IGBT 스택을 이용한 Marx Generator 구현

김종현, 민병덕, 김종수, 임근희
한국전기연구원

Marx Generator Implementation Using IGBT Stack

J. H. Kim, B. D. Min, J. S. Kim, and G. H. Rim
Korea Electrotechnology Research Institute (KERI)

ABSTRACT

High voltage pulse power supply using Marx generator and solid-state switches is proposed in this study. The Marx generator is composed of 12 stages and each stage is made of IGBT stack, two diode stacks, and capacitor. To charge the capacitors of each stage in parallel, inductive charging method is used and this method results in high efficiency and high repetition rates. It can generate the pulse voltage with the following parameters:

Voltage: up to 120kV
Rising time: sub μS
Pulse width: up to 10μS,
Pulse repetition rate: 1000pps

The proposed pulsed power generator uses IGBT stack with a simple driver and has modular design. So this system structure gives compactness and easiness to implement total system. Some experimental results are included to verify the system performances in this paper.

1. 서 론

Marx generators have been used for pulse power sources[1]. In the past they were usually implemented using spark gap technology and had low pulse repetition rates[2]. In recent years Marx generators based on semiconductor switches are proposed for high pulse repetition rates. Marx generators with high repetition rates could be used for solving the ecological problems[3], the electron-beam generation[4], the microwave generation[5], and plasma source ion implantation (PSII)[6,7]. PSII is an emerging technology for surface treatment of metal and polymer materials. Through this technology it is possible to improve surface properties of the materials such as metals, plastics and ceramics. In this paper a Marx generator with high repetition rates is implemented as a pulse power source for the PSII.

A number of Marx generators based on semiconductor switches have been proposed[8]. But these generators have a low output pulse voltage due to the limitation of voltage rating of semiconductor switches.

In this paper, a Marx generator for plasma source ion implantation is implemented using IGBT stacks. The Marx generator is composed of 12 stages and each stage is made of IGBT stack, two diode stacks, and capacitor. To overcome the limitation of voltage rating, twelve IGBTs are used in series at one IGBT stack. To charge the capacitors of each stage in parallel, inductive charging method is used and this method results in high efficiency and high repetition rates.The proposed pulsed power generator uses IGBT stack with a simple driver and has modular design. So this system structure gives compactness and easiness to implement total system. Some experimental results are included to verify the system performances in this paper.

2. 본 론

2.1 제안된 시스템의 설명

The typical Marx generator configuration is shown in Fig. 1. The main switches (S_1 ~ S_N) are implemented using the spark gap switch. The resistors are used in Marx generator to provide for charging the capacitors in charging mode and for isolation purpose in discharging (high voltage generation) mode. As the resistance values are higher, the system loss becomes lower. But the high value of resistance means a long charging time and high pulse repetition rate is impossible.

The proposed Marx generator circuit is shown in Fig. 2. The Marx generator is composed of 12 stages, which are made of IGBT stack, two diode stacks, and capacitor. And diode stack is made of nine diodes that have the rating of 1,800V and 60A. The proposed Marx generator uses inductor L1 and 24's diode stacks (DS1 ~ DS24) for charging the capacitors in charging mode and for isolation purpose in discharging mode. So the implementation of high pulse repetition rate is possible with a small loss.

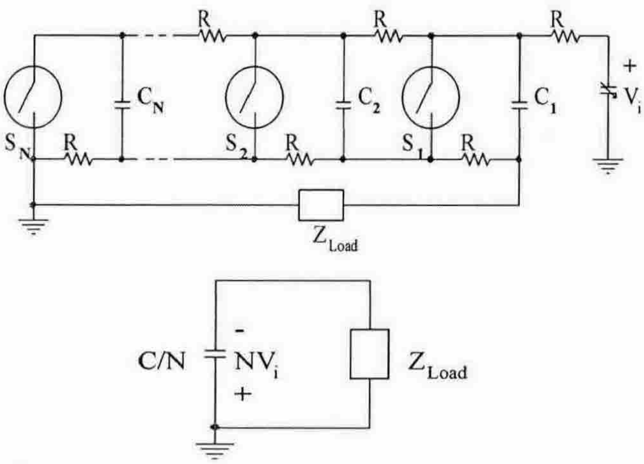


그림 1 Marx 발생기 구조 및 등가 회로
Fig. 1 Marx generator schematic and equivalent circuit.

