MEASUREMENT OF THE PRE-ARCING TIME AND THE FULGURITE LENGTH IN HBC FUSE IN THE CASE OF TESTS PERFORMED WITH AN A.C. 100 KVA STATION

William Bussière[1], David Rochette[2], Steeve Memiaghe[1], Gérard Velleaud[2], Thierry Latchimy[1] and Pascal André[1]

[1] LAEPT CNRS UMR 6069, Phys. Bât. 5, Université Blaise Pascal, 24 Avenue des Landais, F63177 AUBIERE Cedex, France, Phone: +33 4 73 40 77 04, william.bussiere@univ-bpclermont.fr, steeve.memiaghe@univ-bpclermont.fr, thierry.latchimy@univ-bpclermont.fr, pascal.andre@univ-bpclermont.fr
[2] LAEPT CNRS UMR 6069, Université Blaise Pascal, IUT de Montluçon, Avenue Aristide Briand, BP 2235, F03101 Montluçon Cedex, France, rochette@moniut.univ-bpclermont.fr, gerard.velleaud@moniut.univ-bpclermont.fr

Abstract: **This study deals with a specific test device especially designed to perform tests on HBC fuse on a scale of a non industrial laboratory. In fact it is not possible for most of academic laboratories to build up a device supplying the same current and voltage ranges as in an industrial test station. Moreover the capacitor bank discharges are often used in academic laboratories to test electric fuses. But the main drawback of the capacitor bank is to supply a non 50 Hz-sinusoidal current waveform for one half period only. We present the first measurements performed on experimental HBC fuses using a 100 kVA station built up from a single phase transformer. These first measurements are performed using various fuse elements with the same geometries as in industrial fuses of the middle voltage range. The filling material is silica sand or quartz sand and it is chosen with the same properties as in industrial fuses.**
The fuse working is studied experimentally on the whole duration of the fuse working which depends on the values chosen for the power factor and the closing angle. The results are given for the pre-arcing time and the fulgurite length. The power factor put in the tests is equal to $\cos\varphi \sim 0.9$ and $\cos\varphi \sim 0.1$, and the closing angle is increased from 0 ° to 180 °. The results are discussed by taking into account the influence of the energy to dissipate, namely the Joule energy and the inductive energy.

Keywords: **closing angle, power factor, fulgurite, energy, experiment.**

1. Introduction

This paper deals with the first measurements obtained with a novel supplying device built up from a 100 kVA single phase transformer. Up to now our experimental study of the fuse working has been performed using a capacitor bank discharge with fitted resistive and inductive constants to obtain a current waveform close to the 50 Hz-waveform [1-5]. For modelling and experimental purposes an A.C power station is now used with a power factor varying in the range from $\cos\varphi \sim 0.9$ down to $\cos\varphi \sim 0.1$, and a closing angle varying in the range from 0 ° to 180 ° [6].

The current study concerns High Breaking Capacity (HBC) fuses that usually comprise: two metal electrodes of high conductivity ending, a helicoidal core in insulating material, around which a fuse element or fuse strip in silver of high purity with reduced sections is coiled, and the filling cavity filled with the arc quenching material, silica sand or quartz sand of high purity.

Whatever the type of the electrical supply a specific experimental fuse has been designed according to the electrical and/or physical properties studied. This is detailed in Section 2. The characteristics of the power station are given in Section 3. In Section 4 the experimental results are given and discussed, mainly for two properties, the pre-arcing time and the fulgurite characteristics. Finally we conclude in Section 5.

