THE HONG KONG
INSTITUTION OF ENGINEERS
ELECTRICAL DIVISION

One day Symposium
Wednesday 8 June 1983

The 15th Edition IEE Wiring Regulations and their Compliance in Hong Kong

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SYMPOSIUM PROGRAMME

08.45 **Registration and coffee**

09.15 **Welcome and Introduction** – Chairman: Dr. L.H. Lees, Ph. D. FHKIE, CEng FIEE, Head of Electrical Engineering, Hong Kong Polytechnic

?.20 **Opening Address** – President HKIE: Mr. D.A. Morris, BSc Eng (Lond), DIC, FHKIE, CEng FICE, FIStructE.

09.30 **"The 15th Edition IEE Wiring Regulations – The Supply Industry Aspects"** – Speaker: Mr. J.H. Henderson, MHKIE, CEng MIEE, Senior Consumer Installation Engineer, Hongkong Electric Co. Ltd.

10.10 **Panel Discussion on Supply Industry's requirements and policies** – Panelists: Representatives from HEC & CLP

10.40 **Coffee**

11.00 **"Down To Earth"** – Speaker: Dr. R.K. Edgley, MSc PhD, FHKIE, CEng FIEE, FIEAust, Senior Partner, Kennedy & Donkin International Consulting Engineers

11.30 **"Recent and Future Trends in Design of Electrical Accessories"** – Speaker: Mr. Norman Reyrolds, Divisional Technical Manager, Accessories Division, M.K. Electric Ltd. (UK)

12.10 **Panel Discussion**: Speakers (Morning)

12.40 **Lunch**

14.00 **"Implication in the Implementation of the 15th Edition of IEE Wiring Regulations"** – Speaker: Mr. S.T. Tam, MHKIE, CEng MIEE, Mr. K.C. Wong, Sen.MIIE, MIEEE, MBIM, Hong Kong & Kowloon Electrical Contractors' Association Ltd.

14.40 **"The IEE 15th Edition Requirements for Miniature Circuit Breakers"** – Speaker: Mr. Arnold Horton, Chief Engineer, Federal Electric Limited, Wolverhampton, U.K.

15.20 **Coffee**

15.50 **"British Standard L.V. Switchgear and The Implication of the 15th IEE Wiring Regulations"** – Speaker: Mr. R.A. Upton, Electrical Laboratories Manager, Midland Electrical Manufacturing Co. Ltd., U.K.

16.30 **Panel Discussion**: Speakers (Afternoon)

17.00 **Closing** – Vice President HKIE: Mr. G.J. Osborne, FHKIE, CEng FIMechE, MBIM, JP, Director of Elect. & Mech. Services Department

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Mr. K.C. Wong

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Paper No. 1

The 15th Edition IEE Wiring Regulations
– The Supply Industry Aspects

Speaker: Mr. J. H. Henderson,
Hong Kong Electric Co. Ltd.

The New Regulations for
Electrical Installations
15th Edition
The Supply Indsutry's View Point

Introduction

When we are faced with a new task or problem one is usually advised "begin at the beginning and take it step by step from there." It is therefore logical that the Supply Industry – the Power Companies in Hong Kong should have the honour of starting off the detailed talks of this symposium. We are starting, as it were, at the source of supply and going on from there.

Firstly, a word as to what this talk is trying to cover. Any producer should always be very much concerned with the safety of his product, be it a car, a tool, a fuel or a service since if it is dangerous or even gets the name of being dangerous he may lose sales, potential customers or law suits Electricity has fortunately a good safety record but the new Regulations take this safety feature a giant step forward by getting at the scientific causes of fatal electric shock – voltage, time and current and for Hong Kong conditions at least, make virtually mandatory earth leakage protection for all socket outlet fed appliances, which are those also likely to be hand held. It has other clear improvements on earthing and means of protection against overcurrent and short circuit but none will so dramatically improve the statistics of deaths due to electrocution as the use of earth leakage circuit breakers.

Secondly, for the first time, the I.E.E. Regulations takes the user behind the scences, as it were, into the Supply Company's network and explains the means and method of supply so that the user can follow for himself the technical reasons behind the power utility's requirements which have been imposed on him and he can appreciate why following these recommendations or regulations is good for both parties.

In this we are thinking mostly about the methods of earthing of the source, the earth fault current return path and the all important fault level, quoted in MVA or fault current value at that point.

Thirdly, the Power Supply Companies can use this opportunity to state the conditions of supply which apply in Hong King in accordance with the Electricity Supply Ordinance. This eliminates very quickly large sections of the new Regulations as being not applicable to Hong Kong.

Fourthly, the Power Supply Companies in Hong Kong are also required to be the party who are required, under the Electricity Supply Ordinance to ensure that all installations connected to their supply meet their Supply Rules, which in turn refer to ther latest edition of the I.E.E. Regulations. The Power Company's inspection staff therefore have the task of checking all installations against the new Regulations, and an opportunity to say what we hope to find, will be helpful to those involved in providing the installations.

We shall now deal with these various items in more detail.

The Source of Supply and Conditions of Supply

In Hong Kong for "low voltage" supply, the voltage of supply is nominal 200 Volts single phase to neutral or 346 Volts between phases and subject to statutory limits of + 6%. Frequency is defined as 50 Hertz and the limits, although quoted at + 2% in the Supply Rules, are nearly always much better, say 49.98 to 50.02 hertz.

The system of supply for Hong Kong has been publically declared by both Power Companies as of the form "TT"., as defined in the new Regulations, i.e. the neutral of the transformer is earthed at the transformer and no earth is extended towards the consumer by a conductor or a cable sheath.

(China Light & Power have made a practice of extending a bond from their cable sheath, where this is practicable, to the consumers main switch outer metal work, and connect this up after the consumers own earth electrode has been tested.)

From this follows a great many important points:

a) The consumer must provide his own earth electrode and use it for all earthing.

b) The resistance of the mass of the earth between the consumers earth electrode and the transformer neutral earth will be part of the earth fault return path and affect its value and therefore the size of other protective conductors.

c) It will require other regulations to be effective in its wake. For example, the mandatory requirement for residual current (earth leakage) protective device for every socket outlet whether inside or outside the premises.

Since this is an important point, a word of explanation should be given to explain the reason why the Power Companies consider themselves a TT system. They consider they cannot practically guarantee that the sheaths of their low voltage cables are electrically continuous and therefore capable of extending an earth to the consumers premises.

With regard to the value of the fault level to be expected at the point of supply, which determined the short-circuit prospective current there, there are clearly two clear methods of supply.

a) From the terminals of a transformer by very short busbars or large single core cables to the consumers main switch, where the prospective fault current is determined by the size and the internal impedance of the transformer. Both Power Companies use transformers up to 1.5 MVA with % impedance values yielding fault level values of 24 MVA or 40,000A. No great allowance has been made for the 11kV network impedance as in some cases, the transmission substation operated at 132/11 kV or other voltage, may be very close.

b) Similarly, if a building is supplied by a cable then, of course, allowance can be made for the length and size of cable used from the nearest transformer room. However, since it is possible that this source may change in accordance with changes of load and distribution network, and indeed as is more likely, change of buildings, it would be unwise to lower fault levels by much to take this into account. In this case also, the fault level is considered to be 24 MVA.

The important point here is that the Supply Companies are stating that the fault level will not exceed this value at any future time, and if any user insisted on rating his switchgear's fault level to something lower based on the method of supply initially used, then this user would be required to change the switchgear to a higher value if the method of supply was changed to have shorter cable to busbar methods of connection, or expansion of the supply system. Since, changing of switchgear to suit every change in the Power Supply Company's network is administratively impossible, expensive and inconvenient to the user, the stated value should be adhered to.

Few users, and it seems also smaller contractors, are aware of the dire results of asking a piece of switchgear to handle faults currents greater than its fault current rating and they frequently have to be reminded of the higher fault levels required of quite low normal full load rated MCCB's which are teed to busbars fed directly by transformers and therefore at the fault level of the main ACB.

However, once some lengths of cable extend the supply to other parts of the building then fault levels reduce dramatically and since these cables are controlled by the building, and unlikely to change to that section of the building fed, then calculated reductions (or reference to tables) will allow other switchgear to reduce considerably in fault level.

Since the Supply Company will not provide an earth, as such, the user has to provide his own earth electrode and connect it back to a convenient point where it can be distrubuted throughout the building.

A convenient disconnecting point preferably at the electrode itself should be provided

A convenient disconnecting point preferably at the electrode itself should be provided so that the quality of earth can be checked by measuring it's value against other test earths.

Having stated the supply conditions in Hong Kong large sections of the Regulations can be disregarded.

These are:

a) Those sections concerned with methods of supply other than T.T.

b) Similarly, for practical purposes, we can forget about those regulations concerning non-conductive locations, or systems with earth free equipotential bonding which seldom arise in practice.

However, we do have to remember that all the tables of earth loop impedance or similar which are based on the common U.K. voltage of 240 Volts connot be used as given and the values have to be multiplied by 200 ÷ 240 i.e. 0.83 which are given for example in tables 41A1 and 41A2. This makes the earth loop values smaller and therefore harder to achieve in practice than those quoted.

The clearance of earth faults

Arising out of the Power Supply Companies' statements the most important aspect concerns the clearance of earth faults and hence the protection of the user from electric shock.

Before we go on to talk about this in detail, it is very often useful to remind ourselves as to why we earth our electrical systems at all. It is a point which seems to be quickly forgotten, since we are constantly reminding contractors who want to set up their own system of site supply at various non-standard voltages, of the dangers of supplying a LV system from the delta windings of transformers with no neutral or earth. With these system, the first earth fault may go undetected, but the second may cause arcing to earth faults starting fires or producing unexpected high voltages. We have therefore inherited a sensible system of low voltage supply using 4 wires with the neutral connected to earth at the low voltage transformer start point.

This means that we can very easily detect earth faults by residual currents or unbalance either on a 3-phase or a single phase basis.

This is a considerable advantage since most faults begin as earth faults due to contact of phase conductors with earthed metal which is acting as physical protection or due to the presence of water or dampness.

Earth faults if not detected cause local heating, ionisation and nearly always lead to phase faults. Since earth faults can be detected at very low levels of current, the damage to cable or equipment is small and localised and extensive damage due to high current values required before overcurrent protection operates is prevented.

A large amount of the new regulations are concerned with this and great stress is placed on the earth loop impedance value as the means of allowing earth faults to develop values which can blow fuses or operate MCB's.

As a further extension of this, the size of the circuit protective conductor is gone into great detail taking into account the length of time the fault current can exist-in that conductor without danger or fire to adjacent materials and as a corollary the speed and reliability of the protective device itself. These devices are generally in four classes:

a) Earth fault (or residual current) detecting devices.

b) MCCB's or MCB's.

c) Enclosed fuses of various classes normally referred to as HRC. fuses.

d) Semi-enclosed rewireable fuses.

Resulting from the relationship of the heat produced in a conductor being dependent on current squared, time and the materials used, we get the adiabatic equation

$S = \sqrt{\frac{I^2 \times t}{K}}$ which relates

S the minimum protective conductor size in sq.mm.

I the prospective fault current i.e. the fault current which will make the protection device operate.

K the constant dependent on the materials of the cable.

This formula, despite it being the key to understanding and calculating earth or protective conductor sizes and to the making of effective savings in the costs of wiring installations, has become the main stumbling block to the practical user of the new I.E.E. Regulations.

For those who do not delight in mathematics, and that includes the majority of us, sets of tables or rules of thumb, are required.

Some examples of these tables are attached covering common examples, along with an explanation of how they can be built up.

Note that the nearest practical size of conductor is very often much larger (especially in the case of aluminium cores) than the calculated size and that the minimum earth conductor size can very easily be obtained by the use of conduit, trunking or armouring wires.

I shall not go into detail on the changes to BS Standards for MCB's which are a direct result of these new regulations because others will be bringing out these salient points, and their effect on international standards.

We should however, point out that the earth protective conductor sizes affect earthing and equipotential bonding conductor sizes.

i.e. the main earth should have the full size of the circuit protective conductor as calculated and the equipotential conductors half this size.

Inspection of installations

As has already been stated, Hong Kong will follow the U.K. programme, by requiring that as from 1st January 1985 all new installations will be in accordance with the 15th Edition, and up to then the 14th or 15th Edition is acceptable.

