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<th>All solid state pulsed power system for water discharge</th>
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<td>Author(s)</td>
<td>Sakugawa, Takashi; Yamaguchi, Takahiro; Yamamoto, Kunihiro; Kiyan, Tsuyoshi; Namihira, Takao; Katsuki, Sunao; Akiyama, Hidenori</td>
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Abstract

Pulsed power has been used to produce non-thermal plasmas in gases that generate a high electric field at the tip of streamer discharges, where high energy electrons, free radicals, and ozone are produced. Recently, all solid state pulsed power generators, which are operated with high repetition rate, long lifetime and high reliability, have been developed for industrial applications, such as high repetition rate pulsed gas lasers, high energy density plasma (EUV sources) and water discharges. We have studied and developed repetitive all solid state pulsed power system for applications to water discharge. The developed system consists of a photo-voltaic generator, a Pb battery, an inverter, a controller, a command charger, a high-speed thyristor, a magnetic pulse compression circuit and a pulse transformer, and has mobility. This system can generate an output peak voltage of over 100 kV with voltage rise time of 200 ns. In this work, large volume streamer like discharges in water were produced by the developed system and this discharge plasma used to treat water with point-to-plane simple electrodes.

I. INTRODUCTION

In recent years, researches on practical industrial applications of repetitive pulsed power generated by a magnetic pulse compression circuit (MPC) have been increased. These researches have focused on lasers for a long time. In particular, the excimer laser, which is used as a microlithographic light source in semiconductor fabrication, requires a high repetition rate, a high stability, and a long lifetime. Therefore, most of the excimer lasers for microlithography use a semiconductor switch and a MPC for their exciter [1,2]. Moreover, the applications to environmental fields involving the decompositions of harmful gases, removal of volatile, toxic compounds such as dioxin, the generation of ozone, phenol removal, and atomized organic dye utilizing pulsed power discharges have been studied [3-8]. In these applications, the repetitive operation and the long lifetime are also necessary for the pulsed power generators. Here, all solid state repetitive pulsed power system and large volume streamer discharges in water are described. These streamer discharges in liquids are able to produce a high electric field, high energy electrons, ozone, chemically activate species, ultraviolet rays, and shock waves, which readily sterilize microorganisms and decompose molecules and materials. An application of this phenomenon to the cleaning of lakes and marshes is also described. We described the details in this paper because we developed the maintenance free all solid state pulsed power system for the discharge in water.

II. PULSED POWER SYSTEM COMPONENTS

A block diagram of repetitive pulsed power system that we developed is shown in Figure 1. The developed system consists of a photo-voltaic generator, a Pb battery, a DC/AC inverter, a controller, a command charger, a high-speed thyristor, a MPC, a Blumlein type pulse forming network (B-PFN) and a pulse transformer, and has mobility.

The Photo-voltaic generator can generate maximum electric power of 200 W. The electric power that generated power with the photo-voltaic generator is stored to the Pb battery with the DC voltage of 24 V. The DC power that was stored to the Pb battery is inverted to power of AC 200 V by using the DC/AC inverter. Even using the AC power supply from the commercial electric power is possible directly.

The controller does the supply of electricity to the each module of this system, and generate control signal. The main control signals are charging voltage, pulse repetition frequency and trigger of thyristor. There is an abnormal diagnosis function to this controller.

The charger is high voltage power supply using resonant inverter (202A, LAMBDA EMI). An average capacitor charging rate is 2000 J/s (Joule per second).

A. Thyristor switch and MPC unit

The thyristor is high speed thyristor for pulsed power application (5STH20H4501, ABB). This thyristor is the structure that resembles in a gate-turn-off (GTO) thyristor. And a higher gate current is necessary for high speed switching. We used the gate circuit (FXP35Z, Meidensha) where it was developed for the high speed switching of the pulse power exclusive use. As for in this gate circuit
the higher current flow in peak turn-on gate current 120A, the current rise time 2 µs are possible. Furthermore, it was adding magnetic assist that used the saturable inductor to the switching of the thyristor. Magnetic assist has the effect that reduces the switching loss of the thyristor [8]. The switching voltage and current waveforms of thyristor using magnetic assist shown in Figure 2. The switching voltage is 3.5 kV, and the peak current is 8.6 kA, the current pulse width ($\tau_0$) is 4.4 µs.

