MODELING OF THE IGNITION VOLTAGE IN A GLIDING DISCHARGE POWER SYSTEM BASED OF NON-LINEAR TRANSFORMERS

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Abstract - The paper presents PSPICE numerical simulation of the integrated power system of the plasma reactor with gliding arc. The system takes advantages of the higher magnetic flux harmonics generated in the transformer cores to ignite the arc discharge while the operating of the plasma reactor after discharge ignition is maintained at fundamental frequency. Results of the investigation of the influence of the nature of the neutral conductor impedance on the ignition voltage and on the cooperation of plasma reactor with mains together with results of experiments are presented and can be useful in the designing of the plasma generating power systems.

1. Introduction

Modern industrialized and urbanized communities generate huge volumes of pollutants, which are emitted into the atmosphere. It is mainly the result of power production and services for members of our society.

In recent years new methods of water and air cleaning by means of low temperature non-equilibrium plasma, named „cold” plasma, have been investigated and introduced to industry. The non-thermal plasma is generated for industrial scale by electrical discharges and almost each type of discharge is the potential source of the cold plasma. One of such a discharge, called „gliding arc discharge”, produced between knife-shaped electrodes directly in the treated gas [1], seems to be very promising and efficient source of cold non-equilibrium plasma.

Every plasma generation system represents a unique load for its power system. It usually operates at high AC voltage, often at increased frequency and its current and voltages are very distorted. The power supply system is always the inseparable part of the whole plasma generation plant and properly designed can considerably increase its efficiency.

The plasma reactor with gliding arc requires from the supply system to ignite the discharge at relatively high voltage and then to maintain it at much lower than ignition voltage. The arc current after discharge has to be limited and the system should properly cooperate with the supply network. Therefore, the voltage-current characteristic of the supplier should be formed according to these requirements.

For industrial application the plasma generation system should present the high efficiency of energy transfer to the plasma, low power consumption, proper cooperation with the mains, as well as simple servicing and reliable and save operation. Enumerated requirements can be successfully fulfilled by the integrated power system [2]. The system utilizes the non-linearity phenomena of magnetic circuit in transformer cores and is protected by Polish Patents [4]. A few prototype arrangements, designed and constructed on the basis of this idea, have been already tested and applied in laboratory and, within a certain extent, in industry.

The paper presents modification of the integrated supply system of the arc plasma reactor that allows energising the plasma generation system directly from the three-phase three-wire sub-transmission grid. Due to this modification, based on the creation the artificial neutral point, the ignition voltage of the discharge increases and the co-operation of the system with the mains can be improved. The properties of the proposed system are discussed and results of PSPICE simulation as well as the laboratory investigation are presented. Examinations confirm the advantages of the system and can be useful in designing plasma reactors for industrial applications.
2. **Integrated power supply system**

The idea of the integrated supply system of the plasma reactor with gliding arc is based on the special connection of single-phase transformers, which magnetic cores form close paths for the higher magnetic flux harmonics. The scheme connection of the integrated power system to supply three-electrode gliding arc reactor is presented in Fig. 1. Higher magnetic flux harmonics occur in the transformer cores due to the non-linearity of its magnetising characteristic and, in the three-phase system, the third magnetic flux harmonic \( \Phi_{3h} \) achieves the largest value equal to (20-25)% of the fundamental flux harmonic \( \Phi_{1h} \). The third magnetic flux harmonic induces voltage, which is used in the integrated supply system for the ionisation of the inter-electrode gap. This voltage appears between the neutral point of the supply network \( N \) and the star point of the primary windings of single-phase transformers \( N_1 \) and is transformed by the ignition transformer to the value required for the discharge ignition. The power from the supply network is transferred to the reactor by operating transformers that simultaneously limit current of the main discharge. Therefore, the operating transformers can be constructed for the voltage several times lower than the ignition voltage and the efficiency of the plasma generation system is very high [2]. The ignition voltage frequency is three times greater than the frequency of the supply network, so the current-less breaks during the development of the arc discharge are shorter and the discharges between electrodes are more stable.

The discussed power system integrates all the functions required by the plasma reactor with gliding arc. This integration allows reducing the number of the system elements and makes it very efficient and reliable. The main advantages of the integrated system are the inherent ability of the system to supply both ignition and steady state operating circuits and their natural mutual co-operation, the symmetrical load of the supply network and possible construction of multi-electrode systems.

