POWER —AND— WATER AUTHORITY

STANDARDS BRANCH
– Power Division

PAGE	:	1 OF 8
DATE	:	25 FEBRUARY 1992
REVISION	:	NEW
DISTRIBUTION	:	VOLUME 1 HOLDERS
PREPARED BY	:	A GREENWOOD
AUTHORISED BY	:	BRIAN KENT

STANDARDS BULLETIN No. : S1-045

MAJOR CENTRES FUSING POLICY

SUBJECT:

INTRODUCTION

Following on from a recent investigation into the fusing policy for minor centres, this standards bulletin sets out the philosophy behind the selection and grading of various HV fuse/LV fuse or HV fuse/LV circuit breaker combinations. This policy is applicable to major centres where larger system fault levels are expected. It covers EDO fuses, air insulated switchgear, oil sealed switchgear, with either LV fuses or LV Terasaki Tembreak moulded case circuit breakers (MCCB) for the protection of distribution transformers in major centres.

Fault Levels

The investigation has included two distribution voltage levels, ie. 11kV and 22kV. The corresponding 3 phase symmetrical fault levels at these voltages have been assumed at 200 MVA and 100 MVA respectively based on average fault levels throughout major centres of the Northern Territory.

An assumed average transformer impedance has also been used for each transformer rating. To enable grading of LV protection with HV protection the reflected HV current is dependent on type of fault, transformer turns ratio and winding connections. The current ratio for a Delta-Star, 11kV/433V transformer was found to be:

25.4:1 for a three phase fault.

44:1 for a phase to ground fault.

22:1 for a phase to phase fault.

The phase to phase fault was considered to be a low probability occurrence, hence the ratio 25.4:1 has been adopted for grading of HV fuse with LV protection.

The ratio 50.8:1 has been adopted for 22kV systems.

Minor Centre Application

Full details are included in Standards Bulletin, No. S1-035.

Major Centre Application

In major centres where large LV reticulation systems exist it may be necessary from time to time for paralleling of LV feeders, hence distribution transformer fusing is sized to allow for loads up to 150% of the rated transformer capacity.

It is desired that the HV fuse be able to clear an LV terminal to ground fault within one second. In cases where this cannot be achieved due to the characteristic of the HV fuse, LV protection should be installed as close as is practicable to the transformer. In 3 phase URD areas LV protection exists on all transformers, however in some overhead LV reticulation systems, LV fuses are not installed at the transformer due to difficulties in grading with the HV fuse protecting the larger pole-mounted transformers. Clearance of an LV fault in these cicumstances is performed by the HV fuse. In single phase URD areas no LV protection exists in the majority of cases, the Standards Branch is currently addressing this issue and it is envisaged that LV fuses will be installed on these transformers.

Name plate ratings on HV HRC fuses are determined by temperature rise tests carried out in free air at an ambient temperature of 25°C.

When these fuses are placed in an enclosed environment they are unable to dissipate the heat generated by the load current flowing through the fuse elements. (I^2R. Where I = load current, R = internal resistance of fuse) The load current has to be reduced otherwise the temperature of the fuse cartridge will rise above the limit of 105° and result in thermal runaway with the fuse operating below the minimum breaking current with catastrophic consequences.

Temperature rise tests in various pieces of switchgear have established derating factors for HV HRC fuses used in the PAWA system.

Fuse Derating

The following criteria is used to establish derating values for HV HRC fuses.

Ambient Temperature	INDOOR	OUTDOOR
	40°	65°
Watts Loss		
Oil Immersed	79W	-
Krone	55W	30W
Hazemyer	30W	23W
BBC	38W	-

Load cycle not considered.

Example. Derating of 50A Bowthorpe fuse fitted in Krone switchgear in an outdoor package substation.

Fuse type	=	50A DIN AIR INSULATED
INTERNAL Resistance (measured)	=	17.1mΩ
MAX watts loss @ 65°C	=	30W

Thermal limit derated current Id $= \sqrt{\frac{W}{R}}$

$= \sqrt{\frac{30}{0.0171}}$

Id $= 42A$

ie. Max continuous current through fuse not to exceed 42 amperes.

The following criteria are used in choosing correct HV fuse/LV fuse or circuit breaker combinations:-

i) HV fuse to permit transformer to be loaded to 150% of name plate rating for 4 hours.

ii) HV fuse to clear LV terminal to ground fault within 1 second.

iii) Withstand transformer inrush magnetizing current of 12 times full load current for 0.1 seconds.

iv) Power dissipation of fuse link not to exceed power dissipation of fuse holder at 150% full load.

v) Discriminate with largest LV fuse, ie. clearance of LV faults by LV fuse or circuit breaker to avoid melting of HV fuse element.