2. Experimental fuse for measurements

The fuse working can be briefly summarized as follows. The appearance of the fault current implies the fusion and the vaporization of the fuse element around the reduced sections because the electrical resistivity is higher. The temperature rise of the fuse element is caused by the energy brought by the fault current. Once the enthalpy necessary to obtain the vaporization of the melted silver is provided, an electric arc is initiated because of the disruption of the fuse element [7]. First this electric arc is mainly composed of metallic vapours [8]. Second, due to the surrounding silica sand grains, the silver plasma interacts with the sand grains and the plasma becomes a silica plasma [9]. The plasma

978-2-84516-363-8/07/$25.00 © 2007
Blaise Pascal Academic Press

temperature increases up to around 20,000 K, the plasma electron density is around 10^{18}cm^{-3} to 10^{19}cm^{-3} at the most, and the plasma pressure is in the range of tens of atm [5,10-11]. Whatever the assessed properties the experimental fuse is always designed: to allow the measurement of the electrical and physical properties, and to avoid the edge effects during the packing operation and the fuse test. In each experiment the industrial sand is used with given values for the mean granulometry and the packing density. The measurement of the electrical properties is helpful to check the reproducibility of the fuse tests.

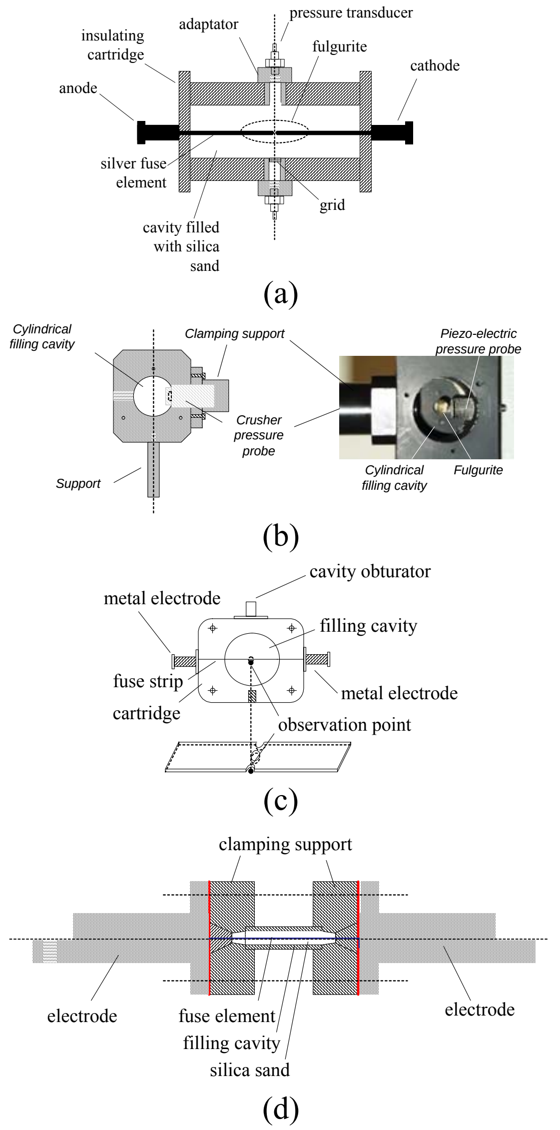
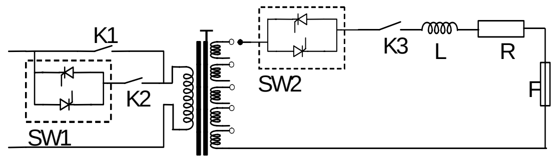


Fig. 1: Different experimental fuses. (a) Measurement of the pressure due to the filler and due to the air in the interstices with piezo-electric sensor [5]. (b) Measurement of the pressure due to the filler with a Crusher probe. (c) Study of the radiation emitted by the plasma [1]. (d) Experimental fuse in this study.

A HBC fuse of industrial type is naturally opaque to the radiation emitted by the plasma due to the cartridge. Two techniques can be used to collect the light: either by inserting an optical fibre close to the reduced section area [12], either by fitting a quartz window close to the fuse element reduced section to collect the light directly via an optical device integrating a focussing lens [3].

The experimental fuse given on Fig. 1(d) has been especially designed to be used in the fuse tests performed with the 100 kVA station. A specific care has been focussed on the interference resistances, the gas tightness, and the reproducibility of the packing operation. Such an experimental fuse can be equipped with several fuse elements in parallel, each of them being equipped with several reduced sections.



