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Conducted electromagnetic interference emitted by plasmatron discharges

***Abstract**. The paper presents issues related to the electromagnetic compatibility of a plasma reactor. A diagram of a gliding arc discharge plasma reactor's column and its power system are presented, as are the measuring system and the preliminary voltage measurement results of conducted electromagnetic disturbance on the power lines of the plasma reactor in question.*

Streszczenie.** Artykuł przedstawia zagadnienia związane z kompatybilnością elektromagnetyczną reaktora plazmowego. Zaprezentowano budowę kolumny reaktora plazmowego ze ślizgającym się wyładowaniem łukowym oraz jego układy zasilania. Przedstawiono układ pomiarowy oraz wstępne wyniki pomiaru napięcia przewodzonych zaburzeń elektromagnetycznych na liniach zasilających omawianego reaktora plazmowego. **(Przewodzone zaburzenia elekromagnetyczne emitowane przez wyładowania w plazmotronie).

Keywords: Electromagnetic compatibility, disturbance conducted, plasma reactor, gliding arc.
Słowa kluczowe: Kompatybilność elektromagnetyczna, zaburzenia przewodzone, reaktor plazmowy, wyładowanie łukowe.

Introduction

Recent years have witnessed rapid development of modern technologies and the improvement of those currently used for the effective protection of the environment. Numerous conferences on global warming and environmental pollution point to excessive emissions of both greenhouse gases and the combustion by-products. The elimination of various harmful chemicals is possible by, inter alia, subjecting them to plasma treatment.

Plasma reactors operate on the principle of processing the electromagnetic wave thus becoming a potential source of electromagnetic disturbances. Such disturbances, when at a level higher than that permitted by relevant standards, may adversely affect both animate and inanimate matter. Electromagnetic disturbances may hinder or prevent communication which uses an electromagnetic wave, they may also interfere with any other electrical or electronic equipment used as intended.

This issue, also known as electromagnetic compatibility, is governed by laws and standardizing documents which outline the limits and procedures for their measurement.

Plasma reactors with gliding arc discharge

Plasma is called the fourth state of matter. It is estimated that over 99 % of matter in the universe is in this state. On Earth, however, it is relatively rare and, in most cases, is generated by humans for technological purposes. One method of generating plasma for technological purposes is electrical discharge [1].

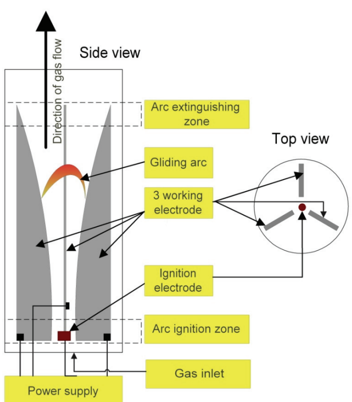

Fig. 1 . Diagram of a gliding arc discharge plasma reactor's column

The paper presents issues related to the electromagnetic compatibility of a plasma reactor. A diagram of a gliding arc discharge plasma reactor's column and its power system are presented, as are the measuring system and the preliminary voltage measurement results of conducted electromagnetic disturbance on the power lines of the plasma reactor in question.

The presented "GlidArc" plasma reactor's column has three working electrodes in the shape of a knife, mounted vertically and symmetrically around the axis of the reactor. At the point of shortest distance between the working electrodes one or more ignition electrode is installed. The ignition electrodes are powered from a supply voltage of about 10 kV and a higher frequency, such as, for example, 150 Hz. Discharges occurring between the ignition electrodes or an ignition electrode and a working electrode ionize the gas between the working electrodes. The ionized gas enables the initiation of discharges between the working electrodes at a supply voltage of about 1.5 kV and a frequency of usually 50 Hz. These discharges create an electric arc. The working gas is blown from the bottom of the reactor's column through a special nozzle into the area between working electrodes. The inblown working gas moves the arc, which, in the upper zone of the working electrode, is being extinguished. In our plasma reactor with three working electrodes four operating states cyclically occur [2]. In the normal operation of the reactor these operation states are not noticeable, but in terms of electromagnetic compatibility they will have a large impact on the value of emitted electromagnetic disturbances.

The first state of the reactor operation occurs when there is no discharge in the column reactor. In this state, the plasma reactor will not generate any electromagnetic disturbances' voltage. The second state will occur when the ignition discharge between the ignition electrode and the working electrode is initiated. In this state, electromagnetic disturbances will be emitted on the lines most involved in the discharge. The third state of operation occurs during the discharge between two working electrodes and it is on their lines that the greatest electromagnetic disturbances will be emitted. The fourth state is a normal operation state of a plasma reactor in which the discharge occurs between all working electrodes. The fourth state lasts the longest, and will have the greatest impact on the levels of the emitted electromagnetic disturbances' voltage.

