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반도체 스위치를 이용한 양방향 고압 펄스 발생기

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Bi-polar High-voltage Pulse Generator Using Semiconductor switches

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ABSTRACT

A semiconductor switch-based fast bi-polar high voltage pulse generator is proposed in this paper. The proposed pulse system is made of a thyristor based-rectifier, DC link capacitor, a push-pull resonant inverter, a high voltage transformer, secondary capacitor, a high voltage IGBT & diode stacks, and a variable capacitor. The proposed system makes bi-polar high voltage sinusoidal waveform using resonance between leakage inductance of the transformer and secondary capacitor and transfers energy to output load at maximum of the secondary capacitor voltage. Compared to previous bi-polar high voltage pulse power supply using nonlinear transmission line, the proposed pulse power system using only semiconductor switches has simple structure and gives high efficiency

1. 서 론

The most frequently used methods for producing the plasma are the dielectric barrier (silent) discharge and the pulse corona discharge. It has been reported[1] that under the same experimental conditions, pulse corona discharge is superior in respect of energy efficiency. But a uni-polar pulse is not suitable for a large capacitor reactor[2]. If a bi-polar pulse voltage is applied, lots of electrons can be produced. Many electrons are produced near the wire electrode while a positive voltage is applied to the wire electrode of the gas discharge reactor and those are emitted to all over the discharge tube when a negative voltage is applied. So, a bi-polar pulsed voltage is good for a large-capacitor flue gas[3].

Uni-polar voltage pulse generators using semiconductor switches are frequently supposed[4],[5]. But this is not proper for a large capacitor reactor. Fast bi-polar voltage pulse generator using nonlinear transmission line[6] can be used for pulse corona discharge. But this technology is not effective in the power efficiency and the total cost.

In this paper, a semiconductor switch-based fast bi-polar high voltage pulse generator for a large capacitor reactor is proposed. The proposed pulse system is made of a thyristor based-rectifier, DC link, a push-pull resonant inverter, a high voltage transformer, secondary capacitor, a high voltage switch & diode module, and a variable capacitor. The proposed system makes bi-polar high voltage sinusoidal waveform using resonance between leakage inductance of the transformer and secondary capacitor and transfers energy to output load at maximum of the secondary capacitor voltage. Compared to previous bi-polar high voltage pulse power supply using nonlinear transmission line, the proposed pulse power system using only semiconductor switches has simple structure and gives high efficiency.

2. 본 론

2.1 Descriptions of the proposed system

The block diagram of the proposed bi-polar pulse system and its total circuit are shown in Fig. 1, 2. The proposed pulse system is made of a preregulator (thyristor based-rectifier), DC link, a push-pull resonant inverter, a high voltage transformer, charging capacitors, a high voltage switch & diode stacks, and a variable capacitor.

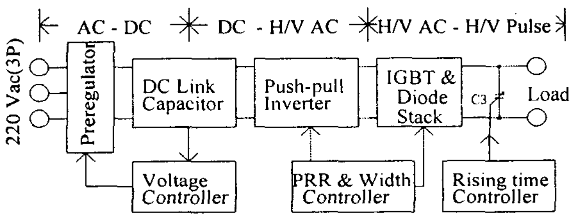


그림 1 양방향 펄스 시스템의 개략도

Fig. 1 Block diagram of the bi-polar pulse system

The proposed pulse system can be divided into three conversion parts as follows:

1) AC DC: DC output of the preregulator is controlled for pulse amplitude control. To obtain controlled DC output of the preregulator, phase controlled rectifier is used.

2) DC H/V (high voltage) AC: The controlled DC voltage is changed to bi-polar high voltage sinusoidal AC voltage. Bi-polar waveform is obtained push-pull inverter and high voltage is determined by transformer turn ratio and sinusoidal waveform is obtained by resonance between leakage inductance of the transformer and secondary capacitor.

3) H/V AC H/V pulse: Bi-polar high voltage sinusoidal AC voltage is changed to high voltage pulse voltage. In this part, timing is very important factor. On timing of switch stacks composed of 80's IGBT (20 series, 4 parallel) is set at maximum of the secondary capacitor voltage. At this moment, the secondary capacitor energy is transferred to load. PRR (pulse repetition rate) & width controller regulate the PRR and pulse width. And the rising time of pulse is controlled by variable capacitor.