Before we go on to look at the new Standards required it would be logical to comment on the existing standards as found on inspection of completed work.

They are at present very unsatisfactory and from Hong Kong Electric statistics of testing new installations only 38% are found acceptable on first test.

The statistics from a sample of typical new installations of small or medium size are given as follows:

Statistics of Electrical Defects found in typical new installations of small or medium size

Percentage of installations which have no technical defects when tested.................... 38%

Percentage having technical defects.. 62%

No. of defects found in typical group of 100 installations = 1293

Classification of defects		No.	%
1.	Unacceptable apparatus	42	21.7
2.	Low insulation resistance	37	19.0
3.	Installation not ready for test	23	11.9
4.	Important item missing	19	9.8
5.	Earth missing where required	17	8.8
6.	Fire barrier missing where required	13	6.7
7.	Error in polarity	11	5.7
8.	Important item cannot be accessed	8	
9.	Earth loop impedance too high	4	2.0
10.	Apparatus found open circuited	4	2.0
11.	Fluorescent light not earthed	4	2.0
12.	Socket found in bathrooms	3	1.5
13.	Switch found in bathrooms	3	1.5
14.	Earth leakage protection not functioning	2	1.0
15.	Circuit breaker poles not linked	2	1.0
16.	Fuse found in neutral	1	0.5

As a result of this it is clear that unless something dramatically changes in the standards of work we can expect that with the new, additional and higher standards of the 15th Editions then we can expect initially that only about 30% of all new installation submitted for tests will pass their first inspection for technical reasons.

This results in a great deal of unnecessary delay, frustration and cost to the Power Supply Company who is eager to sell units to the new consumer and to the user who wants to put the premises into use.

It is to be hoped that the bringing into use of the new Regulations will act as a spur to improvements in installation standards.

To highlight those aspects which will be new or different under the new regulations we would single out the following:

a) Closer attention to be paid to the type of protective device fitted i.e. Rewireable fuse, (preferably eliminated) HRC fuse or MCB. as it affects conductor sizes.

b) The requirement for checking the fitting of, and correct operation of residual current devices (RCCD) (ELCBs) for every socket outlet. A special tester to determine time/current operation will be needed.

c) The closer checking of earth loop impedance value.

d) The closer checking of equipotential bonding of building metalwork to the main earth electrode.

As comments on these items, we would for (b) bring out the possibilities for savings which are possible for smaller installations by utilising common RCCDs for example:

a) combined main switch and RCCD.

b) split busbar distrubution board where one section which covers socket outlets, uses a common RCCD.

   In the above schemes, if the number of circuits connected are excessive, total leakage current due to the sum of A.C. leakage or capacity currents, may add up to values approaching 30mA and lead to nuisance tripping which will cause users to take RCCD's out of circuit.

c) the use of 13 Amp. socket outlet rings will enable one RCCD to serve simultaneously a group of socket outlets on one ring.

On the subject of equipotential bonding there appears to be some confusion.

The object is to produce a "an equipotential zone – a form of "Faraday Cage" of a building by connecting all significant metal work to the main earth bar.

Naturally this will include the main structural steelwork and other accessible reinforcing steel work, along with all metal pipes, ducts, trunkings etc. of building services. It is especially important when these pipes and ducts are of long lengths, say greater than one floor height as they would serve otherwise to carry potential rises to other areas of the building if they became live due to any contact fault. Smaller metal parts such as individual doors or window frames appear to use as unnecessary but advisable to bond except, if they are associated with electrical equipment for example motor operated shutters or lighting, when they must be bonded.

Air conditioning ducting should certainly be earthed at all points where air handling units exist and checked that electrical continuity is maintained. False ceiling grids although difficult to bond should be done and we consider that if each fluorescent fitting set into such a grid is earth connected then the necessary protection for maintenance staff has been assured. Cladding of building faces needs bonding if in continuous lengths and where lighting is associated with it.

Bathrooms and shower rooms are given special bonding treatment where every piece of metal work is connected to the electrical earth irrespective of the fact that water pipes may have been bonded at other points. This is to cover the particular circumstances in bathrooms where skin resistance is at its lowest possible values, and so that any earth fault elsewhere may not bring in voltages which although normally not noticed, in these special circumstances, may be dangerous.

We have at present many instances of outer metal casings of appliances being live, but so long as they were used in dry, non conducting areas with wood floors, or carpets, the voltages are never noticed. In bathrooms, kitchens etc these appliances become lethal.

Building sites will become much safer when all socket outlets have earth leakage protection, as despite the efforts of the inspection staff, the leads for power tools very often have no earth wire, and 110 Volt tools operating from safety transformers to ensure that no voltage over 55 Volt above earth exist are not covered by legislation nor voluntarily provided by the majority of contractors.

Conclusions

The Power Companies have a major role to play in ensuring the new regulations go into service and that the benefits of the additional safety standards are obtained by the public.

We hope that as a result of this and other opportunities which have been given to explain and simplify the new regulations, the cooperation from developers, consultants, contractors and users will be more effective and misunderstandings in interpretation reduced.

The Power Supply Companies are always willing to discuss and assist you in obtaining the service you require and welcome your enquiries.

Acknowledgements

In conclusion, I should like to express my thanks to the Management of Hongkong Electric Co., Ltd for their permission to prepare and present this paper and to colleagues for assistance in the preparation of visual aids.

The Technical Paper Committee's has the following comment:

"The Electricity Supply Ordinance stipulates that the Power Supply Companies have to satisfy themselves that any installations they connect up is safe. Apart from that, the conditions or supply as stipulated in the Power Supply Companies' Supply Rules have no bearing on the existing Electricity Supply Ordinance. It is the prerogative and sole discretion of the Power Supply Companies to make their own Supply Rules which do not require Government's formal approval.

MCB TO BS 3871 TYPE 3 (7 – 10 x F.L.)

M.C.B. Rating (Amp.)				30	60	80	100	150	200	250	300	400	500
Fault current value such that disconnection time is 5 seconds (Amp.)				300	600	800	1000	1500	2000	2500	3000	4000	5000
Maximum earth Fault loop impedance (Zs in ohm) for circuits supplying fixed equipment.				0.67	0.33	0.25	0.20	0.13	0.10	0.08	0.07	0.05	0.04
Minimum Cross-sectional area (mm^2) of protective conductor for compliance with regulation 543-2, when using MCB and assuming actual disconnection time is 0.1 second	(I) Insulated protective conductor not incorporated in cable but with mechanical protection	Copper/ P.V.C. K = 143	Calculated value	0.66	1.33	1.77	2.21	3.32	4.42	5.53	6.63	8.85	11.06
			Min. Standard size	2.50	2.50	2.50	2.50	4.00	6.00	6.00	10.00	10.00	16.00
		Aluminium/ P.V.C. K = 95	Calculated value	1.00	2.00	2.66	3.33	4.99	6.66	8.32	10.01	13.31	16.64
			Min. Standard size	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	25.00
	(II) Bave conductor where there is no risk of damage to any neighbouring material by the temp. indicated Initial temp. 30°C Final temp. 200°C i.e. under normal conditions	Copper/ P.V.C. K = 159	Calculated value	0.60	1.19	1.59	1.99	2.98	3.98	4.97	5.97	7.96	9.94
			Min. Standard size	4.00	4.00	4.00	4.00	4.00	4.00	6.00	6.00	10.00	10.00
		Aluminium/ P.V.C. K = 105	Calculated value	0.90	1.80	2.41	3.01	4.52	6.02	7.53	9.04	12.05	15.06
			Min. Standard size	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00

FUSES TO BS 88 PART 2

(HRC FUSES FOR USE UP TO 1000 VOLTS)

				32	63	80	100	160	200	250	315	400	500
Fuse Rating in AMPS				32	63	80	100	160	200	250	315	400	500
Fault current value such that disconnection time is 5 second AMPS				133	279	400	533	870	1250	1500	2182	2500	3692
Maximum earth fault loop impedance for circuits supplying fixed equipment Zs in OHMS				1.50	0.72	0.50	0.38	0.23	0.16	0.13	0.09	0.08	0.05
Minimum cross-sectional area (in sq.mm.) of protective conductors in compliance with regulation 543-2 assuming actual disconnection time is 5 seconds $S=\frac{\sqrt{I^2 t}}{K}$	(I) Insulated protective conductor not incorporated in cables but with mechanical protection, for example in conduit or trunking.	Copper/pvc K = 143	Calculated value	2.08	4.36	6.25	8.33	13.9	19.7	23.4	34.1	39.1	57.7
			Min. Standard Size	2.5	6	10	10	16	25	25	35	50	70
		Aluminium/ pvc K = 95	Calculated value	3.14	6.57	9.42	12.5	20.9	29.7	35.3	51.4	58.8	86.9
			Min. Standard Size	16	16	16	16	25	35	50	70	70	95
	(II) Bare conductor where there is no risk of damage to neighbouring material by the temperatures indicated i.e. initial temp. = 30°C final temp. = 200°C	Copper/pvc K = 195	Calculated value	1.88	3.92	5.63	7.5	12.5	17.8	21.1	30.7	35.2	51.9
			Min. Standard Value	4	4	6	10	16	25	25	35	50	70
		Aluminium/ pvc K = 105	Calculated value	2.84	5.94	8.52	11.4	18.9	26.9	31.9	46.5	53.2	78.6
			Min. Standard Size	16	16	16	16	25	35	35	50	70	95

FUSES TO BS 1361

(HRC – DOMESTIC TYPE)

Fuse Rating (Amp)				30	60	80	100
Fault current value such that disconnection time is 5 second (Amp)				120	400	500	857
Maximum earth fault loop impedance (Zs in ohm) for circuits supplying fixed equipment				167	0.50	0.40	0.23
Minimum Cross-sectional area (in mm^2) of protective conductors in compliance with regulation 543-2 assuming actual disconnection time is 5 seconds $S = \frac{\sqrt{I^2 t}}{K}$	(I) Insulated protective conductor not incorporated in cables but with mechanical protection	Copper/ P.V.C. K = 143	Calculated value	1.83	6.25	7.81	13.4
			Min. Standard size	2.5	10	10	16
		Aluminium/ P.V.C. K = 95	Calculated value	2.83	9.42	11.8	20.2
			Min. Standard size	16	16	16	25
	(II) Bare conductor where there is no risk of damage to any neighbouring material by the temp. indicated Initial Temp. 30°C Final Temp. 200°C	Copper/ P.V.C. K = 159	Calculated value	1.69	5.63	7.03	12.1
			Min. Standard size	4	6	10	16
		Aluminium P.V.C. K = 105	Calculated value	2.56	8.52	10.6	16.3
			Min. Standard size	16	16	16	25

Note:– **K value in (I) is for conductors using P.V.C. as insulation material** this zone. If further, parallelled, earth electrodes are provided within the zone of influence of the original electrode, one does not obtain a proportionate decrease in electrode earth resistance. The zone of influence is, of course, hemispherical, although usually only the circle on the earth's surface is of importance. It could be taken as the area within which the earth voltage rise exceeds 10% of that of the earth electrode.

Thus, the value of earth resistivity affects the value of the earth resistance for any particular electrode, the radius of the zone of influence of the electrode, and hence its degree of independence from adjacent electrodes, and the voltage gradient across the earth's surface when current flows through the electrode to earth.

What has been said so far has been applicable to isolated earth electrode systems. Whilst these may occur occasionally in rural installations, more usually, and particularly in cities, there are other considerations to be taken into account, including incoming overhead line earthwires and cable sheaths and service pipes (e.g. gas and water mains) bonded to the earth system.

These can only result in a lower effective earth resistance and in diversification of earth currents, hence to a lower rise in earth potential. Often, however, such effects cannot be quantified, either because of lack of knowledge of the extent of the interconnection of earths, or because such interconnections are beyond the control of the user, and may be varied without notification. Unless such interconnections are completely in one's control, they should be recognised as helpful, but not relied upon.

3. EARTHING PROBLEMS IN CITY SITES

A modern city site, being generally compact, situated in a densely occupied area, and in itself a substantial consumer of energy, to the extent that it requires supply at high voltage, e.g. 11kV has many conflicting problems. Apart from the effects of interconnected earths, the most difficult to assess and to overcome is that of non-connected adjacent earthing systems.

3.1 Adjacent Earths on the Same Site

It is common practice for modern buildings to create supposedly independent earth electrodes, for example, for the power company's incoming supply, for the building power distribution system, for the telephone company and for the building computer. Such electrodes are rarely, if ever, completely independent.

