Versatile Protection with HRC fuse links

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The humble High Rupturing Capacity (HRC) fuse link, is seen as perhaps just a relic of the dim and distant past, in today's high technology world. Even with all the advanced electronic circuit protection now available, this seemingly simple unsophisticated product still has a vitally important role to play in modern electrical protection. It is still today the unequalled answer to short circuit protection.

Today's modern HRC fuse links have outwardly changed little since their introduction in the early 1900's. They have, however, changed significantly in terms of performance. Modern materials and manufacturing techniques have enabled the evolution of fuse links with improved voltage capability and breaking capacity, whilst restricting the damaging energy and current let through to the fault. High performance ceramics, computer aided element design techniques, and improved quartz filling methods, have enabled production of extremely high speed fuse links for the protection of power semiconductors.

To understand how the modern HRC fuse link fits into the protective scene, we need to have an understanding of how it works. To look at this we can firstly consider the operation of a simple wire fuse, the earliest type of crude electrical short circuit protection.

Figure 1a. shows this simple wire subjected to an overcurrent. Current flowing down this wire causes it to heat up at the centre, since the ends of the wire allow the energy to escape and dissipate down the conductors. The centre of the wire eventually reaches melting point and parts. The parting of the wire then generates an arc which is fed by the energy stored in the system, this in turn, burns back to a point where the supply is unable to sustain it and circuit interruption occurs.

Figure 1b. shows the same wire fuse now subjected to a high short circuit fault current. The current now flowing down this wire raises the temperature so rapidly that the energy is no longer able to dissipate from the ends, resulting in the whole length becoming molten at the same time. This molten wire than breaks up into a string of molten globules of material which form a series of short arcs (multiple arcing). These arcs then merge together and rapidly form an unstable column which the supply is unable to sustain and interruption occurs.

These natural phenomena are enhanced in the design of industrial HRC fuse link elements. Figure 2a. shows the construction of typical industrial fuse elements. Reduced sections are located along the length of the fuse element creating short circuit zones of high current density, which respond rapidly to high fault currents and quickly produce a multiple arcing condition and subsequent circuit interruption.

The centre of the GEC ALSTHOM industrial fuse link element has a band of pure silver which is formed into a trough and then filled with tin. At a critical temperature the silver and tin merge together and form a low melting point alloy (around 230°C), which causes the centre of the element to melt at this temperature. This phenomenon is known as 'M' effect. Without this metallurgical effect the centre of this element would need to be raised to 960°C (the melting point of pure silver) under overcurrent conditions.

This silver/tin 'M' effect zone is extremely responsive to low overload faults, providing operation and close excess overcurrent protection, in particular, to PVC insulated cables.

The construction of a typical BS 88 Part 2 industrial fuse link is shown in Figure 2b.

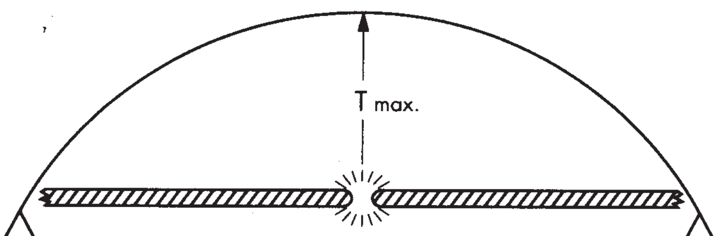
Fuse link bodies are made from high grade ceramic materials, able to withstand both the high thermal and mechanical stresses associated with the arc energy generated during fuse link operation.

Tags and caps are made from high grade copper and brass, all being electro plated to prevent deterioration of conducting surfaces and enable good solder joints to be effected, when soldering the elements to the inner caps.

Sandwiched between the inner and outer caps of the fuse link are patented arc inhibiting sealing discs. These discs help prevent catastrophic failure of a fuse link under the most onerous fault conditions.

