스트리머 발생을 위한 새로운 PDM 고주파 인버터

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A Novel Pulse Density Modulated High Frequency Inverter for Streamer Reactor

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Abstract - This paper presents a novel prototype of a current source resonant inverter using insulated gate bipolar transistors for driving a streamer reactor, streamer generation technology has been recognized as one of the best methods for water treatment, disinfection, industrial wastes utilization, and so on. However, some technological difficulties related to efficient streamer production have been significant problems restricting streamer usage in the industrial plants. Introduced in this paper is a pulse density modulated high frequency inverter for a plasma generate, which is developed with the aim to improve power conversion and control characteristics of the streamer reactor by using advances in power electronic technology. The developed system implements the feedforward control-based pulse density modulation control scheme with pulse width modulation feedback control strategy to compensate temperature and other environmental influences on streamer discharge.

1. Introduction

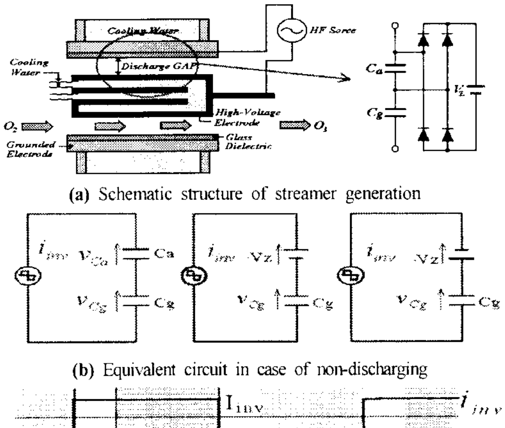
In recent years, the plasma has been widely utilized for chemical processing of water treatment and exhausted smoke treatment, depolarization, color removal and disinfection in industrial systems and public pipeline facilities. It is also particularly recognized that in semiconductor manufacturing industry fields, the broad applications of streamer reactor is hindered primarily because of low efficiency for the plasm generation. To meet this requirement, much effort for improving streamer generation and the switching mode power supplies using power transistors to drive the streamer generation has been directed to raise the streamer generation efficiency. However, there are only a few studies on miniaturization in physical size and weight, high efficiency, high performance, control stabilization of the power supply system from a power electronics point of view which drives nonlinear silent discharge based capacitive load with an active DC voltage source corresponding to the discharge sustaining voltage

In this paper, a new unique power regulation scheme of a single phase current source type parallel inductor compensated parallel load resonance high frequency inverter using a single two terminal switched capacitor type edge resonant DC link snubber is developed for driving the streamer discharge type plasma rector. The steady state power regulation characteristics of this active resonant DC link snubber assisted current source type high frequency soft switching parallel load resonant inverter which works under the principle of PDM control strategy or PDM and PWM hybrid control strategy are illustrated and evaluated as the next generation high -performance streamer generator.

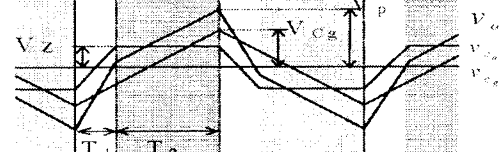
2. A Novel Pulse Density Modulated High Frequency Inverter

The streamer discharge principle in the discharge space is more widely used for the ozone gas generation, CO_2 laser generation, excimer lamp based streamer generation, plasma display panels and electric dust collector in the fields of a variety of industrial and consumer applications. In particular, the main operating principle of the streamer discharge type plasma generation driven by the current source type high frequency inverter using Mos-gate controlled power semiconductor switching devices is schematically illustrated in Fig.1. The internal structure of a newly developed high concentration and high efficient streamer generation is depicted in Fig.1 (a). This has a cylindrical structure with a stainless steel ground electrode in its outside and a high voltage stainless steel electrode in its inside frame. By supplying gas toward the inlet of the streamer generation tube across two electrodes with a stable streamer discharge area. The streamer generation produced here is composed of the discharge gap between two electrodes and the dielectric material substrate of glass spacer as a dielectric barrier inserted into two high voltage AC electrodes. The equivalent electrical circuit model considering discharge and non-discharge operation modes of the streamer discharge type generation driven and controlled by the current source type parallel load resonant high-frequency inverter using IGBTs is illustrated in Fig.1 (b).