Fig. 1 has a number of vertical lines, representative of additional earth electrodes E1, E2, E3 etc. at varying distances from electrode E. The intercepts between the vertical lines and the curves show a range of values of voltage rise on the various electrodes for different earth resistivities related to the voltage rise on electrode E. This gives a possible range from 10% to 90% for practical building sites.

One common reason for providing a separate earth is for telephone and computer system, to limit the voltage rise or "spikes" to which they may be subject. It is clear that in areas of high resistivity, a separate earth is of little help towards this, and it would be better to provide one good earth and connect everything to it.

In areas of low resistivity, safety of personnel becomes the criterion. For the worst case, 80% of the voltage rise of one electrode may be dropped across the site, i.e. there could be a difference of 80% of the voltage rise between two so-called earthbars in the same building. In the case of the incoming 11kV supply earth, a fault on the incoming cable may well give a voltage rise of 1kV or more, and so voltages close to this could appear between items of equipment which had been "earthed" to make them safe.

For this condition, if the earth electrodes were connected in parallel, practically the full effect of the individual earth resistances would be felt, and so the effective earth resistance of the combined electrodes would be only slightly above 1/N of that of one electrode.

Thus, for both high and low values of earth resistivity, it is advantageous, for different reasons, to create a number of earth electrodes around the site and to connect them all together to form a single earth electrode system. A mesh under the site would be even better but somewhat costly. Such earth electrodes should preferably be clear of the perimeter of the building itself, in order that lightning conductor earths, which are required to be separate from power earths, may be created as near as possible to the building line.

3.2 Earths External to a Site

Considering the high density of many modern cities, an earth electrode on an adjacent site may be closer to an electrode than another one on the same site. There are so many possible arrangements that it is not possible to discuss this problem in general, other than to say that in addition to previous considerations, an earth electrode array should be orientated to keep the maximum separation from adjacent sites. Note should be taken, however, of the increasing trend to provide pedestrian access between buildings above ground level by walkways and bridges. When this is done, there is good reason to interconnect the respective building earth electrode systems.

Underground electric railways give a further problem, as would elevated electric railways if their structures were integral with building structures. Admiralty Station in Hong Kong serves the existing MTR and will also serve the Island Line when completed. The Station outline is shown in fig. 2, which also shows the outlines of several building built, or being built, over it. Every MTR station has two earth electrodes, one towards each end of the station, approximately 200m apart, and interconnected by a substantial earthbar. Additionally, the earth electrodes are connected to one another and along the railway tunnels to adjacent earths by so-called fault current return wires, which interconnect the bases of the insulators from which the overhead power conductors are supported. There is thus an "earth bar" throughout the whole extent of the MTR trackwork system, specifically earthed at every MTR station earth, and incidentally earthed also at the points throughout the system where steel tunnel linings are used.

Although no effort is made deliberately to bond the fault-current return wires and the station earth bars to the reinforcement of the station structures, there is no doubt that there must be casual contact at numerous places. It would be over-optimistic to assume that such contact did not exist. Similarly, where a high-rise building is built over the station, there must be many points of structural contact, and of direct metallic contact of the building reinforcement and the station reinforcement.

In the particular case of the Hang Lung Building site, a siding from the railway extends under the building for the cash trains, and the cash handling will take place in the basement of the building itself.

Bearing in mind also that in Hong Kong, and possibly elsewhere in the Southeast Asian Region, cast-in-situ concrete is not notorious for being a good insulator, it is probable that the 4 hectare surface of the Admiralty station box, wholly under the water table, is the best earth electrode in the area. Neglecting this, however, there is the "MTR earthbar" extending under the whole of the area.

It is believed that the earth resistivity in the area is very low, possibly as low as 10 ohm metres. Even so, it is inconceivable that earth electrodes formed in the fill above the station could have potential rises independent from that of the station itself. In areas of higher earth resistivity, no independence could even be contemplated.

Hence it is suggested that the only reasonable solution in this instance is to interconnect the earth systems of all the buildings in the area. By leaving all the existing earth electrodes in situ, it is estimated that an effective earth resistance of the complex of less than 0.1 ohm would be achieved in this way.

4. THE IMPACT OF THE 15TH EDITION

It is evident that the compilers of the Wiring Regulations recognise the complex nature of earth resistance. In the Definitions, for example, the following appear:–

Earth

The conductive mass of the Earth, whose electrical potential at any point *is conveniently taken as zero.*

Electrically Independent Earth Electrodes

Earth electrodes located at such a distance from one another that the *maximum current likely to flow through one of them does not significantly affect the potential of the other(s).*

Extraneous Conductive Part

A conductive part liable to transmit a potential *including earth potential* and not forming part of the electrical installation.

The scope of the Wiring Regulations includes "electrical installations ....in and about buildings generally" (Reg. 11–1), and is limited to systems having voltages up to 1000 V a.c. (Reg. 11–2 (ii)). They specifically do not refer to "systems for distrubution of energy to the public" (Reg. 11–3 (i)). Generally, there is little difficulty in their interpretation with respect to earthing at least for installations which fall within the scope as defined above, although there may be difficulty in complying with the requirements. However, in the Hong Kong situation we are faced with high-rise multi-user buildings, in which not only does the public distribution sytem enter the building at low voltage, since, even if provided by the owner, the supply system is in effect under the jurisdiction of the supply company up to the metering point for each building tenant, but increasingly the 11kV supply system enters the building, with one or more 11kV/346V transformer on the premises.

It therefore becomes increasingly difficult to interpret the advice given in the 4th paragraph of Appendix 3 that for purposes of determining the system of earthing to use "the source of energy should be regarded as separate from the remainder of the equipment on the premises".

It is suggested that this latter advice (which is not a requirement) envisaged an industrial complex which has a separate compound for an incoming supply substation, or a separate building for a generating station, and that it was not intended to apply when such equipment is within the building.

A further difficulty arises from the requirement, mentioned earlier, of, say, the Telephone Company or of the manufacturer of any sensitive electronic equipment, to require separate earths. The reasons for this are understandable – for safety of both personnel and equipment, it is endeavoured to avoid rises in earth-bar voltage resulting from a fault to the public supply system.

As has been shown earlier in this paper, it is virtually impossible within the confines of a building site to obtain "Electrically Independent Earth Electrodes", as defined above, and as necessary to meet the requirements of the separate-earth advocates. There may be advantage in taking separate "earthing conductors" (see Definitions) directly to the "earth electrode" (See Definitions), since in this way any voltage rises resulting from the flow of fault current in a common conductor is eliminated, but it is not possible to eliminate the voltage rise of the earth electrode itself; an adjacent electrode will experience almost the same rise.

It any case, what is the computer manufacturer seeking to achieve? Surely it would be better to tie his equipment firmly to the rest of the building, and accept that if the building rises in voltage so will the computer. If an external computer earth were brought in, sufficiently remote to be "electrically independent", this would maximise rather than minimise voltage differences between the computer and the remainder of the building. If there are connections to the computer from outside the building, *they* should be isolated to avoid the introduction of remote earth voltages. Since such connections would normally require the use of modems, they can be expected to be isolated in any case.

The Telephone Company are faced with a much more difficult problem. A telephone system is normally earthed at the exchange, and radiates d.c. connections over areas several km in diameter to insulated terminals in buildings. The exchange earth is normally designed to prevent any voltage rise of more than 650V, as required by international regulations. This is becoming more difficult as h.v. supplies, 11kV or higher, are being brought into individual buildings. There are normally no special requirements for earthing of buildings housing telephone terminals, however (unless a building is known to be "dangerous"), and there is every possibility of a high voltage rise, because, say, of an h.v. cable fault, appearing across telephone terminal equipment. It need not be a fault within the same building; it may be a fault in an adjacent building causing fault current to flow in an earth electrode have a large zone of influence.

It would appear that the Telephone Co. should be seeking a city-wide earth network, good enough at least to ensure that the difference in voltage rise across the area connected to one exchange is less than the 650V prescribed by international regulations. In the past this has not been a difficulty, both because such an area would have been fed from one electrical susbtation, hence voltage rise was limited, and because electrical cable sheaths, which were then the norm, would have assisted towards the establishment of that necessary earth network. Now that the power companies are tending away from sheathed cables, this valuable contribution to an earth network is lost.

Similarly, water and gas supplies normally involved buried metallic piping, and it is a requirement that building earthing systems be bonded to them, with beneficial results. However, there is not normally any requirement on the water or gas authorities to ensure that the pipes are electrically continuous, nor, normally, to make public the extent and configuration of their systems.

Thus, although such utility systems will be helpful in improving the effectiveness of earth electrodes that are bonded to them, it cannot be said with any certainty that they will form part of a city-wide earth network.

What is of particular concern in this respect is the requirement of both Hong Kong power companies that the TT system of earthing, for which the installation earth must be separate and electrically independent from the source earth, should be used for all installations in buildings. For installations for which the incoming supply is at 346V, the main objection is the loss of the system wide earth connection, especially if sheathed cables earthed at both ends are not used. Where the incoming supply is at 11kV, however, the situation is more serious. In addition to the loss of the system-wide earth network, we now have a situation where 11kV earth faults within the building will involve significant current through earth, and hence significant voltage rise, whereas if there were a metallic connection between the source earth and the installation earth, both earth current and voltage rise would be significantly reduced.

Furthermore, in a region of very low earth resistivity, where it might be possible to obtain two earth electrodes that were substantially independent within a building site, a dangerous situation could arise. A fault on the 11kV incomer could cause a rise of 1kV or more on the supply earth electrode. If there were transformers at high level up the building, it is possible that there could be two earth conductors in the same rising duct, one connected to the supply earth and one to the installation earth, which could have a voltage difference between them approaching that of the supply earth-electrode voltage rise. Such a situation ought not to be tolerated.

It is doubtful, in fact, whether the TT system of earthing is in accordance with the Wiring Regulations when there are transformers within the same building as the installation. Reg. 413-2 requires "equipotential bonding conductors" to "connect to the main earthing terminal extraneous conducting parts", which include water pipes, gas pipes, building reinforcement, etc. Bearing in mind that according to the definition "main" earthing terminal implies the main part of the earthing system, not that there may also be subsidiary earthing systems, the same requirement would apply to all the earthing systems on a site, if there were more than one, and hence they should be connected together.

If this is not sufficient, Reg. 413–7 requires that "within the zone formed by the main equipotential bonding, local supplementary bonding connections shall be made to metal parts .... where those parts are .... extraneous conductive parts (see Definition) and are simultaneously accessible with exposed conductive parts or other extraneous conductive parts . . .".

Whilst it is not thought that the authors of the Wiring Regulations necessarily envisaged the present situation, at least they had the prescience to allow for it. It might be argued on the lines of Appendix 3 that the transformer is part of the source and so should be regarded as separate from the installation. This paper maintains that, from the considerations given earlier, it must be regarded as part of the installation, and hence its earth (provided by the power company) must be thoroughly bonded to the installation earth (provided by the owner).

With the development of modern techniques, such as elastomer insulated cables which of themselves do not require metallic sheaths, there is an increasing tendency for power companies not to provide the citywide earth network that they have in the past. With increasing use of static electronic equipment, both domestically and commercially, there is need for earth voltage rises to be limited to a greater extent than previously.