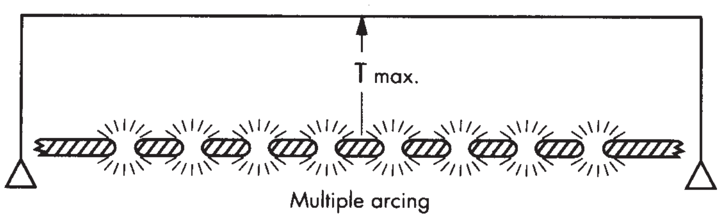
The heart of the HRC fuse link is, of course, the fuse element, or elements in the

Figure 1a



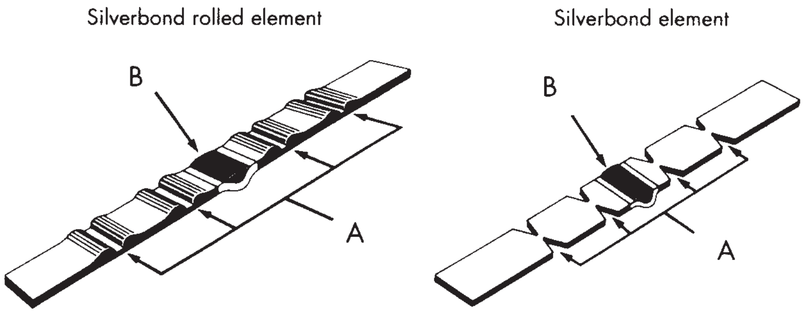
Single short arc

Figure 1b



Multiple arcing

Figure 2a



A Reduced sections in copper portions, where arcing is initiated when a short circuit fault occurs.

B Central silver section, in which a trough is formed and filled with tin, to produce 'M' effect when a prolonged overload fault occurs.

Figure 2b

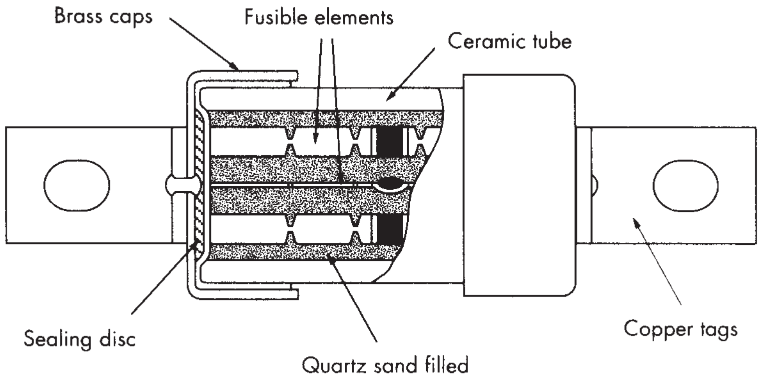
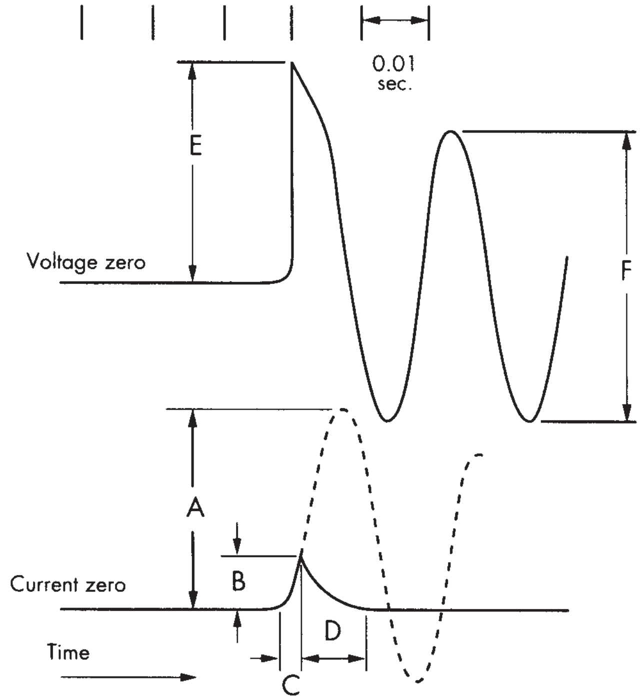


Figure 3



A Asymmetrical peak value of prospective current 182.5kA = 81.1kA RMS SYM.

B Cut-off current : 39.5kA

C Pre-arcing time 1.6 milli sec.

D Arcing time 3.4 milli sec.

E Arc voltage : 930V

F Recovery voltage 461V RMS.

case of higher current ratings. As previously described, these elements normally comprise thin strips of metal, either silver or copper, or a composite form of the two, with reduced sections or necks along the length. The elements are required to be thin and flat to enable the heat generated at the reduced sections under normal load conditions, to be dissipated through the filler.

