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# An Integrated Power Supplying System for a Plasma Reactor

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Plasma reactors demand unique requirements of their power sources such as high-voltage output, variable frequency and a current limiting capability. This paper shows a new means of providing power to a plasma reactor based on a magnetic frequency tripler and transformer. The integration of the tripler and transformer allows one to obtain improved operating characteristics and power utilization compared to other conventional types of power sources.

*Key Words:* Magnetic frequency tripler, Plasma generators, Plasma reactor power source

## 1. Introduction

An electric arc is rarely applied to process large volumes of gas because it can not properly penetrate the limited area of very high energy. Many solutions to this problem have been attempted in the past with little or no success. A new method of non-thermal plasma generation, at an industrial scale, invented and designed at the Orleans University in France has recently been developed further [1].

The method is based on gliding electrical discharges generated in the plasma reactor at atmospheric and increased pressures. A simplified diagram of the reactor construction is presented in Fig. 1.

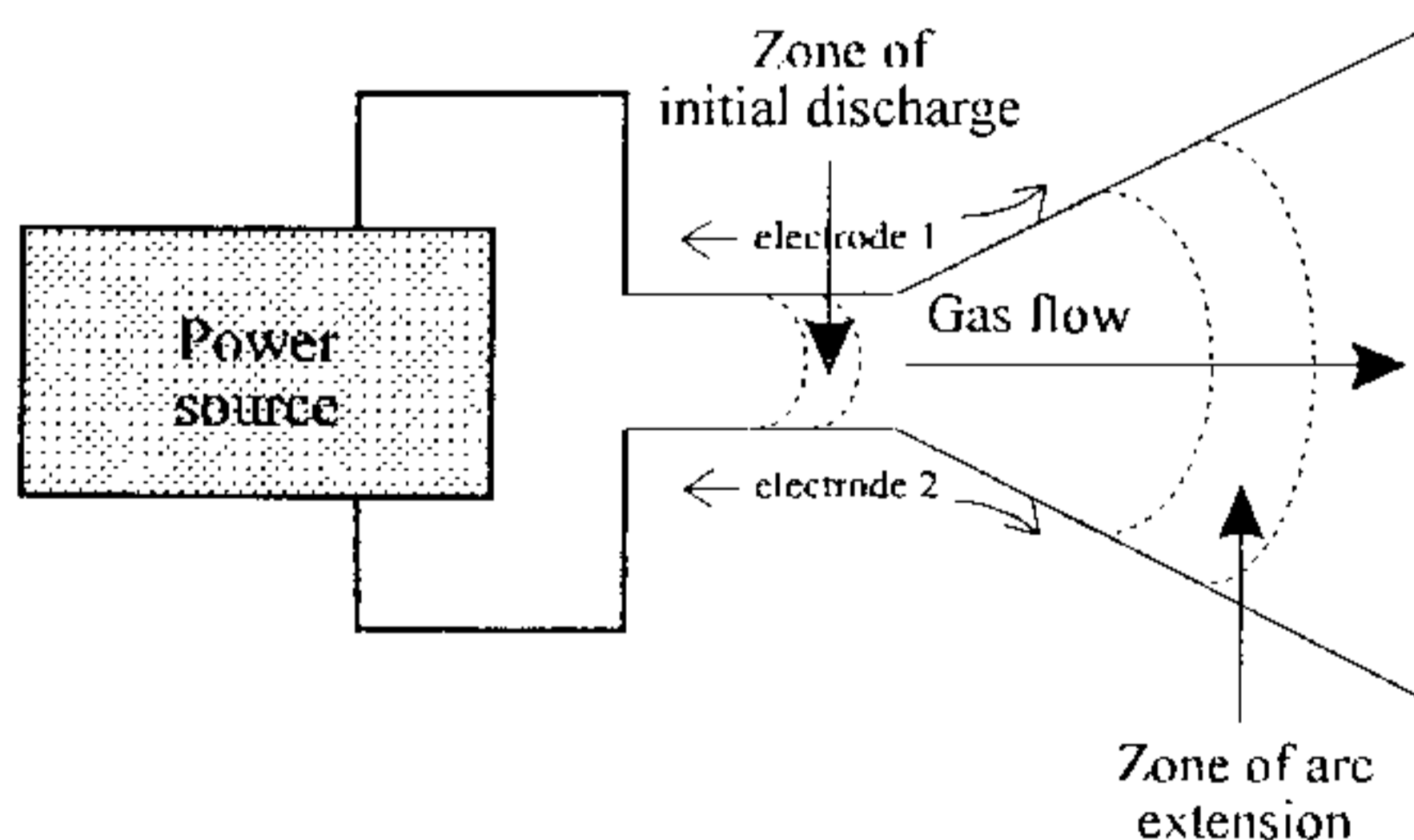


Fig. 1. Basic idea of plasma reactor

The resistance of the gap between the two electrodes shown in Fig. 1 is largest before ignition, when the gas is not ionized. After