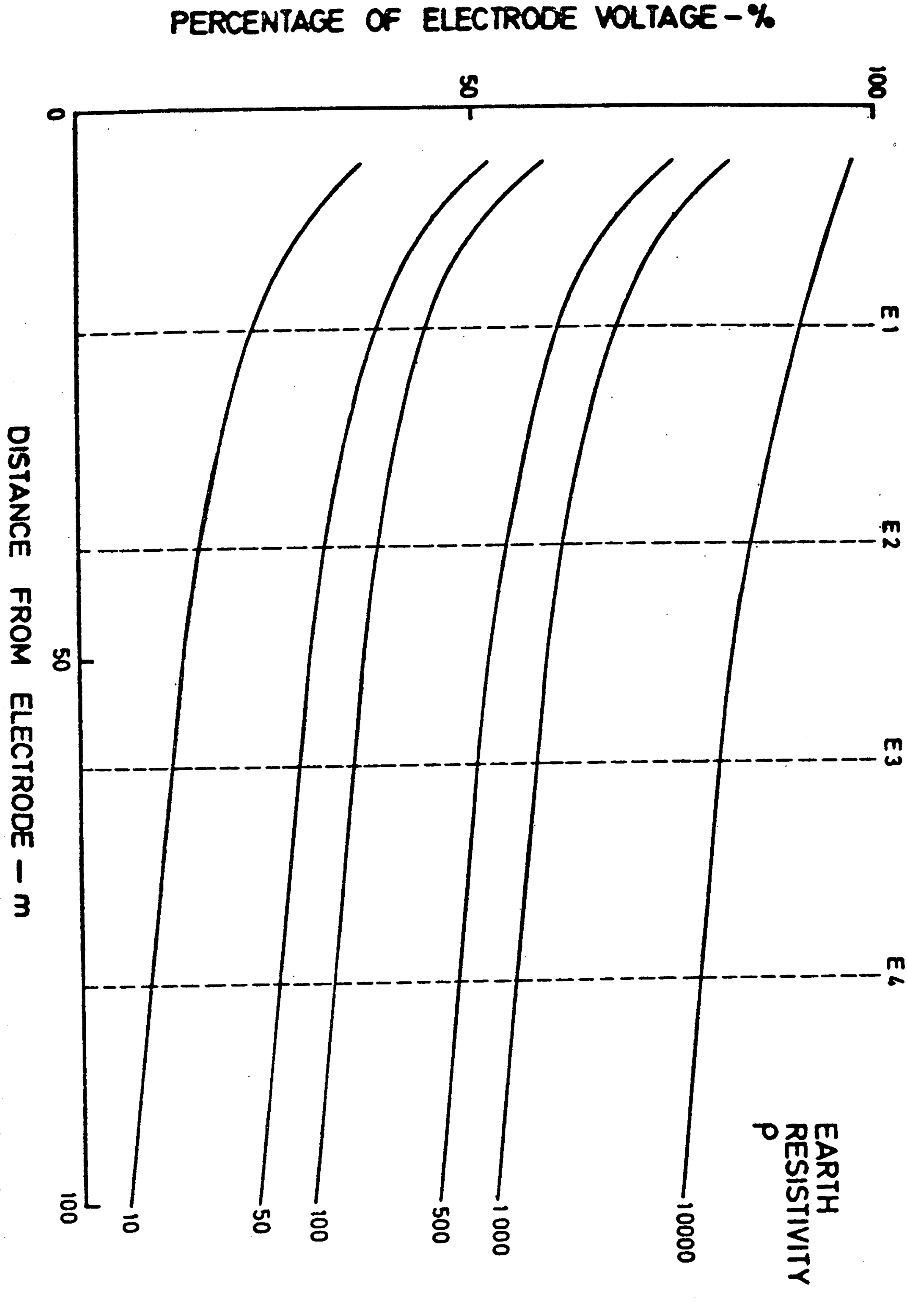
These are diverging trends, and it is necessary to review the situation and to query present practices. There seems to be every reason to augment, rather than to reduce, the citywide earth network, partly by the power company providing low resistance earth connections, where they do not at present exists, along all feeders, and partly by interconnecting all earths, deliberate or fortuitous, which could assist in this process.

5. CONCLUSIONS

(a) Consideration of the relationship between voltage gradient across earth and earth resistivity shows that in areas of very high or low resistivity seperate earth electrodes within the confines of a building site are respectively pointless or potentially dangerous. Hence such electrodes should be bonded together.

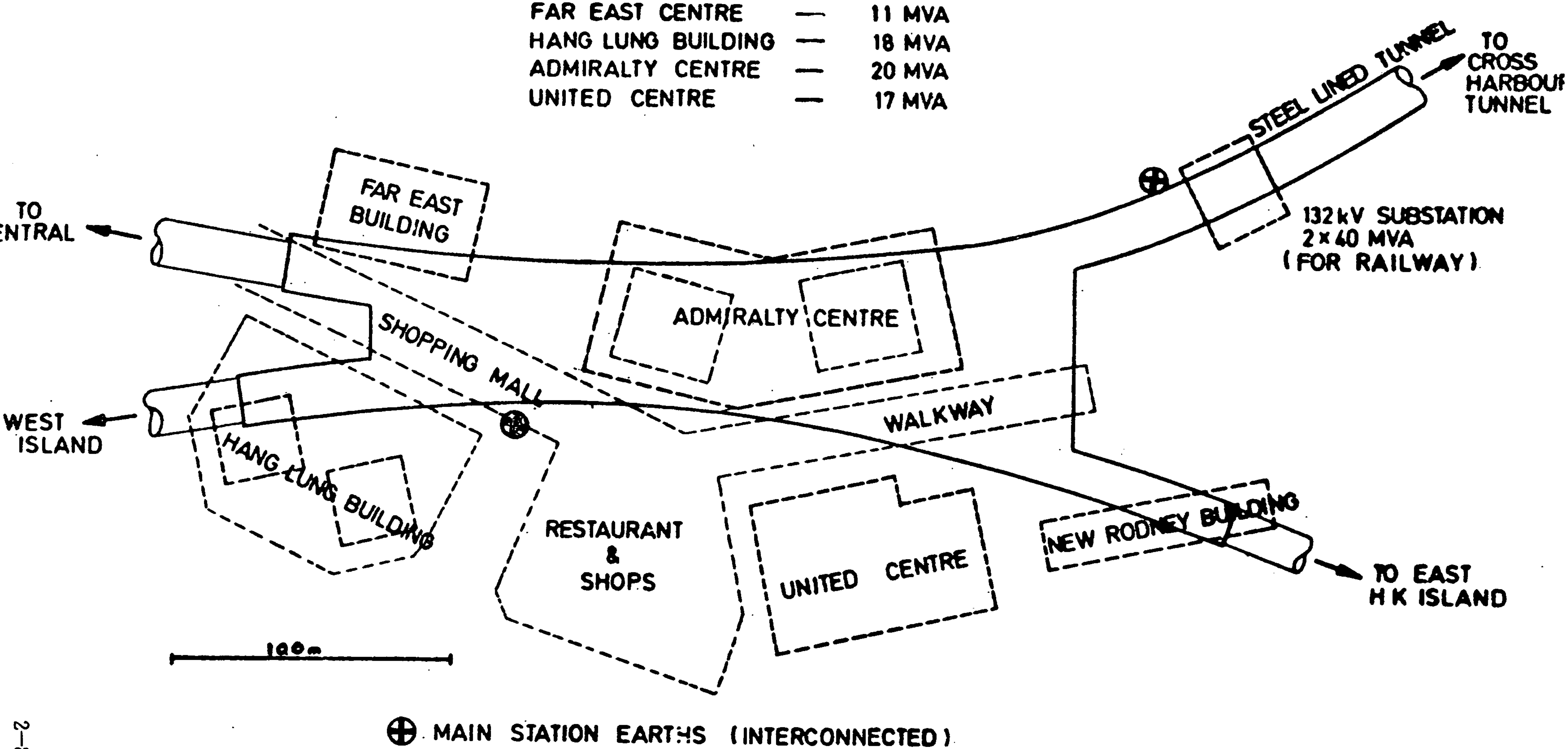
(b) Extension of this consideration shows that power supply authorities should ensure that the best possible citywide earth network is provided for distribution systems in dense city areas, by the interconnection of all available earth electrodes and of the installations of other utilities that provide potential earth electrodes or earthbars.

(c) The impact of the Wiring Regulations on earthing in high-rise buildings is a matter of interpretation, but the view held in this paper is that the "source" is the power company zone substation and that the 11kV/346V transformers within the building form part of the installation—hence all earth electrodes within the building site must be securely bonded together.


PERCENTAGE OF ELECTRODE VOLTAGE - %
0
50
100
DISTANCE FROM ELECTRODE — m
50
100
E1
E2
E3
E4
EARTH RESISTIVITY ρ
10
50
100
500
1000
10000

BUILDING LOADS

STATION	—	8 MVA
WALKWAY / MALL	—	4 MVA
FAR EAST CENTRE	—	11 MVA
HANG LUNG BUILDING	—	18 MVA
ADMIRALTY CENTRE	—	20 MVA
UNITED CENTRE	—	17 MVA



Paper No. 3

Recent and Future Trends in Design of Electrical Accessories

Speaker: Mr. N. Reyrolds

M.K. Electric Ltd. (U.K.)

RECENT AND FUTURE TRENDS IN DESIGN OF ELECTRICAL ACCESSORIES

As the title indicates I will be dealing with the design of wiring accessories, their development and the effect on development of the availability of new materials, new production methods, changing market requirements and the effect of the 15th Edition of the IEE Wiring Regulations. First of all I would like to define the word "accessories" in this context after all it is a word with a thousand meanings, we are not talking about ladies handbag and shoes, nor are we talking about go slower goodies to hang on your latest old banger. We are talking about items of equipment which are used to make connections in an electrical wiring installation including the connection of electricity consuming devices, known as appliances, also items for the functional control of circuits and appliances. We are talking about switches, plugs and sockets, junction boxes ceiling roses etc., – you can see how the term Accessories becomes appropriate.

The first task when considering a new design is to make sure that all the features which are the essential requirements for the new product are fully understood.

Next the requirements of any specification which may be relevant must be studied and taken into account.

In this particular industry, nearly every product is covered by some sort of national or international specification.

Next we consider the production methods available, or which can be made available. Then we consider materials.

A designer must of course have some knowledge of all these fields in order that he can design an acceptable product and consultation between the various departments concerned needs to be frequent to obtain optimum results. Market research is an essential element in determining essential features and where world wide markets are concerned it must be recognised that each market has its own particular requirements even though the specification may be similar.

Regarding specifications more and more countries are introducing their own and these days of course IEC recommendations form the basis for many of them resulting in new terminology – new test methods and more standardisation.

Production methods are always changing, new technology give us new processes, machines which form a number of functions in place of a number of machines, for example, higher speed machines also help to reduce costs. One problem, however, where high volume production is concerned in the high capital cost of making changes, changing the design of a plug could involve scrapping say 96 mould tool impressions of each of the cover and base and replacing them with completely new tooling, a very expensive undertaking which must be very carefully considered.

As for materials, in the 1930's porcelain was the principle insulator, phenolic mouldings were coming into use but it was not until the mid 40's that urea mouldings were introduced into the accessory business.

Urea formaldehyde to use its full name has the advantages over phenol of high tracking index and availability in light colours also the price is very reasonable.

For these reasons urea is still used extensively for accessories. Urea is, of course, a thermoset material which means that it is hard and brittle, consequently mouldings must be thick enough to stand up to rough handling in manufacture and use.

In more recent years the IEC – International Electrotechnical Commission, has standardised acceptance requirements for heat and fire resistance of insulating materials which has enabled material manufactuers to modify their materials to meet these new requirements.

Take nylon for example, straight nylons will burn readily but with the addition of various fillers and modifiers, nylons can be made self extinguishing and suitable grades are now available for most purposes.

Consequently, there is now a much wider choice available to the designer and this gives him more scope in his designs, parts can be clipped in for example instead of using screws or rivets, ultrasonic welding can also be employed.

Metal and metal processing is another area where new techniques give more scope, Silver is necessary for contacts where low contact resistance with low contact pressure is required, new methods of providing a thin layer in exactly the right place enables greater economy to be achieved.

It has been common practice in the past for terminals to be made from extruded brass section but now other forms of manufacture are becoming more common which result in reduced wastage of material and faster production rates.

Now this symposium is on the 15th Edition of the IEE Wiring Regulations and it is time that I came to that subject, with regard to the design of electrical accessories – what effect do they have on the design of accessories – fortunately for us not as much as they might have had but there are some worrying asepcts.

We must remember that 14 editions have gone before starting in 1882 – therefore it is reasonable to assume that the 15th edition does not, on the whole, introduce too many new features.

However, anyone familiar with the 14th edition will realise straight away that the format has changed and most of us are still struggling with that aspect alone.

The object is of course the same – to save lives and injuries, to avoid fires, consequently the fundamental requirements are much the same.

