ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 5, May 2016

Generation of HVDC from Voltage Multiplier Using Marx Generator

Dwarakanath S.K[1], Prateek Raj[2], Praveen K.S[3], Saurabh[4], Shwetha[5]

Asst. Professor, Dept. of EEE, SJBIT, Bangalore, Karnataka, India[1]

UG Student, Dept. of EEE, SJBIT, Bangalore, Karnataka, India[2,3,4,5]

ABSTRACT: The Marx Principle was developed by Erwin Otto Marx. Its principle is to generate a high voltage pulse using a number of capacitors in parallel to charge up during the on time and then connected in series to develop higher voltage during the off period. This principle is used to generate voltages in the range of KV's in real-time for testing the insulation of the electronic appliances like transformers and the insulation of the power carryinglines. This project consists of 4 stages and each stage is made of one MOSFET, two diodes, and one capacitor. MOSFET is used as a switch; diodes are used to charge the capacitor at each stage without power loss. A 555 timer generates 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. Finally, number of capacitors used in series (4 in our project) adds up the voltage to approximately 3 (4 capacitors-1 capacitor) times the supply voltage. This system structure gives compactness and easiness to implement the total system.

I. INTRODUCTION

With the development of solid-state electronics, solid-state devices are becoming more and more suitable for pulsed power application. They could provide the pulsed power systems with compactness, reliability, high repetition rate, and long life time. The rising of pulsed power generators using solid-state devices eliminates limitations of conventional components, and promises pulsed power technology to be widely used in commercial applications.

However, solid-state switching devices such as MOSFET available now are only rated up to a few kilo Volts. Most of pulsed power systems demand much higher voltage ratings.

II. DEVELOPMENT OF MARX GENERATOR

Conventional Marx Generator

The generator capacitance C is to be first charged and then discharged into the wave shaping circuits. A single capacitor C may be used for voltages up to 200 kV. For producing very high voltages, a bank of capacitor are charged in parallel and then discharged in series. The arrangement for charging the capacitors in parallel and then connecting them in series for discharging was originally proposed by Erwin Otto Marx in 1923 as shown in Fig.1. Usually the charging resistance is chosen to limit the charging current to about 50 to 100 mA, and the generator capacitance C is chosen such that the product CRs is about 10s to 1 min. The gap spacing is chosen such that the breakdown voltage of the gap G is greater than the charging voltage V. Thus, all the capacitances are charged to the voltage V in about 1 minute. When the impulse generator is to be discharged, the gaps G are made to spark over simultaneously by some external means. Thus, all the capacitors C get connected in series and discharge into the load capacitance or the test object. The discharge time constant CR1/n (for n stages) willbe very small compared to charging time constant CRs which will be few be very small be very small compared to charging time constant CRs which will be few seconds.

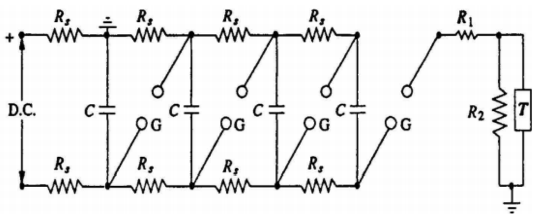

Fig.1: Conventional Marx Generator

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There are some demerits in the conventional Marx circuit as follows:

- Long charging time because the charging current flows through the charging resistors.
- Low efficiency because of the same reason mentioned above.
- Low repetition rate because of the same reason.
- Few output voltage appearance in charging period because the charging current flows through the charging resistors and a load.
- Turn-off is impossible because of using the spark gap switches.
- Short life time of the spark gap switches.

In order to solve these problems, some new Marx circuits are proposed. These new improved circuits use semiconductor switches such as MOS-FETs or IGBTs.

Modern Marx Generator

With the development of solid-state electronics, solid-state devices are becoming more and more suitable for pulsed power application. They could provide the pulsed power systems with compactness, reliability, high repetition rate and long life time. The rising of pulsed power generators using solid-state devices eliminates limitations of conventional components, and promises pulsed power technology to be widely used in commercial applications. However, Solid-state switching devices such as Metal Oxide Semiconductor Field Effect Transistor (MOSFET) available now are only rated up to a few kilo Volts. Previously, it employed spark gaps as switches which are replaced by electronic switches such as (MOSFETs) and resistors as isolator is replaced by diodes. Therefore, Convention Marx generator had drawbacks such as low repetition rate, short life time, inefficiency are eliminated by modern Marx generator as shown in Fig.2.