ignition the resistance rapidly decreases. Also subsequent to ignition the arc moves from its two previous contact points to, two contact points which are separated by a greater degree. The increased length of the arc results in an increase in the arc resistance.

In order to accommodate for the large range in resistance, between the pre and post ignition state, it is necessary to decrease the supply voltage immediately after ignition has taken place. This means that the electrical supply of the plasma reactor should have very soft output characteristics, i.e. the voltage must quickly decrease as the current increases.

The easiest means of accomplishing this task is to use a transformer to energize the Glidarc plasma reactor. The mains' voltage is transformed to the value required by the reactor. Moreover due to the special construction of the transformer, it is possible to limit the secondary current subsequent to arc ignition. This scheme can be implemented for one pair of electrodes or a three electrode system for a the three-phase supply. Usually, to obtain high process productivity several tens of electrode pairs for the single phase system or three electrode systems with a total power capacity of hundreds of kilowatts are installed. The secondary voltage of the transformer under open-circuit conditions should be approximately equal to 7-10kV, depending on the gap distance. However under loaded conditions, when the discharge is taking place, the voltage is about 1kV. Both of these operating states can be achieved by using a

$U_1$  - primary transformer voltage,  
 $U_i$  - ignition voltage ( output shunt voltage ),  
 $U_{arc}$ ,  $I_{arc}$ ,  $P_{arc}$  - arc discharge voltage, current  
and power, respectively.