When we come to definitions however there are some changes and a lot of additions, some as a result of IEC influence. An Earth Continuity conductor is now the Circuit Protective Conductor. The Earth Fault Loop Impedance is now defined together with Exposed Conductive Part and Extraneous Conductive Part. Emergency switching, Mechanical Maintenance and Systems are other definitions which have been added and we need to consider. In the U.K. greater attention is being paid to the earth loop impedance circuit with the result that manufacturers are taking steps to improve joints in the earth circuits of accessories, for example accessories with metal front plates now have lower resistance values between the plate and the earth terminal, the plate of course being an Exposed Conductive Part which must be earthed. Go quote an example of an Extraneous Conductive Part let us consider a blank metal plate on an insulated box – either flush or surface, if the box does not contain live conductors the plate need not be earthed, if however it contains live conductors say connected to a terminal block even if the circuit is extra low voltage then it is liable to transmit a potential including earth, therefore it must be earthed.

Isolation and Switching – the requirements for these operations are now clearly defined and the necessary features for Isolation, Mechanical Maintenance and Emergency switching can now be incorporated in the designs of the respective switches for these purposes. For isolation the contacts must have the required break and must be visible or their position indicated by a reliable means, which even if the contacts weld together a false indication cannot be given.

Switching off for Mechanical Maintenance requires that switches are suitably identified and preferably provided with a means of locking-in the off position. For emergency switching, again identification is important, it is preferred that the operating means shall be coloured red and the switch must be situated in a readily accessible position as close as possible to the equipment concerned.

Here again we come up against new terms but not in the wiring regulations but in new and revised specifications. An Isolator in IEC terms is a disconnector and is not capable of breaking a current of more than a small fraction of its current rating. An Isolating Switch in IEC terms is a switch-disconnector and of course must be capable of meeting the requirements for both an isolator and a switch.

Protection against shock is a very important subject and we find that the requirements for a room containing a fixed bath or shower are more specific, for example a lampholder within a distance of 2.5mm from a bath or shower cubicle must be made of or shrouded in insulating material and if of the Bayonet type shall have a protective shield to BS 5042. Reference is also made to the controls of instantaneous water heaters complying with BS3456.

Incidentally, the shaver supply unit specification BS 3052 will shortly be withdrawn and the requirements included in a revised edition of BS 3535 – Safety Isolating Transformers. This revised edition will be in line with IEC 742 which was recently published. As far as shaver supply units are concerned the principle differences are the acceptance of positive temperature coefficient thermistors for overload and short circuit protection, and a change in the tolerances on the output voltage which are now bi-lateral instead of unilateral.

Boxes – where the 14th edition implied that all boxes were required to withstand the non-combustible test of BS 476 the 15th Edition makes it clear that compliance with the relevant British Standard is required.

Protective conductors are given much more attention, the type of insulation is taken into account whether it be on the conductor itself or in contact with it.

The conductor size is based on the maximum acceptable temperature which the insulation can withstand without undue loss of its properties.

The requirement is satisfied if the conductor is equal to the phase conductor up to $16mm^2$ or of half section for sizes above with a minium of $16mm^2$ – however, calculated sizes may be smaller and there may be some advantage in making the calculation. The de-rating of cables when installed in contact with or entirely within thermal insulating material is now required and ratings of 75% and 50% apply. This can cause problems with some accessories and care should be taken to ensure that the accessory is capable of accepting the conductors.

For example, 13 ampere sockets would not be suitable for the two conductors of a ring circuit plus a spur conductor if they were of $6mm^2$ cable. If you are misguided enough to use rewireable fuses to BS 3036 then you might be faced with using $10mm^2$ cables. The principles of protection depending upon a zone created by equipotential bonding are rendered ineffective if portable appliance such as a lawnmower is used outside the zone. In this case the socket supplying the offending appliance should be protected by means of a Residual Current Circuit Breaker – another name for an ELCB. Sockets incorporating RCBs are now available for this purpose.

Functional switching is now clearly defined, Plugs and Sockets up to 16A can be used for this purpose and even higher current ratings may be used for a.c. where the breaking capacity has been proved.

The use of semiconductors has been controversial but draft amendments to the 15th edition now include provision for functional switching – obviously not for Isolation, Mechanical Maintenance or Emergency switching.

To sum up – whilst there are several changes in requirements for the use of accessories, in general it has not been necessary to make any changes to the accessories themselves, this is a very fortunate situation for us as manufacturers and I believe reflects the attention to detail which manufacturers have made in the past to ensure that their products are safe.

EXAMPLE – CALCULATION OF PROTECTIVE CONDUCTOR SIZE

Example to show how to calculate the minimum cross-sectional area (in sq.mm.) of protective conductor for a fixed equipment which is protected by 53 Amp. Fuse to B.S. 88.

Procedure

(i) For fixed equipment, in compliances with 15th Edition I.E.E. Regulations 413 – 4 (ii), the maximum disconnection time is 5 second.

(ii) Maximum earth fault loop impedance of 63 Amp. fuse rating to B.S. 88 from table is 0.72 ohm.

(iii) Fault current value of 63 Amp. fuse rating to B.S. 88

$$\text{is} = \frac{200}{0.72} = 277 \text{ Amp.}$$

(iv) K value for copper conductor using p.v.c. as insulation material is 143.

(v) Using the formula given in Regulation 543–2.

$$S = \frac{\sqrt{I^2 \times t}}{K}$$

$$= \frac{(277)^2 \times 5}{143}$$

$$= 4.33 \text{ mm}^2$$

(vi) The minimum cross sectional area of protective conductor to the nearest standard conductor size i.e. 6mm^2 copper.

Paper No. 4

Implications in the implementation of the 15th Edition of IEE Wiring Regulations

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Mr. K.C. Wong

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IMPLICATIONS IN THE IMPLEMENTATION OF THE 15TH EDITION OF THE IEE WIRING REGULATIONS

1. Introduction
2. Electrical Contracting Practice in Hong Kong
3. Electrical Contractors
4. IEE Wiring Regulations
5. Introducing the 15th Edition of the IEE Wiring Regulations to Hong Kong
6. Implementation Cost to the Contractors
7. Proposals/Suggestions
8. Conclusions

IMPLICATIONS IN THE IMPLEMENTATION OF THE 15TH EDITION OF THE IEE WIRING REGULATIONS FOR ELECTRICAL INSTALLATIONS

1 Introduction

The IEE Wiring Regulations for the Electrical Equipment of Buildings have been used by us, local Electrical Contractors, for years as a general guide in the electrical contracting business. Since the 14th Edition of these regulations was published in 1966, the subsequent revision from time to time has caused some inconvenience. However, due to the fact that there were no drastic changes in either the content or the format of such revisions, the effects of which were not of major consequence. Thus when information that a new edition of the Regulations was being compiled, we did not pay much attention to it. Even if we wanted to obtain more information, draft copies could not be obtained because participants undertaking the revision work were not allowed to disclose details. Besides, unlike our counter-parts on the U.K., we have no representives in the Wiring Regulations Committee. When the 15th Edition was published and made available in Hong Kong, it came as a shock to us, Electrical Contractors, in that the basic format has been changed. The concepts are different; and there are major changes to the original rules.

On 13th Jan., 1982 both China Light & Power Co., Ltd. and Hong Kong Electric Co. Ltd. announced that the 15th Edition would be adopted as part of their Supply Rules and were to become effective by 1st Jan., 1983. Having discussed with the parties concerned, the implementation date has since been deferred.

2 Electrical Contracting Practice in Hong Kong

In principle, electrical contracting practice in Hong Kong fall into two main catagories as follows:-

(a) An installation is designed by Consulting Engineer and/or Architect who is appointed by the owner of the building and the work is to be carried out by the successful Electrical Contractor.

Our study reveals that the specification from the Consulting Engineer and/or Architect as regard complying with the requirements of the IEE Wiring Regulations were in most cases not specifically described. What we see in the specification is that "all work should be carried out in strict accordance with the specification, IEE Wiring Regulations and the requirements of the local Supply Authority. It is the responsibility of the Contractor/Sub-contractor to ensure that the work is carried out according to the set requirements". Since this type of specification has been used for years and the Electrical Contractors are fully aware of what the Designers want, disputes between parties concerned rarely occurred on this particular section of work. Hence, this kind of specification is acceptable in the trade.

(b) In the case of a package deal installation is designed, installed and commissioned by the Contractor. Majority of the small projects are handled in this manner by the Electrical Contractors who are appointed directly by the owner. Such a system normally works because most Electrical Contractors have a thorough knowledge of the client's requirements, thus offering good services.

In order to submit a competitive bid, the Electrical Contractors need to submit a preliminary design with a brief specification of the work upon which the tender is based. In most cases, they will put less description about the standard of work. A normal clause such as "All the work would be carried out in accordance with Supply Rules and IEE Wiring Regulations" is used.

3. Electrical Contractors

As you are aware, 95% of the population in Hong Kong are Chinese. It is also a fact that over 95% of the Electrical Contractors in Hong Kong belong to Chinese type of organization and run by Chinese managers and engineers who take up the trade and acquire the knowledge by accumulation of working experience. Many of the latter have little or no academic and formal practical training in Electrical Engineering. They are thus handicapped in studying and understanding Regulations especially in a foreign language.

Only few Electrical Contractors (about 15%) belong to large setups and have resources to employ qualified managers and engineers whilst the majority are relatively small in size and lack resources. These small organizations either have their business confined to installations for the Chinese community or act as sub-contractors to the major organizations. Thus communications with clients are basically in Chinese. They have always encountered difficulties in understanding Regulations which are written in English. In most cases, the Consulting Engineers and the Engineers in major organizations would have to, in addition to the business relationship with them, take up the work of advising and training on the requirements of the 15th Edition IEE Wiring Regulations.

Having gone through briefly the background and setup of Electrical Contractors in Hong Kong I am sure you will appreciate the difficulties that we face at the present moment if the 15th Edition of the IEE Wiring Regulations were to be introduced at such a short notice. From our contacts with the Electrical Contractors Association in the U.K. we understand that even they in the U.K., with English as their mother tongue, have decided not to replace the 14th Edition by the 15th Edition as originally intended for introduction on 1st Jan., 1983. We in Hong Kong obviously will require a longer period for the change-over.

4. IEE Wiring Regulations

We do not intend to go into details on all the major differences between the 14th Edition and the 15th Edition as most of you present, would have already made the comparison yourselves, some of these would have been covered by other speakers today. However, we would like to concentrate on a few points which have either contractual cost implications and/or difficulties in implementation to us as Electrical Contractors.

(a) Protection against Electric Shock

a.1 The 15th Edition Reg. 433–3 allows a common protective device to protect cables in paralled. The 14th Edition Reg. B22 does not specify this point and this sometimes leads to confusion since some schools of thought advocate separate protection for each of the parallel cables.

a.2 Protection by a residual current device is now required for all socket outlets on a type TT earthing system which has been adopted by both Supply Companies, i.e. when local earth electrodes are provided independent of the earth at the supply point (Reg. 471–13). One such device can protect a number of socket outlets, or individual protection can be provided for each socket. The regulation does not mention the protection of circuits other than socket outlets under the above conditions.

a.3 It is now permissible under regulation 473–2 for the overload protection to be located along the run of the conductors being protected, provided that there are no branch connections from the beginning of the run and the protective device. There is now no limitation on the length of the run before the protective device.

(b) Selection of Equipment

Guidance on the selection of the type of cable is given in Chapter 52 and Appendix 10.

b.1 The Appendix requires mineral insulated cables buried in the ground to have an overall p.v.c. sheath. This is not mentioned in Chapter 52 and is also not specifically stated in the 14th Edition.

b2 Cables with mechanical protection such as armour or metal sheath or both, the use of suitable marking tape is permitted as an alternative to cable covers. (Reg. 523–23)

b3 A residual current device should be capable of withstanding without damage, the thermal and mechanical stresses to which it is likely to be subjected to in case of a short circuit occurring on the load side of the point at which it is installed. (Reg. 531–8)

b4 The calculation of the size of protective conductors (Reg. 543) is much more complicated than that in the 14th Edition.

b5 The classification of premises for diversity has been altered but excludes recommendations for large premises. These values should be assessed by a qualified person.

(c) Testing and Inspection

The tests outlined in Appendix 15 for verifying ring circuit continuity are much more elaborate than those in the 14th Edition (Reg. E10) which merely state that a test should be made to verify the continuity of ring circuits. Two methods are outlined in the 15th Edition and both involve resistance measurements, i.e. round the ring from the distribution board and from the distribution board to the mid-point of the ring. The term "Mid-point" is not well defined but it probably means that the mid-point is based on the route length.