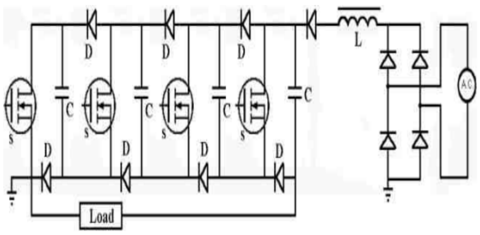

Fig.2: Contemporary Structure of Marx Generator

Charge Mode

In this mode, IGBTs are at off-state. As shown in Figure 2, the high frequency transformer T passes the energy to the secondary winds from a generator of high repetition rates sine voltage. Via the large inductor L and diodes D, the capacitors C in parallel are charged by the high voltage (HV) and high frequency rectify bridge. The large inductor acts as a current limiter and cause boost of the voltage of capacitors.

Discharge Mode

In this mode, IGBTs turn on simultaneously. Then they are at on-state and, consequently, the capacitors are linked in series. Thus, the load could acquire a negative high voltage which is the sum of the voltage of capacitors. Via IGBTs, the capacitors discharge their energy to the load. Diodes take place of resistors as the isolator in conventional Marx generator. Capacitors C, inductor L and diode D1 compose of another discharge loop. In this mode, the inductor L isolates high output voltage apart from the rectify bridge.

Some demerits of conventional Marx circuit are improved as follows.

- Relatively short charging time because the charging current flows through the diodes instead of the charging resistors.
- Relatively high efficiency because of the same reason mentioned above.
- Relatively high repetition rate because of the same reason.
- Turn-off is possible because of using the semiconductor switches instead of the spark gap switches.
- Long life time of the switches.

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III. SYSTEM DESCRIPTION

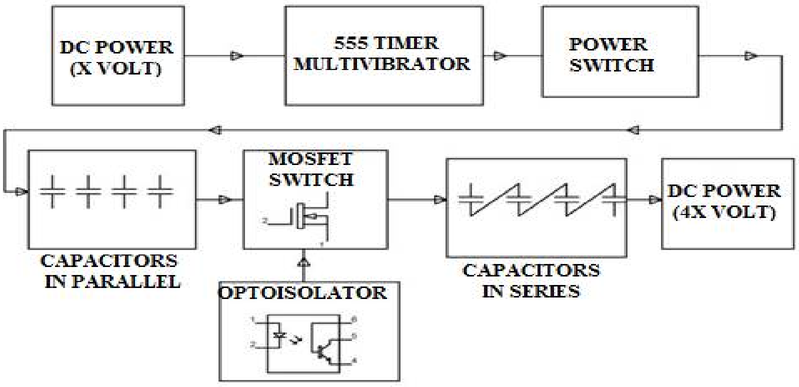

Fig.3: Block Diagram

Primary energy source is taken as a step down AC supply. It is step down to suitable voltage and rectified to get constant DC supply for charging of capacitors. Capacitors are charge storage device. The charging of capacitor takes place as they are parallel connected to the rectifier. When capacitor is having appropriate charge stored in it, switches are used to connect all capacitor in series and discharge of capacitor take place and we get n times of rectifier voltage across the load. Due to various practical constraints, the output voltage is somewhat less than n×V (where n is stages).

IV. CIRCUIT DIAGRAM

A 555 timer is used astable mode, i.e., pin 2 and 6 are shorted and output is connected to base of BC547 Q6. Collector of Q6 is connected to base of Q5. Pin 3 of timer is also connected to base of Q12 which drives Q11. Collector of Q11 is connected to base of Q7, Q8, Q9 and Q10. Collectors of Q7, Q8, Q9 and Q10 are connected to pin 2 of U4, U3, U2, U1 opto-isolator IC resp. pin 1 of U4, U3, U2 and U1 is connected to Vcc. Emitters of Q7, Q8, Q9 and Q10 are grounded.

