Novel Compact Current Type Pulse Power Generator

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Abstract

This paper proposes a compact pulse generator for NOx removal application for diesel automotive. The rising time is important factor to increase NOx removal efficiency in pulsed corona discharge method. Manufacturing cost and compactness of the pulse power generator should be satisfied for automotive application. The proposed pulse power uses a low voltage thyristor, a pulse transformer with the function of saturated magnetic switch, and series connected general diodes as opening switch to satisfy that requirements. With 200 resistor load, the experiment results show that the output voltage is 21kV, the rising time is about 21ns, and the pulse width (FWHM) is about 42ns.

I. INTRODUCTION

At the last years pulsed power technologies are used more and more widely for various industrial applications, in particular, for pollution gas treatment for engine car. For this purpose a compact, long lifetime, reliable, inexpensive system is needed for generating high-voltage pulses with amplitude of 10~30 kV [1-4], pulse width of 20~50 ns (time of primary streamer propagation) [5], rising time of less than 20 ns, and average power of less than 100 W.

Semiconductor closing switches such as thyristors, IGBTs, MOSFETs are the most popular for such pulse generators because of their compactness, low cost, high repetition rate. However, they have limitations on rate voltage and switching speed. To generate high-voltage pulse it needs to connect these semiconductor devices in series for high-voltage stacks, or to use step-up transformers. Because both of them increase inductance of a discharging circuit, that system has the inherent drawbacks for short pulse generation. Therefore, additional pulse compression circuits are required between the primary capacitive energy storage and the load.

In [6] the pulse generator employing a saturable step-up pulse transformer is reported to transfer and compress the electric energy. At the output of the pulse compression circuit, a high-voltage diode stack using semiconductor opening switch (SOS) with an inductive energy storage system is used to obtain shorter pulse duration. Specially designed diode is used as an opening switch, SOS-60-4 (produced in Russia). Peak voltage of 13 kV, pulse width (FWHM) of 20 ns and rise time of 20 ns were obtained on the resistive load of 200 Ω at repetition rate of 1 kHz.

II. ELECTRIC CIRCUITRY AND DESIGN

The effect of super-fast recovery of high-voltage diode (Drift Step Recovery Diode, DSRD) in nanosecond time range is known from 1980s [7]. It has been found that under certain correlation between diode base layer characteristics and forward and reverse pulse currents the recovery process may be two orders faster in comparing with usual one.

We examined several types of commercial diodes and reached a conclusion that the diode built in thyristor TD46F12KFC (EUPEC) has suitable characteristics to be used as DSRD diodes. Only the diode in the thyristor-diode module is extracted and stacked 20 pieces in series to reduce their total inductance. The simplified electrical scheme of the proposed pulse generator is presented in Fig. 1.

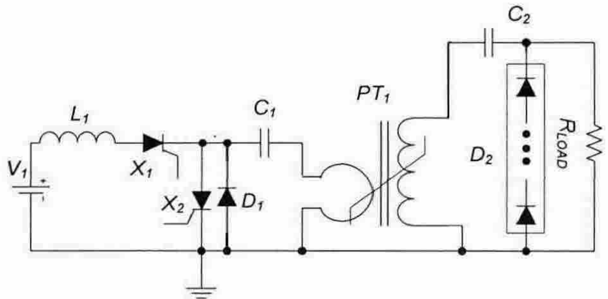

Figure 1. The simplified electrical scheme of the proposed pulse generator

Here, the primary capacitor, C_1 is charged up to 1 kV from DC power supply via inductor, L_1, the thyristor X_1, and the primary winding of the saturable pulse transformer PT_1 using toroidal ferrite core. The secondary winding has 18 turns with high voltage cable. One-turn primary winding is made by a copper foil, 0.2mm. The winding structure of the pulse transformer is made with minimal gap to reduce the leakage inductance. The inner layer is n turns secondary winding with high voltage cable and the outer layer is one turn primary winding with copper foil. The main initial pulse switch X_2 is the thyristor of type of TD46F12KFC (EUPEC). Because this thyristor is used in non-typical mode for high amplitude of current (the order 1kA) and high value of *dI/dt* (several kA/ms), the special triggering system with high current and fast rising time is required to operate the thyristor in this non-typical mode. Parameters of the triggering system are that amplitude of the trigger pulse current is 30 A, and the rise time of the triggering pulse current is equal to 40 ns. To secure the recovery time of thyristor X_2, the triggering signal of thyristor, X_1 to charge the capacitor, C1 is delayed for 400μs before next charging processor. The inductor, L_1 does not only limit charging current but also provides the demagnetization current for ferrite core PT_1 saturated after transmitting energy to the secondary capacitor C_2. The operating modes of the proposed pulse generator are divided as follows:

Mode 1

In this mode shown in figure 2, thyristor X1 is turned on and the energy is charged to capacitor C_1 from DC power source through inductor L_1, thyristor X_1, and pulse transformer PT_1.