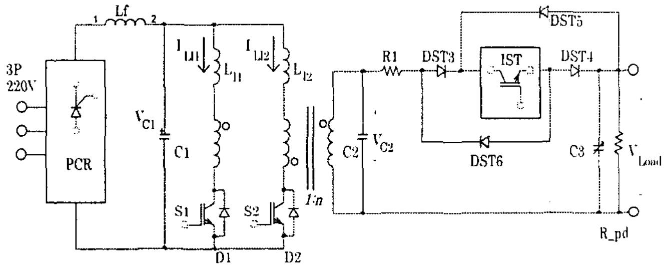


그림 2 제안된 펄스 시스템의 회로도

Fig. 2 Circuit of the proposed pulse system

2.2 Operational principle

The equivalent circuits of positive sinusoidal voltage generation mode are shown Figs. 3(a), (b). The capacitor $C1$ is DC link capacitor and $L_{l1,2}$ are transformer leakage inductance. Secondary side capacitor $C2$ is transferred to $n^2.C2$ and secondary side capacitor voltage V_{C2} is transferred to V_{C2}/n in the primary side.

Fig. 4 shows the simulation waveform during one cycle of operation. Simulation parameters are same as the experiment parameter as shown part 2.3. The operation mode can be divided into positive sinusoidal voltage generation mode and negative sinusoidal voltage generation mode. Positive sinusoidal voltage generation mode(resonance between L_{l1} and n^2C2) begins when the switch $S1$ is turned on at $t=t_0$.

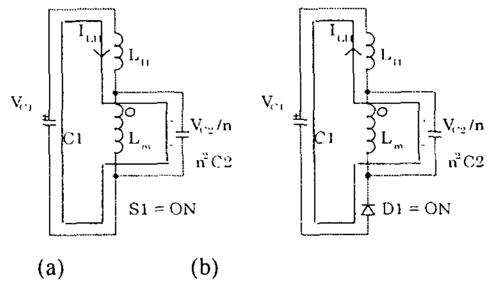


그림 3 푸시풀 인버터의 등가회로

Fig. 3 The equivalent circuit of push-pull inverter

The transformer leakage current I_{Ll1} and the secondary capacitor voltage V_{C2} are increased by the voltage source V_{C1} as shown Fig. 3(b). When V_{C2}/n is equal to V_{C1} at $t=t_1$, I_{Ll1} begins to decrease. But V_{C2} continues to increase due to positive leakage current I_{Ll1}. When I_{Ll1} comes to zero at $t=t_2$ and the secondary capacitor voltage V_{C2} has maximum value. After $t=t_2$, the direction of leakage current I_{Ll1} changes to negative, the leakage current I_{Ll1} conducts through diode ($D1$) across $S1$as shown Fig. 3(c) and V_{C2} begins to decrease. When V_{C2}/n is equal to V_{C1} at $t=t_3$, I_{Ll1} begins to increase. But V_{C2} continues to decrease due to negative leakage current I_{Ll1}. When I_{Ll1} comes to zero at $t=t_4$, positive sinusoidal voltage generation mode is completed. One cycle time of this generation mode can be expressed as follows;

$$T = 2\pi\sqrt{L_{l1}n^2 \cdot C2} \tag{1}$$

For one cycle completion of the sinusoidal voltage generation mode, on time (T_{on}) of the switch $S1$ must be greater than $T/2$ and less than T. Negative sinusoidal voltage generation mode begins when the switch $S2$ is turned on and the operation principle is similar to that of positive sinusoidal voltage generation mode.