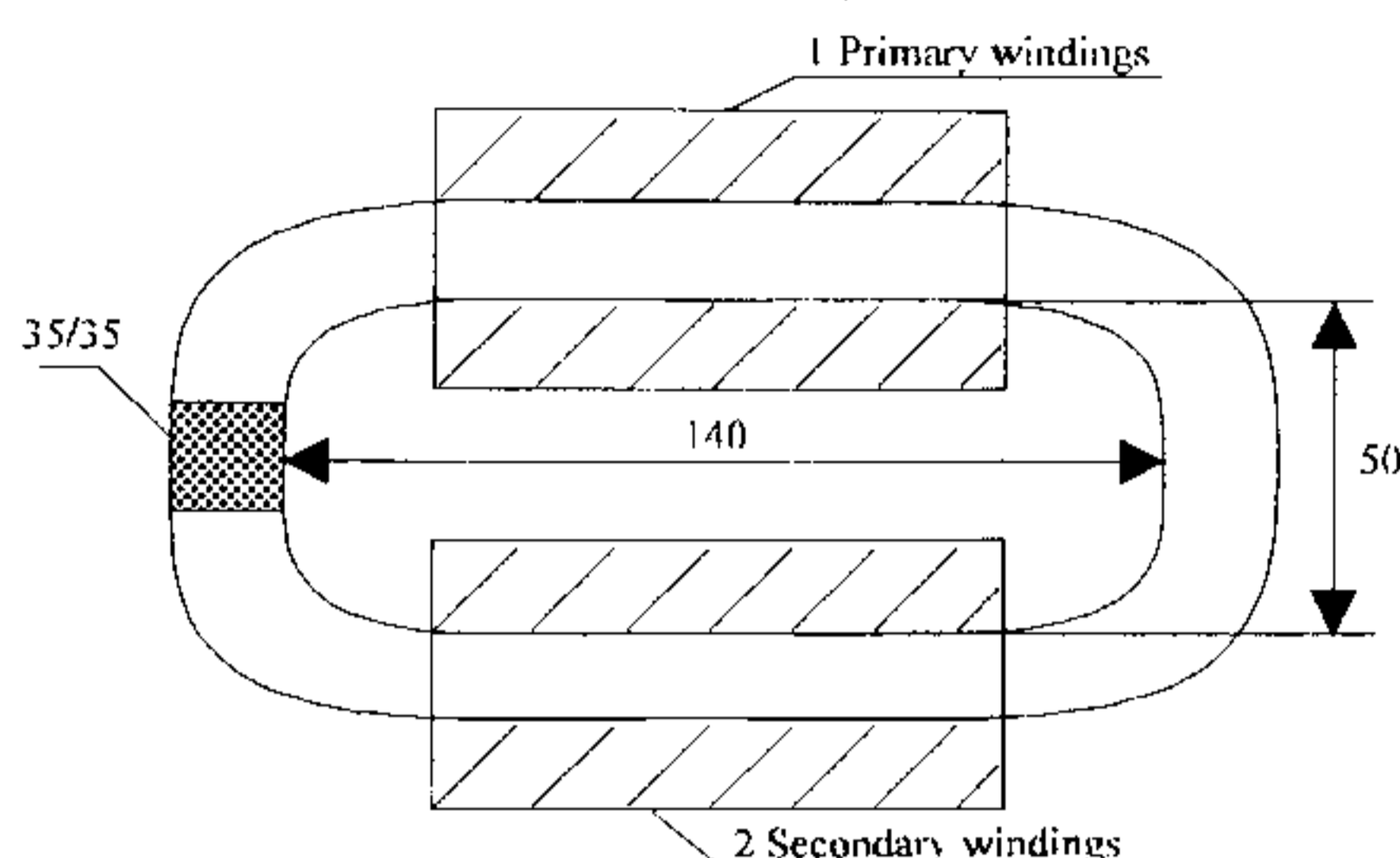


Fig. 5 Winding core

The proposed integrated system provides a discharge power equal to the transformer nominal power. Moreover limiting current chokes and primary condensers, which are necessary in other solutions, are eliminated.

### 3. Conclusions

Plasma reactors require special power sources. Transformer solutions are inefficient because only a small part of the rated transformer power is transferred to the discharge. Magnetic frequency multipliers that have characteristics similar to the arc discharge can energize the plasma reactor without requiring additional current limiting elements. Good performance is demonstrated by the integrated system composed of a transformer and magnetic frequency tripler. Arc ignition is instigated by the large induced voltages contributed by the higher order harmonic fluxes in the cores of the transformers. On the other hand, the arc power is generated by the induced voltage contributed by the fundamental component of flux. The power utilization in the integrated system is an improvement over that in other systems.

(1994年3月16日受付)

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The plasma reactor power source consists of four single phase transformers. Three of these transformers 1 are alike with their secondary voltages equaling the free standing arc voltage and the output frequency being equal to the mains' frequency. The fourth one is the shunt transformer 2 with a nominal output voltage rating equal to the ignition voltage and with a frequency three times greater than the mains' frequency. The main transformer 1 primary windings are connected in star and to the three phases of the low voltage mains RST. The secondary windings are designed for the free standing arc voltage and current and are connected in star. Their terminals a, b, c are connected with the symmetric three phase electrode system r, s, t of the plasma reactor 3. The shunt transformer 2 has a secondary winding designed to withstand the ignition voltage and a maximum current of 10% of rated arc current. This winding is connected to the neutral point  $N_2$  of the working windings' star and to the ignition electrode  $Z$  of the plasma reactor 3.

