International Conference on Control, Engineering & Information Technology (CEIT'14)
Proceedings - Copyright IPCO-2014
ISSN 2356-5608

Investigation on the AC electrical arcs under electric domestic network's conditions–220V AC

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***Abstract*—Electrical installation precisely in domestic environment must ensure the safety of persons and property. Several researches have been performed on AC arcs as they occur in the domestic field. The object of this work is to study the electrical arc's parameters in the electric domestic network (220V AC). This study allows to extend knowledge of electrical arc characteristics in the alternating current. To study the parameters of the arc such as arc duration as well as consumed electrical energy between AgNi contacts, experimental studies were performed under 220V AC, current from 0.5A to 4A with resistive and inductive load. Thus, the influence of the load on the mass loss of material was studied. Measurements reveal that the arc duration depends on the current and inductance value. It increases when their values increase. Indeed, for the inductive load an overvoltage is observed in the arc's extinction which is more important by increasing the inductance's value. The measurement results of mass loss have shown a mass loss for movable contacts. The mass loss is very close because of the energy difference is almost close to each ignition phase. Also, the presence of long and short arc duration because of the voltage variation over time. This is not the case in the direct current's field which allows having constant arc duration throughout the life of the contact so helps to estimate the erosion rate and the mass transfer which is not yet valid in the case of the alternating current.So study the characteristic of the AC arc may help better understanding the phenomena that causes a fire in the domestic environment and try to improve these characteristics in order to avoid fire and to ensure security.**

Keywords—domestic environment's security; alternating current; arcs opening; erosion; arc duration.

I. INTRODUCTION

Electrical installation precisely in domestic environment must ensure the safety of persons and property. The electrical arc witch appears between the electrodes' switches at each operation of closing or opening can cause fire. Several researches have been performed on AC arcs as they occur in the domestic field such as, the capability of ignition and re-ignition of arc [1], characteristics of arcs between carbon electrodes, the peak arc current value for some type of loads, mass transfer and arc duration [2-5]. These researchers were performed under different conditions for example the study of arcs when the insulation of a cable is damaged [6] for isolated and switches contacts [7-8] and under different loads [9]. The object of this work is to study the electrical arc's parameters in the electric domestic network (220V AC). This study allows to extend knowledge of electrical arc characteristics in the alternating current. The contact's material used in tests is AgNi (Nickel Silver: in weight 90% Ag, 10% Ni) because of its low contact resistance and low rate of welding [10-11]. To study the parameters of the arc such as arc duration as well as consumed electrical energy between the AgNi contacts, experimental studies were performed under 220V AC, current from 0.5A to 4A with resistive and inductive load and with a constant opening speed 20cm/s.

Arc duration depends on the load's nature, resistive or inductive one [12-16]. Thus, the influence of the load on the mass loss of material was studied. So the study of AC arc characteristics may help better understanding the phenomena that causes a fire in the domestic sphere and try to improve these characteristics in order to avoid fire and to ensure security.

II. EXPERIMENTAL METHOD

The experimental device, shown in Fig. 1, is composed of an electrical part (a power supply 220V AC, a variable resistance and a variable inductance) and a mechanical part to allow the opening and closing contacts which are fixed in the two supports. The first support is fixed (on which is attached the first contact (plat surface) and the second is moved with a stepping motor (on which is attached the second contact (curved surface)).

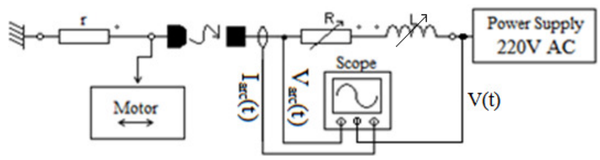

Fig. 1. Schematic of the experimental test apparatus.

A digital oscilloscope is used for data acquisition such as the voltage characteristics of the supply voltage V(t) and of the arc during opening step Varc(t) and current Iarc(t). All the data are transmitted to a computer via GPIB bus, to be analysed to

ISSN 2356-5608

determine the arc duration, the energy and the arc's ignition phase. Table I illustrates the test parameters.

TABLE I. TEST PARAMETERS

Voltage	Current	Disconnection speed	Loads
220V AC	0.5A to 4A	20cm/s	Resistive Inductive (5mH-75mH)

III. ARC PARAMETERS

Electrical arc appears at each operation of closing or opening contacts, so after important numbers of making and breaking current, contacts failures can happen and cause critical troubles and insecurity, such as contacts welding, excessive wear or other harmful effect. Thus, parameters which characterize the electric arc have been studied, such as arc duration and consumed electrical energy between the contacts.

