HIGH CURRENT AND HIGH-FREQUENCY ARCS IN A PLASMA SOURCE

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The ac high-current arc is accompanied by an ordinary arc with $f \geq$ ≥ 1 MHz. It is found that the former runs without current interruptions and with $\cos\varphi \approx 1$. The arc current and voltage can be sinusoidal under certain conditions, and these allow the current to be varied via the power supplied to the hf arc.

1. Existing low-temperature plasma sources (plasmatrons) use high-current ac arcs as energy sources, and these are made to operate without current interruption by including a suitable inductance in the supply circuit. This results in a $\cos\varphi$ of only 0.6–0.7.

It is clearly desirable to provide conditions such that a high-current arc will run not only without a series inductance but also to provide a sinusoidal voltage. Such conditions are possible if between the electrodes there is an accessory high-voltage low-current dc discharge, for then the electrode gap will always have a conducting channel along which the high-current arc can develop at any time. This accessory arc causes no difficulty; instead, the difficulty arises in decoupling the ac and dc circuits. For this reason, we examined the use of a high-voltage high-frequency discharge for this purpose. It is then possible to block out the hf supply from an ac or dc high-current source.

2. The frequency for the accessory discharge is determined by the deionization line, which is given [1] for arcs running freely in air as 100–1000 μsec (even shorter times if gas is blown into the arc). We have found that frequencies of the order of 1 MHz provide stable running in a plasma source with gas-vortex stabilization and axial gas injection. The arc goes out at lower frequencies.

Tests have shown that an accessory arc having a power of a few kW provides stable continuous running of an ac arc in a source with gas stabilization. It would seem desirable also to use this hf supply to strike the arc. An axial source has a gap of 4–7 mm between the electrodes, which is set by the gas flow rate and the permissible radial velocity, and this requires a striking voltage of 20–30 kV. A simple addition to the circuit allows one to raise the no-load voltage of the hf source to this level.

3. Figure 1 shows the theoretical circuit of the dual power supply. The electrodes 1 and 2 receive the line voltage via a coil L, resistor R, and air-cored coil L_z, while the hf supply is connected via the capacitor C_{z_2}, which prevents the line supply from being short-circuited by the air-cored coil L_k in the tuned circuit. L_z and C_{z_1} form a divider for the hf supply and restrict the hf current through the arc. If necessary (e.g., for striking), the hf voltage can be raised substantially by choosing C_{z2} and L_z such as to give series resonance. The condition for series resonance no longer applies when the arc strikes, but it is automatically restored if the arc goes out, provided this is not due to failure in the hf source.

The circuit of Fig. 1 thus provides striking as well as continuous burning.

4. The experiments described below employed this dual supply. Since the hf power was comparatively small, the physical conditions in the chamber were virtually unaltered. Figure 2 shows voltage-current curves for the ac arc as recorded with p = 1 bar and d = 20 mm, with G = 7.45 g/sec for curve 1, which was recorded with an inductance but no hf supply. Curve 2 represents G = 7.45 g/sec, inductance, and hf supply; 4 represents G = 9.15 g/sec, no inductance, hf arc; and 3 represents G = 9.15 g/sec, no inductance, no hf.

The voltage-current curves of Fig. 1a relate to an inductance present in the line supply, and here the hf arc has little effect, as curve 2 (with hf) runs only a little below curve 1. Low power (I ≈ 50 A) results in only 4% difference in power, and higher power (150 A) results in less than 2%, which approximately represents the hf current. The hf current drawn varies by not more than 20% as the resistance in the ac line is varied from 0 to 10^3 ohm; the hf supply thus acts as a current-limited source.

The picture is entirely different if the inductance is omitted (ac current interrupted, Fig. 2b); curve 3 (no hf) runs far above curve 4 (with hf). In both cases the gas flow was 9.15 g/sec. Figure 3 shows the reason for this via voltage and current oscillograms (no hf in a, hf in b) with no inductance. The hf discharge eliminates the period of zero current and so raises the effective arc voltage. The hf thus provides uninterrupted running of the ac arc with $\cos\varphi$ close to 1. The arc voltage is then less than the peak supply voltage.