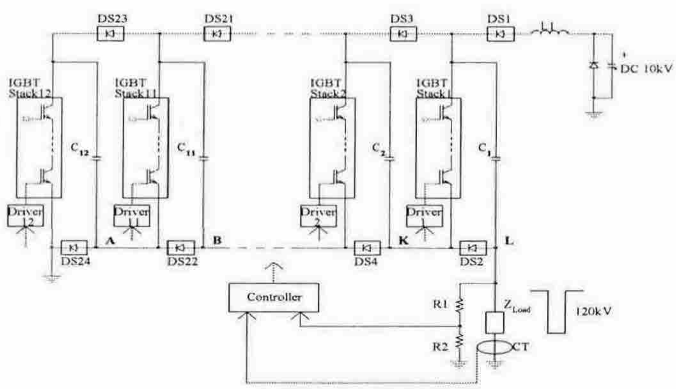
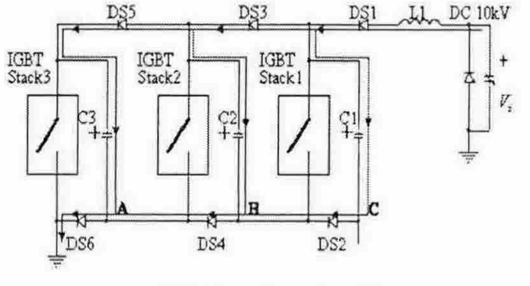
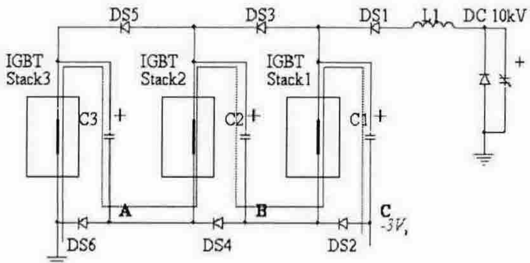


그림 2 제안된 12단 Marx 발생기의 전체 회로
Fig. 2. Overall circuit of proposed Marx generator with 12 stages.

The proposed Marx generator with 12 stages is simplified to 3 stages Marx generator as shown in Fig. 3 for simple explanation. The input DC voltage (Vi) charges each high voltage capacitors (C1 ~ C3) through an inductor (L1) and diode stacks (DS1 ~ DS6) as shown in Fig. 3, when IGBT stacks are off. The proposed Marx generator uses an inductor and diode stacks to charge 3 capacitors in parallel to the input DC voltage. The merit of using an inductor is that it could be very quickly charged and is a very efficient method. If IGBT stacks are turned on at the same time, the capacitors are simultaneously switched into a series configuration, delivering a voltage pulse to the load that is theoretically $N*V_i$ (N=3), as shown in Fig 3.



(a) Charging circuit



(b) Discharging circuit

그림 3 간단화된 Marx 발생기의 충전 및 방전(고압발생)회로
Fig. 3. Charging and discharging (high voltage generation) circuit of simplified Marx generator.

The proposed Marx generator has 12 stages and has the input voltage with maximum 10 kV. So the maximum output voltage is 120 kV. Because the proposed system uses IGBT stacks as main switches, it has a following flexibility such as pulse width and pulse repetition rate (PRR).

2.2 동작 원리

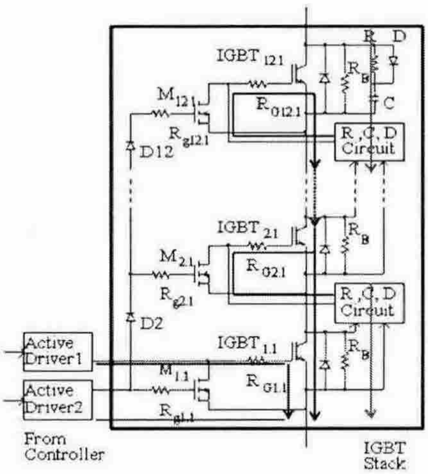
2.2.1 IGBT스택

IGBT stacks are used as main switches. Twelve IGBT stacks are utilized in the proposed system. Each IGBT stack consists of twelve IGBTs and has only two active drivers and eleven passive drivers (composed of only passive components such as resistors, capacitors, and diodes). This RCD circuit acts as a gate driver and a snubber to each IGBT switch.

