ACTIVE CONTROL OF ATMOSPHERIC PRESSURE DISCHARGES

J. Sláma[1], J. Bauer[2], S. Flígl[2], V. Kříha[1]

[1]Czech Technical University in Prague, Department of Physics, Prague, Czech Republic;

[2]Czech Technical University in Prague, Faculty of Electrical Engineering, Department of Electric Drives and Traction, Prague, Czech Republic

E-mail: slamajan@fel.cvut.cz

Two types of dielectric barrier discharge (DBD) powering principles were compared in this study. The variable autotransformer (sinusoidal shaped voltage) and the semiconductor H-bridge converter generating pulse width modulation (PWM, square wave shaped voltage) were used as a voltage source. Differences were found in the discharge current waveforms. Powering the DBD by PWM provides promising features for plasma application.

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INTRODUCTION

Electrical discharges as sources of plasma have been for more then hundred years in the scope of scientists and engineers. The power sources construction depends on the character of the discharge; whether it is pulse or continuous one; whether it is powered by direct or alternate voltage. Nowadays, the power electronics offers many opportunities how to control the discharge by setting the frequency, shape and amplitude of the voltage or current temporal evolution. Until now the power electronics was mostly used to control electric drives. There are many methods how to generate the voltage [1], [2]. This know-how is a good start point for behavior of the discharge active control.

1. POWER PART AND CONTROL

There are many converter topologies that can be used to generate a voltage with sinusoidal shape. However when we also consider requirement of high voltage for feeding the discharge on the output of the converter, then as a simplest solution comes the H-bridge inverter made of four transistors $\mathbf{T}_1 \ldots \mathbf{T}_4$ [3] and a high voltage transformer (HVT) with input/output voltage 0.1/35 kV (Fig. 1). The converter is supplied from a DC source with constant voltage u_{DC} and the converter's output voltage is given by the means of transistor switching.

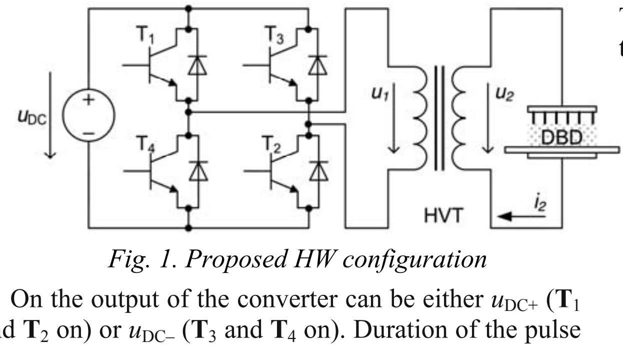

Fig. 1. Proposed HW configuration

On the output of the converter can be either $u_{\mathrm{DC+}}$ ($\mathbf{T}_1$ and $\mathbf{T}_2$ on) or $u_{\mathrm{DC-}}$ ($\mathbf{T}_3$ and $\mathbf{T}_4$ on). Duration of the pulse corresponds to the average value of the voltage

$$\bar{u}_{\mathrm{out}} = \frac{1}{T_{\mathrm{s}}} \int_0^{T_{\mathrm{s}}} u(t)\, \mathrm{d}t \qquad (1)$$

The temporal dependence $u(t)$ has square wave shape with amplitude of $u_{\mathrm{DC+}}$ for t_s<0, t_{on}> and $u_{\mathrm{DC-}}$ for t_s<t_{on}, T_{s}>, therefore we can rewrite (1) into

$$\bar{u}_{\mathrm{out}} = \frac{1}{T_{\mathrm{s}}}\Big(\int_0^{t_{\mathrm{on}}} u_{\mathrm{DC+}}(t)\,\mathrm{d}t + \int_{t_{\mathrm{on}}}^{T_{\mathrm{s}}} u_{\mathrm{DC-}}(t)\,\mathrm{d}t\Big) = \frac{t_{\mathrm{on}}}{T_{\mathrm{s}}} u_{\mathrm{DC+}} \quad (2)$$

The average value of the voltage u_{out} (2) during one switching period T_{s} can be easily controlled by the length of t_{on}. Output voltage with sinusoidal shape can be produced by slow changing of the pulse widths compared to the frequency of transistor switching. This principle is well known as the pulse width modulation (PWM).