A. *Influence of the load on the arc duration*

To study the influence of the load on the arc duration with 220 alternating current which is used in the domestic field two load's nature are used, resistive and inductive one for different values' current. Fig. 2 presents the variation of the arc duration vs. current from 0.5A to 4A, 20cm/s opening speed and for resistive load. The results show the increasing of the arc duration with the increasing values of current. For example, for 0.5A and when the arc's ignition phase is equal to 45°, the arc duration is about 5.5ms and increases to 7.5ms for 4A. The arc duration depends on the current's value.

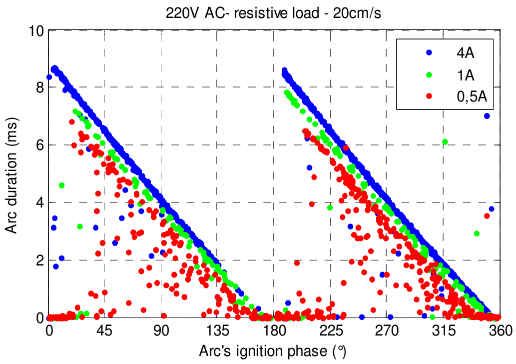

Fig. 2. Arc duration vs. Current (resistive load)

Fig. 3 shows the variation of the arc duration vs. inductance (5mH, 55mH and 75mH), a current value of 4A and 20cm/s opening speed.

The arc duration increases with the increasing values of inductance. For example, for 5mH and when the arc's ignition phase is 100°, the arc duration is about 4ms and reaches 5.5ms for 75mH. Indeed, the arc duration does not only depend on the current but also on the value of inductance.

The results show at the beginning of each half period (when the ignition phase is near to 0° and 180°) the arc duration is maximum for resistive and inductive load.

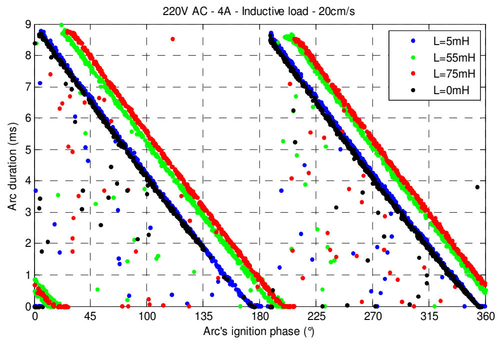

Fig. 3. Arc duration vs. Inductance (4A)

The arc duration's values are illustrated on a histogram for a current of 4A with resistive and inductive load (Fig. 4). The results show that the arc duration does not follow a normal distribution. A peak is observed at short periods for different load.

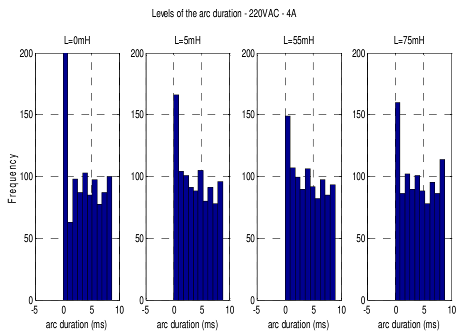

Fig. 4. Histograms' arc duration

Some examples of the arc voltage Varc(t), the supply voltage V(t) and arc current Iarc(t) are illustrated in Fig. 5, Fig. 6, Fig. 7 and Fig. 8 for different arc's ignition phase. The measurements are under 220V AC, 4A, resistive load and 20cm/s opening speed.

As shown, the arc duration varies between short and long duration as working in alternating current. This is not the case in the direct current's field which allows having constant arc duration throughout the life of the contact so helps to estimate the erosion rate and the mass transfer [12-15] which is not yet valid in the case of the alternating current.

This opening arc voltage shows that more arc starts near zero voltage, more the arc will take time to develop before natural extinction or forced (return to zero voltage).

