Power Dissipation in AC Discharge of Argon at Low Pressure in The Frequency Range 100-1000 Hz

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Abstract
This work investigates the influence of AC frequency, in the range 100-1000 Hz, on the power dissipation of an argon AC discharge at low pressure. It is observed that the power dissipation increases with frequency in the range 100-750 Hz and decreases with frequency in the range 750-1000 Hz for gas pressures 50-80 mTorr. It is also deduced that the dissipated power decreases with increasing the discharge pressure and the minimum power is dissipated at Paschen curve minimum.

Keywords: AC discharge, power dissipation, relation between power and AC frequency, low pressure AC discharge, argon AC discharge.

1. Introduction
Studies of electrical discharge in gases provide useful information about discharges which are very significant in plasma applications. Most recent works have been done by [1,3]. They have been given an overview of gas discharge plasmas. Other authors [2,4] have been shown that the electrical breakdown time delay can be expressed as the sum of the statistical time delay and the formative time delay. W. J. M. Brok [6] have been discussed the various modes of a discharge in a low-pressure gas environment. Kuschel, *et al.* [7] showed that for some discharge conditions relaxation oscillations are present.

For AC discharge, the authors [8,9,10,11] have been deduced that the breakdown voltages of glow discharges be a function of frequency, this can be understood qualitatively from build-up times and the increase of pre-breakdown current caused by particles remaining from previous periods. It found that AC breakdown depends on the relative values of the transit time of the ions and T/2 of the AC potential and that the breakdown potential depends on a third independent variable, the dark current. It also shown that the starting potential increases to about 2.6 times the zero frequency value as the applied frequency is increased from 20 to 20,000 Hz for an AC discharge in air at pressures near about the Paschen's law minimum. It is deduced that the increase in starting potential is due to the decrease in the time for which the instantaneous voltage exceeds the DC threshold voltage in a half cycle.

The aim of the present work is to further demonstrate the behavior of a low pressure Argon discharge excited by alternating current at frequencies 100 to 1000 Hz. The analysis is carried out in terms of AC I-V loop area which represents the power dissipation per cycle.

2. Experimental Setup
The experimental arrangement is shown in figure (1). The discharge chamber is a 9.5 cm length, 8 cm diameter glass tube. O-rings fitted to the two aluminum disk electrodes at the two ends. The sinusoidal high discharge voltage waveform is initiated by 10 V_p sinusoidal audio frequency oscillator. The output of the oscillator is applied to an audio frequency power amplifier (Tellewatt E120). The amplified output 100 V_p is then fed into a custom made transformer capable of supplying up to 750 V and 20 mA from the first secondary coil L2 and up to 10 V and 50 mA from the second secondary coil L3 in the frequency range 100 Hz to 20000 Hz. L3 is used for voltage sampling. The discharge current sampling is carried through the voltage measurement across the series resistance R1 (510 Ω). Discharge AC I-V loop shown on the oscilloscope screen and captured using an accurately aligned digital camera. The captured pictures are used in the further analysis.

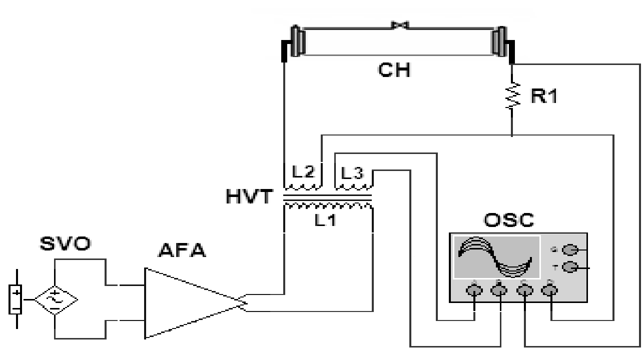

Figure (1). Schematic of the experimental set-up

Measurements are carried out at four discharge pressures near the Paschen curve minimum (pd ≈ 0. 6 Torr .cm) [12]. These pressures are 50, 60, 70, and 80 mTorr. The sine voltage applied to the discharge tube is fixed at 400 V_p. The discharge AC I-V loops are studied at 17 frequency values in the range 100-1000

Hz. The digital pictures of these loops are converted to numerical data using a Matlab image processing program [13]. Typical results of such conversions are shown in figure (2).

