INVESTIGATION OF ELECTRIC AND MAGNETIC FIELDS GENERATED BY A SYSTEM FOR FORMATION OF HIGH VOLTAGE DISCHARGE PROCESS IN LIQUID BASED ON CAPACITIVE ENERGY STORAGE

Emil S. Barudov[1], Assoc. Prof. PhD
Milena D. Ivanova[2], Assist. Prof. PhD

[1]*Nikola Vaptsarov Naval Academy, Varna, Bulgaria*
[2]*Technical University of Varna, Varna, Bulgaria*
e-mail: ugl@abv.bg; m.dicheva@tu-varna.bg

Abstract: Various technological applications require formation of a high voltage discharge pulse in liquid medium. The process is accompanied with generation of UV radiation, production of chemically active species in the medium, intensive increase of the temperature of the discharge channel, generation of shock waves, etc. The last are caused by the release of large amount of energy especially at the beginning of the discharge process.
The experimental system used for generation of a high voltage pulse discharge is based on capacitive energy accumulation. The formation of the pulse in the liquid considering the specifics of the process in such medium also affects on the processes in the electrical circuits in the device – loading of the elements, creating electromagnetic disturbances in the power supply system, generation of electromagnetic field around the device.
The paper is dedicated to investigation of a system with capacitive energy storage for generation of a high voltage periodically attenuating pulse discharge The purpose is to be measured the electric and magnetic fields generated during the charging and discharging processes near the system for assessment of the device electrical safety for the personnel.

Keywords: High voltage discharge, Pulse discharge in liquid, Electromagnetic field, Safety requirements

1. Introduction

Pulse high voltage discharges in water are object of study of many scientific researches. They give the possibility for appearance of highly ionized plasma in a limited volume (the plasma channel), assume secondary effects such as arising of a hydraulic wave, UV radiation, generation of chemically active components, which spread in large volumes of the water medium, etc. (Anpilov, 2001, Kang, 2003).

For generation of such discharges in liquids systems based on capacitive energy accumulation are mainly used. The structure of these devices includes charging and discharging circuits. The processes in them are mutually connected and influence each other as they have a common element from the electrical scheme – the work capacitor battery. It is usually charged to units or tens of kV, which provides high energy for the discharge pulses in the liquid. The charging and discharging process create electromagnetic fields (EMF) around the devices and more specifically near the commutation and switching elements. They can be harmful for the working staff if they exceed certain norm values.

The evaluation of the generated EMF is performed by comparison of the measured values of the electric field strength E [V/m] and magnetic flux density B [μT] with the action levels (ALs) for the respective frequency range, which are set in terms of external field quantities, defined in the (Directive 2013/35/EU, 2013).

The EMF Directive defines two ALs for low frequency electric fields - low and high. Compliance with the low AL will ensure that neither of the applicable exposure limit values (ELV) will be exceeded and will also prevent spark discharges in the work environment. If the electric field strengths exceed the low AL, it is necessary to implement additional technical, organisational and, if appropriate, personal protective measures to limit spark discharges (Non-binding guide to good practice for implementing Directive 2013/35/EU, 2013).

The paper is dedicated to investigation of a prototype system with capacitive energy storage for generation of a high voltage periodically attenuating pulse discharge with respect to the generated electromagnetic fields during the charging and discharging processes in them.

2. Experimental setup

The experimental system used for generation of a high voltage pulse discharge based on capacitive energy accumulation is shown in Fig.1 (Ivanova, 2013).

The system is supplied by AC voltage with U=220V/ 50Hz.

The charging circuit consists of an autotransformer ATr, a high voltage transformer HVTr, rectifier ($D_1 \div D_4$), through which is charged the work capacitor battery with capacitance C (C_1, C_2, C_3=1μF) to voltage U_c. The discharge circuit comprises a high voltage controllable switch (HVCSw), a coaxial cable and the discharge gap in the water.