F: experimental fuse ; K1: power switch ; K2: security switch ; K3: security switch ; L: inductive load ; R: resistive load ; SW1: primary static switch ; SW2 : secondary static switch ; T: 100 kVA single phase transformer.

Fig. 2: Diagram of the 100 kVA single power station.

3. Power station

The diagram of the 100 kVA power station is given on Fig. 2. It is built from a single phase transformer with a 100 kVA true power which can be supplied with 230 V.A.C. or 400 V.A.C. at the primary. The secondary can be supplied from 100 V.A.C. to 500 V.A.C. The corresponding nominal current is 200 A. Moreover the whole of the electrical device, that is to say the magnetic circuit and the electrical circuit, is designed to allow a secondary A.C. current of 2000 A for 500 ms. The load is composed of a set of coils up to 2860 µH. By using fitted electrical resistances the power factor $\cos\varphi$ can vary in the range from 0.1 to 0.9 with loading A.C. currents up to 2000 A.

The fuse test is performed in two steps. Firstly the calibration of the test circuit is done with a given set of resistive and inductive loads to obtain the experimental values of the closing angle and the power factor, and the waveform corresponding to the prospective current. Secondly the experimental fuse is inserted in the test circuit and the fuse test is performed with a calibrated load.

978-2-84516-363-8/07/$25.00 © 2007
Blaise Pascal Academic Press

Due to the A.C. power supply the prospective current is written as:

$$I(t) = \frac{\hat{V}}{\sqrt{R^2 + L^2\omega^2}} \times \left(\sin(\omega t + \theta - \varphi) - \sin(\theta - \varphi) \times e^{-\frac{R}{L}t} \right)$$

where $\hat{V}$ is the supplied voltage peak, R is the resistive load, L is the inductive load, ω is the pulsation at 50 Hz, θ is the closing angle, $\cos\varphi$ is the power factor, t is the time. The calibration allows the measurement of the resistive load and the inductive load for the given prospective current.

Table 1: Experimental values of the closing angle θ.

Presumed closing angle θ (°)	θ (°) for $\cos\varphi$ ~ 0.9	θ (°) for $\cos\varphi$ ~ 0.1
0	6.7	12.1
90	87.4	90.3
160	157.2	160.7

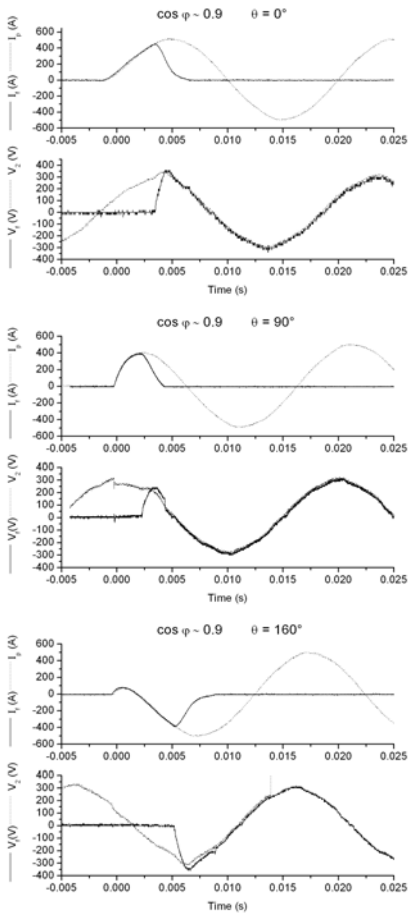


Fig. 3: Evolutions versus time of current and voltage for $\cos\varphi \sim 0.9$ and $\theta = 0°, 90°, 160°$.

4. Measurements

4.1 Conditions of the tests. Prospective currents

Whatever the case, namely calibration or fuse test, the experimental conditions are given in Table 1. The first column gives the presumed closing angle, and the two last columns correspond to the experimental value obtained for the test of the fuse.