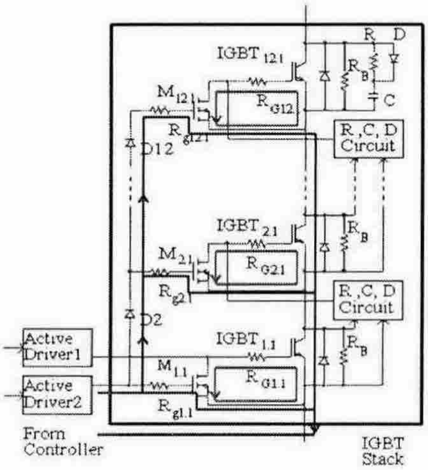
The operation of blocking mode (IGBT off state) is shown as green line in Fig. 4(a). The capacitor in the RCD circuit is charged to high voltage. And then active driver1 turns on the bottom $IGBT_{1.1}$ (red line in Fig. 4(a)). If the bottom $IGBT_{1.1}$ is turned on by the active driver1, the collect-emitter voltage of the bottom $IGBT_{1.1}$ begins to decrease (blue line in Fig. 4(a)). The decreased collect-emitter voltage of the $IGBT_{1.1}$ gives turn-on energy to gate-source of the upper $IGBT_{2.1}$. Then collect-emitter voltage of the $IGBT_{2.1}$ begins to decrease. Similarly, this decreased collect-emitter voltage of the $IGBT_{2.1}$ provides turn-on energy to gate-source of the upper $IGBT_{3.1}$. $IGBT_{4.1}$ ~ $IGBT_{12.1}$ are driven in the same method. All twelve IGBTs of the stack are turned on at the same time in this method.

With all twelve IGBTs being turned on, if the active drive2 turns on twelve FETs $M_{1.1}$ ~ $M_{12.1}$ (red line in Fig. 4(b)), then gate-source voltages of twelve IGBTs are discharged (green line in Fig. 4(b)) and all twelve IGBTs are turned off. In this method, twelve IGBTs are turned on or off simultaneously using only two active drivers.

The voltage balancing during the blocking mode is achieved using balancing resistor (RB) in parallel to the IGBT and the voltage sharing during the transient is obtained from RCD circuit. In this moment, the RCD circuit acts as an RCD snubber.



(a) Off state and transient (from on to off)



(b) transient (from off to on)

그림 4 스택 구조와 동작 원리

Fig. 4 Stack configurations and its operation principle

2.2.2 구동전원 및 신호

IGBT Stacks need isolation driver power and signal. Two active drivers need isolation power that has maximum 120kV insulation level. In this paper, the isolation voltage with 120 kV insulation level is implemented using two toroidal cores and three 50 kV insulation wires as shown in Fig. 5.

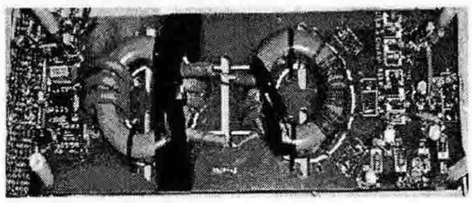


그림 5 구동전원 사진

Fig. 5 Photograph of driver power

2.2.3 커패시터

The capacitor in the Marx generator can be determined according to the discharge time constant. We design system that it allows 20% voltage drop of the output pulse voltage at maximum pulse width and maximum load. To meet above condition, capacitor should satisfy following equation (1)

$$C_n \le \frac{\tau \times V_o}{\Delta V_d \times Z_{Load}} \qquad (1)$$

Where is a maximum pulse width, V_O is the output pulse voltage, and V_d is voltage drop of the output pulse voltage. Under the 20% voltage drop condition and the parameter of Table 1, C_n is 1.5 μF. We use three 0.47 μF (20kV) capacitors to meet this value