The filler which totally surrounds the fusible elements consists of high grade silica sand, which is extremely low in impurities and is of tightly controlled grain size. The purpose of this filler is twofold. Firstly, because of its close proximity to the fuse elements it is able to effectively cool them and therefore, enable less material to be used for a given rated current. More important, however, is the effect of the filler when a fuse link operates on a short circuit fault current. In this instance the fuse element suddenly disintegrates under the effect of such a current, rapidly dispersing it through the adjacent silica sand and forming a high resistance material known as fulgurite. The formation of fulgurite rapidly forces the current down to zero, severely restricting the current and energy let through to the fault.

It is these phenomena that give the HRC fuse link its current limiting and high breaking capacity properties.
The operation of an HRC fuse link can be seen in the oscillogram (Figure 3) as shown. The top trace representing the voltage across the fuse link and the bottom one the current flowing.

A = Peak asymmetrical value of prospective current

B = Peak cut off current of the fuse link

E = Peak arc voltage across the fuse link

Operation of the fuse link occurs after the pre-arcing time C has passed, at which point the fuse elements go into multiple arcing creating the arc voltage E across the fuse link and limiting the peak current let through to B, the cut off current.

During arcing time D, the current is rapidly forced down to zero, as previously described, severely restricting the energy let through.

These two zones of operation can be expressed in terms representative of energy, since energy let through is proportional to the square of the RMS current and the time it flows (I^2t), and can be expressed in Amp^2 seconds.

Performance data is produced for all fuse links and expressed in terms of three prime relationships:

1. Time current characteristics, Figure 4a, which are log-log graphs of nominal prospective fault current

(A) versus pre-arcing time (sec), i.e. melting curve.

These characteristics are the ones most frequently used. They enable the fuse link's ability to withstand surge currents, such as, motor starting currents, to be assessed. They are also used in discrimination studies.

2. Cut off current characteristics, Figure 4b, which plot the peak let through, or cut off current, kA (Peak), versus prospective fault current kA (RMS symmetrical), under the worst case conditions of asymmetry that would normally be encountered. The point where the individual characteristics depart from the line of peak asymmetry would approximate to the 10ms time current point, i.e. the point where the fuse link starts to limit current (cut off), which would be 1/2 cycle (10ms) at 50Hz.

3. I^2t characteristics, Figure 4c, express the two most important quantities representative of energy for a fuse link. Firstly, the absolute minimum value of pre-arcing energy (min pre-arcing I^2t), which indicates the minimum energy in A^2s that will result in the melting of the fuse element. If this is exceeded then the fuse link elements may be damaged, thus altering the characteristics.

Secondly, the total energy let through (Total I^2t) which is a measure of the maximum energy in A^2s that the fuse link will let through at a particular voltage. It is important to note that the operation of fuse links under short circuit is dependent upon the applied voltage and a significant reduction of total I^2t can be seen with lower values of applied voltage. Under no circumstances should fuse links be applied on systems above their rated voltage, without reference to the manufacturer.