FUSE TABLES

11kV & 22kV EDO FUSE/LV FUSE

MAJOR CENTRES :- EDO/L.V. FUSE (POLE SUBSTATIONS)

TRF. kVA	11kV				22kV			
	H.V. EDO (1)	L.V. FUSE (1)	H.V. EDO (2)	L.V. MAX. FUSE (2)	H.V. EDO (1)	L.V. FUSE (1)	H.V. EDO (2)	L.V. MAX. FUSE (2)
15 1 ø	10	80	10	80	10	80	10	80
25	10	63	10	63	10	63	10	63
50	10	100	10	80	10	100	10	80
100	10	N.R.	16	160	10	200	10	160
200	16	N.R.	31.5	315	10	N.R.	16	315
300	25	N.R.	40	400	16	N.R.	20	400
500	40	N.R.	50	500	20	N.R.	25	500

NOTES : 1. TYPE 1 FUSE APPLICATION FOR OPEN WIRE RETICULATED L.V. MAINS.
2. TYPE 2 FUSE APPLICATION FOR DEDICATED CUSTOMER SUBSTATIONS.
3. FUSING TYPE 1 SUITABLE FOR L.V. PARALLELING TO 150% OF TRANSFORMER RATING.

TABLE 1

EDO fuse switches are used to protect pole mounted distribution transformers, some underground/overhead cable connections and some ground mounted distribution transformers connected by cable to an overhead system.

Because PAWA mount high voltage surge protection on the load side of EDO fuses, minimum size fuse elements must be used otherwise lightning current and 50Hz follow through current will rupture the fuse every time the surge diverter vents to earth.

For major centres the minimum EDO fuse size is 10A.

In the case of transformers feeding open wire reticulated LV mains the fuses where fitted are sized to allow for LV paralleling to 150% of the transformer rated capacity.

With the larger sized pole mounted transformers it becomes difficult to grade LV fuse with HV fuse, hence the LV protection is not required in these cases and clearance of LV faults is performed by the HV fuse.

Where the pole mounted transformers are supplying a dedicated customer, 150% loading is not required and the maximum LV fuse that can be used is stated in the tables. In order to grade with HV fuse this necessitates in some cases using a larger HV fuse than what would have been used on the open wire reticulated mains.

Take for example a 300 kVA pole mounted transformer connected to open wire reticulated mains. The transformer in this case may be required to supply 150% of its capacity in the event of LV paralleling. This corresponds to an LV load current of 600 amps. The HV fuse required to grade with this fuse would be in the order of 80 amp which would be too large to clear some faults on the LV side, hence the LV protection is dispensed with and a 25 amp HV fuse enables 150% of transformer capacity and clearance of LV faults within one second. In the case where the transformer is supplying a dedicated customer only, an LV fuse (400 amp) sized to 100% capacity of the transformer is adequate as there would normally be no requirement to parallel LV supplies. In this case it is possible to use a HV fuse (40 amp) that will grade with LV protection, and also clear an LV phase to ground fault within one second.

11KV RMU/LV FUSE (INDOOR)

MAJOR CENTRES :- 11kV RMU/L.V. FUSE (INDOOR SUBSTATIONS)						
TRANSFORMER RATING IN kVA	AIR INSULATED SWITCHGEAR					
	BBC		HAZEMEYER		KRONE	
	H.V.	MAX.L.V.	H.V.	MAX.L.V.	H.V.	MAX.L.V.
300	40	400	40	400	40	400
500	50	630	50	630	50	630
750	80	800	100	800	80	800
1000	* 100	1250	NOT TO BE USED		100	1250
'T'OFF 1 ø	- - -	- - -	100	- - -	100	- - -

NOTES : * MAXIMUM 4 HOURS LOAD AT 140% TRANSFORMER RATING.

TABLE 2

The chart on the previous page is for 11kV ring main units incorporating air insulated switchgear in indoor subs and takes into account the different thermal dissipation values for varying switchgear types. For example a 1000kVA transformer using BBC ring main unit can only have 76 amps passing through a 100 amp fuse to avoid thermal runaway of the fuse. Hence the load in this application is limited to 140% transformer rating and is an exception to our criteria of allowing transformers to be loaded to 150% of name plate rating for four hours.

11kV RMU/LV FUSE (OIL SEALED & PACKAGE)

MAJOR CENTRES :- 11kV RMU/L.V. FUSE						
TRANSFORMER RATING IN kVA	INDOOR AND OUTDOOR SUBS		PACKAGE SUBSTATIONS			
	EMP/B&S, LUCY GEC, REYROLLE		HAZEMEYER		KRONE	
	H.V.	MAX.L.V.	H.V.	MAX.L.V.	H.V.	MAX.L.V.
300	40	400	40	400	40	400
500	63	630	63	** 500	50	** 500
750	80	800	100	** 500	100	** 500
1000	90	1250	- - -	- - -	- - -	- - -
'T'OFF 1 ø	- - -	- - -	100	- - -	100	- - -
'T'OFF 3 ø	125	- - -	- - -	- - -	- - -	- - -

NOTES : ** FOR LARGER LOADS, A CIRCUIT BREAKER IS REQUIRED.

TABLE 3

The package substations use striple fuse units and the maximum size striple fuse that may be used is 500 amp due to thermal limitations on the unit bases. If applications arise where loads of greater than 500 amp occur on package substations then the option of using an LV circuit breaker becomes a requirement. Refer to table 8 for these applications.