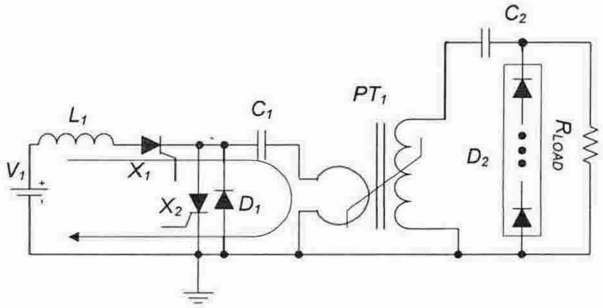

Figure 2. Charging mode

Mode 2

Thyristor X_2 is turned on. The energy charged in capacitor C_1 is transferred to the capacitor C_2 through pulse transformer PT_1 and stacked diode D_2 in forward direction. This mode is shown in figure 3.

Mode 3

When the voltage of capacitor C_2 reached at saturation voltage of pulse transformer PT_1, the transformer PT_1 is saturated. Therefore the transferred energy in capacitor C2 is transferred to the small inductance of the saturated transformer. In this time, the current flowing through the stacked diodes is reverse direction shown in figure 4. The stacked diodes are in the state of the reverse recovery mode of diode.

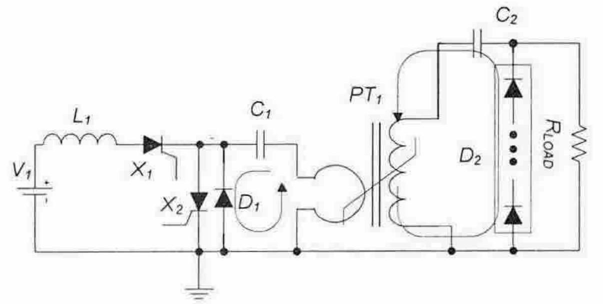

Figure 3. Transferring mode

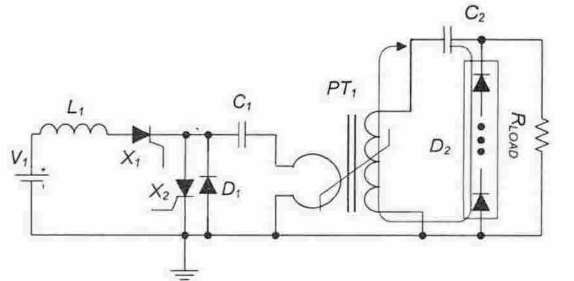

Figure 4. Reverse recovery mode

Mode 4

At the end of reverse recovery mode, the current flowing through stacked diodes is abruptly interrupted. And then the stored energy in the inductance of saturated pulse transformer is transferred to the load shown in figure 5. Because opening speed of stacked diodes is very fast, very sharp output voltage can be obtained.

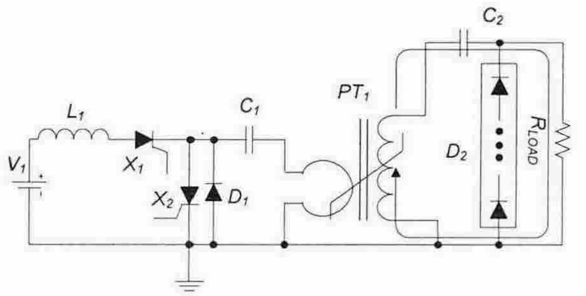

Figure 5. Output power delivery mode

III. EXPERIMENTAL RESULTS

The parameters of experimental system are as follows:

C1=0.83μF, C2=2.1nF, Load = 200Ω
Primary turn : 1, Secondary turns : 18.

The proposed compact pulse system is shown in Fig. 6. The load is the non-inductive resistor with resistance of 200 Ω inserted into coaxial conducting cylinder. To measure the pulse load current and the output pulse voltage it was designed the coaxial shunt inside a common construction together with the load. The resistance of the shunt is equal to 0.4 Ω. Therefore, the ratio coefficient of the high-voltage divider is equal to 500. The waveforms of the pulse voltage across the capacitor C_2 in the secondary winding of the pulse transformer and the pulse load voltage are shown in Fig. 7. It is seen, that energy is transferred from the capacitor C_1 to the capacitor C_2 during about 520 ns. The capacitor C_2 is charged up to 13 kV. The energy transferred to the secondary capacitor C_2 is 177mJ from initial energy (415 mJ) stored in the capacitor C_1. During the process, the remained energy which is not transferred to the secondary capacitor is in reactive elements, namely, the inductance of the primary winding and the capacitor C_1.