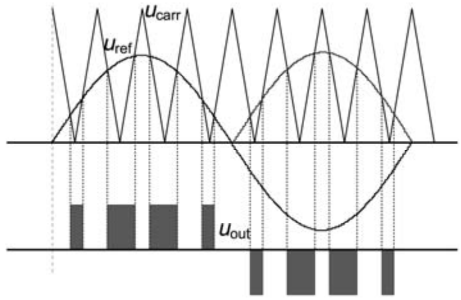

Fig. 2. The PWM principle

Formerly such a modulator was realized with a help of analogue elements by the means of comparing of a sinusoidal reference u_{ref} with a triangular carrier u_{carr} mostly in operational amplifier (Fig. 2). Such a modulator can be easily realized. However, the analogue components suffer the aging. Also effort to change modulator values causes change of the circuit components. Therefore digital realizations of the modulators come to the forefront.

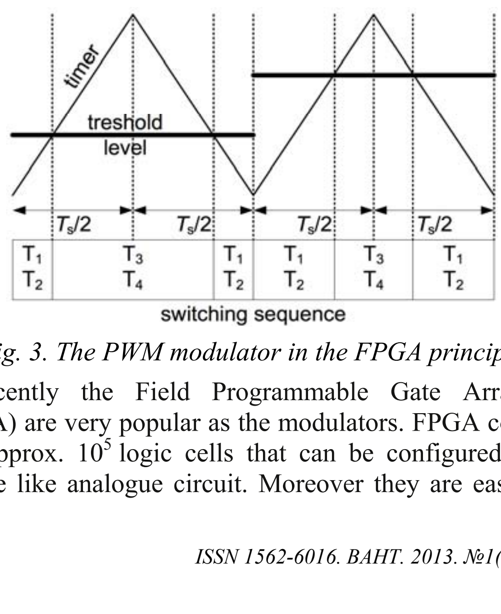

Fig. 3. The PWM modulator in the FPGA principle

Recently the Field Programmable Gate Arrays (FPGA) are very popular as the modulators. FPGA contain approx. 10^5 logic cells that can be configured to behave like analogue circuit. Moreover they are easily reprogrammable. The modulator parameters can be simply changed and also offers possibility to work with greater resolution and frequency of the output signal in comparison with the analogue realization. Triangular carrier is therefore replaced by free running counter and sine wave reference is replaced by threshold value. Therefore the threshold value must be calculated in each sampling period by superset controller (Fig. 3).

For our converter we decided to choose configuration of products offered by RTD company. Superset controller was realized by PC 400 MHz with specially modified DOS operating system. It enabled real time execution of control algorithm. Next part – the software modulator – was a board with FPGA Xilinx Spartan II. The boards communicated via PC104 bus. Switching frequency of the modulator was 20 kHz. It enabled to generate output sinusoidal voltage with frequency in range of 1 Hz to 2 kHz. This range is suitable to study discharge behavior.

2. PHYSICAL APPLICATION

Characteristic temporal intervals of discharge forming processes at atmospheric pressure plasmas are in order of 10^{-8} s [4]. An occurrence of such rapid phenomena in most electrical circuits leads to involve current/voltage oscillations; especially in circuit designed for DC or low frequency powering. Electric discharge ignites by reaching the critical value of the outer feeding voltage, breakdown electrical intensity value respectively; the ignition is given by discharge space conditions as well. However, precise quantification and prediction of discharge ignition time consequent only on outer conditions isn't usually easy; in many cases it is impossible at all.