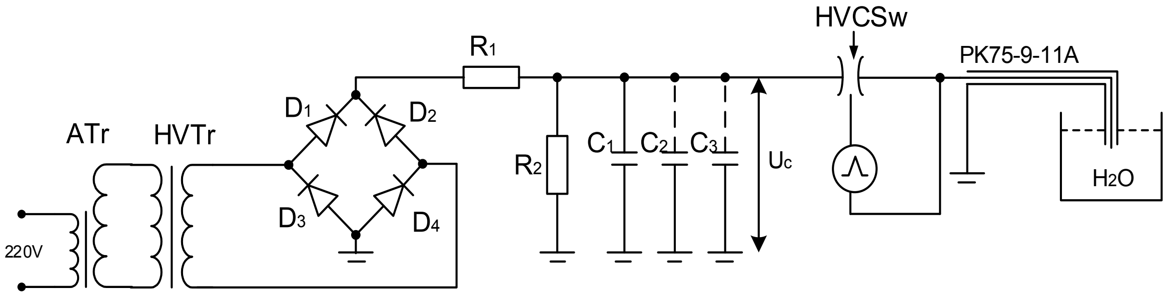

Fig. 1. Experimental prototype

For the case, as a HVCSw is used a controllable air discharge – trigatron (Fig.2) with two separated discharge circuits and two spatially divided gas-discharge channels, evolving consistently in time (Ivanova, 2012). The first channel ensures the appearance of a discharge between the control electrode and the electrode adjacent to it on the base of a single packet of high voltage high-frequency pulses. The other channel forms a high voltage pulse discharge on the base of the energy accumulated in the capacitor battery between the two main electrodes.

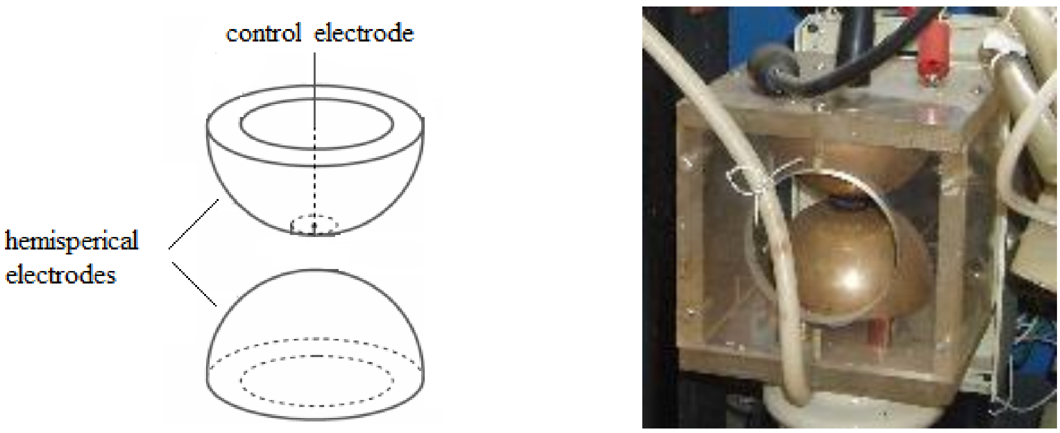

Fig. 2. Trigatron

The electromagnetic fields near the commutation and switching elements (autotransformer, high voltage transformer and trigatron) are measured at the following system parameters:

- Capacitance of the work capacitor battery C=2;3μF;
- Voltage, to which the work capacitor battery is charged – U_c=1÷6kV (charging process) and U_c=7÷11kV (discharge process).

Experimental data by using a Multi Field EMF Meter EMF 450 (Fig.3) is recorded.

In the operating frequency range of the system f=1Hz÷100kHz (including both the processes in the charging and discharging circuits) the effects over the human body are non-thermal, expressed in sensory, nerve and muscle stimulations (Non-binding guide to good practice for implementing Directive 2013/35/EU, 2013).

Assessment of the compliance with the limits, presented within the Directive 2013/35/EU is done by the maximum field value, measured near the system elements, where the field is at its maximum. The device is tested in a laboratory so there could be open live parts during the measurements. The personnel can be standing very close to the device elements and could be exposed to the maximum field values. If the measured parameters of the electric (E) and magnetic fields (B) comply with the specified norms (Tables 1 and 2) it won't be necessary to perform spatial averaging of the generated fields.

Table 1. ALs for exposure to electric fields from 1Hz to 10MHz.

Frequency range	Electric field strength Low ALs (E, Vm^{-1}) (RMS)	Electric field strength High ALs (E, Vm^{-1}) (RMS)
$1 \leq f < 25$ Hz	2×10^4	2×10^4
$25 \leq f < 50$ Hz	$5 \times 10^5/f$	2×10^4
$50 \leq f < 1{,}64$ kHz	$5 \times 10^5/f$	$1 \times 10^6/f$
$1{,}64$ kHz $\leq f < 3$ kHz	$5 \times 10^5/f$	$6{,}1 \times 10^2$
3 kHz $\leq f < 10$ MHz	$1{,}7 \times 10^2$	$6{,}1 \times 10^2$

Table 2. ALs for exposure to magnetic fields from 1Hz to 10MHz.

