bipolar pulse obtained from the solid state bipolar Marx Generator [5]

Figure 7 shows the discharging of the negatively charged load capacitances. Figure 8 shows the bipolar pulse which is obtained from the solid state Marx Generator [5].

B. Using five Switches

In order to achieve a more reliable, easy to operate and cost effective topology, it is advantageous to reduce the number of switches used in each stage. The most significant change consists of eliminating the semiconductors D_{hi} and T_{gi}.

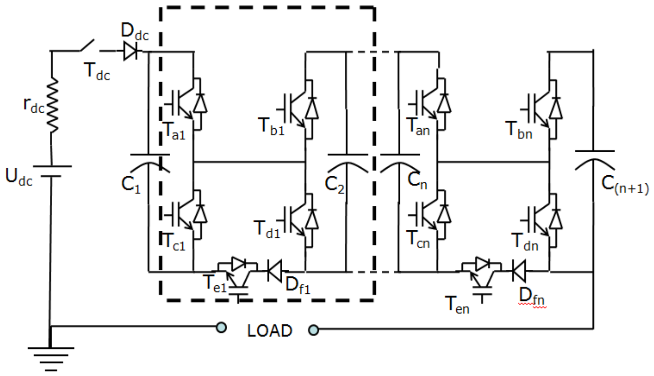

Fig. 9 Solid state Marx type Topology for bipolar pulse generation with five switches.

Figure 9 is representing a five switch topology of Marx Generator in which five ON-OFF semiconductor switches are being used for each stage of voltage pulse generation. The dotted lines represent a single stage of the topology.

Thus, the voltage polarity is controlled by the H-bridge switches. In order to achieve the bipolar pulse, the switches A+ and B- are turned ON first and then the switches B+ and A- are turned ON for equal interval usually after the switches A+ and B- are turned OFF. From figure 11 we can observe

In five switch topology the charging path is same as shown in figure 3 [6]. In this topology only one charging path is possible which includes T_{an}, anti-parallel diode of T_{bn}, diode D_{fn} and T_{en}. During positive pulse formation as in figure 4 the switch T_{an} is again coming into the discharge path of the capacitor and thus getting overstressed. For obtaining the negative pulse in this topology the path is same as that of six switch topology which is mentioned in figure 6. Another disadvantage is that of switching losses. Here switching losses is more.

C. *Using High Voltage source*

Figure 10 shows another topology for the generation of bipolar pulses. This topology has a conventional H-bridge configuration that allows a flexible configuration in order to achieve both the unipolar and bipolar pulses. In this configuration the input stage which produces high voltage level is represented by the high voltage source and the switch S_p.

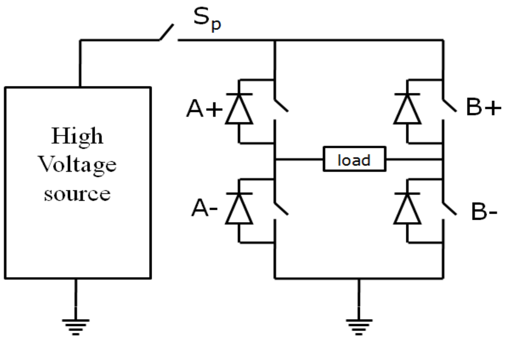

Fig. 10 Concept for bipolar high power pulse generator

Figure 10 shows the approach required to achieve the bipolar pulses [7]. The four switches of the H–bridge works in pair, the pair being between the alternate switches of each leg i.e. A+/B- and A-/B+.