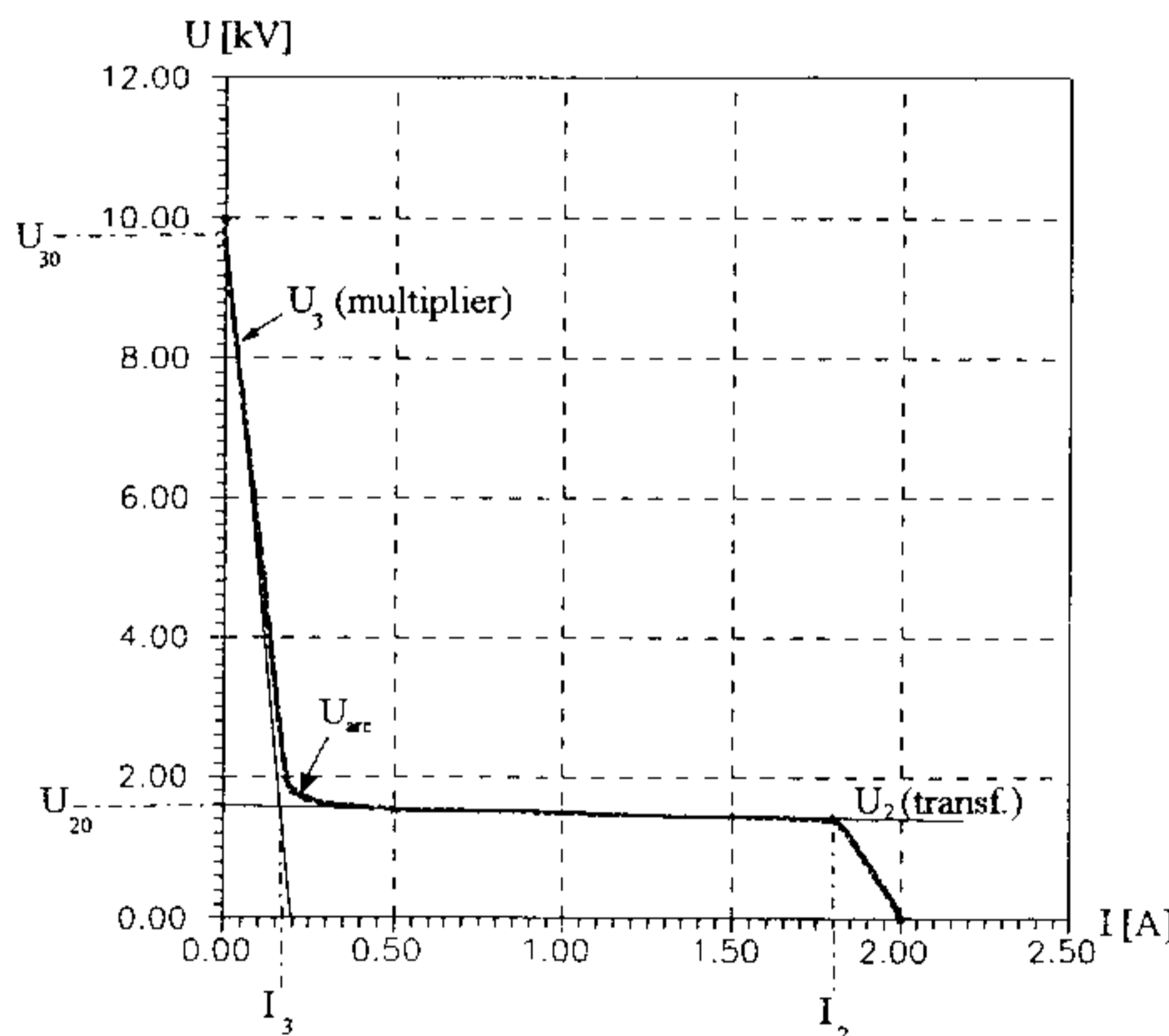


Fig. 4 Experimental characteristics of the integrated system

The primary winding of the shunt transformer is designed for a voltage equal to 0.3 times the mains voltage. This winding is connected to the mains neutral point N and to the neutral point  $N_1$  of the transformer 1 primary windings. Moreover, the primary and secondary windings of the main transformer are placed on separate columns of the magnetic circuit. In this case the transformer

leakage reactance is increased and the current can be limited to the required level.

The prototype of the reactor as shown in Fig. 3 was constructed. The transformer and shunt data as well as experimental results are presented in Table 1, Table 2 and Fig. 5.

Table 1. Specifications of the transformer prototype and shunt data.

| TRANSFORMER DATA               |                      |                       |
|--------------------------------|----------------------|-----------------------|
| <b>windings</b>                |                      |                       |
| Rated output power             | [VA]                 | S=4000                |
| Nominal output voltage         | [V]                  | $U_{2n}=1500$         |
| Nominal secondary current      | [A]                  | $I_{2n}=1.5$          |
| Nominal input voltage          | [V]                  | $U_{1n}=380$          |
| Nominal primary current        | [A]                  | $I_{1n}=6.1$          |
| Primary turns number           |                      | $z1=483$              |
| Secondary turns number         |                      | $z2=2100$             |
| Primary wire cross section     | [mm <sup>2</sup> ]   | $\theta_1=3.14$       |
| Secondary wire cross section   | [mm <sup>2</sup> ]   | $\theta_2=0.78$       |
| Windings current density       | [A/mm <sup>2</sup> ] | $j=2.0$               |
| <b>core</b>                    |                      |                       |
| Cross section of magnetic core | [mm <sup>2</sup> ]   | $12.0 \times 10^{-4}$ |
| Length of magnetic circuit     | [m]                  | 0.55                  |
