TIME CORRELATED TECHNIQUES TO INVESTIGATE ARCING DYNAMICS ABOUT THE PEAK VOLTAGE INSTANT DURING CURRENT INTERRUPTION IN SAND FILLED FUSES USING AN OPTICAL SPECTRUM ANALYSER

Robert E. Brown
Director, Sensdata Limited,
Unit B1, Sheffield Technology Parks, 60 Shirland Lane, Sheffield,
South Yorkshire, United Kingdom, S9 3SP
Tel: 0044 (0) 1709 739228, Email: robert.brown@sensdata.com, Web: www.sensdata.com

Abstract: **This paper will present attributes of apparatus and results from a study of disintegration and arcing in quasi short notched HBC sand filled fuses. Discussion will be centred around the aspects of time correlation of data captured from several data sources yet focusing on data acquired from a scanning optical spectrum analyser. Techniques for synchronising the scanning cycle of the spectrum analyser to the disruption period of the fuse element yet more accurately to the sub time domains of element disintegration will be discussed. Importantly, results indicating the possible nature of arcing phenomena about the peak fuse voltage instance will be presented.**

Keywords: **Fuse, Disintegration, Arcing, Spectrograph, Instrumentation.**

1. Introduction

Many studies have been carried out to evaluate the magnitude and nature of parameters of fuse operation using a spectrographic type instrument to capture data related to light spectra emitted during the arcing phase of the interruption of high fault current by the fuse. Moreover, in these investigations many different forms of spectrograph have been used as the focus of data capture, however only a small amount of time correlated spectral data exists which relates to the transient nature of the arc relative to the phenomena of element disintegration. The possible cause of this is proposed to be accountable to the very short time period of operation of the fuse relative to the data capture time period of the spectrograph and the difficulty in correlating the data to fuse voltage and current waveforms. With the advancement of data logging equipment and optical image capturing devices the investigation of the transient nature of light spectra inherent in the fuse arc during the sub time domains of the arcing period are now possible. Consequently, the phenomena of fuse element disintegration during the passage of fault current can be hypothesised.

Many researchers have studied attributes of the voltage developed across a fuse during the prearcing and arcing phases of the fuse operation. Moreover, much attention has been given to the nature of the voltage measured across the fuse terminals during the arcing phase in an effort to understand the physical phenomena of element disintegration in anticipation of developing a model to replicate fuse operation and subsequently to aid future fuse component manufacture.

Great attention has been given to the way the voltage quickly rises [1] which is generally believed to be at the onset of arcing and the subsequent multiple fragmentation [2] of the fuse element provoking multiple arcing [3].

Moreover, consideration has been given to the magnitude of the voltage peak [4] and its correlation with current density, filler compaction and filler material type.

Finally, much interest and postulation has been focused on the causation of the decreasing voltage trend following the voltage peak and the causation and association with multiple arcing [5].

Gomez and McEwan [6] referred to the phases of arcing relative to the peak of the voltage transient wave as, pre-peak arc and post peak arcing time periods and as such developed a hypothesis as to the nature of the course of the voltage transient wave relative to fuse element disintegration.

It was during the course of studying the disintegration and arcing in electrical fuses [7] by the author that the spectral observations of the fuse arc were undertaken.

2. Evaluation of Spectroscopic Studies of Fuse Arcing

A brief evaluation of the portfolio of fuse/spectrograph investigative work is worthy at this point yet focusing on the attributes of the data capturing apparatus.

Numerous experimental set ups have been used to monitor the characteristics of the fuse arc. The range of fuse designs which allow the light, emitted from the arc to be monitored are numerous and include,

 978-2-84516-363-8/07/$25.00

- Standard HBC fuse designs with optical fibers inserted through the walls of the fuse to penetrate the arc column [8].
- Fuse patterns with 'glass windows' with the fuse element pressed against the window so that light from the arc can be detected directly by a spectrograph or conveyed again via an optical fiber [9]
- In studies of the attributes of an ablation arc, fuses have been constructed of very thin wires and subjected to very high current densities to provoke arcing whilst surrounded by a tube of ice, which provided access to directly monitor and observe the arc [10].

The type of spectrograph used in investigations can be categorised thus.