These conditions are chosen to scan the experimental domain accessible and to study the influence of the closing angle and the power factor on the quoted properties. The discrepancy between the presumed values and the experimental values is linked to a first version of our numerical control. It has been improved now. The whole conditions allow us to study the fuse working for various cases between the symmetrical and the asymmetrical case.

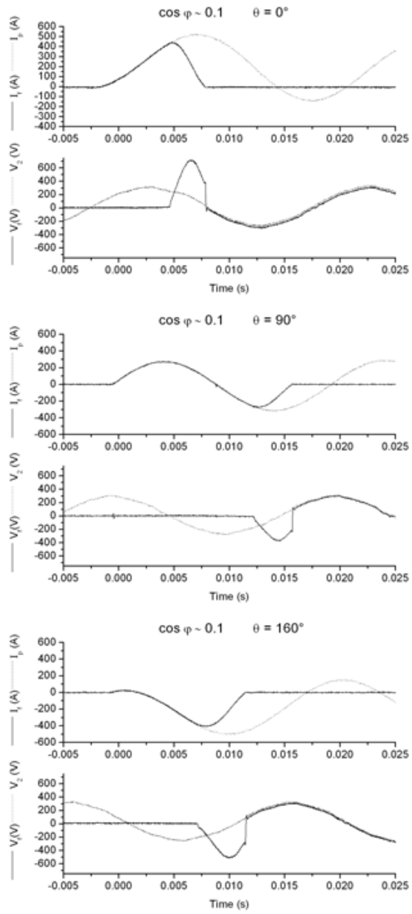


Fig. 4: Evolutions versus time of current and voltage for $\cos\varphi \sim 0.1$ and $\theta = 0°, 90°, 160°$.

The evolutions versus time of the prospective current I_p, the voltage of the supply V_2, the current in the fuse I_f, and the voltage across the fuse V_f are given in Fig. 3 and Fig 4 respectively for the power

978-2-84516-363-8/07/$25.00 © 2007
Blaise Pascal Academic Press

factors $\cos\varphi \sim 0.9$ and $\cos\varphi \sim 0.1$ and the quoted values of the closing angle (Table 1).

4.2 Fuse tests

The fuse tests performed with the conditions defined in Section 4.1 are given in Fig. 3 and 4, with the evolutions versus time of the current in the fuse I_f and the voltage across the fuse V_f. The fuse tests have been performed from $\theta = 0$ ° to $\theta = 160$ ° by step of 30 ° and the results can be found in [6]. As it can be seen from Fig. 3 and 4 the total duration of the fuse working, namely the pre-arcing time plus the arcing time defining the extinction time, varies from one to around two half-periods of the 50 Hz supply.

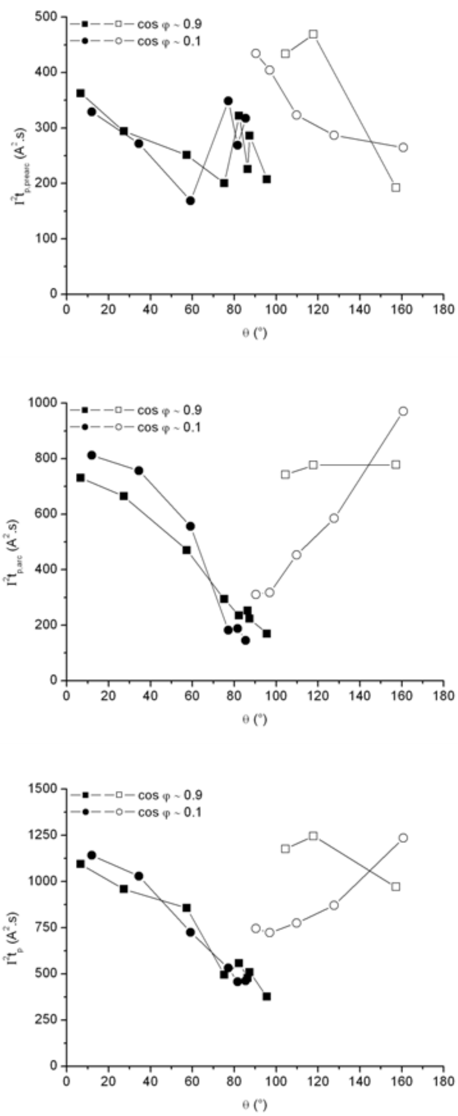


Fig. 5: Experimental Joule integral for the pre-arcing time, the arcing time, the total duration of the fuse working, for the two power factors, versus the closing angle.