(d) Extraneous Bonding

The problem of bonding to extraneous conductive parts prompts questions on how to bond to a cooling water piping system. The suggestion that the bond should be made to the pump base has been rejected on the grounds that the piping system may have been sealed by rubber anti-vibration pad and/or rubber flexible joints. However, it has been accepted that one could bond to both inlet and outlet pipes of the pump-set in addition to the pump base, thereby ensuring that the cooling water piping system would be totally bonded. In practice, it is just not possible at the tendering stage to tell where it should be bonded.

It is even more difficult to carry out bonding where provisions are not available for such connections on the fixtures such as bath tubs, towel rails, drain traps, wash basins or even window frames etc. It would also create rather unsightly networks of cables which Architects would undoubtedly object. There is also the question of maintaining the bonding in an effective manner after the installation has been handed over. Other tradesmen and the general public will have to be educated on the importance of maintaining such bonding in a good condition.

(e) Correction Factor

Reference is next made to "conductor sizing of cables for more that two bunched together." If the two sides of two ring circuits are run in the same conduit, this means eight cables for the two ring circuits will be in service without applying a correction factor. Such a situation needs to be clarified.

General

The 15th Edition in some respects is more specific than the 14th Edition and much is left to the discretion of the Design Engineer.

The effect on this may be that more detailed specification will be necessary from the Consulting Engineer and/or the owner. Otherwise, conflicts can arise between Electrical Contractor and Consulting Engineer/Architect or the owner as well as the inspection staff from Supply Companies regarding the interpretation of the Wiring Regulations.

5. Introducing the 15th Edition of the IEE Wiring Regulations to Hong Kong

When the 15th Edition was published in the U.K., mail orders from Hong Kong for over 300 copies were placed through either the local book shops or the engineering organisations. Most likely additional copies were made for distribution to the electrical trade and students.

Seminars on the 15th Edition were organised by interest commercial concerns, engineering professions and the Hong Kong Electrical Contractor's Association. 15 classes were also held by the educational institutions on this topic. In all about 1,100 students (both full-time and part-time) participated.

By comparison with the statistics published by the Vocational Training Council, it is apparent that less than 5% of the electrical personnel have been made aware of the requirements of the 15th Edition. In other words, the specific training during 1981/82 was far below the actual requirement.

Apart from engineering institutes, training by the Hong Kong Electrical ContractorsAssociation has been planned. 10 sessions of 60 members will participate in discussion of the 15th Edition during 1983 - 1984, about 3,000 persons would be knowledgeable on the 15th Edition. (i.e. about 15% of the manpower in the trade).

Based on the foregoing, we feel that both the Electrical Contractors and the educational institutes are conscientious to provide training to the electrical industries. It is hoped that the resistance from the electrical trade and inconvenience will be minimised to a certain extent when people in the trade familiar with the 15th Edition begin to practise it.

It is also true that the Supply Authority would also have a high degree of interest in introducing the 15th Edition to Hong Kong. They had announced on 13th Jan., 1982 that the 15th Edition would become effective as from 1st Jan., 1983. By this announcement, the IEE 15th Edition became a part of the Supply Rules in Hong Kong.

After this announcement, numerous discussions were held among the electrical contractors and comments on the following have been sent to the Supply Authorities for their considerations:

a. Practical implementation date.

b. Some of the regulations may require modification and clarification prior to being made applicable to Hong Kong.

c. The problem of short supply of electrical materials and equipment to meet the requirements of the 15th Edition.

On 30th Nov., 1982 we learned that the new edition would come into force on 1st Jan., 1985.

It is unfortunate that up to now, there has been no formal discussion held on this subject amongst all interested parties.

6. Implementation Cost to Contractors

Before 1982, most of the building projects took 24–36 months to complete. This construction time has now been prolonged due to the present economic recession. During the period of 1980–1982, an amount of some HK$1,735.5 million for electrical projects (excluding MTRC projects) were awarded. It is estimated that about HK$600 million of the electrical installation work would not be completed before 1984. We have reason to believe that most of these projects were design in accordance with the 14th Edition. Thus, the successful contractors will, no doubt, face the difficulty in meeting Supply Company's requirements, the Contractor will have their work requirement changed but with additional costs. In the worst case it could lead to liquidated damage claims from the owner due to extended time required to modify the installation to suit the 15th Edition.

In order to acquire the knowledge of the 15th Edition, Contractors have to send their staff to attend seminars both full-time and part-time. This would cost the Contractor an extra amount of expenditure in manhours and training fees.

It is common practice for the Contractor to meet the market competition. Most of them have to purchase materials in advance based on yearly consumption and/or in bulk purchase in order to lower their operating project cost. Due to the introduction of the 15th Edition, a lot of purchased materials/items may have to be scrapped or modified. Thus, it would require the Contractor to bear an extra cost which cannot be compensated in any way.

The Contractor may have contracts with overseas manufacturers for equipment designed for use in accordance with the 14th Edition. For certain reasons, these manufacturers/suppliers may have difficulties in modifying their products to suit the requirement. In order to meet the 15th Edition, Contractors may have to purchase materials from other organizations at higher cost.

The Contractors, who have factories to manufacture metal items for the installations based on the 14th Edition such as MCB distribution boards etc, have to give up the existing manufacturing moulds and invest additional cost for the new design together with the manufacturing tools to meet the newly introduced 15th Edition. Similarly, lots of premanufactured items and manufacturing processes have to be modified to suit at the Contractor's cost.

Extra cost in terms of time has to be allowed for testing and inspection of the installation in order to ensure that the installation satisfies the Supply Company's test to the 15th Edition requirements.

Additional costs will be incurred to convince other personnel on the same project to provide more information on interface work as well as in work co-ordination required by the 15th Edition such as the bonding of extraneous conductive parts.

7 Suggestions/Proposals

Since the 14th Edition has been used for over 17 years and it has proven to be a guide for safe electrical installation, we feel that technical personnel in Hong Kong as well as in the U.K. are not as yet ready for the changes required. It would be advisable not to jump into these drastic changes until we have more time to suudy the full implications of the changes. In deferring the application of the new regulations, it would no doubt reduce the Contractors' operation cost, minimise the resistance from the trade to accept the regulation and made the changeover smooth.

Based on this concept, we would propose to set up an Advisory Committee with representatives from the related trade associations, Supply Authorities, Government bodies, academic institutions etc This Advisory Committee will study the implications in the implementation of the Regulation and put forward a constructive recommendation to the Supply Authorities and Hong Kong Electrical Contractor's Association for implementation. This Advisory Committee will continue to monitor the implementation of the new regulation after it comes into effect.

Since Hong Kong Institution of Engineers is a government recognised independent body with professionals from all engineering fields, it is our opinion that Hong Kong Institution of Engineers is the most suitable organization to convene such a Consultative/Advisory Committee.

Meantime, it is also suggested that to have the following organized by various related bodies:-

a. Conduct seminars should be provided with greater emphasis on the actual method of implementation of the regulations and practical guidance to practising Electrical Contractors.

b. Conduct seminars for professionals outside electrical industry but related to the building construction industry in order to brief them on the overall scope of the Regulations.

c. Conduct more short courses on the Regulations for different levels of engineering personnel in the electrical industry by the academic institutions.

8. **Conclusions**

It is to the advantage of all parties concerned to have a clear understanding of the Regulations before it is put into practice. This will only be possible through mutual discussion and agreement.

Paper No. 5

The IEE 15th Edition Requirements for Miniature Circuit Breakers

Speaker: Mr. A. Horton,

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THE IEE 15TH EDITION REQUIREMENTS FOR MINIATURE CIRCUIT BREAKERS

The object of this paper is to highlight the requirements of the IEE 15th Edition which relate to the performance and application of Miniature Circuit Breakers in electrical circuits.

It is now two years since the 15th Edition of the IEE Wiring Regulations was first published and Manufactures of M.C.B's have frequently been asked for information of their products. Questions have centred on three main Chapters:–

Chater 41 – Protection Against Electric Shock

Chater 43 Protection Against Overcurrents

Chapter 53 - Switchgear

CHAPTER 41 Protection Against Electric Shock contains three sections:–

1 **Protection against both direct and indirect contact** and this is achieved by the use of extra low voltage, having a maximum of 25v RMS A.C. or 60v ripple free D.C.

2 **Protection against direct contact** and this is achieved by suitable shielding, insulating and by the use of obstacles or by placing out of reach, which are mechanical means of preventing direct contact with parts which are normally live in service. It should be noted that the use of an R.C.D. is not a preferred method of achieving protection against direct contact, although using an R.C.D. in conjunction with these other mechanical means could help reduce this hazard.

3 **Protection against indirect contact** contains five methods to achieve protection against contact with parts which are not nromally live in service but which could become live in the event of a fault. The most important and most widely used of the five methods is by earthed equi-potential bonding and automatic disconnection of the supply, which entails the use of a protective device. The other four measures involves either double insulation, earth free supply or extra low voltages which are specialised methods and not normally for general use.

MINIATURE CIRCUIT BREAKERS

Miniature Circuit Breakers have been used for many years to isolate the supply in the event of a fault, and in conjunction with equi-potential bonding, have proved to be a very effective method of reducing indirect shock hazards. It is recognised that every endeavour should be made to isolate the supply at the lowest possible fault current in the fastest possible time. The basic Regulation requires that during an earth fault the voltage between simultaneously accessible exposed conductive parts anywhere in the installation, shall be of such magnitude and duration as not to cause danger.

To offer the installation designer a protective device to suit each and every application or prospective fault condition would be an impossibility, but effective from January 1st of this year, BS3871: Part 1, the British Specification for Miniature Circuit Breakers has been amended to include four types, according to their instantaneous stripping currents, the values are as per Fig. 1. By instantaneous, we mean to trip in less than 0.1 sec. This is significantly lower than the requirement of Clause 413.4 which is considered to be met if disconnection occurs within 0.4 secs for final circuits supplying socket outlets and 5 seconds for final circuits supplying fixed equipment, when used in conjunction with the Earth Loop Impedance Tables – 41A1 and 41A2 of the 15th Edition.

It can be seen that by using Miniature Circuit Breakers, the need to differentiate for different types of circuits is eliminated and only the Earth Loop figures in Table 41A1 need be used.

Fig.1

Types of circuit breaker according to Instantaneous Tripping Current

Type	Instantaneous Tripping Current
1	$>2.7\, I_n \leqslant 4.0\, I_n$
2	$>4.0\, I_n \leqslant 7.0\, I_n$
3	$>7.0\, I_n \leqslant 10\, I_n$
4	$>10\, I_n \leqslant 50\, I_n$

The requirements of Section 543 which deals with protection against thermal effects for protective conductors are automatically met when Miniature Circuit Breakers are used and the Earth Loop Impedance Tables are observed. Fig.2 shows typical I^2t values for various protective devices.

Fig. 2

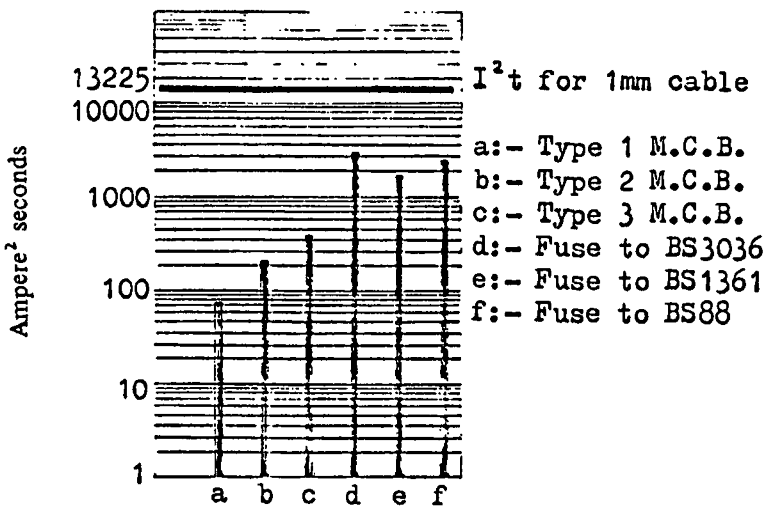

Fig. 2 Typical I^2t let-through values for various protective devices at maximum earth-loop impedances.

By offering four different types of instantaneous tripping within any current rating, the problems of nuisance tripping due to surges in the system can be reduced and because Miniature Circuit Breakers are generally of a modular design a change of type can be effected if surge problems occur, so long as the Earth Loop Impendance figures in Table 41A1 are not exceeded. Typical application details for the four types are shown in Fig. 3.