- Monochromatic Spectrograph: A system where narrow band interference filters and light sensitive devices i.e. photo diodes, are used to monitor pre-selected spectra from the arc spectrum [11].
- Polychromatic: A system where data representative of all spectra between a predetermined light wavelength bandwidth are captured. Polychromatic systems where originally analogue devices where the spectrum was captured by an 'arc array' of photo multiplier tubes or photographic film. These systems have now been superceded by digital systems where collections of charge coupled devices (CCD's) in array or matrix formation have been used [9].
- Time Integrated: These systems can be either analogue or digital, mono or polychromatic, yet the spectrum is captured over a finite time period which, fundamentally is the time period of the light collecting device i.e. CCD or film. The time period can be very short (μSecs) so numerous spectra can be captured during the arcing phase of the fuse [10].
- Scanning: These systems can also be analogue or digital yet here the spectroscope uses a light sensitive device to scan the light output of a diffraction grating. The angular scanning velocity of the device is in the order of 12Hz, hence only a single spectrum can be captured at a specific time instance during the arcing phase of the clearance of short circuit fault current by the fuse [8].

Generally spectroscopic studies of fuse arcing have been carried out to determine arc temperature [11] [12], electron density [13] and arc pressure [13] and most often the studies have paid attention to the vapour medium in which arcing is occurring and at the time instant from the application of fault current that data representative of the arc spectrum is captured and analysed, i.e. from the injection of fault current, the beginning of the pre-arcing time period. Only a small amount of spectral data exists which correlates the intensity and element type of spectra relative to the separate time domains of the voltage waveform during the arcing period in an attempt to propose the evolution and dynamic nature of arcing relative to the phenomena of fuse element disintegration.

Experimental Arrangement for Spectral Data Capture from Arcs in Short notched Element Quasi HBC Sand Filled Fuses

This paper reports a spectroscopic investigation, which was part of a much larger fundamental investigation, undertaken to capture insight into the phenomena of fuse element disintegration and arcing. A scanning type spectrometer was used, and therefore only a single spectrum could be captured for each fuse operation.

Time correlation of the fuse voltage and current is straight forward using dual channel oscilloscopes yet synchronizing these parameters with the exact time instant of data representative of arc spectra is most difficult because of the amount of data, the short data capture time period and because several items of test equipment have to be triggered at the same time instance.

To obtain data that could be cross correlated between fuse samples strict procedures in the manufacturing of fuse samples were adopted so that a near homogenous batch of fuses could be used. To accomplish this a 'jig' was used in the construction of the fuses, so that the fuse elements were consistently aligned with the horizontal and vertical axis of the spectrograph. Furthermore, bespoke equipment was manufactured so that the repeatability of the fuse test duty used was very high (>98%). Consequently, the integrity of any hypothesis regarding the phenomena of element disintegration could be upheld for these circumstances.

3. Experimental Arrangement for Spectral Data Capture from Arcs in Short notched Element Quasi HBC Sand Filled Fuses

3.1 Sample Fuses

Special robust experimental enclosures were devised to monitor arcing in fuse elements, compacted in silica filler to ensure good acuity of arc light emission and the protection of the spectrograph from expulsed arc products as shown in Figure 1. The short-notched fuse element samples were mounted in close proximity to glass slides, and were pressed against the glass by the pressure of the filler, consequential of compaction by vigorous mechanical vibration. Hence the glass slides acted as a data capture window to the arcing phenomena and an arc shield for the spectrograph.

In support of the investigation reported here a short study was a carried out to determine the influence of the glass slide on fuse operation. In a series of tests the short notched fuse element was gradually moved, in 0.5mm increments, away from the glass slide. The fuse voltage, current and spectrographic results for each of the tests indicated no significant deviations enabling the conclusion to be drawn that that the influence of the glass on fuse operation and data capture was minimal.

3.2 Fuse Test Circuit

The experimental energy source was derived from a three-phase ac generator with the generated test circuit ac voltage being obtained from the single phase and neutral of the stator of the three phase star connected generator.

Current flow through the test fuse was accomplished by controlled switching of a thyristor, of type NO60RHX. Switching was initiated relative to the zero crossing point of the supply voltage which was determined using a bespoke 'point on wave' monitoring circuit with additional adjustable time delay circuitry to facilitate fuse operation in accordance with different fuse test duties.