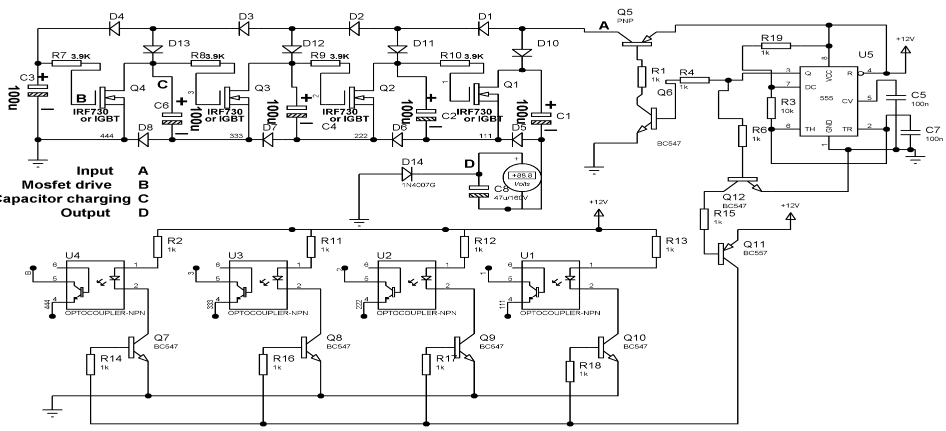

Fig.4: Circuit Diagram

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Capacitors C1 to C6 used supply the driving power to the MOSFETs while C1, C2, C4, C6 are used also for storing the charge in parallel mode while Q5 delivers positive pulses through diodes D1 to D4, D5 to D8 and D10-D13. A 555 timer is used in astable multi-vibrator mode near 50% duty cycle whose ON period delivers the power at point 'A' by 2 switching transistors Q5 & Q6. The ON period also switches to other switching transistors Q10 & Q11 which ultimately switch ON Q7 to Q10 which are used for driving the LEDs of the opto-isolators (MCT2E) U1 to U4. The output of the opto-isolators are connected to gate and source of respective MOSFETs which are thus kept switched OFF as their gate and source are at ground potential. During the OFF time period of the timer all the switching transistor Q5, Q6, Q11, Q12,& Q7 to Q10 remain OFF . This causes the capacitors C2, C3, C4 and C6 to start.

V. DESIGN DETAILS

TIMER

- Ton = 0.693 (R1+R2) C
  = 0.693 (10000+1000) 100*10^-9
  = 0.7ms

- Toff = 0.693*R2*C
  = 0.693*10000*100*10^-9
  = 0.6ms

- Duty cycle = Ton/ (Ton + Toff)
  = 0.7ms/ (0.7ms+0.6ms)
  = 53.8%

CIRCUIT SPECIFICATIONS

- C = (Vo*Δt)/(R)
  = (48*10^-3)/(3900)
  = 98.6uF≈100uF
- Capacitor - 47uF/160V, 100uF/35V, 0.1uF
- Resistors - 1k,10k,3.9k
- [range(10-100k);max voltage(50-100kV)]
- MOSFET - IRFZ44
- Diode - 1N4007
- Opto-coupler - MCT2E

VI SIMULATION

The simulation of conventional Marx generator is done to obtain HVDC upto 2kV. The circuit is shown below:

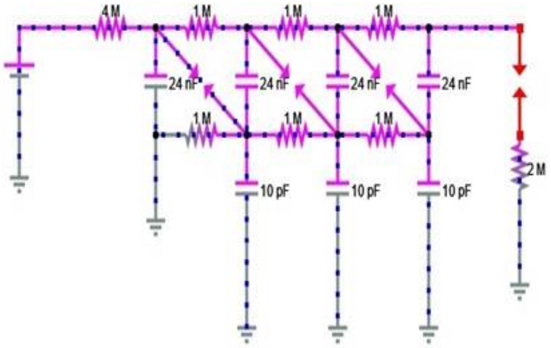

Fig.5: Marx circuit

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VII. EXPERIMENTAL RESULTS

HARDWARE

The input given was 12V for which an output of 30V was obtained due to losses.