The MPC consists of a pulse transformer (PT1), saturable inductors (SI0, SI1), and low inductance capacitors (C0, C1). A Fe-based nanocrystalline magnetic core (FT-1H, Hitachi metals Ltd) was used as the coupling core of the PT1. The PT1 have function of step-up transformer. The nanocrystalline soft magnetic alloys were used as the magnetic switches (SI0, SI1) and the pulse transformer PT1. The voltage gain of the PT1 is 6 (winding ratio, primary : secondary = 4 : 24). The capacitances of C0 and C1 are 6.6 µF and 200 nF, respectively. The charger that can provide a charge whenever the capacitor C0 requires was employed. The thyristor turned on with the current I0, and then SI0 saturated (turned on) immediately after the assist time. The current I0 with duration of 4.4 µs flowed in the primary circuit. As a result, C1 is charged to a high-voltage through the PT1. In this time, SI1 performed as a current blocking, during to charge C1, also acts as a low inductance switch to the discharge of C1. Finally, the pulse current with the duration of about 1.8 µs was generated after saturating the SI1. On the other hand, the B-PFN was charged by the output current from the MPC. Figure 3 shows the voltage waveforms MPC.

B. B-PFN unit

The B-PFN unit consisted of ceramic capacitor, inductor, a magnetic switch (SI2), and a high voltage step-up pulse transformer (PT2). The voltage gain of the PT2 is 6 (winding ratio, primary : secondary = 1 : 6). The MPC is used as a charging generator for the B-PFN. The B-PFN is charged by the MPC output current. A maximum B-PFN charging voltage is about -20 kV.

The capacitance and inductance of the B-PFN were, 200 nF and 640 nH, respectively. The output voltage from the PT2 was successfully as same as the step-up voltage to it. The output voltage was over 100 kV.

Figure 4 shows the typical waveforms of the output voltage and current from the PT2 for discharge in water. It will be observed that the peak voltage, rise time and pulse width (FWHM) were 108 kV, 200 ns and 1µs respectively. While that of the discharge peak current was 5.4 kA.

Figure 5 shows a photograph of the all solid state pulsed power system in a cube box without the photo-voltaic generator. The box dimension is 1 m cubed, and this system is capable of mobility and using out of door.
Figure 3. Each capacitor voltage waveforms in Thyristor and MPC unit.

Figure 4. The typical output voltage and current waveforms of the PT for discharge in water.

Figure 5. The photograph of the all solid state pulsed power system in a cube box without the photo-voltaic generator.

III. STREAMER DISCHARGE IN WATER

In this work, large volume streamer like discharges in water was produced by the developed this system and this discharge plasma used to treat water with point-to-plane simple electrodes. Figure 6 shows a photograph of a streamer discharge in water. The streamer discharge is growing in a radially from the tip of the positive point electrode. The diameter of tip-tip of the streamer is about 70 mm.

Manifestations of streamer discharges have been used in the treatment of exhaust gases, removal of volatile and toxic compound such as dioxin, and the sterilization of microorganism. An algae (Microcystis) called aoko voluminous outbreak in summer, and cause an environmental problem. Here, streamer discharges in water for algae treatment are described. These streamer discharges in liquids are able to produce a high electric field, high energy electrons, ozone, chemically active species, ultraviolet rays, and shock waves, which readily sterilize microorganisms and decompose molecules and materials. An application of this phenomenon to the cleaning of lakes and marshes using pulsed power system for algae treatment is also described. Photographs of algae
treatment is before treatment and after treatment shown in Figure 7. Usually, algae exists surface of the water. The upper photograph of Figure 7 is algae before treatment. The under photograph of Figure 7 is algae after treatment by streamer. After treatment, the algae were precipitated to a bottom.

![Figure 6. Streamer discharge in water](image)

Figure 6. Streamer discharge in water

![Figure 7. Photographs of algae (Microcystis). [Upper photograph of algae before treatment, under photograph of algae after treatment]](image)

Figure 7. Photographs of algae (Microcystis). [Upper photograph of algae before treatment, under photograph of algae after treatment]

**IV. SUMMARY**

We have developed the maintenance free and mobility all solid state pulsed power system for water discharge. The output voltage was observed that the peak voltage, rise time and pulse width (FWHM) were 108 kV, 200ns and 1μs respectively. While that of the streamer discharge peak current was 5.4 kA.

Here, streamer discharges in water for algae treatment were succeed.

The near future plan should be field test of algae treatment.

**V. REFERENCES**