Fig. 3

TYPE	DETAILS OF CIRCUIT
1	No switching or inrush currents, Generally resistive load.
2	Small inrush or switching surges. Small motors, heating loads tungsten lighting.
3	Large switching surges for short duration Discharge lamps, off load motor starting.
4	Longer duration surges; on load motor starting, welding and Xray unit.

RESIDUAL CURRENT DEVICES

Where the earth fault current is lower than the minimum tripping current of a Miniature Circuit Breaker, then a Residual Current Device must be used. They must also be used to protect any socket outlet that is to feed an appliance positioned outise the equi-potential zone, also they are the preferred method or protection against indirect contact on a T.T. System, although Miniature Circuit Breakers could be used. Residual Current Devices must be used on domestic type oscket outlet circuits in this system.. These should have a sensitivity of 30mA or better and again, must disconnect the circuit within 0.1 sec.

There are various types of Residual Current Devices from which a Designer can choose depending on the application: -

a) A miniature Circuit Breaker complete with Overload and Short Circuit Protection with an additional electronic sensing device which trips the breaker in the event of an earth fault.

b) A switch containing a core balanced transformer whose output under an earth fault activates a permanent magnet tripping device.

c) Sensing and tripping devices contained in domestic plug tops or in socket outlets.

d) A sensing device used in conjunction with a separate switch or protective device which contains an Undervoltage Release unit as the means of tripping the main device.

CONDITIONAL TESTING

CHAPTER 43 Protection Against Overcurrent and in particular Regulation 434–4 under a Section headed "Characteristics of Short Circuit Protective Device" states, "A protective device having a lower breaking capacity than the prospective short ciucuit current can be used, if another protective device having the necessary breaking capacity is installed on the supply side".

At the present time there are no tests included into British Specifications to determine the performance of Miniature Circuit Breakers when used in series with a Protective device capable of significantly limiting the energy let through during a short circuit, such as HRC Fuses to BS88 or BS1361 and certain circuit breakers to BS4752: Part 1. Such a test could be as Fig. 4.

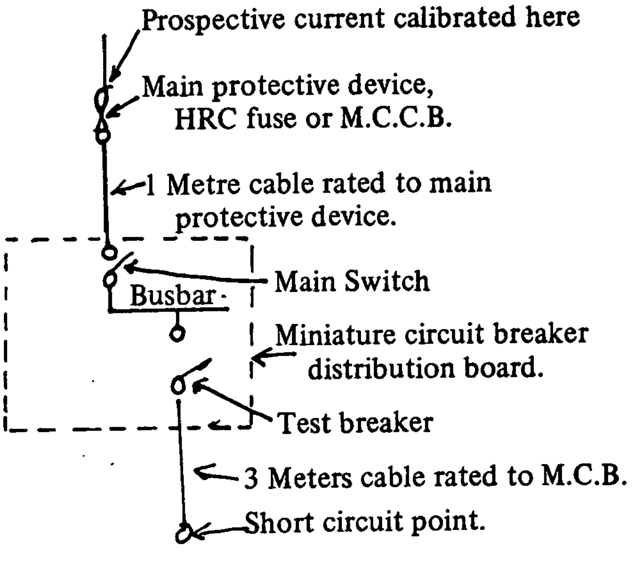

Fig. 4 Conditional Short Circuit Test Diagram

The prospective current should be calibrated at the supply terminals of the main protective device and should be equal to its maximum Interrupting Capacity. In the case of Fuses to BS88 this would be 50KA or 80KA and for circuit breakers that value stated by the Manufacturer.

A test sequence similar to that stated in BS3871: Part 1 should be performed on samples of the lowest and highest current rating. At the conclusion of this sequence a 500 volt megger test followed by a 200% trip test should be carried out. This test has now not only tested the Miniature Circuit Breakers, but also ensures that the main incoming cables, the main switch and busbar system within

the Miniature Circuit Breaker Distribution Board and the outgoing cables can withstand the let through energy. This is particularly important for cables of less than 10mm² which are excluded from Clause 434–6, which states, "It shall be verified that the short circuit current shall not raise the temperature of the conductors above the permissable limit and that they shall not be mechanically damaged". This test, both for voltages up to 240 volts, Single Phase and voltages up to 415 volts, Three Phase, could readily be incorporated into Part 12 of BS5486 – Factory Built Enclosures and if desired as an Appendix to Part 1 of the same Specification. Where Miniature Circuit Breakers are used within custom built Switchboards and are successfully tested, they can give considerable cost savings in sizes of connections from main busbars down to Pan assemblies, particularly if the size of the back-up protective device can be used so that it can feed two or more of these assemblies.

From tests we have carried out at 50KA on our Miniature Breakers using this particular circuit and using 160 amp BS88 HRC Fuses as the main back-up device, maximum I^2t let through energy was 25,400 ampere² seconds for a 5 amp breaker with a maximum peak cut off current of 3.5KA and for 60 amp 81,600 ampere² seconds and a maximum peak of 10 KA compared with a 200,000 ampere² seconds total let through with a peak of 18 KA, published by the Fuse Manufacturer, when tested to BS88. The reasons for this reduction are three fold:–

1) The calculated impedances of the devices and the associated cables reduce the actual short circuit from the prospective value of 50 KA down to 29 KA for a 60 amp breaker and 4 KA for a 5 amp breaker.

2) A further reduction is achieved because of the rise in temperature of all the components; this can vary according to the size and radiation effects, but we would expect a fuse to increase from 0.0005 ohms at 20°C to about 0.0021 ohms just prior to melting and a Miniature Circuit Breaker, 5 amp from 0.045 ohms to 0.068 ohms and a 60 amp from 0.0015 ohms to 0.0025 just before the instant of contacts parting.

Fig. 5 Figure 5 shows the influence of these values on the actual fault current.

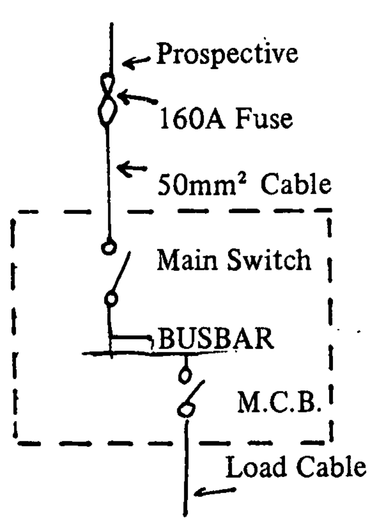

Fig. 5
Typical
Impedance Figures

VALUES OF IMPEDANCE 'Z'

EQUIPMENT	20°C		HOT	
	5A MCB	60A MCB	5A MCB	60A MCB
50KA – 415V PROSPECTIVE	0.0083	0.0083	0.0083	0.0083
160A HRC FUSE	0.0005	0.0005	0.0021	0.0021
1 METRE 50mm² CABLE	0.0005	0.0005	0.0006	0.0006
MAIN SWITCH AND BUSBAR	0.0007	0.0007	0.0008	0.0008
MINIATURE CIRCUIT BREAKER	0.045	0.0015	0.068	0.0025
3 METRES LOAD CABLE	0.06	0.0035	0.08	0.005
TOTAL 'Z'	0.115	0.015	0.160	0.0193
POWER FACTOR	0.87	0.27	0.91	0.28
FAULT CURRENT	3609	27666	2600	21500

3) When two devices in series operate almost simultaneously, then the arc voltage is shared according to their resistances and this would result in a reduction in the total operating time and a corresponding reduction in total let through energy.

From these tests it can be seen that the smaller ratings of Miniature Circuit Breakers can fully discriminate against the Fuse.

If such tests are carried out successfully by the M.C.B. Manufacturer, the Designer of an installation considering the use of Miniature Circuit Breakers need calculate the downstream prospective fault current only as far as the back-up device, which in most cases will not exceed 50KA.

In the event of a large short circuit occurring which causes the back-up Fuse to blow, care should be taken that a larger current rating of fuse cartridge is not substituted, e.g. a 250 amp cartridge should not be fitted in place of 160 amp combination Fuse Switch, which physically prevents a larger cartridge being fitted.

CHATER 53 Switchgear

Section 537 of this Chapter recognises four types of switching:-

1 Switching for Isolation

2. Switching off for Mechanical Maintenance

3. Emergency Switching

4. Functional Switching

Miniature Circuit Breakers have been used for all four of these functions very successfully for many years.

For Isolation the Regulations require a certain contact distance in the open position and in the absence of specific requirements in BS5419, which is the British Specification for Switches, etc., we can use PD6499: 1981 and IEC664: 1980 "Guide to Insulation Co-ordination within low voltage systems including clearances and creepage distance for Equipment" which states "For Phase to earth voltages between 150v and 300v in installation Categories III or IV, the minimum clearance in air up to 2,000 metres above sea level at pollution degree 4 would be between 3mm and 5.5mm". Most designs of Miniature Circuit Breakers would incorporate this. Also for isolation the requirements are that the position of the contacts shall be reliably indicated. BS5419 states "The handle may form such an indicator, providing it can only indicate the 'OFF' position when the contacts are in the open position". Again Miniature Circuit Breakers which contain a positive mechanical connection between the handle and moving contact carrier and have a latch mechanism which is directly connected to this carrier, can conform to this requirement.

Switching off for Mechanical Maintenance requires the same conditions as for Switching for Isolation and, in addition, the device should be capable of cutting off the full load current. M.C.B's can certainly perform this duty, which can be confirmed by the Electrical Endurance Test of 6,000 'ON/OFF' operations at rated current contained in the Type Tests of BS3871: Part 1.

For Emergency Switching the same requirements as for Mechanical Maintenance would apply but if the circuit contains motors, then due account should be taken of stalled motor conditions, again Overload performance Type Testing in BS3871: Part 1 would ensure the Miniature Circuit Breaker was capable of this function.

Functional Switching which is the day-to-day switching duty, needs careful consideration, particularly where heavy switching surges occur, such as in discharge lamps. Miniature Circuit Breakers are primarily protective devices and the day-to-day switching should be carried out by devices designed specifically for that purpose.

CONCLUSION

In conclusion it can be seen that Miniature Circuit Breakers can, by careful selection of type, give more than adequate protection against Indirect Contact shock hazards. When used in conjunction with main current limiting devices, such as HRC Fuses or certain Air Circuit Breakers, they can be applied successfully on High Prospective short circuit installations. They can fulfil the requirements of Isolation, Switching off for Mechanical Maintenance, Emergency Switching and certain Functional Switching duties.

In addition, they provide a simple means of reconnection after a fault has been cleared and the reason for it corrected. They are usually available in a wide range of current ratings and in many designs are a tamper proof device so that for example a householder cannot inadvertantly invalidate the circuit protection as he could by fitting the wrong size of fuse wire or cartridge.

Paper No. 6

British Standard L.V. Switchgear and The Implication of the 15th IEE Wiring Regulations

Speaker: Mr. R.A. Upton.

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BRITISH STANDARD LOW VOLTAGE DISTRIBUTION SWITCHGEAR AND THE IMPLICATIONS OF THE 15TH WIRING REGULATIONS.

Introduction.

Low voltage distribution switchgear is defined by the British Standards BS 5419-1977 and BS 4752 Part 1 1977, covering switchgear and circuit breakers respectively, and is intended for use in circuits rated up to 1000V AC and 1200V DC. These two British Standards are identical with their respective IEC counterparts IEC 408 and IEC 157/1. Hence the British product standards in this field are harmonised with International recommendations, making the products themselves acceptable in practice in many parts of the world.

Low Voltage Switchgear systems have developed on two basic lines in different parts of the world, using either a combination of circuit breakers and fusegear or alternatively the circuit-breaker-only system employing moulded case and miniature circuit breakers. Nowadays in the UK the systems are overlapping with the techniques for both well developed but at present with fuse-switchgear still predominant. The practice of combining fuse-switchgear for distribution with miniature circuit-breakers for final circuit protection is rapidly finding acceptance.

Fuse-Switchgear and Circuit-Breakers.

The application requirements for both fuse-switchgear and circuit-breakers in distribution are the same, there are however fundamental differences in the principle of operation:-

1 The circuit-protective device in the fuse-switchgear is a replaceable component (the fuselink), in the circuit-breaker the protective means is an integral part of the construction.