Fig.6: Hardware Result

SOFTWARE

For an input of 1kV, 2kV output was obtained. The result is shown in Fig.7. The waveforms are shown in Fig.8.

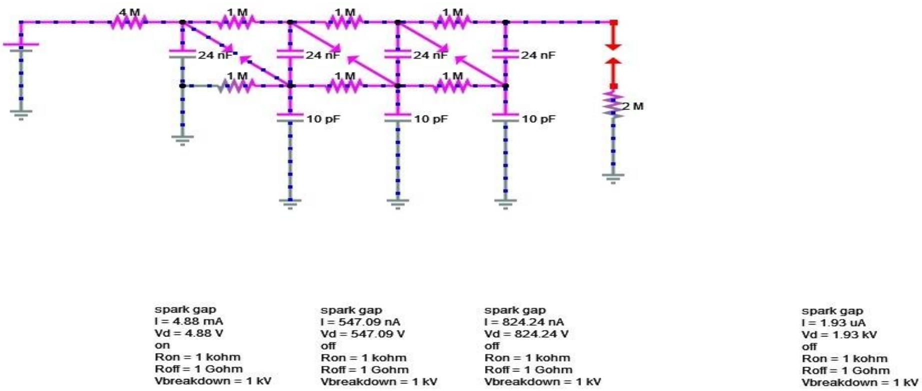

Fig.7: Simulation results

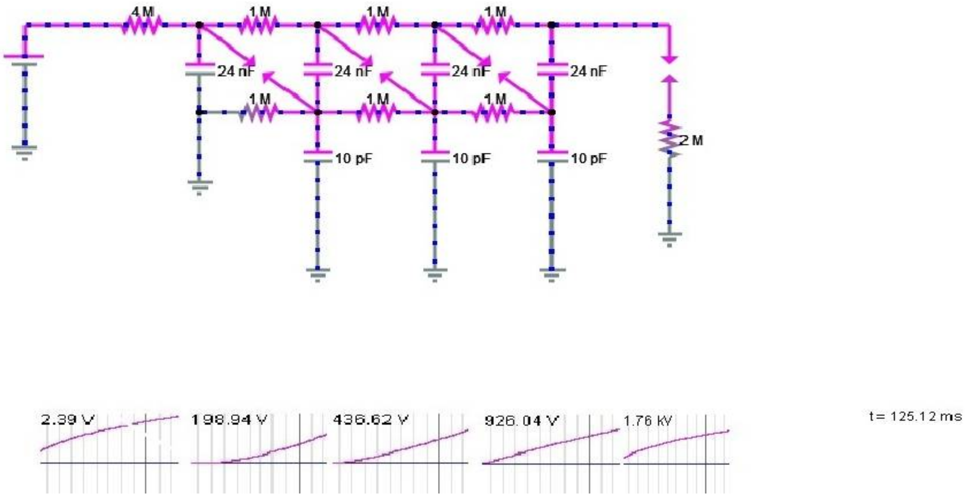

Fig.8: Waveforms from simulation

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VII. CONCLUSION

The simulation gives the idea of HVDC generation i.e., 2kV using sphere gaps. In this study, solid-state devices such as MOSFET and diodes are used in Marx generator to replace of gap switches and resistors. Furthermore, it is reasonable that MOSFET drivers utilize method of self-supplied power. The Marx generator is used to multiply voltage by using MOSFETS. Thenumber of MOSFETS used decides the number of times the voltage should be multiplied. In this study we have used four stages in hardware and the circuit multiplies the input voltage successfully.

VIII. FUTURE WORK

The output voltage can be increased to any required higher value by increasing the number of stages. The switching devices i.e., MOSFETS can be replaced by any other switching devices.

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Tokuchi1,2,3, w. Jiang2, k. Takayama3, t. Arai3, t. Kawakubo3 and t. Adachi3 1pulsed power Japan laboratory ltd., kusatsu, shiga, 525-0027, Japan 2nagaoka university of technology, nagaoka, niigata, 525-0027, Japan 3high energy accelerator research organization (kek), tsukuba, ibaraki 305-0801, Japan.

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