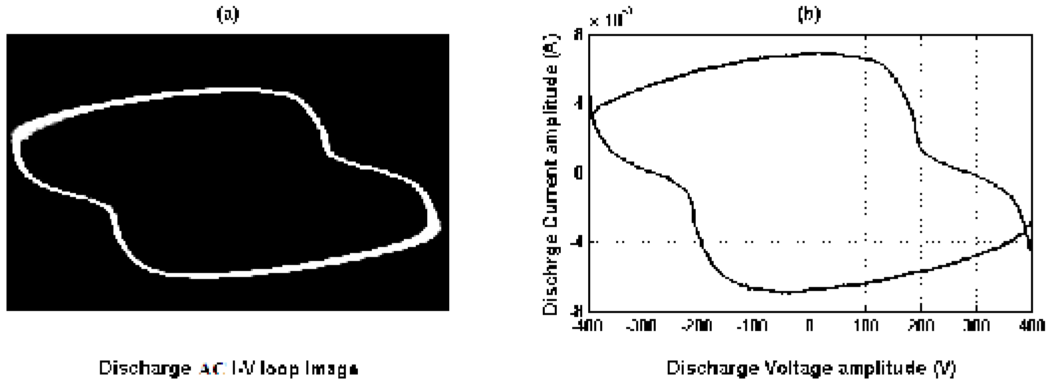

Figure (2). For gas pressure 50mTorr (a) Typical discharge AC I-V loop at 350 Hz. (b) converted numerical data plotted.

3. Results and Discussion

From AC I-V loops images for argon AC discharge at pressure 50 mTorr, figure (3), It is appeared that the shapes and areas of these loops are changed with AC frequency. This means that the discharge mode and the power dissipation in the discharge per cycle both may be changed with the frequency as shown in figure (3).

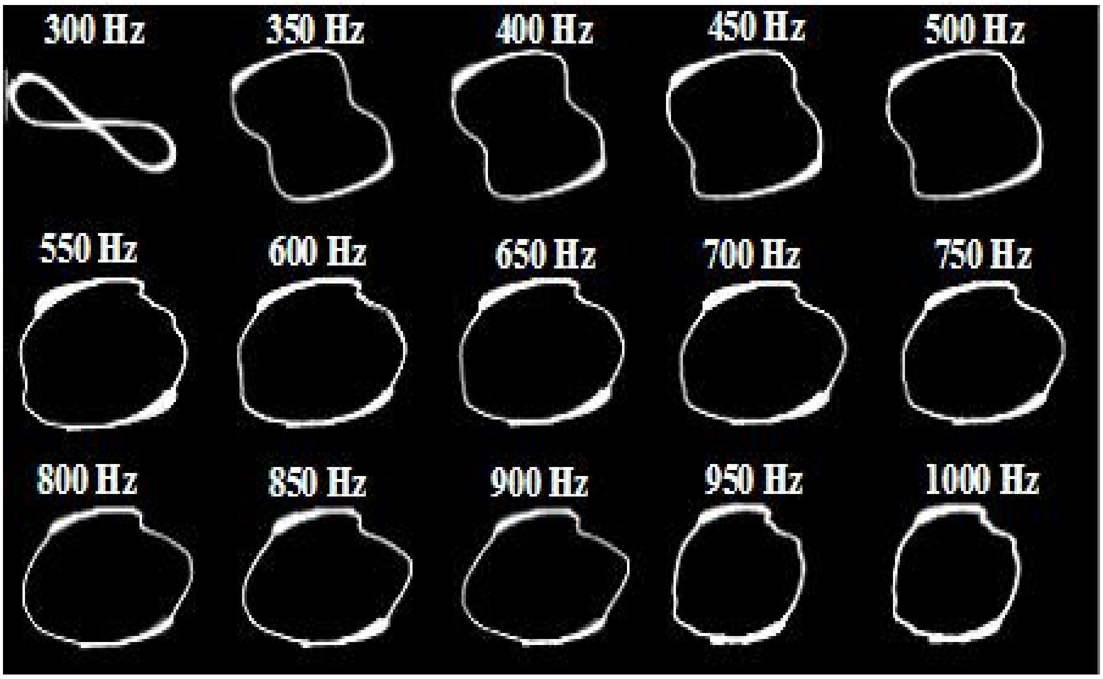

Figure (3). Discharge AC I-V loops for different frequencies at pressure 50 mTorr

