About a New Type of Fuse Based on the Controllable Fusing Effect

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***Abstract*—Fuses are among the best known of electrical devices and there are an extremely large number in use throughout the world. Beside of the advantageous features, the nowadays fuses have certain drawbacks. Therefore, a new type of fuse based on controllable fusing concept is proposed and a study as regards the total clearing time is done. The new concept has been validated through many experimental tests at different current values. The new type of fuse based on controllable fusing concept can be integrated within an overcurrent protection system especially to protect power semiconductors where the Joule integral criterion is better satisfied.**

***Index Terms*—Fuses, control equipment, technological innovation**

I. INTRODUCTION

Fuses have been produced over 100 years and there are now an extremely large number in use throughout the world. They incorporate one or more current-carrying elements, depending on their current ratings, and melting of these followed by arcing, occurs when excessive overcurrents flow through them. Fuses can be designed to interrupt safely the very highest fault currents that may be encountered in service, and, because of the rapidity of their operation in these circumstances, they limit the energy dissipated during fault periods, [1]. This enables the fuses to be of relatively small overall dimensions and may also lead to economies in the cost and size of the protected equipment.

From fuse beginnings, first scientific reference by Sir. Edward Nairne during 1773 and first official US fuse patent of Thomas Edison by 1880, the main improvements have been aimed to use of better materials, to extend the current and voltage application ranges, and towards the development of faster and cheaper construction techniques [2]. Among the fuse improvements the M-effect incorporation by Metcalf during 1939 has to be mentioned [3]. After those improvements many changes into the original fuse design have been presented in order to extend the low current interruption capability, such as:

- using of non-traditional fuse element metals, like aluminium or cadmium [4];
- use of bounded silica sand [4];
- use of two dissimilar bounded or unbounded metals [5];
- current limiting and expulsion elements put together inside a single fuse body [6];
- paralleled combination of high-voltage fuse and Z_nO varistors [7];
- hybrid fuse using SF_6 or vacuum fuse in series with traditional high current part [8];
- repetition fuse and self-healing or permanent fuse using high pressure sodium and mercury as fuse elements [9].

From the literature survey of the main fuse intelligence adding and innovations, the idea of Muth and Zimmermann by 1938 [10], had come out. Afterwards the same idea was developed, especially on the ignition control system, introducing in the market by 1963 the device called *limiter* [16]. By 1990 a technical paper has been presenting a new design applying this concept to low voltage DC systems, called Smart Fuse [12]. During the seventies an interesting idea was proposed, related to the availability in a single fuse cutout of a double fuse time-current-characteristics which was obtained by using a current transformer which working zone included the saturated and non-saturated areas, changing the two paths current sharing depending on the overcurrent level, [13].

Fuses are basically simple and relatively cheap devices, although their behaviour is somewhat more complex than may be generally realised. Surprisingly, the arcing process which occurs when they are interrupting current is still not fully understood, [14].

Research is continuing on this topic with the object of producing fuses capable of meeting the ever-increasing performance demands made on them. In this connection the advent and rapid growth of semiconductor devices, with their limited overload capacities, has introduced particularly stringent requirements.

Beside of the advantageous features, the nowadays fuses have the following drawbacks:

- the time-current characteristic can not be adjusted;
- the current limiting effect is uncontrollable;
- at DC applications they can not operate to reverse current;
- in some cases the correct discrimination among protective devices including fuses is not achieved under all fault conditions;
- the fuse operating depends on previous thermal state;
- on datasheets there is a deviation in the current coordinates of ±8% at time-current characteristics;
- the power loss can reach important values in the case of power converters' protection;

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- they can not be a part of a flexible protection system based on microcontroller, for instance.

Moreover, an improper fuse operating can lead even to blackouts. Britain's biggest blackout for 25 years that occurred in parts of southern London and north-west Kent on 28 August 2003, was the result of a one amp fuse being fitted in place of a 5 amp fuse at a substation, [15]. The shutdown there led to the loss of 20% of the capital's electricity affecting 410,000 homes and businesses at 6.20 in the evening, and paralysing tube and rail services.