Figure 4a

Time/current characteristics

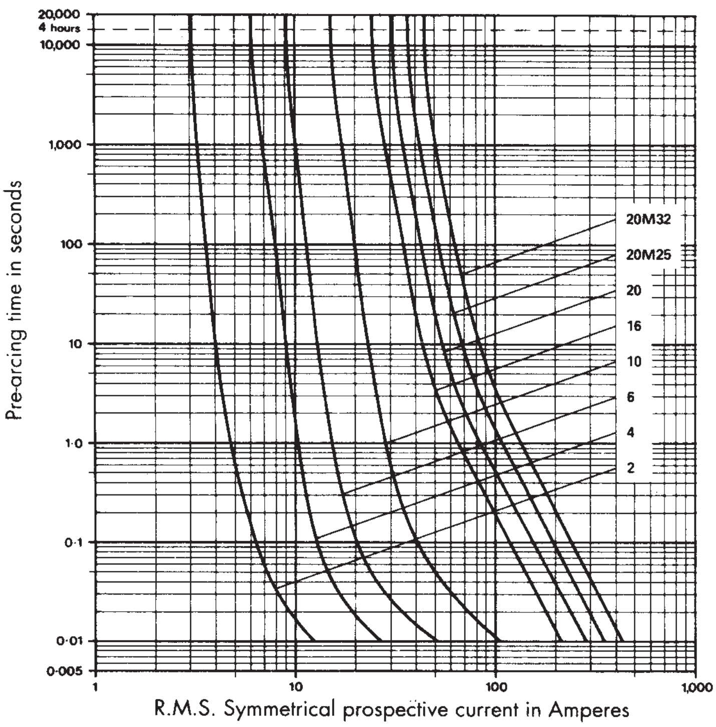


Figure 4b

Cut-off current characteristics

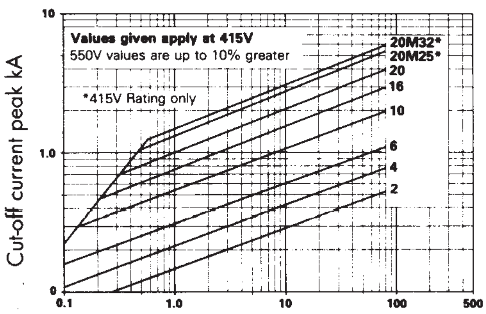


Figure 4c

I^2t Values

Current rating	Pre-Arcing I^2t (A^2sec)	Total I^2t (A^2sec) at:	
Amp		415V	550V
2	2.2	5.4	31
4	7.2	18	70
6	21	60	400
10	100	280	1000
16	300	850	2000
20	540	1000	2500
20M25	900	3000	-
20M32	1100	4000	-

Low Voltage Fuse links

Most applications for low voltage industrial fuse links will be in the area of motor starting and distribution. Hence, the British Standard BS 88 fuses, which also comply with IEC 269 , are ideally suited to motor starting and motor starter protection. The main reasons today for the widespread application of HRC fuses can be summarised as follows:

- **High Breaking Capacity and Energy Limitation**
  In the event of a short circuit, fault energy is severely restricted and contained by the rapid operation of the HRC fuse link. This results in limitation of the amount of damage to equipment, risk of fire, and danger to personnel.
- **Restriction of Electro Magnetic Stress**
  H.R.C fuse links will limit the amount of damage caused by the electro magnetic stress created between current carrying conductors. This stress could cause the severe distortion of busbar copper work or the bursting of cables with consequential risk of a further major fault developing.
- **Reliable Short Circuit and Back-Up Protection**
  By virtue of their precise operating characteristics HRC fuse links can provide protection to devices of inherent low breaking capability, such as, motor starters and miniature circuit breakers. This makes the HRC fuse link the ideal choice to provide Type 2 Co-ordination with motor starters to IEC.947.
- **Accurate Discrimination**
  Protective devices are commonly used in series with one another to provide discrimination. Because of their nature, HRC fuse links will discriminate with each other much more readily and reliably than other protective devices. Typically, they will discriminate with a ratio of 1.6 : 1 between major and minor current ratings.
- **Low Overcurrent Protection**
  HRC fuse links type gG to BS 88

and IEC 269 will provide close excess overcurrent protection and enable maximum ultilisation of PVC cables and their associated equipment.

- **Proven Non Deterioration**
  When properly applied HRC fuse links have virtually an indefinite life. There are no moving parts to jam up or wear out. Examination of typical fuse links has shown them to be in perfect condition, even after many years in service.

Application of Low Voltage Fuse links

The prime applications of low voltage fuse links are derived from the six main reasons detailed above. However, the fuse link characteristic curves can be utilised to easily evaluate the application of fuse links to particular duties. To assess a fuse link's ability to withstand motor starting currents for example, it would be usual to compare the motor's starting current, for the duration of the 'run up' time, against the fuse link's time current curves. In addition to ensuring that the selected fuse link will withstand this surge, it must also have a continuous in-service rating above the motor full load current.

Assessment against other applications will involve similar principles to assess the pre-arcing withstand of fuse links. However, very short duration, or highly repetitive pulses, may require more complex analysis, and advice from the fuse link manufacturer should be sought.

Semiconductor Fuse links

Semiconductor fuse links differ physically from industrial fuse links, mainly in their element construction. The principal difference between the two is a result of the protection requirements of power electronic devices. Diodes and thyristors are devices with relatively low thermal mass which are sensitive to current, energy and voltage surges. It is very important therefore, that fuse links selected for semiconductor device protection exhibit much faster operating characteristics, with lower let through values than those selected for the protection of industrial equipment.