11kV EDO/LV TEMBREAK CB

MAJOR CENTRES :- 11kV EDO/L.V. MCCB								
TRANSF. RATING IN kVA	FUSE TYPE	MCCB TYPE	MCCB SETTINGS					
	ABB OR A.B. CHANCE	TERASAKI TEMBREAK	I_0	I_1	I_2	I_3	T_1	T2 (RAMP ON)
11kV INDOOR SUBSTATIONS								
300	40	XS800NE	0.63	0.80	2	12	30	0.30
500	50	XS800NE	1.00	0.85	2	12	30	0.15
750	63	XS1250NE	0.80	1.00	2	12	30	0.30
1000	* 80	XS1600NE	1.00	0.85	2	12	30	0.15
11kV OUTDOOR SUBSTATIONS								
300	40	XS800NE	0.63	0.80	2	12	30	0.30
500	50	XS1250NE	0.63	0.85	2	12	30	0.15
750	63	XS1600NE	0.63	1.00	2	12	30	0.20
1000	* 80	XS2000NE	0.80	0.85	2	12	5	0.10
TOLERANCES				+ 5% + 25%	± 15%	± 20%	± 20%	+50mSec

NOTES : * NEW FUSE REQUIRED

TABLE 4

The LV Terasaki moulded case circuit breaker is now a stores item and available in 400, 800, 1250, 1600 and 2000 amp ratings. The previous table and this one following outline settings that will grade with HV EDO'S, at 11kV and 22kV respectively.

22kV EDO/LV TEMBREAK CB

MAJOR CENTRES :- 22kV EDO/L.V. MCCB									
TRANSF. RATING IN kVA	FUSE TYPE	MCCB TYPE	MCCB SETTINGS						
	ABB OR A.B. CHANCE	TERASAKI TEMBREAK	I_0	I_1	I_2	I_3	T_1	T2 (RAMP ON)
22kV INDOOR SUBSTATIONS									
300	20	XS800NE	0.63	0.80	2	12	30	0.25
500	25	XS800NE	1.00	0.85	2	12	30	0.15
750	40	XS1250NE	0.80	1.00	2	12	30	0.30
1000	50	XS1600NE	1.00	0.85	2	12	30	0.20
22kV OUTDOOR SUBSTATIONS									
300	20	XS800NE	0.63	0.80	2	12	30	0.25
500	25	XS1250NE	0.63	0.85	2	12	30	0.15
750	40	XS1600NE	0.63	1.00	2	12	30	0.30
1000	50	XS2000NE	0.80	0.85	2	12	30	0.20
TOLERANCES				+ 5% + 25%	± 15%	± 20%	± 20%	+50mSec

TABLE 5

11kV RMU/LV TEMBREAK CB (INDOOR)

MAJOR CENTRES :- 11kV RMU/L.V. MCCB									
TRANSF. RATING IN kVA	H.V. FUSE		MCCB TYPE	MCCB SETTINGS					
	SWITCHGEAR TYPE	FUSE RATING	TERASAKI TEMBREAK	I_0	I_1	I_2	I_3	T_1	T2 (RAMP ON)
11kV INDOOR SUBSTATIONS									
300	OIL SEALED EMP/BLS, GEC, LUCY REYROLLE	40	XS800NE	0.63	0.80	4	8	30	0.20
500		63	XS800NE	1.00	0.85	4	9	5	0.10
750		80	XS1250NE	0.80	1.00	4	9	10	0.20
1000		90	XS1600NE	1.00	0.85	4	8	5	0.10
300	AIR INSULATED BBC OR KRONE	40	XS800NE	0.63	0.80	6	12	30	0.30
500		50	XS800NE	1.00	0.85	4	10	30	0.15
750		80	XS1250NE	0.80	1.00	6	12	15	0.30
1000		* 100	XS1600NE	1.00	0.85	6	12	30	0.30
TOLERANCES					+ 5% + 25%	± 15%	± 20%	± 20%	+50mSec

NOTES : * BBC APPLICATION LIMITED TO 145% 4 HOUR LOADING

TABLE 6

US URD Fuses

A number of US designed URD fuses have been used in the distribution system.

Mcgraw Edison brand dry well fuses with full range capability similar to the LEL Brush fuse are used in some three phase package substations.

RTE oil immersed load break HV Bay-o-net fuses are used in the single phase package substations. These fuses operate under oil and have expulsion type characteristics and are not current limiting.

U.S. STANDARD U.R.D. SYSTEM

TRANSF. RATING IN kVA	H.V. BAYONET FUSE LINK		H.V. CURRENT LIMIT ELX FS		STOCK CODE H.V. FUSE
	11kV				
	1Ø		3Ø		
	H.V.	L.V. MAX.	H.V.	L.V. MAX.	
50	25 *	100	—	—	9845
300	—	—	25	400	11098
500	—	—	40	500	247650

NOTES : * 25 AMP BAYONET FUSE LINK ADOPTED AS STANDARD FOR BOTH G.E. & TYREE TRANSFORMERS IN THE URD SYSTEM.