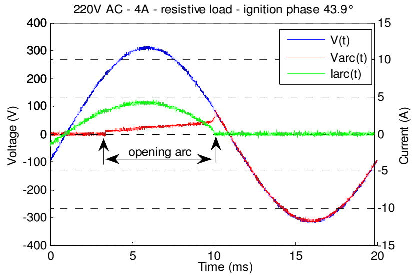

Fig. 5. Arc in 43.9° ignition phase

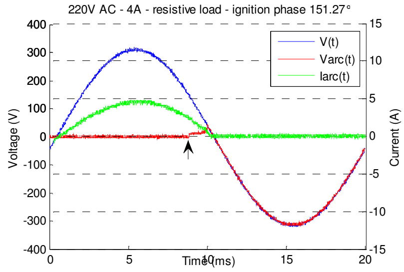

Fig. 6. Arc in 151.27° ignition phase

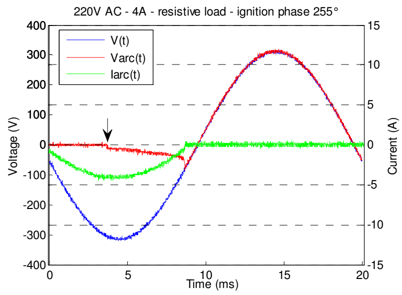

Fig. 7. Arc in 255° ignition phase

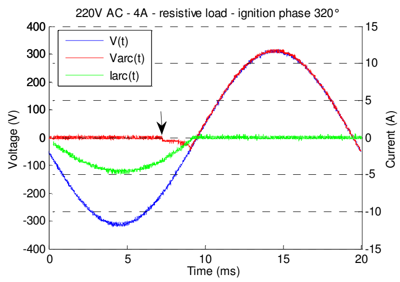

Fig. 8. Arc in 320° ignition phase

For different values of inductance (5mH, 55mH and 75mH), some examples of the arc voltage Varc(t), the supply voltage V(t) and arc current Iarc(t) are illustrated in Fig. 9, Fig. 10 and Fig. 11 for different arc's ignition phase. The measurements are under 220V AC, 4A and 20cm/s opening speed.

Overvoltage is observed in the arc's extinction which is more important by increasing the inductance's value. This overvoltage is about 125V for 5mH and reaches 390V for 75mH.

Thus, the inductance value's variation affects the arc and the presence of overvoltage degrades the contact surface which over time may not provide a good connection in the switching devices and can cause fires and threaten human security.

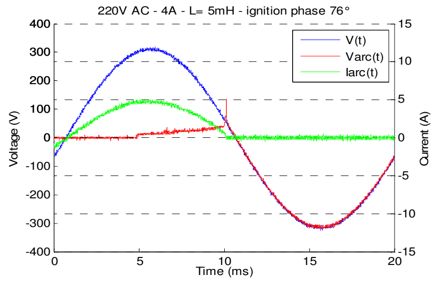

Fig. 9. Arc in 76° ignition phase, 5mH

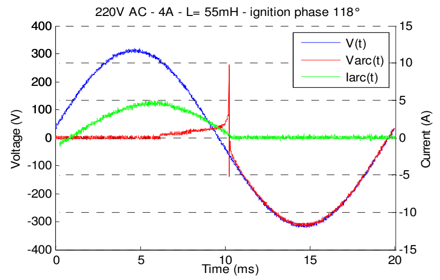

Fig. 10. Arc in 118° ignition phase, 55mH

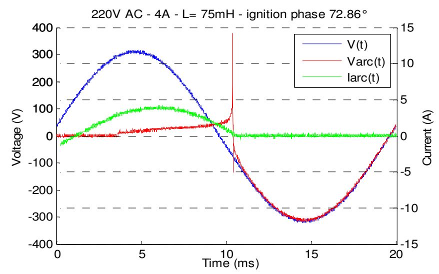

Fig. 11. Arc in 72.86° ignition phase, 75mH

A phase shift (φ) is observed on the different curves between current and voltage. For example, under 220V AC, 4A and 75mH inductance value, the phase shift measured with the oscilloscope in the contact's closing operation shown in Fig. 12 equal to 23.4° and that calculated in theory with equation (1) equal to 23.2°.

$$\varphi_{theory} = \tan^{-1}\left(\frac{L\omega}{R}\right) = 23.2° \qquad (1)$$

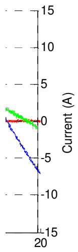

Fig. 12. Arc in 320° ignition phase The arc voltage Varc(t), the supply voltage V(t) and arc current Iarc(t) when the contact is closed under 220V AC, 4A and L= 75mH

B. Influence of the load on the arc energy

To study the influence of the load on the arc energy during opening operation, energy was measured for inductive load (three inductance's values: 5mH, 55mH and 75mH) and for resistive load, with a current of 4A. Fig. 13 shows the evolution of the arc energy as a function of inductance.

The arc energy is maximum at the begining of each half period (when the ignition phase is near to 0° and 180°) under an inductive load that even under a resistive one. When the inductance value increases, it causes higher energy consumption in each half period. Because of the energy expended by the inductance in the electrical arc. This phenomenon explains that arc duration and extinction length are more important for inductive load than for resistive one. The energy of the opening arc is calculated with equation (2):

$$W_{arc} = \int_0^T V_{arc}(t) I_{arc}(t) dt \quad (2)$$

$V_{arc}(t)$ the arc voltage and Iarc(t) the arc current. The maximum arc energy is between 0.6 and 0.8J when the arc's ignition phase is near to 0° and 180° (at the begining of each half period).