3.3 Data Capturing Equipment

3.3.1 Spectrograph

Spectroscopic analysis of arcing phenomena was carried using a 6800 Series Optical Spectrum Analyser (OSA), manufactured by Rees Instruments Limited. A block diagram of the OSA configuration interfaced to the fuse test facility is shown in Figure 2 and a photograph of the experimental arrangements is shown in Figure 3

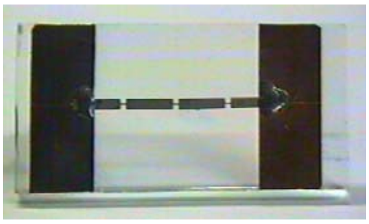


Fig 1i Examples of a short-notched fuse element window/substrate test samples used in experimental investigations.

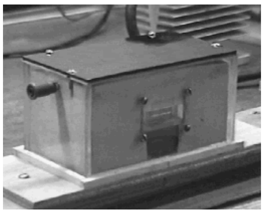


Fig 1ii Fuse test samples and test enclosure showing glass substrate-mounted fuse element

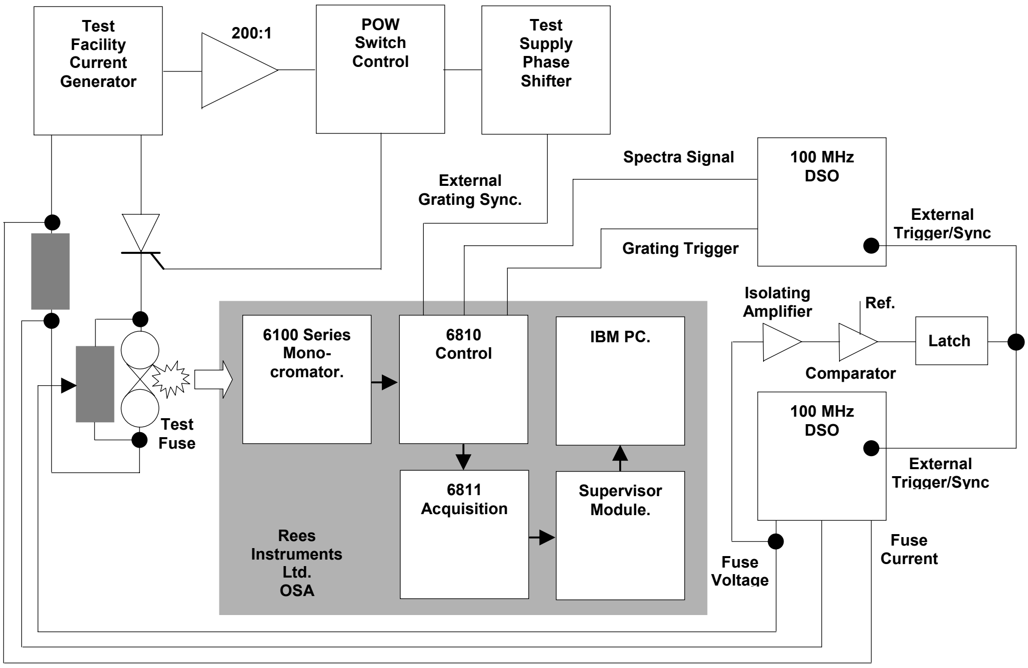


Figure 2 Diagram of optical spectrum analyser interfaced to the fuse test facility

The 6100 monochromator comprised a rotating grating and Si (6111) photo detector with a bandwidth of 200nm~900nm. The 6810 control module of the system, controlled the scanning speed of the monochromator, signal gain of the photo detector and the data acquisition sampling interval. For the investigation the spectrograph utilised a 1200g/mm grating, which provided a sampling wavelength interval of 0.25nm.

Figure 3 Experimental arrangement used in the spectroscopic analysis of HBC conductive film substrate fuse arcing phenomena.

3.3.2 Oscilloscopes

Two separate 100 MHz digital storage oscilloscopes of type DSO 400, distributed by Gould Instrument Systems Limited, were used to capture fuse voltage and current data, a grating trigger signal and light spectra data.

3.4 Time Correlation/Triggering Mechanisms

For this investigation the monochromator was controlled externally to enable synchronisation between the disintegration of the fuse and the sampling window of the OSA.