Frequency range	Magnetic flux density Low ALs (B, μT) (RMS)	Magnetic flux density High ALs (B, μT) (RMS)	Magnetic flux density ALs for exposure to limbs to a localized magnetic field [μT] (RMS)
$1 \leq f < 8$ Hz	$2 \times 10^5/f^2$	$3 \times 10^5/f$	$9 \times 10^5/f$
$8 \leq f < 25$ Hz	$2{,}5 \times 10^4/f$	$3 \times 10^5/f$	$9 \times 10^5/f$
$25 \leq f < 300$ Hz	1×10^3	$3 \times 10^5/f$	$9 \times 10^5/f$
300 Hz $\leq f < 3$ kHz	$3 \times 10^5/f$	$3 \times 10^5/f$	$9 \times 10^5/f$
3 kHz $\leq f < 10$ MHz	1×10^2	1×10^2	3×10^2

The low ALs and the high ALs are the root-mean-square (RMS) values which are equal to the peak values divided by $\sqrt{2}$ for sinusoidal fields.

3. Experimental results

The voltage of the two transformers from Fig.1 – ATr and HVTr is with frequency f=50Hz.

The low and high ALs of the electric field strength for f=50Hz are respectively $1{,}41.10^4$V/m and $2{,}82.10^4$V/m (peak values), according to Table 1.

The low and high ALs of the magnetic flux density for f=50Hz are respectively 1,41.10^3μT and 8,46.10^4 μT (peak values), according to Table 2.

The results from the measurements of the electric and magnetic fields near the two transformers in the system during the charging process of the capacitor battery at different C and U_c are presented in Tables 3 and 4.

Fig. 3. Multi Field EMF Meter 450

Table 3. Electric and Magnetic field values near the transformers in the charging process for C=3μF.

C=3μF	**Autotransformer**		**High voltage transformer**	
Uc, kV	**Magnetic field B, μT**	**Electrical field E, V/m**	**Magnetic field B, μT**	**Electrical field E, V/m**
1	22,9	856	0,36	13
2	25,6	891	0,53	56
3	26	983	1,6	132
4	28,1	1040	10,1	163
5	31,1	1060	13,6	182
6	34,8	1120	18,7	202

Table 4. Electric and Magnetic fields values near the transformers in the charging process for C=2μF.

C=2μF	**Autotransformer**		**High voltage transformer**	
Uc, kV	**Magnetic field B, μT**	**Electrical field E, V/m**	**Magnetic field B, μT**	**Electrical field E, V/m**
1	30,2	985	4,47	49
2	32,6	992	6,47	80
3	35,2	1000	8,57	125
4	37,8	1012	10,26	163
5	39,4	1050	11,8	202
6	41,3	1160	12,8	240

All the measured values are lower than the low ALs for the electric and magnetic fields. The results show that a stronger field is generated by the autotransformer ATr.

Hence, the generated electromagnetic fields are not considered as harmful to the human health.

The discharging process at which a high voltage discharge pulse arises in the liquid medium, has some specifics:

- The accumulated energy in the capacitor battery is transferred in the water as high voltage periodically attenuating discharge pulses (Fig.4) arise in the discharge gaps of the trigatron and in the liquid.
- The discharge processes in the HVSw and in the water have different time duration.
- The maximum amplitude of the discharge current in the water is several kAmp, which leads to generation of a magnetic pulse.
- The generated discharge pulses in the water are with frequency f=50÷70kHz and the pulses repetition rate is 5÷10Hz.