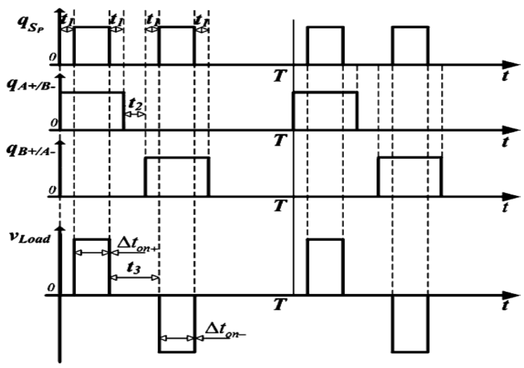

Fig. 11 Switching strategy and load output voltage for bipolar high power pulse generator [7]

that the switch S_p is turned ON only when one of the pair of the H-bridge is in ON state. The delay time t_1 is given in order to avoid the switching losses owed to H-bridge switches slow commutation. The dead time t_2 is provided to avoid the shoot-through currents due to simultaneous turning on of the switches in the same leg. Thus t_3 is the total dead time which is resulted by addition of the time t_2 and twice the time t_1 [7].

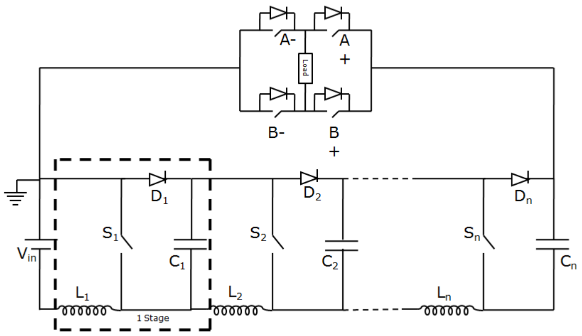

Fig. 12 Bipolar Marx Generator topology with high voltage source

In figure 12 the bipolar topology consists of n number of stages for multiplying the input voltage across the H-bridge terminals. The source V_{in} charges the capacitors to voltage V_c. The number of capacitors required in this topology is n. Once these capacitors get charged, the switches S_1, S_2, S_n are triggered and this high voltage is then applied across the H-bridge. The number of switches required is n + 4.

III. COMPARISON

A. Comparison of solid state Marx Generator with the Conventional Generator

As compared to the conventional Marx, the solid state has several advantages.

- The biggest difference is that the conventional Marx Generator gives only unipolar pulse but solid state Marx Generator gives both negative and positive pulses according to the application.
- Construction wise the driver circuit required for the switches in solid state generator is a bit complex but it is simple as compared to the triggering circuit required for the spark gaps in conventional Marx Generator.
- The conventional Marx Generator required an external wave shaping circuit for proper shaping of the waves which had complex designing whereas wave shaping circuit is not required in the solid state circuit.
- Arc protection circuit is required in the conventional whereas in solid state no such circuit is required.

B. Comparison within the Different Topologies of Bipolar Marx Generator

The number of switches required for five switch topology and six switch topology is 5n and 6n respectively where as for high voltage input source topology it is n+4 switches. From the five and six switch topologies only bipolar pulses can be generated where as for high input source topology both unipolar and bipolar pulses can be generated. The number of capacitors required for five and six switch topology is n+1 where as only n capacitors are required for high voltage input source topology. This has been summarized in Table 1.

Table 1. Comparison between the topologies producing bipolar pulses

Parameter	Five switch topology	Six switch topology	High voltage input source topology
No. of switches	5n	6n	4+n
Polarity	Bipolar	Bipolar	Unipolar and Bipolar
No. of Capacitors	n+1	n+1	n
Type of load	Capacitive	Capacitive, Inductive and Resistive	Resistive

IV. CONCLUSION

Three topologies of the bipolar solid state Marx type generator were compared based on the number of switches, Polarity, and number of capacitors required. In five switch topology the number of switches required is five. Thus the driver circuits required is less. Thus, by reducing the number of switches per stage, a compact and less complex Marx Generator is obtained. In the six switch topology, three charging paths were available as compared to that of a five switch topology where only one charging path is available. Due to this the stress on the switches in the five switch topology is increased as the same switches are again being used for the discharge path also. In these two topologies, the input was small and through the capacitor charging it was added up to be supplied to the load. Unlike this topology, the high voltage input source topology applies the generated high voltage to the load.

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