II. NEW CONCEPT OF CONTROLLABLE FUSING

Nowadays fuse cartridges include one or more elements with variable section and constrictions depending on rated current, inside of a ceramic body which is filled with quartz sand in order to extinguish the electric arc during fuse operating. The controllable fusing means the possibility of fuse to operate at certain time moments when an external command is activated. The key element of the controllable fusing is an electrode which is placed on the fuselink element, as shown in Fig. 1, [16], [17]. The electrode E, is made from graphite and is pressed on the copper strip of the fuse element F. The electrode terminal is made from brass in order to allow a good contact with the supply conductor. With the aim to supply this electrode, a detachable contact Cd, or a plug device is used in the case of more parallel fuselink elements, [18], [19].

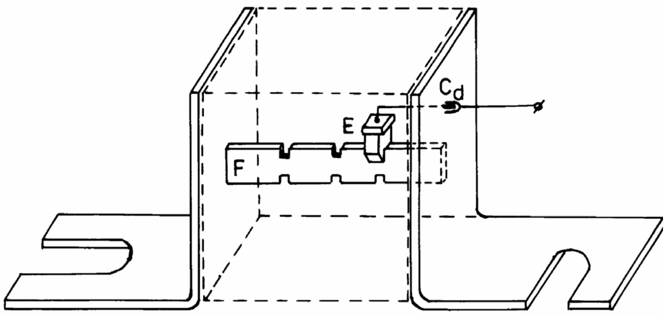

Figure 1. Details of the new fuse cartridge based on the controllable fusing effect.

The basic electric circuit for a fuse which uses the controllable fusing effect is shown in Fig. 2. Hence, the fuse FCF has a modified cartridge which includes an electrode placed on the fuselink element. In the case of more than one fuselink element, the electrodes are mounted in parallel. The electrode is supplied from the secondary of the current transformer CT, through an electronic circuit EC. When the current value outruns a prescribed limit, the secondary voltage of the current transformer CT, will activate the local fusing of the fuselink element. Therefore, the fuse will turn off the main electric circuit.

When an auxiliary supply from an additional transformer AT, Fig. 3, [20], [21] is used, the current transformer CT, through the electronic circuit EC, will send command

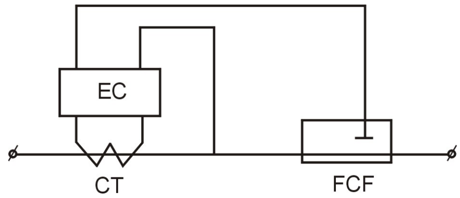

Figure 2. Basic electric circuit of the new type of fuse.

signals in order to turn on the electronic switch SW. Hence, the secondary voltage of the additional transformer AT, will activate the local fusing of the fuselink element from fuse FCF.

III. EXPERIMENTAL TESTS

In order to record the arc voltage and current in the

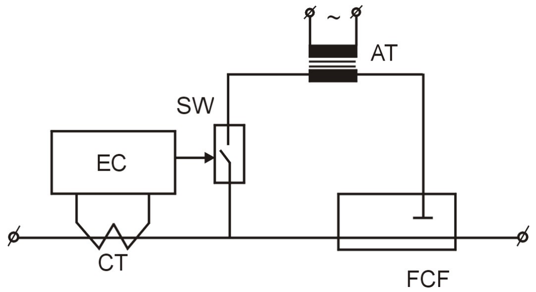

Figure 3. Basic electric circuit of the new type of fuse with auxiliary power supply.

moment of fuse blowing, a test circuit has been used as shown in Fig. 4, [22], [23]. There is a main circuit breaker, CB, which supply the test circuit, two power electronic switches SW_1 and SW_2, made with two thyristors mounted in antiparallel, an autotransformer ATR, which supplies with variable voltage the current source CS. This is an electromagnetic device with variable input voltage and high variable output current which flows through the traditional fuse under test F, or fuse with controllable fusing effect FCF. The controllable fusing for the FCF is obtained with an auxiliary transformer AT, and the electronic switch SW_2, which is turned on/off by the control unit CU.

To record the arc voltage, a voltage divider VD, (made with two resistors R_1 and R_2) is used, and an adequate current probe CT, allows to record the arc current with a digital oscilloscopes OSC. The information about the arc voltage and current can be transferred to a PC.

The first step is to establish the prospective current. That means to close the main circuit breaker CB, and the power switch SW_1, from the control unit CU. This is a pulse generator signals which allows to trigger the gates of both thyristors included into the power electronic switches. Then, the autotransformer ATR and current source CS, are used in order to establish the prospective current. At this stage no fuse is mounted on the output side of the current source.