The cycle time of all these states will depend in particular on such parameters as the flow velocity of working gas, the supply voltage of working electrodes and their shape [2]. Given that the levels of electromagnetic disturbance will vary between the four operation states, in specifying the final measurement time each of the states of the reactor's operation should be taken into account.

Plasma reactors with gliding arc discharge can be powered from different power systems. The simplest systems consist of a power transformer and allow changing the supply voltage of working electrodes and the ignition electrode with the use of an autotransformer integrated into the supply system. More complex supply systems include power semiconductor elements which allow the adjustment of the supply voltage of working electrodes and the frequency of its work, which can reach up to several hundred Hz. Such power systems are designed and analyzed at the Institute of Electrical Engineering and Electrotechnologies at the Lublin University of Technology. In order to determine the effect of the plasma reactor parameters on the value of the emitted electromagnetic disturbance voltage on the power lines of a plasma reactor, power measurement system must be set using the system without the semiconductor elements. Due to voltage keying process, power electronics emit high voltage values of electromagnetic disturbances on the power lines which are not subject to examination in this study.

Electromagnetic Compatibility issues

Electrical and electronic equipment are subject to mandatory evaluation of compliance with the essential requirements for electromagnetic compatibility. This issue is governed by the Directive of the European Parliament and Council number 2004/108/EC from the year 2004. In Poland, the directive is implemented by the electromagnetic compatibility law of the year 2007 [3].

These legal provisions define the two essential requirements which specify that the equipment covered by the assessment of compliance with electromagnetic compatibility should not cause disturbances in its environment that would have values exceeding the electromagnetic immunity to these disturbances of another device working in this environment, and should have the required immunity to such disturbances.

In addition to the essential requirements, the legislation outlines other requirements that should be met by the product. For other requirements, relevant documentation must be collected in the process of evaluating technical compliance. Such documentation should in particular confirm that the product meets relevant harmonized standards - if they are applied - or other evidence of compliance with the essential requirements for such device, e.g. results of the calculations associated with design, research and testing results. After the assessment of conformity is complete, a declaration of conformity should be issued. This, in addition to the product and the entity responsible for it, should include information on which directive the product conforms to and what standards or other solutions have been applied. The information included in the declaration of conformity should indicate what measures have been taken to ensure the product's conformity with the essential requirements. After assessing conformity with the essential requirements, each item of the device should be marked with a CE mark whose shape and dimensions are predefined. Each device must be accompanied by a manual that would outline use restrictions. For fixed installation a declaration of conformity is not issued and such installation is not marked with a CE mark [4].

Conformity assessment in the field of electromagnetic compatibility may be carried out by the manufacturer or his authorized representative - and, for fixed installations - the contractor. In order to carry out a proper conformity assessment, tests should be performed for all representative configurations of the device. All external devices that may be connected by the user as well as the electrical and mechanical parameters that may be changed by the user, and the changing of which may affect electromagnetic compatibility parameters should be taken into consideration. Legislation in this area, however, permits taking measurements for such configurations for which the emission of electromagnetic disturbance is the highest, and for which the immunity to such disturbance is the smallest [3].

Such approach at the initial stage of the conformity assessment can substantially reduce the time of the conformity assessment and the costs associated with it. In order to determine the configuration of the device for which the emission of electromagnetic disturbances is greatest, and for which the configuration of immunity to such disturbance is the least, appropriate calculations can be made.

When assessing compliance with electromagnetic compatibility, such issues as the emission of radiated and conducted electromagnetic disturbances, and the immunity to such disturbances from other devices must be taken into account. Additionally, the phenomenon of electrostatic sensitive device should also be taken into account.

Measurements of the plasma reactor's conducted electromagnetic disturbances

A plasma reactor with the gliding arc discharge will generate electromagnetic disturbances coming from the discharges occurring between working electrodes and ignition electrodes. According to the currently accepted standardization, the measurement of the disturbances' voltage on power lines is carried out in the frequency range of between 150 kHz (for certain devices 9 kHz) and 30 MHz [5]. Frequencies above 30 MHz shall be performed by measuring radiated disturbances. For each of the measurement types the measuring system and the measurement procedure will be different. This work presents the measurement of the disturbances' voltage on power lines powering a plasma reactor with gliding arc discharge in a voltage range of between 150 kHz and 30 MHz.