This is quite logical in so far as the prospective current peak is not high enough to work with high fault current conditions.

The various conditions of the tests can be compared using the Joule integral calculated for the prospective current. The I^2t values are calculated for the pre-arcing stage, the arcing stage, and the total duration of the fuse working. From Fig. 5 we see that $I^2t_{p,prearc}$ decreases from $\theta = 0$ ° to $\theta \sim 90$ ° for $\cos\varphi \sim 0.9$ and to $\theta \sim 100$ ° for $\cos\varphi \sim 0.1$. We observe strong fluctuations around these latter θ values.

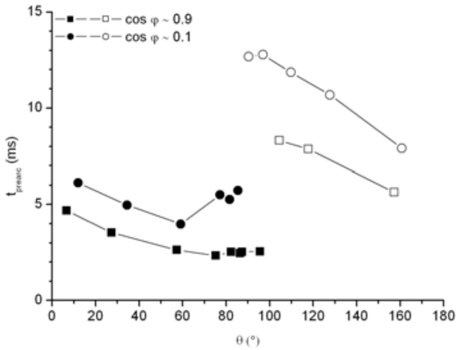


Fig. 6: Influence of the closing angle and the power factor on the pre-arcing time.

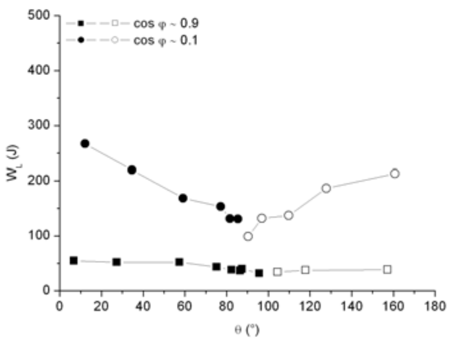


Fig. 7: Evolution versus the closing angle of the electromagnetic energy stored in the coil.

The values are in the range from ~ 160 A².s to ~ 360 A².s. For higher θ values there is a strong increase up to values more than 400 A².s followed by a decrease for $\theta > 90$ ° and 100 °. There is a gap between the lower and the higher values of θ for which the test can not be performed. This is due to the supplied voltage close to around 0. This particular value of the closing angle is defined as the limit closing angle or θ_l.

The evolution of the pre-arcing time is given on Fig. 6 versus the closing angle. We observe a decrease up to θ_l. The pre-arcing time decreases from 6.13 ms to 3.98 ms for $\cos\varphi \sim 0.9$ and from 4.67 ms to 2.33 ms for $\cos\varphi \sim 0.1$. Around $\theta < \theta_l$ there is a slight increase. On the whole θ-values defined by $\theta < \theta_l$ the pre-arcing stage lasts longer in the case $\cos\varphi \sim 0.1$. For $\theta > \theta_l$, there is a strong increase of the pre-arcing time up to around 8.30 ms for $\cos\varphi \sim 0.9$ and around 12.68 ms for $\cos\varphi \sim 0.1$. And for higher θ-values up to 160 ° the values of the pre-arcing time decrease regularly. The discrepancy between $\cos\varphi \sim 0.9$ and $\cos\varphi \sim 0.1$ can be explained by: the prospective current peak inferior in the case $\cos\varphi \sim 0.1$, and the energy brought by the inductive load (Fig. 7).