When a traditional fuse F is tested, this is mounted on the output terminals of the current source CS. Then, the main circuit breaker is closed, and the power switch SW_1 is also

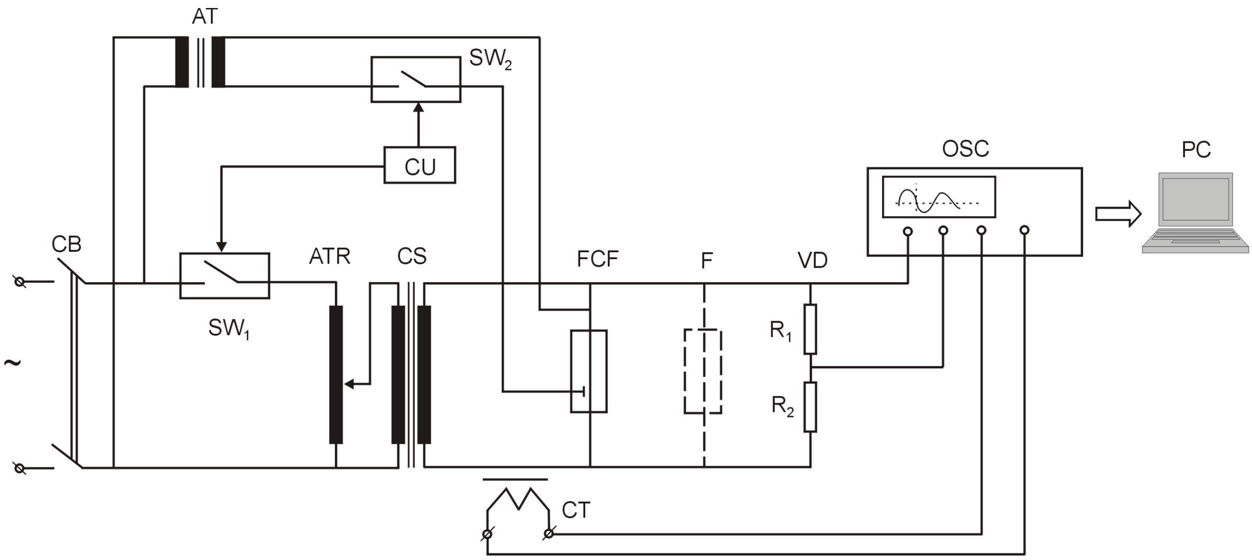

Figure 4. Experimental tests.

closed from the control unit CU. In the case of testing fuse with controllable fusing effect FCF, after its mounting on the output of the current source CS, the main circuit breaker is closed and in the same time the both power electronic switches SW_1 and SW_2 are turned on by the control unit CU.

The experimental tests have been done at different prospective current values. It has been tested high breaking capacity fuses with the rated current of 50A, a rated voltage of 660V, gG operating class and the supplementary current of the auxiliary source was about 10A. The fuse element is made from copper and has the following overall dimensions: length of 48mm, width by 14mm and thickness of 0.12mm. Silica sand used in the tests is the same as the industrial one. It is high purity quartz sand of 99.8% with a granulometry of 0.2mm and a packing density about 0.16g/cm^3. Both traditional and new type of fuse have been tested in the same conditions of ambient temperature and prospective currents.

Further on, a comparison between recorded arc voltage and current at 950A test current for a traditional and new type of fuse is shown in Fig. 5 and Fig. 6. Also, using a program made in MATLAB environment, it has been computed the Joule integral variation for both type of fuses, the traditional and new type one, Fig. 7.

TABLE I. COMPARISON OF CUT-OFF CURRENT

Itest (A)	Cut-off current (A)	
	Traditional fuse	New fuse
850	1750	1240
900	2430	2000
950	2500	1870

From the oscillograms it can be observed that in the case of new type of fuse the cut-off current value is lower than in the case of traditional fuse, and the results for different current tests are shown in Table I.

As regards the operating times for traditional fuse and the new one, their values are closer as it can be seen that from the Table II.