This was accomplished by first monitoring the test facility ‘ac’ generated voltage waveform, and then phase shifting the monitored signal to supply the monochromator and control the speed, which basically controls the angular position of the OSA grating. Consequently, due to the homogeneity of the sample fuses the phase difference could be set so that the spectroscope monitored light emitted during the pre peak or the post peak arc voltage time period.

Both oscilloscopes were triggered relative to the onset of fuse element disintegration, to enable specific light spectra to be correlated to a time instant in the disintegration period. This was accomplished using a fast, accurate comparator and latch circuit.

3.5 Overall Experimental Arrangement

The sample fuses were embodied in an opaque box with a small aperture located exactly in the forefront of the fuse element. The aperture was then accurately positioned so that the horizontal and vertical axis of the fuse element and the OSA grating were in precise alignment (Figure 4).

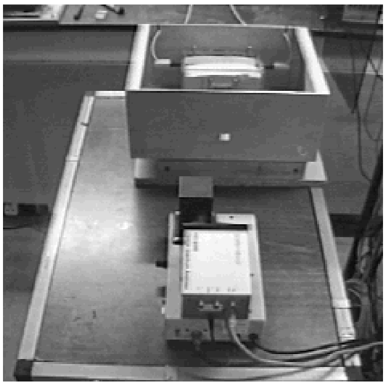


Figure 4 Experimental arrangement of OSA and fuse enclosure (Shown without top cover and opaque shroud)

A nominal distance between the fuse and the OSA was experimentally established to eliminate saturation of the photo detector output by the high intensity arc light and to allow analysis of the relative intensity of spectra. The apparatus containing the fuse and the OSA were finally enclosed in an opaque shroud to prevent ingress of light from ambient sources.

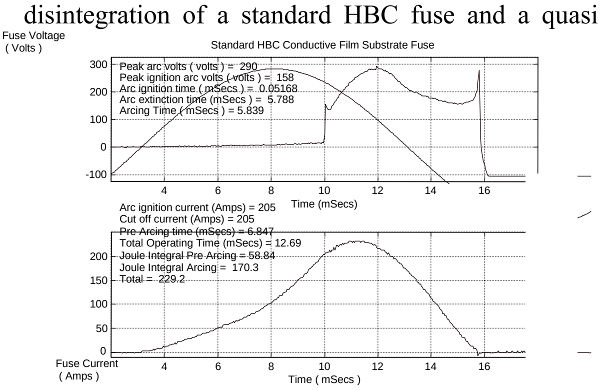
4. Investigation Objective

The spectroscopic analysis of arcing in short notched element quasi HBC sand filled fuses was carried out from separate investigations of the arc light components captured in the pre-peak and post peak arc voltage time periods. The fundamental aim of this investigation was to establish:

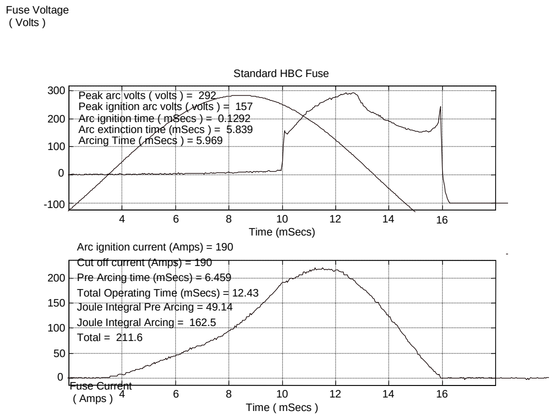
- In the pre-peak arc voltage time period whether the arc light spectrum comprised mainly of spectra of fuse element material wavelengths.
- In the post-peak arc voltage time period whether the arc light spectrum comprised mainly of spectra of fuse filler material wavelengths.

5. Results

Figures 5i and 5ii present time correlated supply voltage, fuse voltage and current data captured during separate instances of the disintegration of a standard HBC fuse and a quasi HBC fuse as used in the spectrographic investigation reported. Figures 6 and 7 present light spectrum data captured during the pre peak and post peak arc voltage time periods of fuse disintegration. The time reference points of the oscilloscope trigger signal and spectrum capture points for wavelengths of 300nm and 500nm are indicated. To clarify the latter, the two wavelengths superimposed on the fuse voltage record indicate the time instances during fuse operation that the spectrograph was sampling light at the specified wavelength. Consequently, some degree of judgement can be gained of the span of the full light spectrum over the course of fuse operation.