TABLE 9

BRIAN KENT
STANDARDS MANAGER POWER

APPENDIX

A typical fault level found on the system in major centres would be around 200 MVA.

ie. $P = \sqrt{3}\,EI$

$$I = \frac{200 \times 10^6}{\sqrt{3} \times 11 \times 10^3}$$

$$= 10496 \text{ amperes RMS}$$

The peak value of this fault current would be,

$$I \text{ peak} = 10496 \times 1.414$$
$$= 14842 \text{ amperes}$$

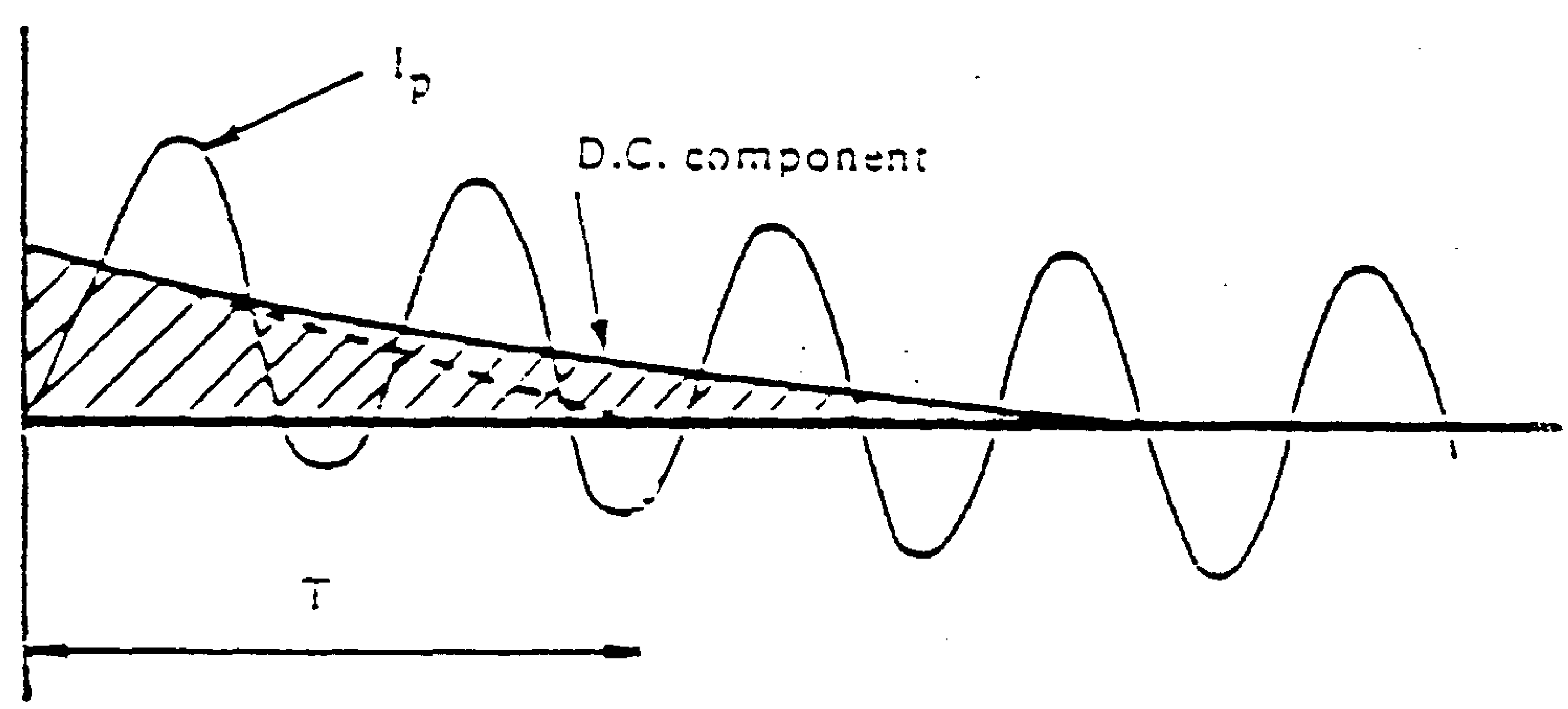
Take the case where the system was closed onto a fault, this peak current value can increase up to 1.8 times the equivalent RMS peak value because of DC offset or Asymmetry.

$$I\text{assym peak} = 14842 \times 1.8$$
$$= 26716 \text{ amperes}$$

Asymmetrical peak currents are caused by the fact that at the point of switch on, the system has no inductive reactance because there is no change in current (ie. di/dt) and the systems DC resistance limits the current. Usually within three cycles the asymmetry reduces and the peak current reduces to fault level RMS equivalent.

Components in the system carrying currents are subjected to electromechanical forces which are proportional to I^2 peak and large asymmetrical currents can cause mechanical failure of equipment. Similarly damage can be caused to equipment by the heating effect of the fault current which is proportional to I^2T. Where T is the time the fault current is flowing.