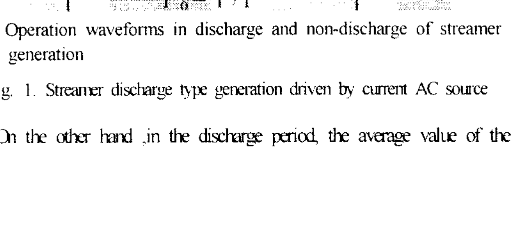
In a non-discharge period of the streamer generation, the electric circuit model of the streamer generation tube represented by the capasitor with the capacitance Ca relating to the discharge gap in series with the capacitor with the capacitance Cg relating to glass dielectric substrate as a dielectric barrier make the capacitive load with the resultant capacitance of Ca and Cg.



(a) Schematic structure of streamer generation



(b) Equivalent circuit in case of non-discharging

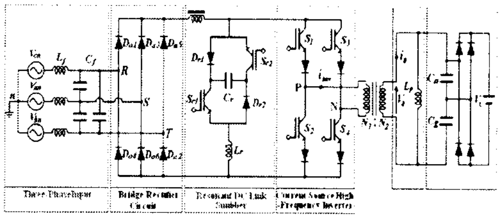


(c) Operation waveforms in discharge and non-discharge of streamer generation

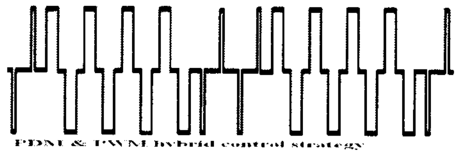
Fig. 1. Streamer discharge type generation driven by current AC source

On the other hand ,in the discharge period, the average value of the voltage across the discharge gap is approximately kept constant as the discharge property of the discharge gap, which is termed as the discharge sustaining voltage Vz represented by the AC voltage source .the positive voltage +Vz and the negative voltage -Vz. In the electric circuit model of the streamer generation, the nonlinear capacitive circuit is depicted with DC voltage source Vz via the full bridge diode rectifier connected in parallel with the discharge gap capacitor with the Ca is connected to a series capacitance Cg of glass dielectric barrier. Fig.1(c) shows the operating voltage and current waveforms of the streamer generation driven by the AC current source provided by the current source type inverter. Where, frequency f of AC voltage, f=60[Hz] discharge gap electrostatic capacitance C_a=6000[pF], glass dielectric electrostatic C_g=9000[pF] discharging sustain voltage V_z= 2000[V].

Fig. 2 shows a schematic configuration of power conversion circuit for a next generation ozonizer driven by a current source type high-frequency parallel load resonant inverter using two terminal switched capacitor type active quasi resonant DC link snubber, which can operate under a principle of zero current soft switching side, high frequency step up transformer, parallel compensation resonance reactor Lp streamer generation represented by a nonlinear capacitive load, The high voltage AC has to be applied for the streamer generation tube Especially, the peak voltage of streamer generation tube is necessary for sustaining a stable silent discharge.



(a) System configuration of current source load resonant inverter with a single soft switching quasi resonant snubber.



(b) PDM&PWM hybrid control strategy

Fig.2 Current source high frequency inverter

A PDM or PDM and PWM hybrid-based power regulation methods proposed newly is effectively introduced for the 60[Hz] streamer generation load which is implemented into the current source type parallel load resonant inverter using IGBTs. The advanced new conceptual of PDM and PWM hybrid based power regulation strategy for the current source high frequency load resonant soft switching inverter with a single active resonant DC link snubber is illustrated in Fig.2(b). The effective power delivered into the streamer generation can be continuously regulated by means of high frequency AC current based PDM and the PWM hybrid control scheme. On the other hand, the PWM strategy is effectively implemented during the discharge condition fluctuation. This PDM control procedure is based upon a time ratio control or duty cycle control of the high frequency AC current pulse number modulation, which is produced by the current source type load resonant inverter employing the magnetizing inductor and the additional inductor as one of the parasitic circuit components of the high-frequency high voltage transformer.