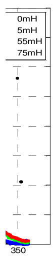

Fig. 13. Energy vs. Inductance-4A

IV. MATERIAL TRANSFER

Arc duration depends on the load's nature so the transfer of material is different. Thus, the influence of the inductance's value on the mass loss of material was studied. Table II shows the mass loss for movable contacts under 220V AC and with an opening speed equal to 20cm/s and inductive loads after 1000 operations.

TABLE II. MASS LOSS FOR A MOVABLE CONTACT, INDUCTIVE LOAD, 220VAC, 20CM/S AND 1000 OPERATIONS

Current (A)	**Inductance (mH)**	**Mass loss for a movable contact (µg)**
4A	0	-8.7
	5	-19
	55	-15
	75	-15

The measurement results of mass loss have shown a mass loss for movable contacts due to the presence of long and short arc duration result of the voltage's variation over time. Indeed, the mass loss is very close beacuase of the energy difference is almost close to each ignition phase. Also, as it is demonstrated the loss mass is more significant after 1000 operations and the movable contact is the most affected [7]. This is not the case in the direct current's field which allows having constant arc duration throughout the life of the contact so helps to estimate the erosion rate and the mass transfer which is not yet valid in the case of the alternating current.

The technical EDX (energy dispersive X-ray spectroscopy) and SEM (scanning electron microscope) are used to determine the nature of the materials present on the surface of contacts [17]. Fig. 14 shows contact's surface with inductive load using a scanning electron microscope (SEM). It's shown an important surface occupied for silver as shown in the spectrum1 of Fig. 15 (89.92% mass of Ag). This phenomenon is explained by electrical arcs that are not very intense at the beginning of the contact's lifetime which allowing only the melting of silver, but not the nickel which has a melting temperature 1452°C against part a melting temperature of the silver which is equal to 961°C [18]. This explains the melting of silver after 1000 operations.

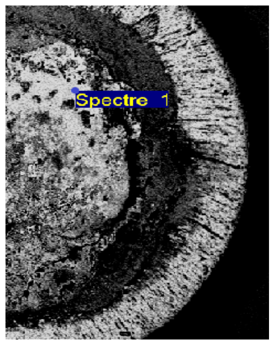

Fig. 14. Contact's surface with inductive load

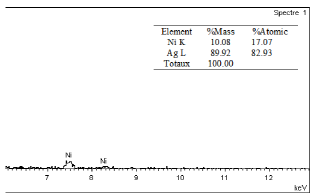

Fig. 15. Spectrum EDX

V. CONCLUSION

This work has presented the characteristics of the electrical arc under electrical conditions in the electric domestic network (220V AC), for a current from 0.5A to 4A with resistive and inductive load and with a constant opening speed 20cm/s.

For the resistive and the inductive load, the arc duration and the arc energy are maximum at the beginning of each half period. That is to say more arc starts near zero voltage, more the arc will take time to develop before natural extinction or forced (return to zero voltage). Indeed, the arc duration depends on the current and inductance value. It increases when their values increase.

The main result with inductive load is that, presence of an overvoltage is in the arc's extinction which is more important by increasing the inductance's value. The presence of overvoltage degrades the contact surface which over time may not provide a good connection in the switching devices and can cause fires and threaten human security. Also, when the inductance's value increases, it causes higher energy consumption in each half period. This is due to the energy expended by the inductance in the electrical arc. This phenomenon explains that arc duration and extinction length are more important for inductive load than for resistive one.

The measurement results of mass loss have shown a mass loss for movable contacts due to the presence of long and short arc duration result of the voltage's variation over time. Indeed, the mass loss is very close beacuase of the energy difference is almost close to each ignition phase. Also, as it is demonstrated the loss mass is more significant after 1000 operations and the movable contact is the most affected. This is not the case in the direct current's field which allows having constant arc duration throughout the life of the contact so helps to estimate the erosion rate and the mass transfer which is not yet valid in the case of the alternating current.

So study the characteristic of the AC arc may help better understanding the phenomena that causes a fire in the domestic environment and try to improve these characteristics in order to avoid fire and security.

ACKNOWLEDGMENTS

The authors would like to thank Metalor France for the materials and express their appreciation to the Laboratory of Physics IPR / UMR Rennes1 for their support of this work.

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