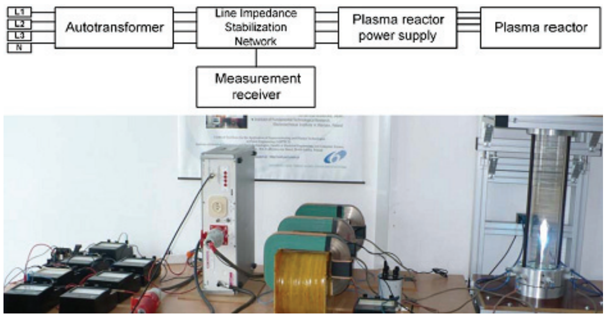

Fig. 2. Measurement system

Figure 2 presents a measurement system for conducted electromagnetic disturbances' voltage on power lines which has been put together and used for measuring plasma reactor with a gliding arc discharge installed at the Institute of Electrical Engineering and Electrotechnologies at the Lublin University of Technology. The plasma reactor was connected to a power system consisting of three separate transformers. In front of the transformer system a three-phase Line Impedance Stabilization Network (LISN) connected to a measuring receiver has been incorporated. LISN performs two essential functions in the measurement system. First, it provides standardized measuring conditions by using an appropriate built-in probe. The value of the amendments to be made at the levels measured is known and given by the manufacturer of LISN. The second important function is the use of filters in the network from the side of the power line. These filters provide adequate attenuation of conducted disturbances from other devices pinned to the same line. LISN was further grounded through a separate connection to the grounding bus.

Measurements were performed in accordance with the current normalization having regard for the acceptable voltage levels of conducted electromagnetic disturbances on the power line defined by the harmonized standard PN-EN 61000-6-4:2004 (Electromagnetic compatibility Part 6-4: Generic standards – emission standard for industrial environments.). This standard (overall - environment) has been applied due to lack of regulatory standards for product and for product groups.

Plasma reactor measurements were carried out in the frequency range of between 150 kHz and 30 MHz on all its lines of supply. Measurements were performed with step retuning of the receiver 4.5 kHz and filter 9 kHz. Single measurement time was set at the initial measurement level of 20ms. Extending single measurement time would significantly prolong the measurement time in the entire frequency range. Ultimately, measurements with long observation time of single measurement (1s) are performed for selected frequencies, most frequently for those which in the initial measurement exceeded the limits defined by the standard. The measurement was performed using a peak (PK) and average (AV) detectors. The final measurement is performed with quasi-peak (QP) and average detectors [5].

The current of the original power supply side's reactor has been set for all measurements at 15A/phase. Blown through the reactor's column were working gases - argon and air - at a constant speed of 1.5 m/s.

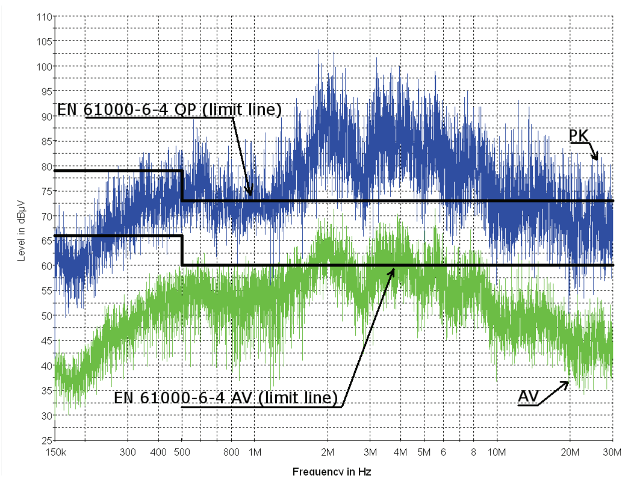

Fig. 3. Levels of electromagnetic interference emission on line L1 powering (working gas - argon)

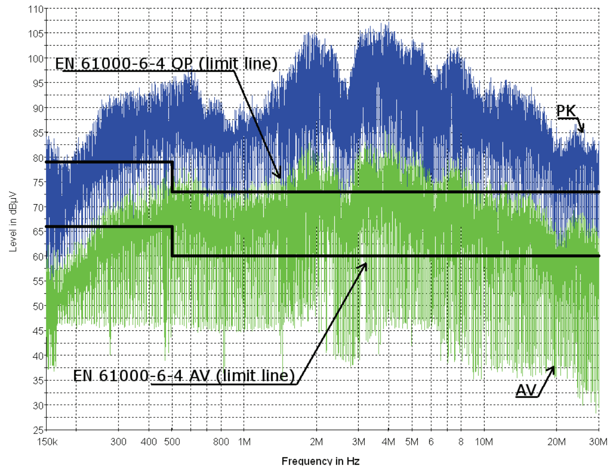

Fig. 4. Levels of electromagnetic interference emission on line L1 powering (working gas – air)