The influence of the two parameters, $\cos\varphi$ and θ, on the fulgurite characteristics is of great importance from the industrial point of view. In the case of a HBC industrial fuse the fuse element is equipped with many reduced sections in series. The gap between each reduced section is chosen carefully to avoid the merging of two consecutive arcs. In this latter case the fuse is conductive on its whole length and the fault current is not interrupt. Thus the influence of $\cos\varphi$ and θ on the fulgurite characteristics has to be known. The evolutions of the mass and the length of the fulgurite are given on Fig. 8 versus the closing angle. The evolution of the length versus the mass is also given. The two parameters, $L_{fulgurite}$ and $m_{fulgurite}$, decrease with increasing θ up to θ_l. For $\theta > \theta_l$ and $\cos\varphi \sim 0.9$ the mass and the length do not vary significantly. On the contrary for $\cos\varphi \sim 0.1$, $L_{fulgurite}$ and $m_{fulgurite}$ increase strongly up to 160 ° by a factor roughly estimated around 2. The trends observed for the length and the mass are very similar to the ones of the Joule integral calculated for the arcing stage on one side, and to the ones of the energy dissipated during the fuse working on the other side.

The discrepancy observed for $L_{fulgurite}$ and $m_{fulgurite}$ between the two power factors on the whole θ range is clearly visible for $\theta << \theta_l$ and $\theta >> \theta_l$. These domains correspond to the higher discrepancies observed for the arcing stage Joule integral and the energy dissipated by the fuse, this latter being linked to the energy of the inductive load.

The results given on Fig. 8 clearly show that strong variations can be observed for the fulgurite characteristics according to the conditions of working. These results have to be explained by taking into account the energy point of view more precisely. Moreover some previous experimental studies [2,4] have clearly shown that the common morphometric properties, namely the packing density and the mean granulometry, play a great role on the plasma properties on one side, and on the fulgurite mass, length, and weight on the other side. Therefore the control of these properties could be very useful to influence the resulting fulgurite characteristics obtained after the fuse operation.

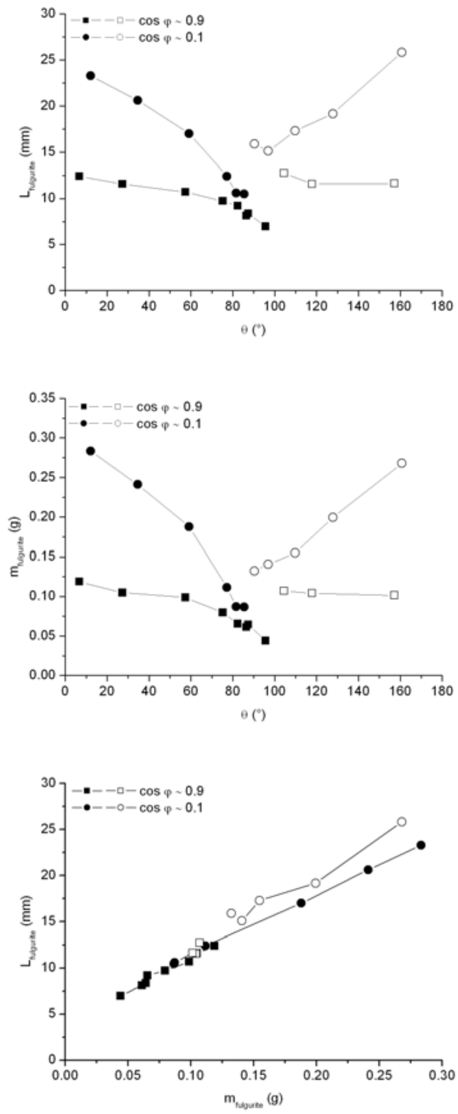


Fig. 8: Evolution of the length and the mass of the fulgurite versus the closing angle and for the two power factors.

5. Conclusion

We have given the first results obtained with an A.C. 100 kVA power station appropriate to perform fuse tests inside an academic laboratory. These results clearly show that fuse tests can be performed with the same conditions as for industrial ones at the condition that the experimental fuse is fitted by taking into account the specificities on the industrial fuse.