(i) Quasi HBC sand filled fuse



(ii) Standard HBC fuse

Figure 5 Supply voltage, fuse voltage and current oscillograms

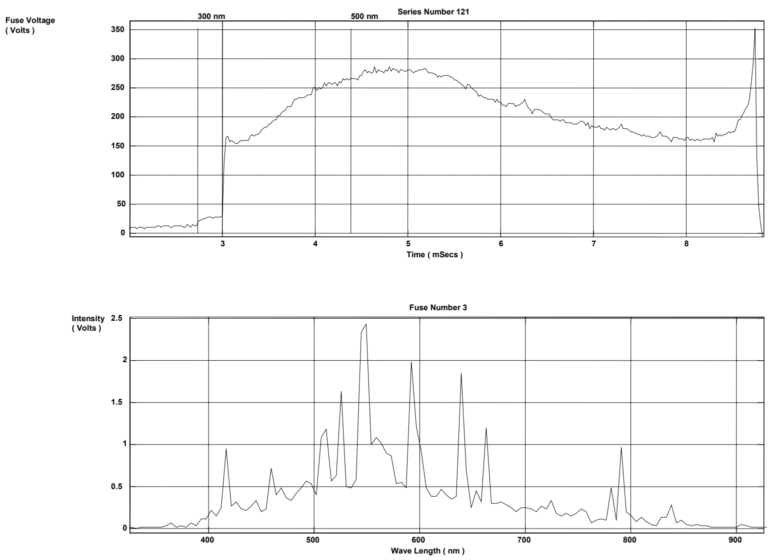


Figure 6 Typical arc light spectrum and correlated fuse voltage oscillogram captured during the pre-peak arc voltage time period of disintegration in a short notch silver element fuse

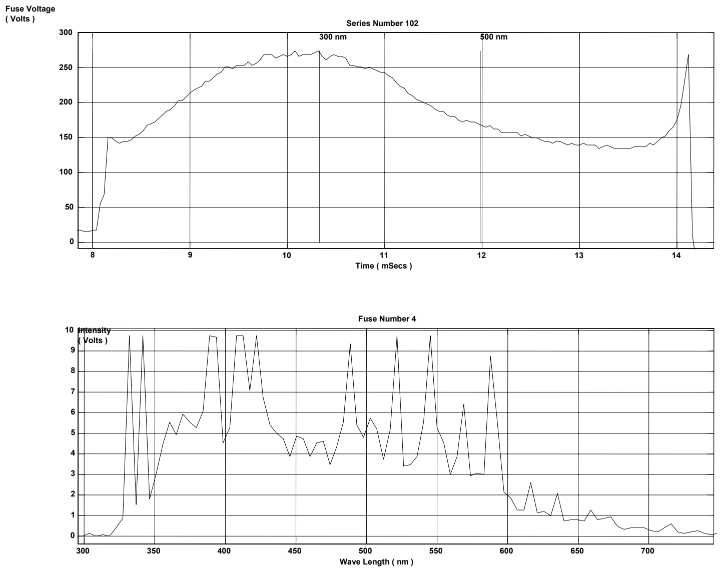


Figure 7 Typical arc light spectrum and correlated fuse voltage oscillogram captured during the post-peak arc voltage time period of disintegration in a short notch silver element fuse

6. Discussions

A large number of fuses were tested to capture data in both arcing time domains of fuse operation (~30/Domain) and generally, the spectrum for each domain was most similar to those presented in Figures 6 and 7.

Relationships between spectral lines and possible fundamental elements of fuse materials have not been identified here since these associations are beyond the scope of this report. However, the spectrums for each arcing time domain in the circumstances of this investigation are suggested to be quite different and hence postulations for element disintegration phenomenon can be somewhat securely presented. For example, it could be considered that during the pre-peak arc voltage time period if element spectra were dominant then notions of arc elongation due to element burn back and the arc being supported between element electrodes could be plausible. Alternatively, if the spectrum in the post peak arc voltage period were dominated by filler spectra then notions of fulgurite commutation of the fault current could be credible.