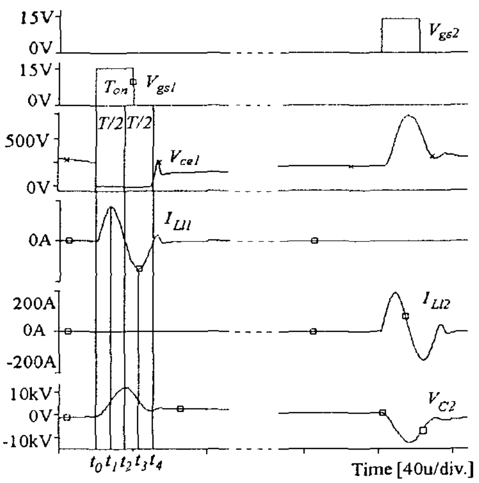


그림 4 푸시풀 인버터의 시뮬레이션 파형

Fig. 4 Simulation waveform of push-pull inverter

Bi-polar high voltage pulse generation circuit of the proposed pulse system is shown in Fig. 5. When the secondary capacitor voltage V_{C2} has maximum value, the IGBT stack (*IST*) is turned on and the capacitor energy transferred to load through the *R1*, *DST3*, *IST*, and *DST4*. When the secondary capacitor voltage V_{C2} has minimum value, the IGBT stack (*IST*) is turned on and the capacitor energy transferred to load through the *R1*, *DST6*, *IST*, and *DST5*. R1 is protection resister for IGBT & Diode stack at fault condition (output short) and *R_pd* is pull down resistor.

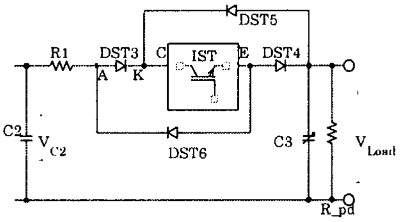


그림 5 양방향 펄스 발생 회로

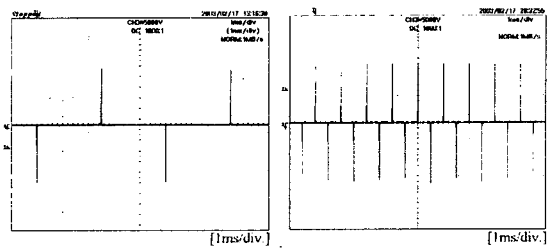
Fig. 5 Bi-polar pulse generation circuit

2.3 Experimental result

In order to verify the proposed pulse system, pulse system shown in Fig. 2 is implemented with the following parameters:

$PRR = 200 \sim 2000\ [Hz]$, $L_F = 150\ [mH]$
$C1 = 6000\ [mF]$, $C2 = 4\ [nF]$,
$L_{l1} \cong L_{l2} = 6.7\ [mH]$, $L_m = 2.8\ [mH]$,
$n = 26.3\ (316/12)$, $C3 = 200 \sim 1000\ [pF]$,
$R1 = 200\ [W]$, $R\_pd = 10\ [k\Omega]$.

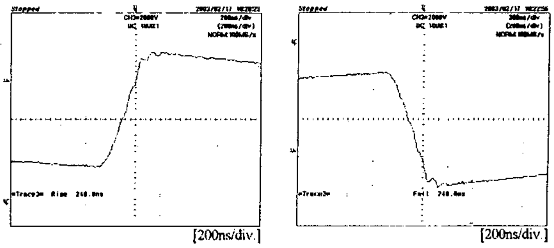
Main IGBTs (S1 and S2) are BSM300GB120DLC manufactured by Eupec and IGBT of the stack (*IST*) is IRG4PH50K manufactured by International Rectifier and diode of the stack (*DST*) is SKR48F12 manufactured by SEMIKRON. Fig. 6 shows positive & negative 11kV output waveform at different PRR. The PRR can be changed easily from 100[Hz] to 1000[Hz]. Fig. 7 shows positive & negative 11kV output with a 250[ns] rising time. This is a very fast rising time. The rising time can be



(a) 100 Hz (b) 1000 Hz

그림 6 다른 PRR에서의 출력 파형

Fig. 6 Output waveform [5kV/div.] at different PRR



(a) Positive 11 [kV] (b) Negative 11 [kV]

그림 7 250[nS] 상승시간을 갖는 출력 파형

Fig. 7 Output waveform with a 250[ns] rising time

adjusted easily by variable capacitor. From the experimental results, it is shown that the proposed pulse system produces a very fast bi-polar pulse.

3. 결 론

A semiconductor switch-based fast bi-polar high voltage pulse generator is proposed and implemented. The proposed pulse system can generator a bi-polar high voltage pulse from a low voltage source. Compared to previous system using nonlinear transmission lime, the proposed pulse system is effective in the power efficiency and the total cost.

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