Fuses in general use in the Authority are of two basic types, ie. current limiting fuses which can limit the peak value of I^2 and interrupt fault currents before the first current zero thus protecting the system from high electromechanical forces and high thermal energy, non current limiting fuses (expulsion types) which do not limit peak values and only reduce "T" thus protecting equipment from thermal damage.



Non Current Limiting Fuses

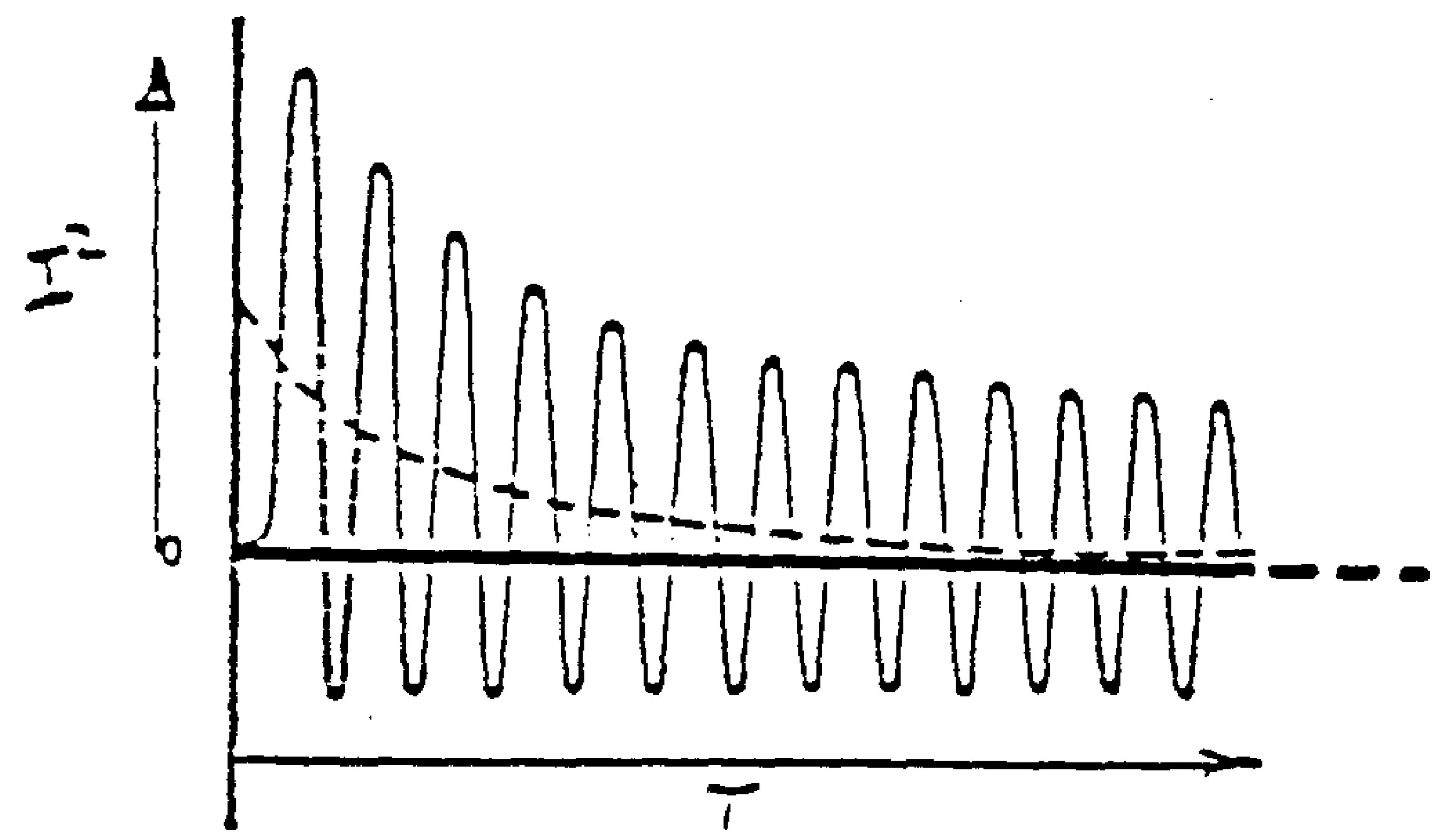
The most common non current limiting fuse in service is the High Voltage Expulsion Dropout Fuse commonly known as the EDO.

These units are used in the system at both 11 and 22kV and have a maximum thermal current rating of 100 amperes, a fault interrupting capacity of up to 6KA and a Basic Insulation Level (BIL) of 125kV.