If we consider the design of a typical

Figure 5

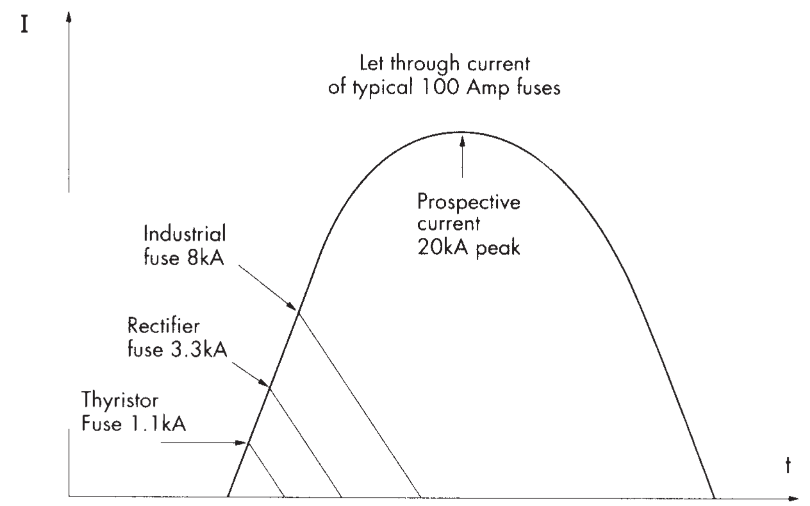
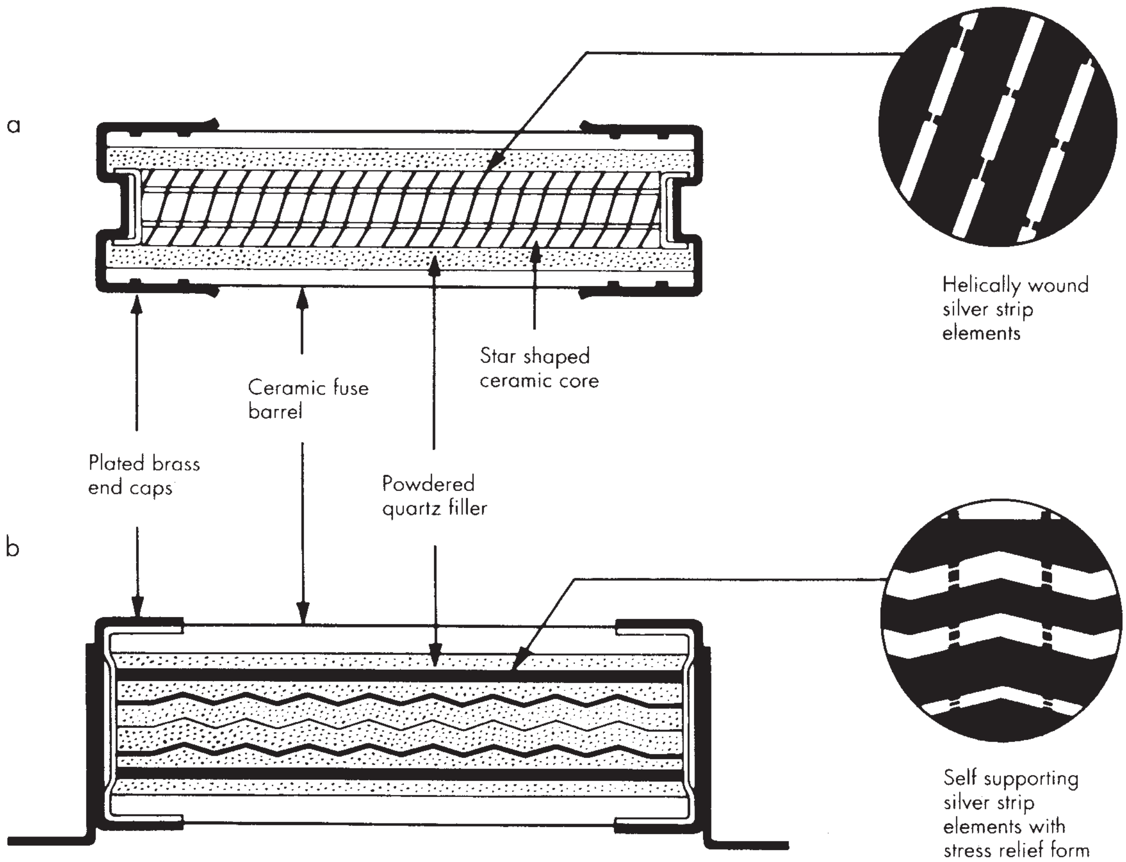