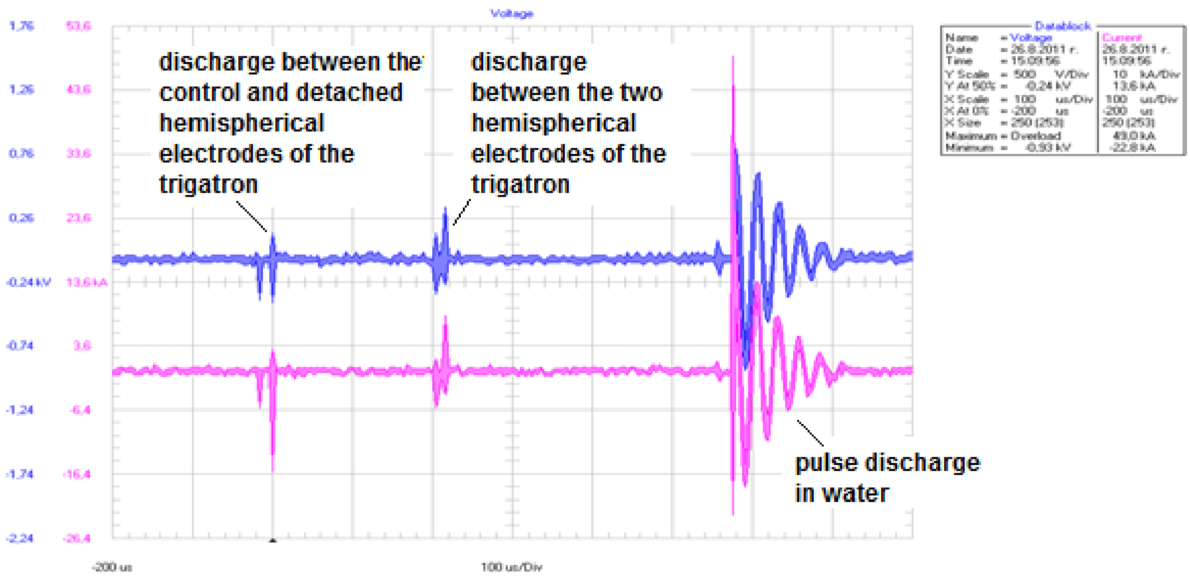

Fig. 4. Discharge process at C=2 μF and U_C=11kV (upper curve – discharge voltage, lower curve – discharge current).

The results for the generated electric and magnetic fields by ATr and HVTr for C=3μF during the discharge process are presented in Table 5.

The received values for the magnetic flux density B for both of the transformers are much higher (approximately by 70% for the highest values of the voltage U_c) than the values measured in the charging process. The generated electric field (E) is 3÷5 times weaker than the generated one in the charging process of the capacitor battery.

Table 5. Electric and Magnetic fields values near the transformers during the discharging process for C=3μF.

C=3μF	Autotransformer		High voltage transformer	
Uc, kV	Magnetic field B, μT	Electrical field E, V/m	Magnetic field B, μT	Electrical field E, V/m
7	27,5	169	20,1	14,7
8	34,6	189	23,6	15
9	45,2	236	27,5	19,2
10	56,8	287	30,7	25,6
11	64,9	321	32,1	34,8

The increase of the magnetic field can be explained by the generation of a magnetic pulse in the discharge process due to the high amplitude of the discharge current. The measured values are again under the low ALs for the electric and magnetic fields.

Measurement near the metal water container when a discharge pulse occurs are performed. Despite the high frequency of the discharge pulse, no significant data for the generated electric or magnetic field is recorded due to field shielding by the container.

For safety precautions, the measurements of the fields generated near the trigaron are done at a distance of 1m so that the measurement equipment and the person working with it could not be subjected to an electric shock by a spark discharge. The results are E = 230 V/m and B = 10 μT for C=3μF and U_c=11kV which are again safe values.

4. Conclusion

Investigation of the generated external electric and magnetic fields in the work of a prototype system based on capacitive energy accumulation for generation of high voltage periodically attenuating discharge pulses in water is performed as:

- The values of the electric field strength E and magnetic flux density B are measured during the charging and discharging processes near the device elements (transformers and discharge gaps);
- Evaluation of the compliance of the measured values with respect to the norm values defined by (Directive 2013/35/EU, 2013) is done;
- Safe work conditions are set at the device operation.

References

Anpilov A., Barkhudarov E., Bark Y., Zadiraka, et al. (2001) Electric discharge in water as a source of UV radiation, ozone and hydrogen peroxide, J. Phys. D: Appl. Phys, 34, pp.993–999.

Directive 2013/35/EU of the European parliament and of the Council of 26 June 2013, The minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields), http://eur-lex.europa.eu

Ivanova M., (2012) Comparative experimental study of the influence of different controllable high-voltage switches over the formation of discharge pulse in liquid medium, Journal of international scientific publications "Materials, methods and technologies", vol. 6, part 2, pp.60-75, ISSN 1313 2539. Available from: http://www.scientific-publications.net/en/archive/

Ivanova M., Barudov S., (2013) Modeling of high voltage periodically attenuating discharge in liquid with a controllable high voltage switch trigatron, Marine scientific forum, Nikola Vaptsarov Naval Academy, pp.118-123, ISSN 1310-9278 (in Bulgarian).

Kang B., Uhm H., (2003) Electrical discharge characteristics in water and shockwaves, Journal of the Korean Physical Society, vol. 42, pp. S880-S884.

Non-binding guide to good practice for implementing Directive 2013/35/EU, Electromagnetic Fields, Volume 1: Practical Guide, European commission, November 2014.