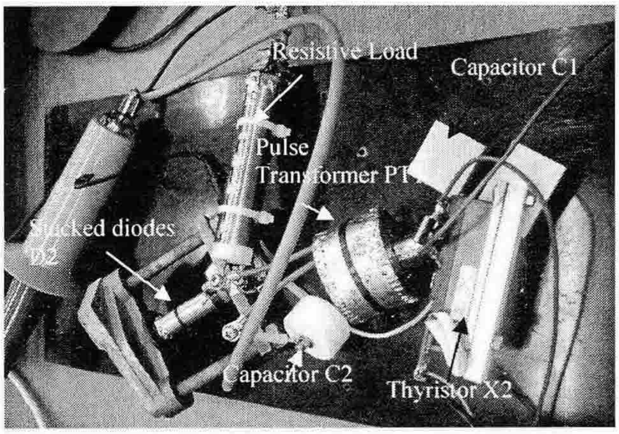

Figure 6. The experimental system of the proposed system

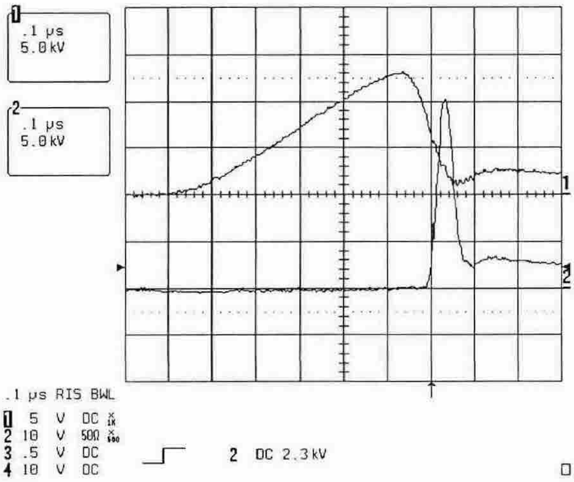

Figure 7. The voltage waveforms of secondary capacitor

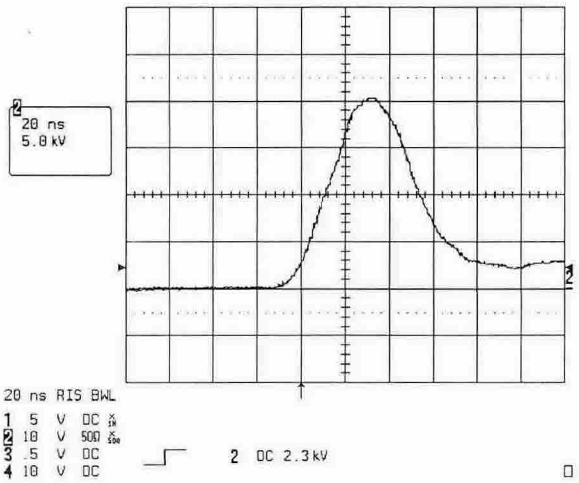

Figure 8. Output Voltage Waveforms(5kV/div)

C2(CH1:5kV/div) and load(CH2:5kV/div). The waveform of the pulse load voltage is shown in Fig. 4. Its amplitude is about 21 kV, the rising time (0.1 ~ 0.9 of amplitude) is about 21 ns, the pulse width in full width at half maximum (FWHM) is about 42 ns. The pulse current via the thyristor reaches to 1.8 kA. This high pulse current causes high loss in the thyristor. It is estimated that approximately the half of initial energy dissipated in the thyristor and diodes. Therefore we did not speed up testing on high repetition frequency. The amplitude of forward pulse current via the DSRD diode is about 90A, and reverse current is 200A. However, only half of this current passed into the load, because the difference between the load and the equivalent resistance of DSRC diodes is large.

IV. CONCLUSIONS

In this paper, a compact pulse generator is proposed to obtain the high speed pulse output without the special devices like SOS diode or SI thyristor. The effect of super-fast recovery of high-voltage diode (Drift Step Recovery Diode, DSRD) in nanosecond time range is used for opening switch function. The characteristics of the high speed opening switch can be achieved using only commercial diodes. The remained theme of research is to improve efficiency of the system and to provide high repetition rate.

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