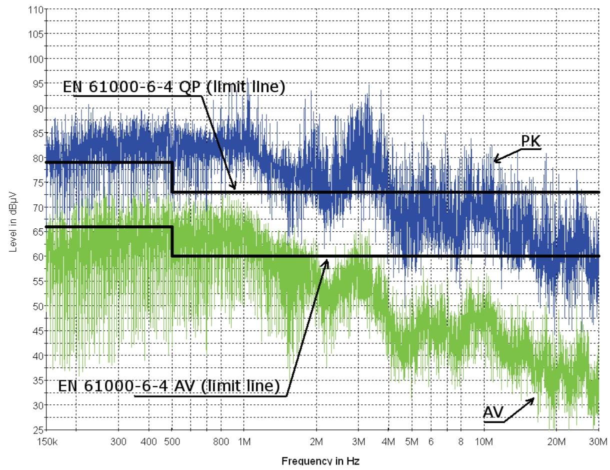

Fig. 5. Level of electromagnetic interference emission on line N powering (working gas – argon)

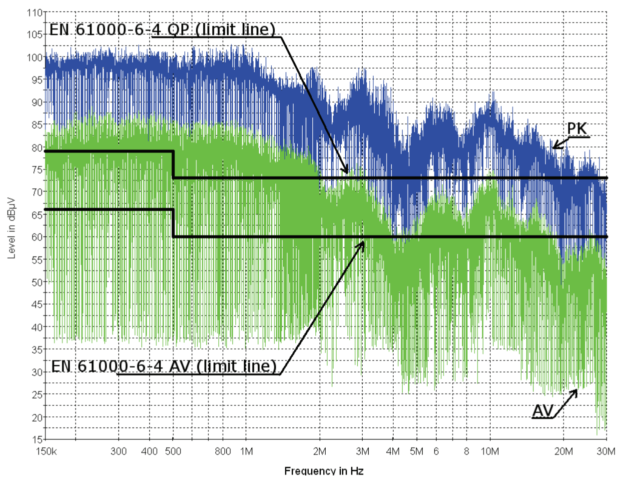

Fig. 6. Level of electromagnetic interference emission on line N powering (working gas – air)

The charts above present the results of electromagnetic disturbances' voltage measurements on the power L1 and N lines of a plasma reactor working with a gliding arc discharge, into which working gases - argon and air – were blown. In each of the presented preliminary measurement results, the measured electromagnetic disturbance voltage on the power lines exceeds the limits set by the environmental standard PN-EN 61000-6-4:2004.

During the measurements a more unstable arc in the reactor's column could be observed when air was used as a working gas. The representation of this fact can also be seen in the presented measurement results where the measured values of disturbances on both N and L1 lines are much higher and more volatile for successive measurements in adjacent frequencies with air used as a working gas than when argon was used. The characteristics' shape of the measured voltage disturbances on power lines itself is very similar for both working gases and is largely dependent on the damping characteristics of transformers used in the power system. The level of disturbance voltage measured on the N power line of the plasma reactor is highest in low frequency ranges from about 150 kHz and remains constant at a relatively high frequency of approximately 1 MHz. Above the 1 MHz frequency, the measured level of disturbance voltage decreases significantly.

When measuring electromagnetic disturbance voltage on the L1 power line of the plasma reactor, the highest values occur in the frequency range of 2 MHz and 4 MHz. The largest excess of the measured values for the initial measurement occur when air is used as a working and are approximately of the 30dB value on the N line and about 35dB on the L1 line.

Conclusion

The presented measurement results indicate that a plasma reactor the gliding arc discharge emits conducted electromagnetic disturbances of a high level on the power lines. This level in the initial measurement significantly exceeds acceptable levels set by the environment harmonized standard. If the long observation time measurement shows that the measured conducted voltage levels exceed the permissible levels, such reactor system should not operate until appropriate filters are designed and installed. As this publication shows, changing even such parameter as the working gas significantly affects the measured values of disturbances' voltage at different frequencies. The values of the measured disturbance voltage are also different for the supply lines L1 and N.

In order to carry out conformity assessment in the field of electromagnetic compatibility properly, all the variables of the plasma reactor that may affect the measured values of disturbance voltage must be taken into account. What should be taken into account, in particular, is: the values of voltage and current supply for the working electrodes and the ignition electrode, the nature of the working gas and its flow velocity through the reactor's column, the reactor's power systems and the mechanical construction of the reactor – for example the shape of the electrodes. Determining the impact of changing various reactor parameters will allow us to identify those parameters that have the greatest impact on the measured electromagnetic disturbances on the power lines, thus reducing the future costs and measurement time.

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