2.3 실험 결과

In order to verify the proposed Marx generator, Marx generator shown in Fig. 2 is implemented with the parameters in Table 1. IGBTs of the IGBT stack have the ratings of 1,200V and 300A. Fig. 6 is a photograph of the proposed Marx generator with 12 stages. Fig. 7 shows pulse waveforms at resistive load of 400 Ω. Pulse voltage and current are 120 kV and 300 A, respectively. The pulse width is 3 μs and the rising and falling time of the output pulse voltage are 300 ns and 2 μs, respectively. The proposed pulse generator has high flexibility of the output voltage with respect to the PRR, the pulse width and the voltage magnitude. Fig. 8 shows waveforms of pulse voltage magnitude variation at resistive load of 400 Ω. The pulse voltage can be controlled from 20 to 120 kV. Fig. 9 shows waveforms of pulse width variation at 80kV output. The pulse width can be controlled from 2 to 10 μs. Figs. 10(a), (b) show waveforms of different pulse repetition rate at resistive load of 400 Ω. Pulse repetition rate can be controlled from 10 to 1000 pps.

표 1 시스템 상세 명세서 및 변수

Table 1. System specifications and parameters

PRR	10 ~ 1000 pps	Width	2 ~ 10 μs
Rising time	Sub μs	Falling time	2 μs
Current	Max. 300[A]	Voltage	20 ~ 120kV
L1	7 mH	C1 ~ C24	1.5 μF

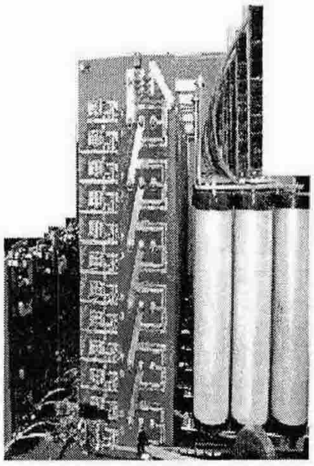


그림 6. 제안된 Marx 발생기의 사진
Fig. 6.Photograph of the proposed Marx generator.

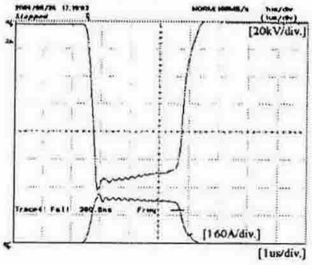


그림 7 120kV 펄스 출력 파형
Fig. 7. 120kV pulse output waveforms.

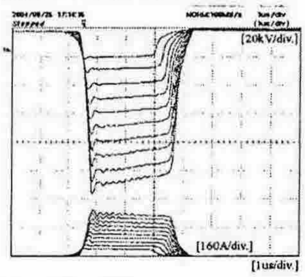


그림 8 펄스 전압 변화 파형
Fig. 8 Waveforms of pulse voltage variation

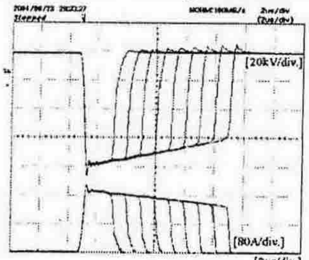
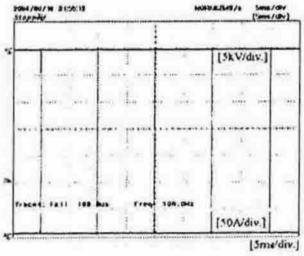
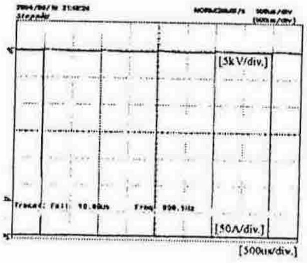


그림 9 펄스 폭 변화 파형
Fig. 9 Waveforms of pulse width variation.





(a) 100 pps (b) 1000 pps
그림 10 다양한 펄스 반복률에서의 파형
Fig. 10. Waveforms of different pulse repetition rate

3. 결 론

The Marx generator using IGBT stacks is proposed and implemented in this study. The Marx generator is composed of 12 stages and each stage is made of IGBT stack, two diode stacks, and capacitor. The developed system has the advantages of high efficiency, long lifetime, and high parameter flexibility such as voltage magnitude, the PRR, and the pulse width. The experimental results show the possibility of the proposed system as pulse power generator for the plasma source ion implantation source.

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