Very important feature of the integrated power system is the capability to shape its voltage-current output characteristic accordingly to the plasma reactor static characteristic (Fig. 2). It is achieved by the right selection of the magnetic flux density level in magnetic cores in operating transformers and by some special construction of transformer windings as to obtain the required level of their internal reactance [3].

In the case of large power industrial systems of plasma generation, there could be the necessity to supply the plasma reactor directly from the sub-transmission grid, which is usually three-wire. The solution of the supply system presented in Fig. 1 cannot be further applied, as the neutral point \( N \) is not available in the sub-transmission grid. Moreover, the large power plasma reactor energised from the three-phase four-wire network could load the neutral conductor what is not acceptable. Therefore, the modification of the integrated supply system was proposed and its description, simulation and experimental investigation are presented in the following part of the paper.

3. **Three-phase integrated supply system without neutral**

In the modified system, presented in Fig. 3, the artificial neutral point \( N \) is created by means of additional impedance \( Z_N \). The impedance \( Z_N \) should be symmetrical and could be of optional nature, but in the paper the investigation were carried out for the impedance of pure capacitive nature \( C \) and for the case when resistors \( R \) create the artificial point.
The simulations of the presented systems are carried out with the aid of PSPICE Package and results are verified by laboratory investigations. For the purpose of comparison we present also results of investigations of the unmodified system from Fig. 1, which is making use of the mains neutral point.

The three following cases were examined:
A. System making use of the supply network neutral point, presented in Fig. 1
B. System, in which resistors $R=1000\Omega$ were applied to form the artificial neutral point,
C. System, in which the artificial point is formed by the capacitors $C=10\mu F$

The analysed system has all specified previously advantageous of the integrated system. By applying the impedance $Z_N$ of capacitive nature we become able to compensate the reactive magnetising power of the supplier and to improve the ignition.

The PSPICE model of the gliding arc is based on the Mayr and Cassie model with some modification [5], which takes into consideration changes of the discharge length and velocity during the cycle of the reactor operation, permits modelling voltage ignition of the discharge in the cold inter-electrode gap and describes true course of the voltage-current characteristic of the discharge.

The modelling of the non-linear cores is based on Jiles-Atherton model that is the part of the PSPICE Package. The calculations are carried out for the no-load condition of the integrated power system, as we would like to investigate the influence of the nature of the neutral artificial point impedance on the value of the ignition voltage. The PSPICE model of the integrated system with artificial neutral point formed by capacitors is presented in Fig. 4.

Fig. 6. Courses of the ignition voltage and currents calculated for the case A ($C=10\mu F$)

Fig. 5 Courses of the ignition voltage and currents calculated for the case C (power system from Fig. 1)

Fig. 7. Courses of the ignition voltage and currents calculated for the case B ($R=1000\Omega$)
Results of the simulations are presented in Figures 5 to 7 in the form of courses of the ignition voltage and current as well as primary currents of the modified power system as to check the influence of the neutral point impedance on the value and course of these currents. Near the figures and in the Table 1 the values of ignition voltage $U_n$, neutral conductor current $I_n$, primary voltage $U_p$ and current $I$ and power losses $P$ for all investigated cases are presented.

Fig. 8. Measured course of the ignition voltage in no-load conditions for the case C  
Fig. 9. Measured course of the ignition voltage under load the case C

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<th>Case A</th>
<th>Case B</th>
<th>Case C</th>
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<tbody>
<tr>
<td></td>
<td>Neutral point from mains</td>
<td>Artificial point $R=1000\Omega$</td>
<td>Artificial point $C=10\mu F$</td>
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<tr>
<td>Primary voltage</td>
<td>$U_n$</td>
<td>V</td>
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<tr>
<td>Primary current</td>
<td>$I_n$</td>
<td>A</td>
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<tr>
<td>Neutral current</td>
<td>$I_n$</td>
<td>mA</td>
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<tr>
<td>Ignition voltage</td>
<td>$U_{ig}$</td>
<td>kV</td>
<td>12,1</td>
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4. **Discussion**

Both the simulations and measurements give results that confirm that the nature and value of the impedance forming the artificial neutral point of the integrated power system influence the ignition voltage. In the case C, when the artificial point is formed by capacitors, we observe more than 20% increase of the ignition voltage value and even two times decrease of the primary current of the integrated power system, what means that capacitors also compensate the reactive power of the integrated power system.

5. **References**