7. Conclusions

The procedures for the manufacture of fuse samples in this investigation were strict with tight tolerance limits in order to produce homogenous batches of fuses. This provided high repeatability of the onset of fuse element disintegration with respect to a time instant on the supply voltage waveform. Subsequently, this allowed the spectrographic instrument to monitor light emitted from the fuse during separate time periods of the arcing phase.

In this investigation four separate parameters relative to fuse element disintegration were captured simultaneously. Subsequently, the separate data sets could be cross correlated with respect to time due to use of a single time datum signal source, i.e. triggering of the comparator/latch circuit.

The overall data capture time period of the spectrographic instrument used in this investigation was relatively slow compared with current technology however it was considered, at the time of the investigation to be marginally capable of capturing data for subsequent analysis and differentiation of spectra from the sub time domains of the fuse arcing phase and hence able provide evidence for possible disintegration phenomena hypothesis.

With currently available fast spectrographic instruments and using the techniques reported, the results of this investigation have shown that it is most possible to cross correlate several data sets with respect to a single instance in time so that a better understanding of the phenomenon of fuse element disintegration and arcing could be forth coming.

References

[1] Wolny A.: "Effect of Fuse Element Confinement on the Rate of Rise of Fuse Arc Ignition Voltage". *Conference Proceedings of the 6th ICEFA, Turin (Italy) Sept. 1999, pp135-139.*

[2] Nasilowski, J.: "Unduloids and Striated Disintegration of Wires" *Exploding Wires Vol. 3, Planum Press, New York U.S.A., 1964, p 295-313*
[3] Hibner, J.: "The Number of Arcs Initiated during Striated Disintegration of the Uniform Strip H.B.C. Fuse Elements at AC Short Circuit Current Interruption" *International Conference on Electric Fuses and Their Applications, Trondheim Norway, 13-15 June 1984, p 60 - 69*.
[4] Hibner, J.: "Calculation of the Over Voltage Peak Values when breaking Short Circuits by means of Multi Strip Fuses", *Conference Proceedings, 2nd International Symposium on Switching Arc Phenomena, Lodz, Poland, September 1973, pp269-274*.
[5] Rex, H.: "A Simple Method to Calculate the Maximum Voltage that Arises When a Fuse Link Breaks a DC Short Circuit Current" *Conference Proceedings, 6th International Symposium on Switching Arc Phenomena, Lodz, Poland. 1989*.
[6] Gomez, J.C., McEwan, P.M.: "Experimental Investigation of Wall Stabilised Arc Mechanisms of Wires in Fuse Filler", *International Conference on Electrical Fuses and their Applications, Ilmenau, Germany, September 1995 pp243-250*
[7] Brown, R.E., "Investigation of Disintegration and Arcing in Electric Fuses", Ph.D. Thesis, Sheffield Hallam University, UK, January 2000.
[8] Barrow, D.R., Howe, A.F.: "The use of Optical Spectroscopy in the Analysis of Electrical Fuse Arcing." *Conference Proceedings, 4th International Conference on Electrical Fuses and their Applications, Nottingham, U.K., September 1991, pp221-225.*
[9] Bussiere W., Besborodko P., Pellet R.: "Spectroscopic Study of a Cutting Electric Arc inn H.B.C. Fuse", *Sixth International Conference on Electrical Fuses and Their Applications, Turin, Italy, Sept. 1999, pp113-117*
[10] Cao, L.J., Stokes, A.D.: "Spectrum Analysis of an Ablation Stabilised Arc in Ice" *Conference Proceedings, 4th International Conference on Electrical Fuses and their Applications, Nottingham, U.K., September 1991, p27-32.*
[11] Cheim, L.A.V., Howe, A.F.: "Spectroscopic Observations of High Breaking Capacity Fuse Arcs.", *IEE Proc.-Sci. Meas. Technol., Vol. 141, No. 2, March 1994, pp 123-128.*
[12] Chikata, T., Ueda, Y., Murai, Y., Miyamota, T.: "Spectroscopic Observations of Arcs in Current Limiting Fuse through Sand", *Conference Proceedings, International Conference on Electrical Fuses and their Applications, Liverpool, U.K., 1976, pp114-121.*
[13] Bussiere W., Rochette D., Andre P.: "Study of the SiO_2Plasma Physical Parameters: Temperature, Electron Density, Pressure Radiation" *Seventh International Conference on Electrical Fuses and Their Applications, Gdansk, Poland Sept. 2003 p119-125*

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