| High of column                 | [m]                  | 0.14                  |
| Length of yoke                 | [m]                  | 0.50                  |
| Core sheet thickness           | [mm]                 | 0.35                  |
| Sort of sheet                  |                      | cold-rolled           |
| <b>SHUNT DATA</b>              |                      |                       |
| Nominal power                  | [VA]                 | $S_2=50$              |
| Input voltage                  | [V]                  | $U_{1n}=10000$        |
| output voltage                 | [V]                  | $U_{2n}=100$          |

Table 2. Results of experiments

| $U_1$ | $I_1$ | $U_i$ | $U_{arc}$ | $I_{arc}$ | $P_{arc}$ |
|-------|-------|-------|-----------|-----------|-----------|
| [V]   | [A]   | [V]   | [V]       | [A]       | [W]       |
| 380   | 6.0   | 10100 | 1500      | 1.6       | 3100      |

where;

transformer with increased leakage reactance and can be accomplished by separating the primary and secondary windings, using a magnetic shunt or using other methods [2]. A direct connection between the electrodes and the secondary of the transformer causes a decrease in the output voltage and makes it more difficult to ignite the discharge between all the electrodes.

Power sources with a transformer, are rather inefficient, because transformers need to be constructed to withstand and supply the ignition voltage and to operate at a voltage which is significantly smaller than the ignition voltage. Therefore only about 10 % of the transformers nameplate power rating is utilized during the discharge.

### 2. Systems with a magnetic frequency tripler

Magnetic frequency multipliers are constructed from special transformers in which the non-linearity of the magnetizing characteristics generates frequencies higher than the mains' frequency. The simplest multiplier and most often applied is the magnetic frequency tripler [3].

The output characteristics of the power source with a magnetic frequency tripler power of rating 5kVA are presented in Fig. 2.