The influence of the closing angle has been shown for two power factors, $\cos\varphi \sim 0.9$ and $\cos\varphi \sim 0.1$. These values have been chosen to test our power station in the case of two limit cases, respectively the resistive and the inductive case.

The analysis of these measurements must be improved by taking into account the energy (Joule, inductive) as far as it has been shown that for example the morphometric properties can strongly influence the dissipation of the energy brought by the fault current.

Acknowledgements

We thank both for their financial support and their help through many discussions, Mr. J.L. Gelet and Mr. T. Rambaud from Ferraz Shawmut, Mr. J.C. Perez Quesada from Mesa, and Mr. F. Gentils from Schneider Electric.

References

[1] W. Bussière, P. Bezborodko, Measurement of time-resolved spectra using a new experimental arrangement, J. Phys. D: Appl. Phys., 32, 1693-1701, 1999

[2] W. Bussière, Influence of sand granulometry on electrical characteristics, temperature and electron density during high-voltage fuse arc, J.Phys.D:Appl. Phys. 34, pp 925-935, 2001

[3] W. Bussière, P. Bezborodko, R. Pellet, Spectroscopic study of a cutting electrical arc in HBC fuse, Proceedings of the 6th Icefa (IEN Galileo Ferraris, Torino, Italy), 20-22 Sept., pp 113-118, 1999

[4] W. Bussière, Estimation of the burn-back rate in high breaking capacity fuses using fast imagery, J.Phys.D:Appl. Phys. 34, 1-10, 2001

[5] D. Rochette, W. Bussière, Pressure evolution during HBC fuse operation, Plasma Sources Science and Technology, 13, 293-302, 2004

[6] W. Bussière, D. Rochette, G. Velleaud, T. Latchimy, J.L. Gelet, F. Gentils, J.C. Perez Quesada, T. Rambaud, and P. André, A specific test device for HBC fuses. Influence of the closing angle and the power factor, Submitted to IEEE Trans. Mag, Ref. TMAG-07-07-0225, 2007

[7] D. Rochette, W. Bussière, R. Touzani, S. Memiaghe. G. Velleaud, P. André, Modelling of the pre-arcing period in HBC fuses including solid-liquid-vapour phase changes of the fuse element, Proceedings of the 8th Icefa (Blaise Pascal University, Clermont-Ferrand, France), 10-12 Sept., Session III, Part I, 2007

[8] P. André, J. Aubreton, W. Bussière, M.F. Elchinger, S. Memiaghe, D. Rochette, Basic Data: Composition, Thermodynamic Properties and transport Coefficients applied to fuses, Proceedings of the 8th Int. Conf. on Electric Fuses and their Applications (Blaise Pascal University, Clermont-Ferrand, France), 10-12 Sept., Session III, Part I, 2007

[9] P. André, W. Bussière, D. Rochette, Transport coefficients of Ag-SiO_2 plasmas, To be published in Plasma Chemistry and Plasma Processing, DOI. 10.1007/s11090-007-9086-y, 2007

[10] W. Bussière, P. André, Evaluation of the composition, the pressure, the thermodynamic properties and the monatomic spectral lines at fixed volume for a SiO_2–Ag plasma in the temperature range 5,000 K – 25,000 K, J. Phys. D: Appl. Phys, 34, 1657-1664, 2001.

[11] M.A. Saqib, A.D. Stokes, P.J. Seebacher, Pressure inside the arc channel of a high-voltage fuse, Proceedings of the 6th Int. Conf. on Electric Fuses and their Applications (IEN, Torino, Italy), 20-22 Sept., 83–88, 1999.

[12] M.A. Saqib, A.D. Stokes, B.W. James, I.S. Falconner, Arc temperature measurement in a high-voltage fuse, Proceedings of the 6th Int. Conf. on Electric Fuses and their Applications (IEN, Torino, Italy), 20-22 Sept., 107-112, 1999