The auxiliary active DC resonant link commutation switched capacitor circuit connected in current-source DC busline is composed of the resonant capacitor C_r, each IGBT (S_{r1} or S_{r2}) in series with each fast recovery diode (D_{r1} or D_{r2}) and resonant inductor Lr. Current commutation of a single power switch in the bridge leg side of the full bridge inverter circuit to another active power switch is to be performed on the basis of zero current soft switching transition PDM or PDM and PWM scheme. In this case, the DC bus-line current of this inverter has to be commutated from the full bridge resonant inverter power circuit to the auxiliary active resonant snubber circuit. This allows all the active power switch of the full bridge inverter to turn on and off under zero current switching conditions in spite of PWM regulation in addition to some load parameter disturbances.

Fig.3 illustrates the soft commutation operating principle based on the equivalent circuits and the steady state voltage and current operating waveforms of the resonant inductor current i_{Lr} and resonant capacitor voltage V_{cr} in the current source type switched capacitor type quasi resonant DC link snubber circuit. The steady state circuit operation of this current type parallel load resonant soft switching inverter incorporating the current source type switched capacitor resonant DC link snubber is illustrated as follows.

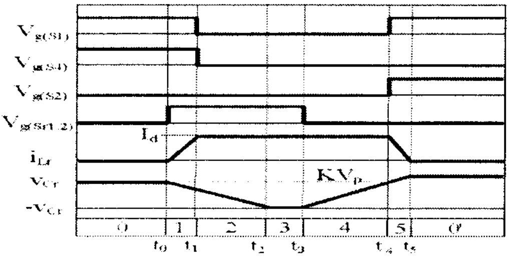
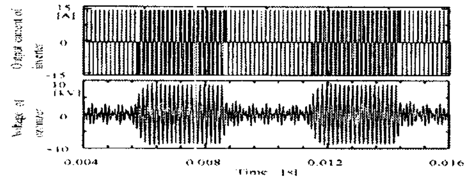
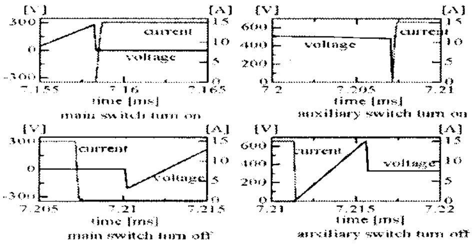


Fig.3 Timing pulse segucuces of gate voltage and operating waveforms of resonant



(a) Voltage and current waveforms



(b) Voltage and current switching wafeworms

Fig.4 Characteristic of current type ZCS-PDM & PWM inverter

The voltage and current waveforms of this parallel load resonant inverter operating under a new Pulse Density Modulation (PDM) and Pulse Width Modulation (PWM) hybrid regulation scheme are shown in Fig.4 (a). The stable inverter operation in repetitive steady state condition includes a positive polarity based charging and discharging modes in streamer generation tube as well as a negative polarity based charging and discharging modes in the streamer generation. The voltage across the discharge gap during a discharge period maintains a certain high voltage Vz when this gap voltage exceeds a specified voltage enough to start a streamer discharge. The streamer discharge type generation driven by a current source type high frequency parallel load resonant soft switching inverter using IGBTs has non-linear characteristics. Accordingly, the high voltage AC across the streamer generation has to be kept a specified peak value (7[kV]-12[kV]). In this case, its output power is delivered from the current source type high-frequency parallel load-resonant soft switching inverter. If the high-frequency AC voltage across two high voltage AC electrodes is to be much lower, the discharge phenomena does not occur at all and comes to a partial discharge phenomena. In case of a rated voltage across two high voltage AC electrodes, the electrical insulation is destructed on an edge of an streamer generation and a harmful discharge is possible to generate around two high voltage AC electrodes.

Fig. 4 (b) shows the magnified operating voltage and current switching waveforms in the case of the turn on and off soft-commutation of the main active power switch of the bridge arm of the full bridge inverter. It is proven that the switching mode transition is basically performed under a condition of no switching power losses. In addition, this figure illustrates the turning on and turning off voltage and current waveforms of the auxiliary active power switches in two terminal capacitor type active resonant DC link sunbber. It is understood that all the auxiliary active power switches in two terminal switched capacitor type resonant DC link snubber circuit do not essentially generate the switching power losses of IGBTs because of zero voltage soft switching as well as electromagnetic interference noise.