3.1 Changing of Discharge Mode with AC Frequency

The full breakdown process of gases takes typically 0.1 msec or less at low pressure [4,6] and the time needed to lose most of the charge particle afterglow due to volume recombination and diffusion decay takes typically at least 1 msec [3,4,6]. This means that the time of breakdown is smaller than that of charge particles loss.

The root mean square value of AC voltage (V_{rms}) which needed to breakdown the gas (argon) at pressures 50-80 mTorr is on average $V_{rms} \approx 258$ V [11,12] and it can be considered for all frequency range 100-1000 Hz because of the change in AC breakdown voltage with frequency is small [9,11] and may be neglected. Since the relation between the time of one period and the frequency of a wave is T=1/f, Therefore the time of a half period of a sine wave of AC voltage is $T_{1/2}=1/2f$, which means that at each half period of our AC discharge there are two times: the first for glow discharge given by $t_g \approx 0.27/f$ (It is the time for which the instantaneous value of the discharge sine voltage exceed 258 V at a given pressure) [10] and the second is for Townsend discharge and given by td≈0.23/f . This means that $T_{1/2}$=tg+td and there are two modes of discharge (dark and glow) at each half period of AC voltage.

3.2 Changing of Discharge Power with AC Frequency

The power dissipation in argon AC discharge per cycle at each frequency was calculated from AC I-V loops areas using a special Matlab program [14] and the resulting data have plotted with the corresponding fit curve in figure (4).

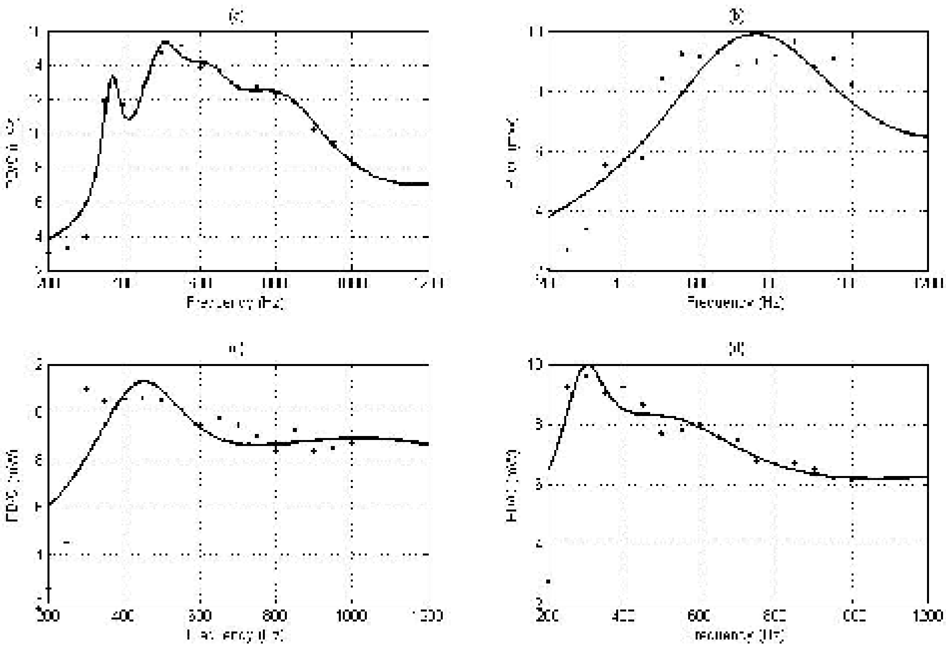

Figure (4). Discharge power dissipation per cycle (PD/C) for AC frequencies 200-1000 Hz at (a) 50 mTorr, (b) 60 mTorr, (c) 70 mTorr and (d) 80 mTorr.