Figure 6



semiconductor fuse link compared to an industrial type, we can see the differences. The elements for a semiconductor fuse link are usually made from pure silver, with much smaller reduced sections. They are also much thinner than those of an industrial type of fuse link of similar current rating. This results in an element that is much more responsive to fault current, with the reduced element sections running at much higher current densities.

Comparison between the operation of semiconductor fuse links and industrial fuse links can be seen in Figure 5, which includes both fast acting and ultra fast acting types.

Ultra fast acting fuse links are normally selected when co-ordination is required with an individual semiconductor device, most likely a thyristor, and are closely matched to the device withstand levels.

Fast acting fuses would normally be selected to disconnect a failed device within a group of healthy devices connected in parallel on a large convertor stack, or perhaps to protect a single diode, which would have a greater withstand than a thyristor. The slower speed of these fuse links relative to ultra fast types, will also enable discrimination to be achieved with other fuse links or circuit breakers.

A semiconductor fuse link is normally required to provide only short circuit protection to an electronic circuit, with overcurrent protection being provided by other means, such as, a circuit breaker or overload relay.

Application of Semiconductor Fuse links

The application of semiconductor fuse links can be extremely complex. Generally they need to be closely assessed for energy and current limitation, to enable co-ordination with devices having critical withstand values. They may also be required to withstand highly repetitive pulsed duty cycles which can have a significant influence on the selection of the fuse link. The superimposition of a.c. and d.c. fault currents, along with high frequency discharges and positioning of fuse links in some applications, can make assessment a very complex problem. Manufacturers' characteristics, however, will still provide the basic data for assessment.

High Voltage Fuse links

High voltage fuse links can be split into two major categories:

1) Distribution transformer fuse links
2) Motor circuit fuse links

Distribution fuse links have time current characteristics which are designed principally to withstand a transformer magnetising inrush current, provide good overload withstand and clear secondary terminal faults in a reasonable time. Motor circuit fuse links, however, require time current characteristics which are the exact opposite to that of distribution fuse links, with fast operation at the short time end, to limit energy let through to motor starters, and a heavy characteristic around the 5–10 second region to provide a good withstand of motor starting surges.

Construction of the two different types can be seen in Figure 6. Due to their application on high voltages, distribution fuse links have a number of long thin elements connected in parallel and wound around a ceramic former inside the fuse tube. This enables the fuse link body dimensions to be kept to a reasonable length.

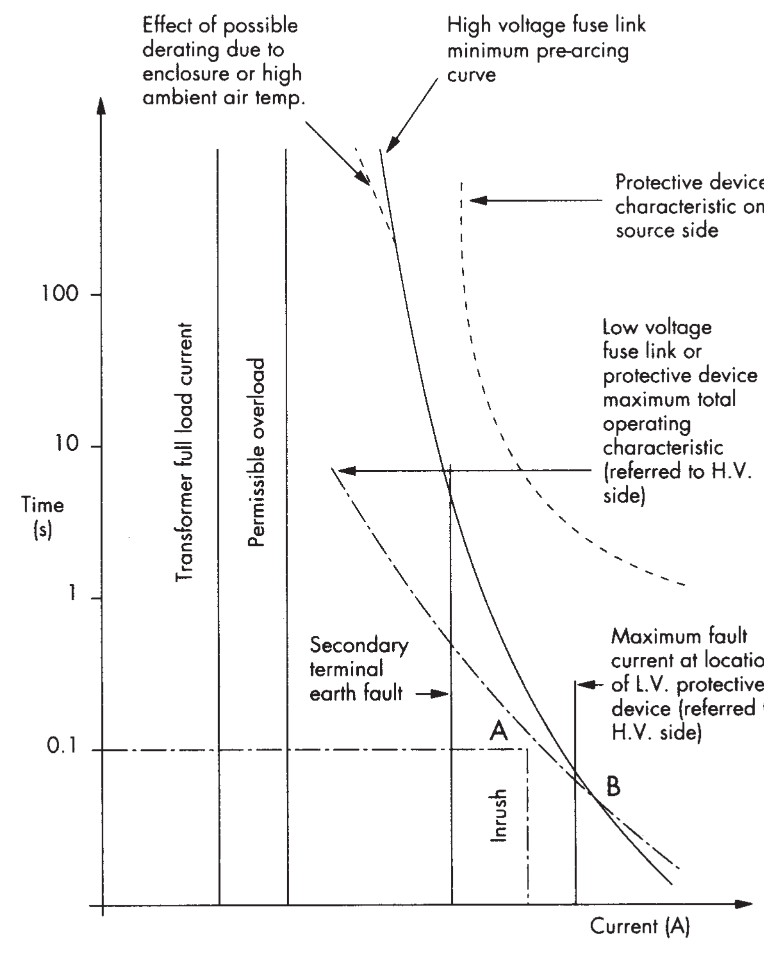
High voltage motor circuit fuse links, usually of somewhat lower voltage rating, have a number of much heavier stress relieved fuse elements running direct from end to end of the fuse tube. The addition of stress relief to these elements makes a dramatic difference to the fuse link's ability to withstand frequent motor starting surges.