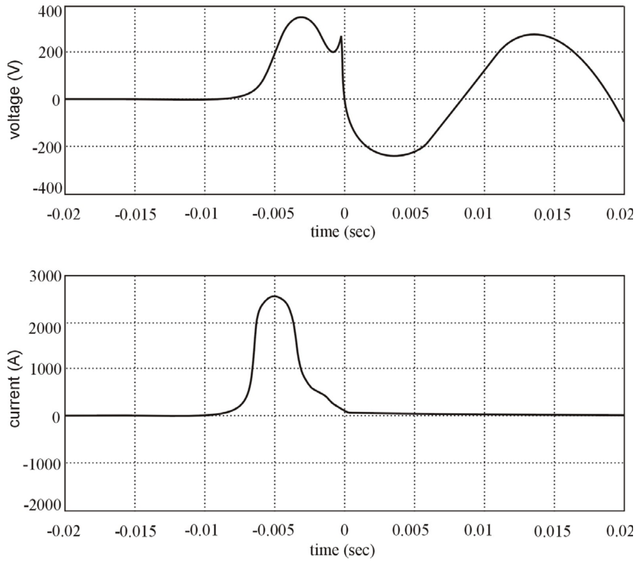

Figure 5. The arc voltage (upper graphic) and current (lower graphic) variation for a traditional fuse at a test current of 950A rms.

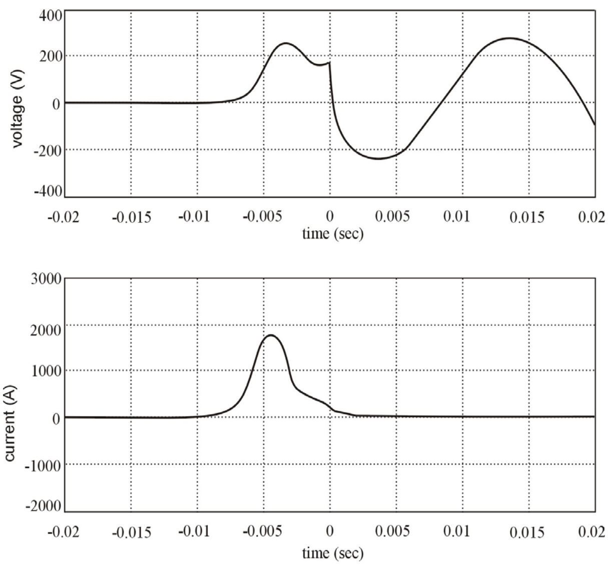

Figure 6. The arc voltage (upper graphic) and current (lower graphic) variation for the new fuse at a test current of 950A rms.

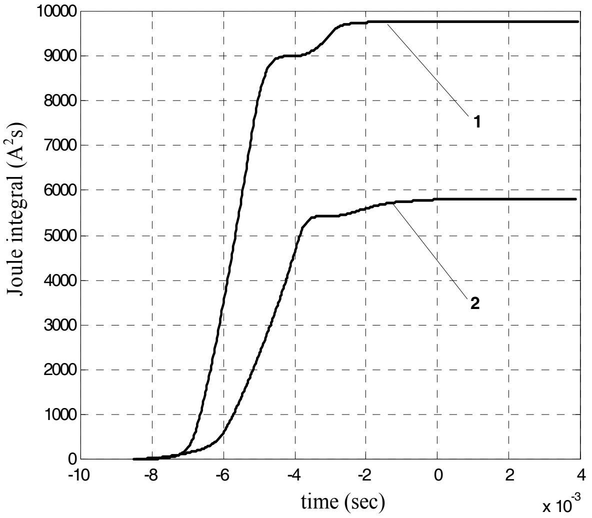

Figure 7. The Joule integral variation for the traditional fuse (curve 1) vs. new fuse (curve 2) at a test current of 950A rms.

A similar time variation of the Joule integral for both types of fuses can be noticed from the above graphics. The maximum value of the Joule integral in the case of the new type of fuse is lower than the traditional one which means a better effect in the case of power semiconductors' protection because the Joule integrals condition is better satisfied (the Joule integral of the fuse has to be lower than the Joule integral of the power semiconductor).

IV. CONCLUSION

The theoretical aspects as regard new type of fuse and all the experimental tests outline that there is the possibility to extend the current protection range both to overloads and shortcircuits. Lower operating times in the case of the new fuse can be obtained for a command in advance through an adequate transducers, depending on di/dt parameter, for instance. That means a current transformer and external devices for control breaking process. Hence, respect to traditional fuse, the new one involves some technological complexity and bigger dimensions. Therefore, the price will be higher than the traditional one.

In order to prove the decreasing of Joule integral of the new fuse respect to traditional one, because of the material properties variations, a statistical evaluation will be made into a next research work taking into account a comparison between two rectifier bridges equipped with fast fuses.

Depending on the application, a secure protection even to overloads, could lead to chose the new type of fuse to protect power semiconductor devices.

ACKNOWLEDGEMENTS

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