From figure (3) and (4) we can deduce that:

1- For frequencies 100 to 300 Hz, tg is 2.7 - 0.9 msec. There is enough time to ignite glow discharge at a given pressure. There is also sufficient time, td=2.3-0.77 msec, to lose most of the charge particles afterglow. As a result, the discharge is periodically turned on and off and the AC I-V characteristic shows relaxation oscillation [7,15], as shown in figure (3-first image). The dissipation power per cycle is increased slowly with frequency at this rang due to the decreases of loss of charge particles during the time td.

2- In the range 350 to 750 Hz, the time of glow discharge is 0.77-0.36 msec and that of dark or diffusion discharge is 0.66-0.3 msec. This means that the time available to lose the charge particles afterglow is less than 1 msec. Thus, there is a volume charges left over afterglow. These charges were accelerated towards the electrodes in the second half of the AC sine voltage will increase the electron avalanches in the next breakdown process. As a result, the discharge current and the dissipation power per period will be increased with frequency as shown in figure (3-image 2-10) and figure (4).

3- For frequency band 800 to 1000 Hz, we have 0.34-0.36 msec for glow discharge and 0.29-0.23 msec for dark discharge. The time of afterglow (td) is still less than 1 msec, but the time of glow (tg) that needed to accelerate the afterglow positive ions towards the cathode during breakdown process is not enough for most of them. Therefore, the discharge current and the dissipation power per cycle will be decreased with frequency as shown in figure (3-image11-15) and figure (4).

3.3 Changing of Discharge Power with Pressure

From figure (4), it is clear that the maximum power dissipation increases as gas pressure decreases and it accrues at a specific frequency. The minimum power dissipation obtained at Paschen minimum pressure (60 mTorr). This is due to the well known fact that as pressure decreases the mean free path, mobility and drift velocity of charge particles increase [3,4,16].

4. Conclusions

An AC I-V image of a low pressure argon AC discharge gives a clear view on the power dissipation per cycle at a given frequency. A clear relationship between AC frequencies from 100 to 1000 Hz and power dissipation per cycle has been established. The power increases slowly with frequencies from 100 to 300 Hz due to the long dark discharge time td ≈ 1 msec, which leads to decay most of afterglow charge particles, thus the discharge has relaxation oscillation. For band 350 to 750 Hz the power dissipation per cycle increases sharply with frequency because of about 50% of afterglow charge particles can be used in the breakdown process during the second half of each cycle. For frequency rang 800 to 1000 Hz, the power dissipation per cycle decreases with frequency because of there is no enough time to accelerate all the afterglow positive ions towards the cathode in the second half of the discharge voltage cycle. The inverse relation between gas pressure and discharge power dissipation is similar to the inverse relation between pressure and the mean free path, mobility and drift velocity of charge particles.

5. Acknowledgements

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6. References

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القدرة المبددة خلال التفريغ بالتيار المتناوب لغاز الاركون عن ضغط واطئ لمدى الترددات (100-1000 Hz)

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قسم التقنيات الالكترونية ، المعهد التقني الموصل ، الموصل ، العراق

الملخص:

في هذا البحث تحققنا من تأثير تردد التيار المتناوب ضمن المدى (100-1000 Hz) في القدرة المبددة في التفريغ بالتيار المتناوب لغاز الاركون عند ضغط واطئ ضمن المدى (50-80 mTorr) .لقد لوحظ ان القدرة المبددة تزداد بزيادة التردد لمدى الترددات (100-750 Hz)، وانها تتناقص بزيادة التردد لمدى الترددات (750-1000 Hz). وكذلك تأكد لدينا بان القدرة المبددة تتناقص بزيادة ضغط التفريغ وان اقل تبديد للقدرة يحدث عند النهاية الصغرى لمنحني باشن.