The output tripler characteristics  $U_2=f(I_2)$  are very flexible ("soft") with a shape similar to the arc characteristics. Thus the current is limited in a natural way. The open circuit output voltage can decrease to an optionally low value under loaded conditions. Therefore, the plasma reactor can operate stably without the need for additional current limiting chokes [4].

It seems that the most optimal system for supplying the plasma reactor can be obtained by

integrating the function of a magnetic frequency multiplier with a transformer [5,2]. The circuit connection of the power converter is presented in Fig. 3 and its operating principles presented in Fig. 4.

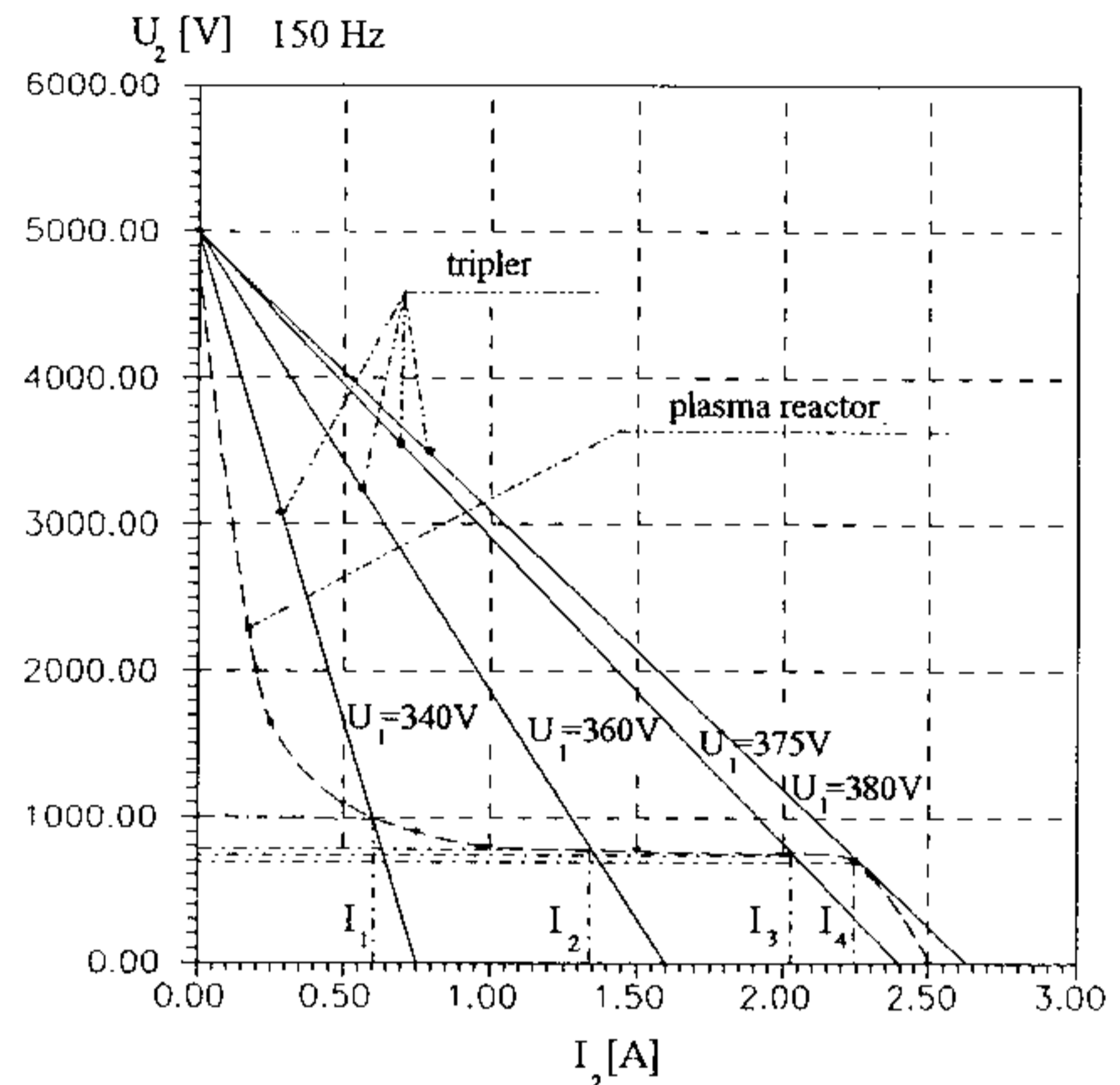


Fig. 2 Measured output characteristics of the model of plasma reactor for various mains' voltages

In the solution proposed in Fig. 3, we make use of the neutral conductor of the transformer 1 primary windings in which the shunt transformer 2 is included. The voltage of the tripled frequency appearing between the neutral point of the mains and the star point of the transformer primary windings is transformed by the shunt and is supplied to the ignition electrode Z. This voltage is sufficient to ignite the arc.

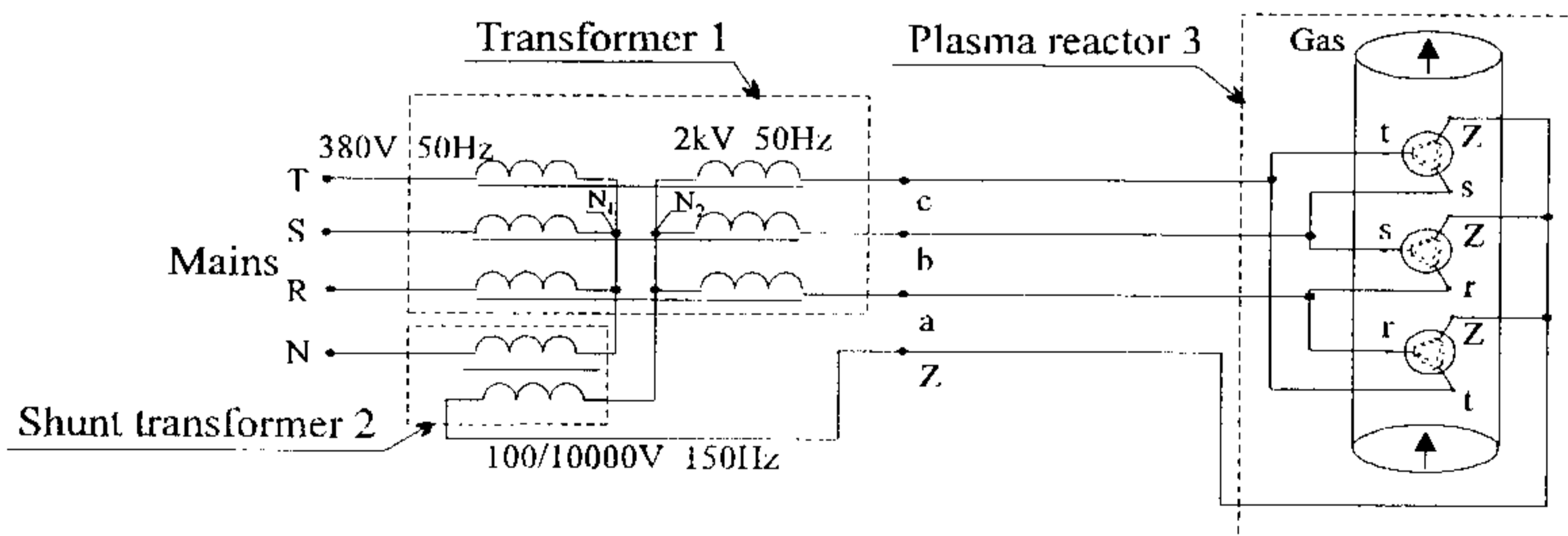


Fig. 3 Integrated system with nine electrodes and with separated high voltage ignition transformer