Most high voltage fuse links are designed for back-up short circuit protection. Whilst excellent low overcurrent performance is often provided, they are not designed to operate under extremely low overcurrent fault conditions, i.e. below the fuse link's minimum breaking current. This would typically be between 2–3 times rated current. Fuse links of this type are normally equipped with striker pin mechanisms which are used to provide three phase tripping of a fuse switch or contactor under certain fault conditions. The operation of the striker pin in the event of a single phase fault will provide protection to the equipment downstream of the fuse link. Under low overcurrent fault conditions operation of the striker pin will enable the disconnection of the supply and, hence, provide protection to the fuse combination under these onerous conditions. Explosively charged striker pins, as well as spring charged types, are common in this type of fuse link and are used extensively in British Standard fuse links. Operation of the striker pin would occur as soon as the main fuse link elements commence arcing. An explosive charge ignited by the arc voltage across the fuse link forces the striker pin to project out of the end of the fuse link and impact upon the trip bar, if fitted, of a fuse switch or contactor. Operation of such a mechanism providing "trip all phases" will make the combination self-protecting under all fault conditions.

Application of HV Fuses

The normal application of a high voltage

Figure 7



distribution fuse link can be seen in Figure 7, which shows the significant parameters for fuse link selection.

On the time current curve is shown the magnetising inrush current which the fuse link must withstand, typically 10 – 12 times transformer full load current for 0.1 seconds. Also indicated are secondary terminal fault currents, overload currents and both up stream and down stream protective device characteristics, all referred to the primary side of the transformer. Some, or all, of this information will be required to assess a fuse link's suitability for a particular transformer. The time current curve may also be compared with the non damage curve of equipment.

Figure 8 shows the co-ordination of a high voltage motor fuse link co-ordinated with a vacuum contactor motor starter. Here it can be seen that the selection process is not unlike that for the low voltage fuse link in a motor circuit. However, correct co-ordination with the overload relay, below the contactor switching capability is essential. Other protective devices, such as, an earth fault relay can shift the takeover point and make co-ordination difficult to achieve.

Fuse link manufacturers' data, such as that produced by GEC ALSTHOM, will simplify the selection of the correct fuse link for a motor duty. The co-ordination with other protective devices, however, can be extremely complex.

NOTE: HV fuse links to BS 2692 or IEC 282-1 have voltage ratings based on their use in three phase circuits, having solid impedance or resistance earthed neutral. For use in single phase circuits or other three phase systems, recommendations contained within these Standards should be followed.

Future Trends

Future trends will be towards more compact fuses and fusegear, such as, GEC ALSTHOM's 'SAFECLIP' range to BS 88 Part 6, and proposed for incorporation into IEC and CENELEC Standards.

The most significant technological trends and advances will be happening in the power semiconductor protection field to meet advances in modern thyristor technology, requiring much faster acting fuse links, and the commercial constraints of price and size.

In conclusion, after more than 100 years since their introduction, fuses and fuse technology has made significant advances from the early wire fuses to the modern high performance devices of today. The versatility of the HRC fuse link, for the protection of electrical circuits, cannot be matched by any other device on the market.

Figure 8