Figure 2 shows that the arc has a negative-resistance characteristic, so stability conditions have to be met, e.g., by adding a ballast resistor. However, the hf supply can provide stable operation without a ballast. Then the dynamic voltage and current characteristics are nearly sinusoidal, and the supply is fully used.

5. If the static U-I relation for the ac arc is such that $U > U_m \times$ $\times \sin\omega t$ in the working current range, the arc cannot burn alone, because the required voltage is less than that actually available. The ac arc can run in the presence of the hf arc, and the current waveform follows

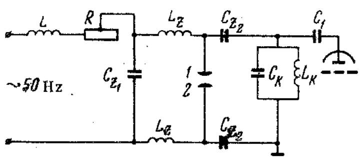

Fig. 1

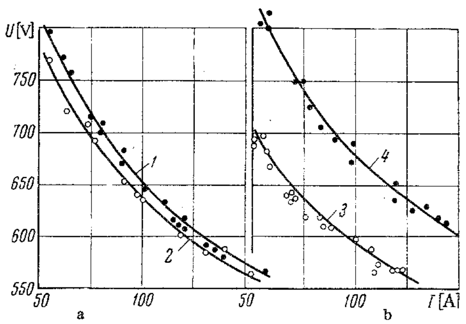

Fig. 2

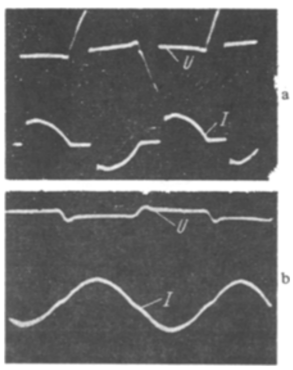

Fig. 3

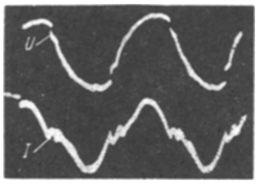

Fig. 4

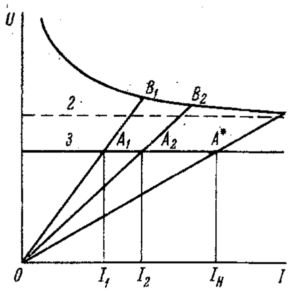

Fig. 5

the supply voltage. Such an arc is not self-maintaining. It has the feature of completely utilizing the output from the power supply. This arc system was tested with a single-phase plasma source, where the arc could be self-maintaining at U = 400 V and I = 240 A, which implies a source with an exit electrode 30 mm in diameter, an air flow rate of 7 g/sec, and a pressure of 1 bar. The source was connected to a 380 V line (U_m = 537 V) via a 0.6-ohm resistor, which reduced the effective supply voltage to less than that needed for a self-maintaining arc. The arc ran only with the hf arc running, and the waveforms were roughly sinusoidal (Fig. 4). This arc drew 52 kW (U = 217 V), with only 0.75 kW from the hf arc. The circuit calculations (including cable resistance) agreed well with the measured values.

Similar conditions were produced with an argon arc. A phase source with an exit electrode 50 mm in diameter was used with 110 g/sec of argon and the arc connected directly to the 380 V line (nominal current 2400 A). At I = 1500 A the voltage for the self-maintaining arc was 270 V. The additional resistance was provided by the cables and the air-cored coil used to keep the hf out of the 50-Hz line, and this reduced the voltage at the arc to 200 V, which corresponded to a non-self-maintaining arc. A 300-kW arc required only 4 kW of hf power, i.e., slightly over 1%.

The hf arc thus allows the ac arc to burn stably without a ballast resistor and to use 100% of the source power when the static U-I curve (Fig. 5, curve 1) for a self-maintaining arc lies above the peak voltage (curve 2). Curves such as OB are expected if the ac supply voltage is varied with the hf arc running.

If the arc is not self-maintaining, the hf supply can be used to control the ac power drawn; increase in hf power raises the ac power to the nominal value, and the arc uses 100% of the source output.

This mode of adjustment is possible for ac and dc sources. Preliminary tests have shown that vortex-stabilized argon sources draw arc currents that increase from 240 A to 2500 A (gas flow 110 g/sec) as the hf power is raised from 2 to 4 kW.

REFERENCES

1. A. M. Zalesskii, High-Voltage Electrical Equipment [in Russian], Gosenergoizdat, 1957.

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