Dielectric barrier discharge (DBD) in filamentary mode was chosen as typical load characterized by both low amplitude current noise and high amplitude ultrafast current peaks caused by filaments and sparks occurring in the discharge region. A DBD reactor made in "spike set – plane" configuration with isolated plane (barrier made of 0.1 mm thick polyethylene terephtalate) was used (similar reactor was used for polyethylene powder surface modification [5], seed treatment [6] etc.). The electrode system was powered by the HVT (see Fig. 1).

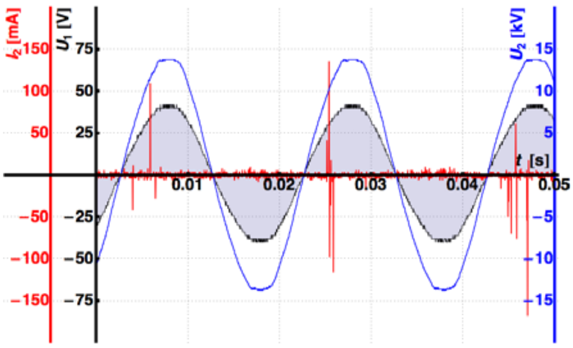

Fig. 4. 50 Hz sine powering (2½ period view, time range of 500 ms)

In cases above, there was used sinusoidal 50 Hz voltage, which was taken as a reference (Fig. 4). Typically, given by capacitive phase shift, in rise of the voltage, there appeared short current peaks with hundreds mA in amplitude.

Trying to feed the VMT in a way getting same or at least similar output high voltage to voltage given by conventional way (i.e. VMT powered by variable autotransformer), we decided to use powering based on the PWM. By contrast to sinusoidal powering (see Fig. 4) we got a square shaped voltage on the VMT's input (Fig. 5).

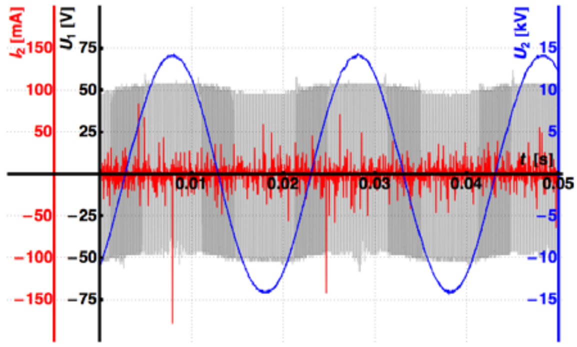

Fig. 5. 50 Hz PWM powering (2½ period view)

Comparing both figures (Figs. 4 and 5) at the first glance, the main difference is in VMT's primary voltage $U_{1,}$ i.e. sinusoidal vs. square PWM. In used time scale there is no other remarkable difference, hence a shorter timescale we captured (Figs. 6 and 7).

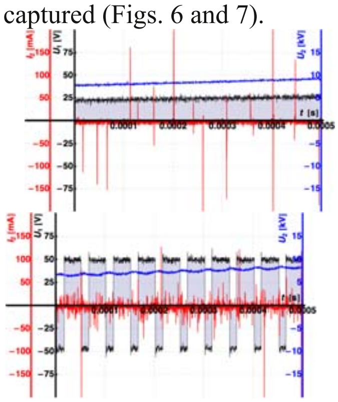

Fig. 6. 50 Hz sine (left) and PWM (right) powering (detail view, time range of 500 µs)

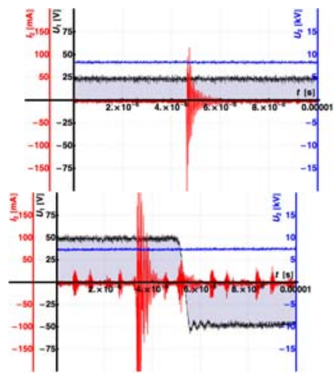

Fig. 7. 50 Hz sine (left) and PWM (right) powering (detail view, time range of 10 µs)

The first couple of measured waveforms (see Fig. 6) shows primary voltage U_1 (black), secondary high voltage U_2 (blue) and discharge current I_2 (red) in 500 µs range. On the left powered by the sinusoidal input voltage, on the right powered by the PWM. Analogically, second couple (see Fig. 7) was recorded for time range of 10 µs.