3. Review of Experiment Results

In this study, commercial AC power at 380[V], 60[Hz] is boosted up to 12[kV], 60[Hz] by means of voltage type inverter and neon transformer under the influence of DC voltage without any ripple as induced by diode rectifier and partial resonant converter. Then the voltage required for discharge becomes generated by serial resonant circuit that comprises resonant reactor and capacitance.

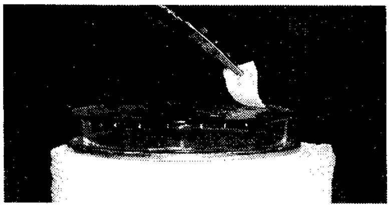


Fig. 5 Plasma reactor

Fig. 5 indicates the plasma reactor used in the experiments of this study. The reactor is flat-bed reactor that can generate the most typical unequal electric field. This reactor allows us to clearly identify the growth of plasma depending on the boost of input voltage. Therefore, the flat-bed reactor is used for this experiment, because it is considered most fit for shape analysis to determine sterilization effects depending on input voltage. Fig. 6 shows the picture of moulds cultured according to input voltage and time when sterilizing real moulds.

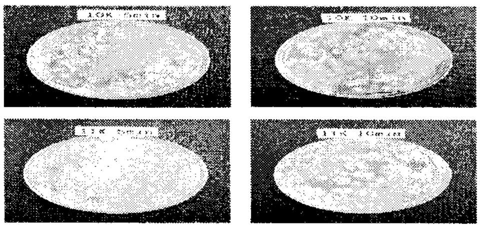


Fig. 6 The picture of mould cultivated after sterilization depending on input voltage and time

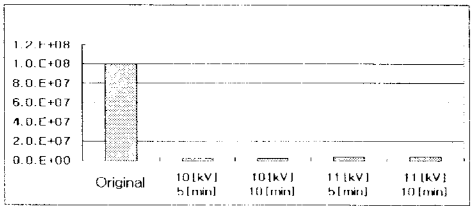


Fig. 7 The relationship between mould sterilized, input voltage and time

The shapes of specimen used for this experiment belong to fine powder type(at the size of several micron[u]) like wheat flour. Fig. 7 shows the variation in the number of moulds sterilized depending on input voltage level and time upon sterilization of real moulds. Conclusively, as the input voltage was boosted up and processing time went by, sterilization rate reached 98[%] at 10[kV], 10[min] and even saturation curves were shown under circumstance beyond 10[kV], 10[min]. Notably, it was found that sterilization efficiency could reach the best at 10[kV], 10[min] and 11[kV], 5[min]. The reason why sterilization rate was a little more decreased at 11[kV] than 10[kV] is possibly attributed to error resulting from failure to irradiate plasma energy within reactor at constantly uniform density.]

4. Conclusions

A novel prototype of the current-source type parallel compensated inductor load-resonant high frequency inverter using IGBT modules which operates under a soft commutation based upon a single two-terminal switched capacitor type active resonant DC link snubber circuit has been developed and demonstrated for driving high performance 60[Hz] streamer discharge type generation. In accordance with this PDM and PWM hybrid control strategy of the current type parallel load resonant ZCS inverter type streamer generation, in the future generation the effective output power of this current type soft switching inverter could be linearly regulated over a wide PDM duty factor range from 10[%] to 100[%] of the rated power, the soft-commutation of this current type inverter could be completely achieved under the principle of ZCS condition in the main active power switches of the inverter bridge arms and ZVS condition of auxiliary active power switches in current source type resonant DC link snubber. It was proven that excellent streamer production characteristics of the current source inverter treated here can be achieved in spite of PDM and PWM power regulation schemes. The novel current source inverter based PDM control method was more cost effective for efficiency improvement, performance enhancement of this power inverter and much more improvement of the power regulation characteristics on the nonlinear discharge and non discharge capacitance load as the streamer generation load.

In the future, the comparative studies between current type parallel load resonant soft switching inverter and voltage series load resonant soft switching inverter with PDM or PDM and PWM hybrid control schemes should be implemented for the future generation from a practical point of view. The advanced current type parallel load resonant inverter using the latest trench gate controlled IGBT modules and IPM should be evaluated and discussed for driving the streamer generation.

ACKNOWLEDGMENT

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