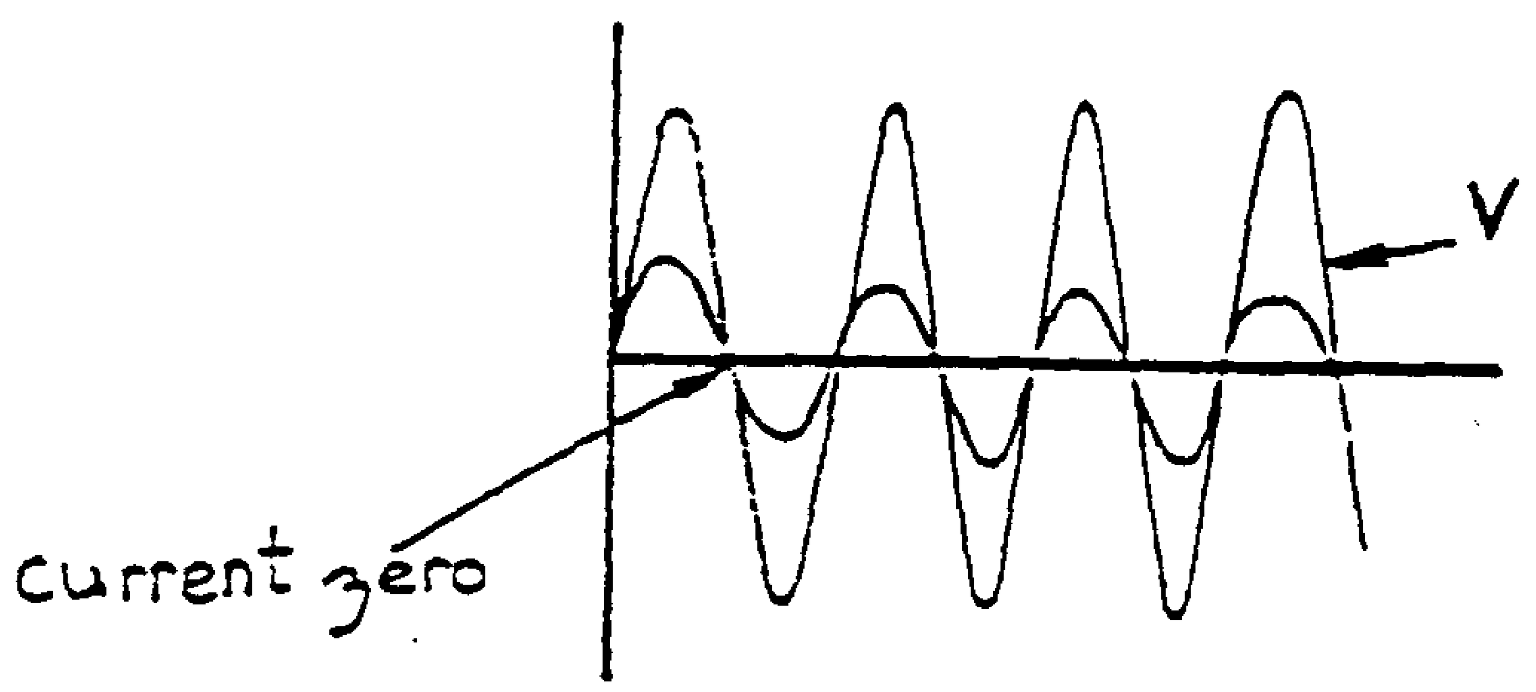
The EDO fuses operate on the following principle:

The fuse element which is made from either tin alloy or silver nichrome alloys is placed within a tube which is closed at one end. The fuse tail is attached to a spring loaded over centre device which when tensioned extends the overall length of the tube. The tube is constructed of two materials with the inner lining material being a sacrificial product made from bone fibre.

When the current through the fuse element exceeds the melting temperature of the element an arc is generated which burns the bone fibre tube creating a pressurised gas which extends the arc towards the open tube and thus increases the resistance of the arc until the voltage across the arc is insufficient to continue the current and the current is interrupted at a current zero.