CONCLUSIONS

Focusing on waveform details (Fig. 6 and 7) we found further differences between sinusoidal and PWM input voltage. In comparison with sinusoidal, in case of PWM powering we found a huge amount of current peaks with amplitude of 10…20 mA. Roughly the same number of current peaks with amplitude of up to about 200 mA were found in both cases. These peaks appeared stochastically in ascending interval of positive voltage U_1. in case of sinusoidal powering. On the other hand, we observed noticeable association of high current peaks and transistor H-bridge commutation process (i.e. change of PWM voltage).

Quasi-periodic low current amplitude peaks (tenths of mA) emerged in PWM powering experiments only. These phenomena were not found in cases of sinusoidal powering and it should be promising for novel plasma applications.

ACKNOWLEDGEMENTS

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REFERENCES

1. M.P. Kazmierkowski, L. Malesani: Current control techniques for three-phase voltage-source PWM converters: a survey // *Industrial Electronics, IEEE Transactions on* . Oct. 1998, № 5, v. 45, p. 691-703.
2. J. Lettl, S. Flígl. PWM strategy applied to realized matrix converter system // *PIERS 2007. Proceedings of* , Czech Republic. 2007, p. 122-125.
3. H. Dehbonei, L.J. Borle, C.V. Nayar. Design and implementation of a low cost sine wave inverter // *Industrial Electronics, 2003, on* 9-11 June, 2003, v. 1, p. 280-285.
4. R. Hippler, H. Kersten, M. Schmidt, K.H. Schoenbach. Low Temperature Plasmas: Fundamentals, Technologies and Techniques // *Weinheim: Willey-VCH.* 2009*,* v. 1-2, p. 891.
5. J. Píchal, J. Hladík, P. Špatenka. Atmospheric-Air Plasma Surface Modification of Polyethylene Powder // *Plasma Processes and Polymers*. 2009, v. 6, № 2, p. 148-153.
6. B. Šerá, I. Gajdová, et al. How various plasma sources may affect seed germination and growth // *13th International Conference on Optimization of Electrical and Electronic Equipment (OPTIM)*. 2012, p. 1365-1370.

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АКТИВНЫЙ КОНТРОЛЬ РАЗРЯДОВ АТМОСФЕРНОГО ДАВЛЕНИЯ

J. Sláma, J. Bauer, S. Flígl, V. Kříha

В этом исследовании сравнивались два принципа питания диэлектрического барьерного разряда (ДБР). В качестве источника напряжения был использован регулируемый автотрансформатор (синусоидальное напряжение) и мостовой полупроводниковый инвертор напряжения, генерирующий широтно-импульсную модуляцию (ШИМ, прямоугольное напряжение). Были найдены различия в осциллограммах электрического тока разряда. Питание ДБР с помощью ШИМ предоставляет перспективные возможности для применения плазмы.

АКТИВНИЙ КОНТРОЛЬ РОЗРЯДІВ АТМОСФЕРНОГО ТИСКУ

J. Sláma, J. Bauer, S. Flígl, V. Kříha

У цьому дослідженні порівнювалися два принципи живлення діелектричного бар'єрного розряду (ДБР). Як джерело напруги був використаний регульований автотрансформатор (синусоїдальна напруга) і мостовий напівпровідниковий інвертор напруги, що генерує широтно-імпульсну модуляцію (ШІМ, прямокутна напруга). Були знайдені відмінності в осцилограмах електричного струму розряду. Живлення ДБР за допомогою ШІМ представляє перспективні можливості для вживання плазми.