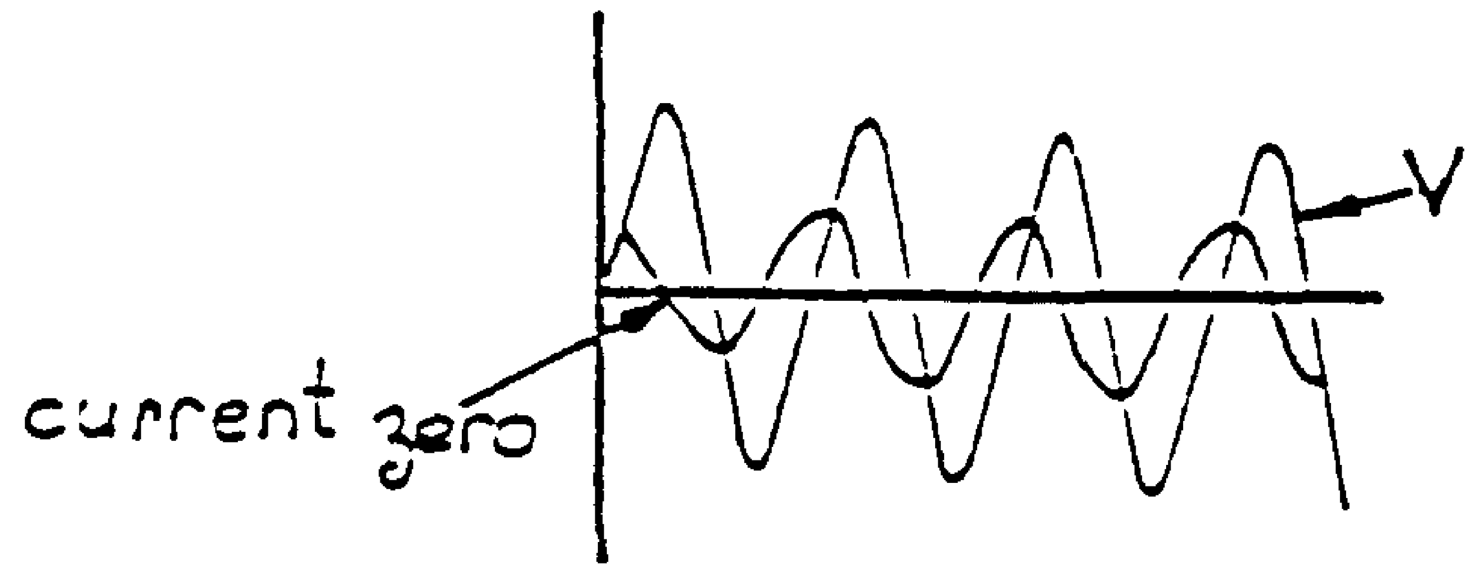


There is no reduction in the value of I only the time is reduced. The period taken to interrupt the current depends on the fault level (ie. arc energy) and the power factor.



In figure 3 above, at unity power factor, at a current zero, the system voltage is also zero and therefore there is little or no voltage across the arc and faults will be interrupted within a few cycles depending upon the fault level.

In figure 4 with a lagging power factor the system voltage can be at a maximum at the time of a current zero requiring increased time for the arc resistance to increase to a point where it will interrupt at a zero crossing. This period of time is also dependent upon the arc energy ie. fault level.



The switching mechanism of the unit is not rated to switch any loads greater than the Magnetizing current of the transformer. The fault is interrupted within the tube and when the tension is reduced on the fuse tail the switch mechanism falls free indicating a fuse operation.

The internal diameter of the fuse tube is of importance as it is related to the level of arc energy (fault level) ie. high fault levels with large arc energy require large diameter tubes otherwise the tube could burst. Conversely small faults require small diameter tube bores otherwise the gas pressure will be insufficient to extinguish the arc.

The single vented EDO resolves this problem by having a fuse tube with a stepped internal bore diameter. For fault levels up to 6KA the fuse element is located at the top end of the tube in a small diameter. For fault levels over 6KA the fuse element is extended to the lower end of the fuse tube, which has a larger diameter, by way of an "arc shortening" rod attached to the top contact. (Not currently used by PAWA).

Fault levels less than approximately 800 amperes do not generate enough arc energy to vaporise the fuse element materials and molten arc products are ejected from the end of the fuse tube. These fuse products have been found to retain sufficient thermal energy to ignite combustible materials at ground level.

Sparkless type fuse elements have been developed which incorporate an additional small diameter expulsion tube around the fuse element which will generate sufficient gas pressure to interrupt the fault within the auxiliary tube thus containing any arc product within the tube.

PAWA has directed that sparkless elements be used in fire risk areas.

<u>Current Limiting HRC Fuses</u>

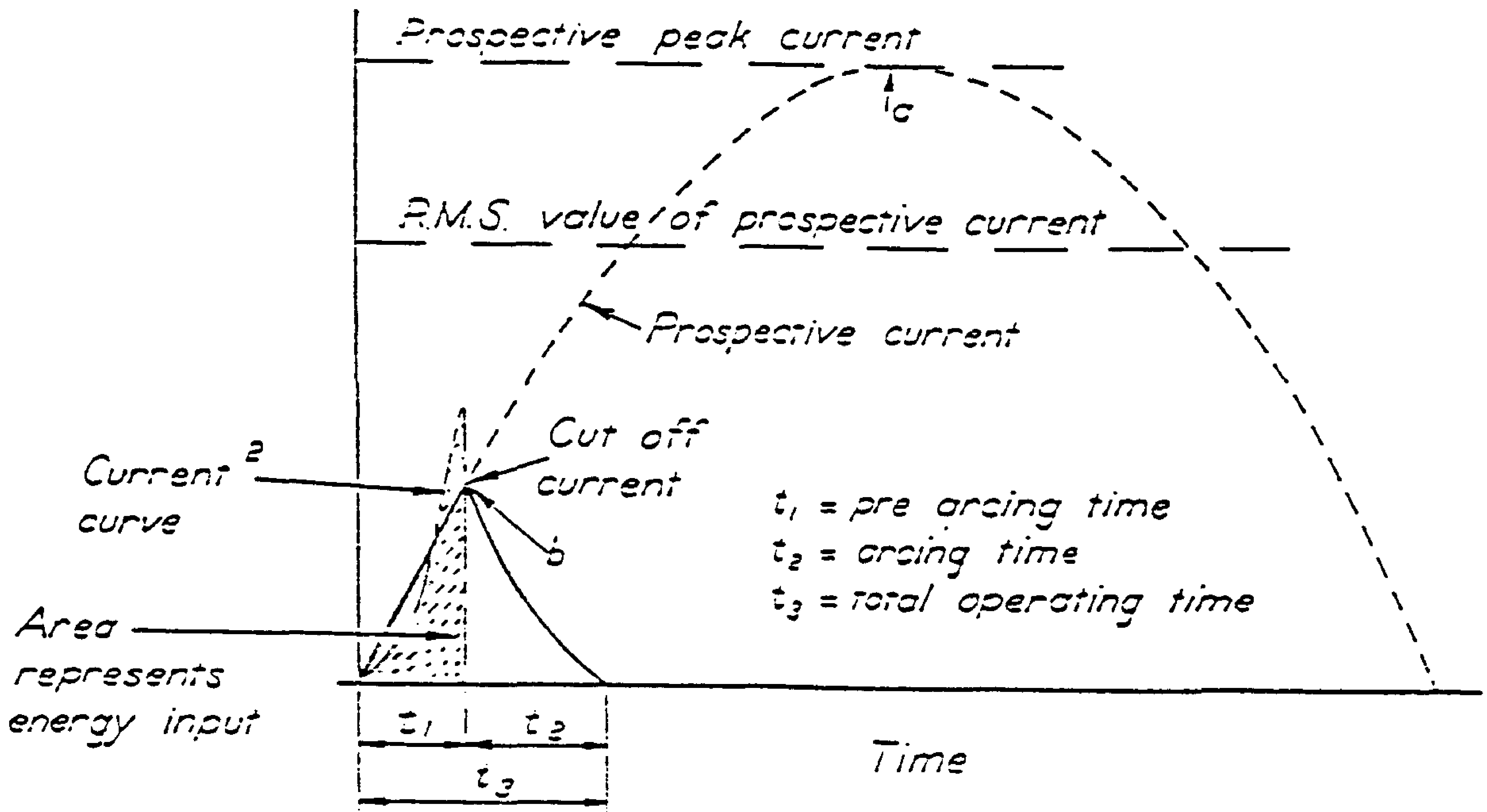
High Rupturing Capacity (HRC) current limiting powder filled fuses are used extensively where fuses are required to be mounted indoors in switchgear and where fault levels are exceptionally high on the overhead system. (Above 150 MVA)

HV HRC current limiting fuses are of two types: for use under oil and for use in air.

There are a number of designs available BS types from Britain, DIN type European and Nema type from USA.

The HV HRC fuse consists of a number of parallel fuse elements wound on an insulating bobbin which is placed inside an insulating tube which is filled with fine silicone sand.

When the current in the fuse element exceeds the melting temperature of the fuse element an arc is generated which melts the sand and turns it into a glass "Fulgurite" which insulates the arc increasing its resistance. This process happens simultaneously in each parallel path at many nodes, depending on the fault level (again arc energy) the increase in arc voltage (arc resistance) is so rapid that the fault current will be interrupted before the first current zero.



As can be seen from the above figure the fault current can be interrupted before the prospective current peak thus protecting the equipment from damaging electromagnetic forces and thermal energy.

"General Purpose" HRC HV Fuses have a minimum breaking current limitation, that is, they are not able to break currents between the minimum melting current and the minimum breaking current. Arc energy at this level is relatively small and the time taken to interrupt the current is so long that the fuse cartridge cannot dissipate the heat (I^2T)) and the cartridge can rupture from thermal expansion.

General purpose fuses are to be used only as short circuit protection and must be carefully graded so that any low voltage fuse downstream will discriminate.

Outdoor HV HRC Fuses

HV HRC powder filled fuses are available for outdoor use where current limiting is required. They can be fitted in a switch assembly where the fuse striker pin will release a swing away mechanism giving a 'drop out' type indication that the fuse has operated. Fuses are available in 25A and 90A sizes.

Fuse Application

As stated above PAWA is adopting two basic philosophies for fuse application. One philosophy for low fault level "Minor Centre" application. One philosophy for higher fault level "Major Centre".

Fuse Handling

EDO fuse elements must be carried in tubes or packets to avoid kinks as these sharp protrusions will generate corona discharge with subsequent erosion of the fuse tail material. EDO fuse tails should be tensioned correctly and excess tail length cut off and not pushed back into the end of the tube. The tube end must be kept clear otherwise it may fail to clear fault and could rupture.

HRC HV Fuses

Special attention must be given to handling of these fuses to ensure the integrity of the internal fuse elements. Breakage of a single parallel fuse element will cause an increase in the fuse resistance and a subsequent increase in heat which will result in fuse rupture.

Fuses should be carried in their packaging.

All fuses are checked at the time of purchase by the TSE for compliance with internal resistance values. Fuses are marked with PAWA test certificate. Fuse internal resistance cannot be checked with a multimeter as values are typically less than 0.02 ohms.

Fuses should always be replaced in sets of threes with unblown fuses being returned to the Testing section for re-checking.