2 The switch in fuse-switchgear is not intended to break short-circuit currents whereas the circuit breaker must be capable of switching all currents up to its breaking capacity. The common operational requirements may be summarised as follows;
either type of device must provide:

1 Means of isolation and switching according to the specific application.

2. Overload and short-circuit protection to the circuit conductors.

3. Indirect shock protection for systems relying on e.e.b.a.d.
(e.e.b.a.d. = earthed equipotential bonding and disconnection of the supply.)

4. Co-ordination between series devices ensuring back-up protection and satisfactory discrimination.

Fuse-Switchgear Principles.

The predominance of fuse-switchgear in UK practice today can probably be attributed largely to two major technological factors, these being firstly the high breaking-capacity and energy limitation of the cartridge fuse and secondly the inherent positive isolation provided by a direct drive mechanical switch. Since there is no requirement to break short-circuit currents the switchgear is designed on the basis of tolerance to energy let-through in the closed position with only basic measures for arc control, sufficient to achieve a breaking capacity equivalent to overload conditions only.

Two basic types of switchgear have evolved, the switchfuse and the fuseswitch. The switchfuse (See Fig. 1) has a fuse connected in series with one or more of the switch poles. A typical design will have 'knife – blade' contacts providing a wiping contact action with a quick-make, quick-break movement and substantial contact breaks for isolation. The fuses may be HRC or semi-enclosed (rewirable) types. The switch action is interlocked to the cover-mounted operating mechanism to ensure isolation of the fuse or fuses when the switch is opened. This type of switch is used up to about 160 Amp thermal rating or 22 kW motor rating at 550 volts, 3-phase.

In the fuse switch (See Fig. 2) the fuselink forms parts of the moving contact system leaving the fuse totally disconnected in the 'off' position regardless of the direction of feeding the supply. Silver-faced contacts are used to carry continuous load currents up to 1200 amperes. The contact design typically employs the pinch-effect of two parallel current-carrying conductors to achieve effective contact pressures under fault conditions, permitting the use of this type of switch with fuses up to 800 ampere rating on faults up to over 60 KA prospective. At the higher rated currents arc control boxes and cooling grids may be employed to provide overload switching capabilities of over 2000 Amps on systems rated up to 550V. 3-phase.

BS/IEC Classification.

The switch-fuse and fuse-switch are classified by BS 5419 as Fuse Combination Units. The complete list of Classifications, according to the type test requirement, is shown in table 1. All devices within the scope of BS 5419–1977 have to complete tests for temperature rise, dielectric properties and mechanical endurance. Certain other tests which are obligatory are as shown in table 1 and any further tests are only made if the product manufacturer wishes to claim additional ratings. A further test for Rated Conditional Short-Circuit is under consideration and is not therefore included, but may for example be applied in future for disconnectors where the energy let-through is limited by moulded-case or miniature circuit-breakers.

The values of test current for making and breaking capacity and electrical endurance are relating to a Category of Duty (See table 2) which reflects the application of the switchgear. The switch may have several different ratings for different categories of duty and different voltages. A switch is conventionally known by its AC22 Category, for general purpose duty, which will be equal to its maximum thermal rating when fitted with fuses. For example, a device referred to as a 100 Amp switch, may have a full specification as follows:–

Ith = 100 Amps with fuses, Ie = 100 Amps, AC22, Ue = 550 Volts, 3 phase, 50 Hz

Ith = 160 Amps with solid links, Ie = 160 Amps, AC 21, Ue = 550V, 3 phase, 50 Hz

Ui = 660V AC Ie = 55 Amps, AC 23, Ue = 415V, 3 phase, 50 Hz

Ie = 41 Amps, AC 23, Ue = 550V, 3 phase, 50 Hz

Where Ith = Rated thermal current, Ie = Rated Operational Current, Ui = Rated Insulation Voltage, Ue = Rated Operational Voltage.

The Cartridge Fuse

In fuse-switchgear the functions of circuit protection and protection against shock risk from exposed metal work are performed by the cartridge fuse-link and hence the characteristics of this component are of vital importance. British Standard cartridge fuses fall within the scope of BS 88 Part 1, 1975 which includes standardised dimensional requirements to ensure interchangeability between the products of different manufacturers. The operating characteristics of the low-voltage high breaking-capacity fuse depends upon two distinct principles according to the method by which the elements are ruptured (See Fig. 3). Firstly under overload conditions the power developed by the product of the element resistance and current-squared causes the temperature of the element to rise to a point where the low melting-point alloy begins to melt. This gives rise to the phenomena known as the 'M' effect in which the alloy combines with the silver of the element to form an increased resistance section in the element. The additional heat thus generated by the power loss (I^2R) in this section results in eventual fusing at this point, despite the fact the cross-sectional area in this region is larger than that at the necks. This enables the production of a lower fusing factor (fusing factor = ratio of minimum fusing current to rated current) than would be possible with a simple uniform material element. The characteristic produced is sharply inverse/time in configuration as shown in Fig. 4.

Under short-circuit conditions the production of heat at the reduced section neck is sufficient to melt the silver since during the short operating time at very high current, less than once half cycle, the transfer of heat by conduction is negligible. The increase in resistance caused by this heat has the effect of current limitation and hence low let-through energy ($i^2 t$). Arcing is generated by the fusing of the necks and the effect of multiple arcs in series is a rapid voltage build-up across the fuselink and consequent reduction of the current to zero. The filler material fuses in the region of the arcs to produce a non-conducting barrier on cooling. The elements are either of silver or a silver/copper bi-metal housed in a ceramic body. The body material has particular characteristics of good insulation and high resistance to thermal shock. The filler material is a granular quartz of controlled grain size and packing density. Stringent quality control of materials and construction is essential to produce reliable products and in this particular case, fuselinks, a specific scheme has been introduced by ASTA (The Association of Short Circuit Testing Authorities in the U.K.) to monitor the quality of Cartridge fuses carrying ASTA certification.

BS 88 Part 2, 1975 details time/current zones for fuselinks of all standard ratings thus ensuring that the level of protection is substantially equivalent between fuses of different manufacture. The operating characteristics are reproduced on a standard log/log scale grid for ready comparison with other device characteristics.

The Semi-Enclosed Fuse (Rewirable) (See Fig. 5)

This fuse unit is, as its name suggests, a fuse in which the link (tinned – copper wire) is partially enclosed by the insertion of the fuse handle into the base, the withdrawal of which allows rewiring of the fuse after operation. This simple and chaeap construction provides a low breaking capacity protective device adequate for fault levels between 1 and 4 KA according to design and rating, generally at not more than 250 volts to earth. It should be noted that the rating of fuse switchgear for short-circuit capacity and operational voltage (Ue) is dependent on the ratings of the furses fitted. Particular care is required where cartridge and rewirable fuses are interchangeable in the same equipment.

Factory-Built Assembly (F.B.A.)

The products already discussed, switches and fuses, are supplied in the form of components for installation by contractors and as such they are covered, by the product standards for those components. The alternative form of supply is as an assembly of equipment put together by the manufacturer in the form of a switchboard, panel-board or distribution board. Such units are referred to as Factory-Built Assemblies (F.B.A.'s) and come within a scope of BS 5486 Pt. 1, 1979. Compliance with the requirements of this specification ensures that the assembly is adequate in terms of short-circuit rating i.e. withstand current levels for busbars, risers and inter-connections and also dielectric properties and earth continuity arrangements. Where such assemblies may be said to be standard, or at least typical, then temperature rise requirements can be proven by type-test. Two forms of switchboard assembly are generally available, the unit construction in which surface-mounted switchgear is assembled around a standard busbar chamber (Fig. 6) or the modular switchboard (Fig. 7) which consists of flush-mounted switchgear assembled into standard panel modules. Facilities for instrumentation, earth leakage protection and power-factor correction are readily incorporated into the modular pattern switchboard.

A.S.T.A. Certification.

The process of certification of fuses and switchgear in the U.K. usually involves the Association of Short Circuit Testing Authorities which is basically an Association of owners of short-circuit testing facilities. ASTA undertakes to certify the performance of the products submitted for test at any of their accredited Test Stations. A stringent series of controls ensures the integrity of the testing process by accreditation of the actual test plant and appointment of an accredited observer to witness tests.

Although the scope of ASTA is broad, the pattern generally is for manufacturers to submit to ASTA equipment for certification of short-circuit rating and switching capacity only and to verify for themselves the other aspects of performance such as temperature rise and operating characteristics. Hence the manufacturer will generally hold ASTA certificates of the following items:–

Breaking capacity of HRC fuses to BS 88

Fused short-circuit current of switchgear to BS 5419

Short-circuit making capacity of switchgear to BS 5419

Making and breaking capacity of switchgear to BS 5419

Fuse short-circuit rating of busbars to BS 5486

Short-time withstand current of busbars to BS 5486

The manufacturer should be prepared to issue his own certification, often based on work carried out in his own ASTA approved laboratory, for type tests of all his products to the relevant specifications for the following:–

Temperature rise, dielectric properties, mechanical endurance, electrical endurance and operating characteristics.

Wiring Regulations.

Up to this point I have discussed the products and their characteristics without reference to current Wiring Regulations, now however the relevance of the various design aspects must be related to the 15th Edition requirements. This topic can be separated into two areas, firstly the particular requirements applicable to switchgear and secondly the requirements for protection, in this case by means of the fuse.

Switches are classified in terms of their suitability for:–

a. ISOLATION

b. MECHANICAL MAINTENANCE

c. EMERGENCY SWITCHING

d. FUNCTIONAL SWITCHING

Dealing with each of these in turn:–

ISOLATION is the provision of safe electrical working clearances in all live conductors to an installation. To achieve this the Regulations call for specific clearances to be established when a switch is open and also when the indicating means show that a switch is open. It shall only be possible for the indicating means to show the 'OFF' position when the contacts are open, this being referred to as reliable indication. Alternatively it is acceptable if the position of contacts is externally visible. Unintentional re-closure, such as by mechanical shock or vibration must be prevented.

The isolation clearance distance is specified by reference to BS 5419 and in that standard the actual figures are still under consideration. However the distances obtained by fuse-switchgear in current use are likely to be more than adequate, based on knowledge of the work now taking place on this subject within the IEC technical working groups. It is being suggested that the distances will eventually be determined by resistance to impulse-type voltage surges.

The ON/OFF indication of fuse-switches and switchfuses depends either on handle postion or flag indicators linked to the operating mechanisms and is therefore positive. Consideration in the design needs to be given to the possibility of failure of the indicating device due to mechanical weakness, in the event of contact welding. New standards work is proposing methods of verification based on applying specified forces to the handle with the contacts held closed.

When the isolating switch is located remotely it shall be capable of being locked with a key unique to that part of the installation and an additional isolator shall be provided adjacent to the equipment supplied. Every motor circuit shall be supplied with an isolator.

SWITCHING OFF for MECHANICAL MAINTENANCE differs from isolation only in that it is regarded as being essential that a device for this purpose, which may be operated by a non-electrically-qualified person, has a load switching capability; in terms of the switch-gear standard it must have the appropriate rating at the correct Category of Duty for the load being supplied.

DEVICES FOR EMERGENCY SWITCHING must also be on-load switches and in particular should be able to cope with stalled motor currents ie having an AC 23 rating appropriate to the motor size. Emergency switches shall preferably be manually operated and must be readily accessible. A particular case of emergency switching is the FIREMANS SWITCH which is automatically latched when in the OFF position to prevent inadvertent reclosure.

The term FUNCTIONAL SWITCHING is used to describe the normal service function of switches and it is the duty of the installer to select equipment with ratings appropriate to the load. In particular it is required that switches for discharge lighting circuits shall have a nominal current rating of twice the steady state load current.

Protection Against Electric Shock.

Overcurrent protective devices (e.g. fuses) may be used for protection against electric shock by INDIRECT CONTACT ie faults to exposed metal-work of the installation. The device characteristic will determine the permissible earth-loop impedance figure and the relevant figures for some sizes of BS 88 fuse are reproduced in the Regulations, tables 41 A1 and 41 A2. The figures are derived from the BS 88 time/current zones to achieve disconnection within 0.4 seconds for socket-outlet circuits and 5 seconds for fixed equipment circuits. The published figures are relevant to 240 volt-to-earth systems and should be multiplied by the ratio Uo/240 for any alternative voltage-to-earth (Uo).

Protection Against Overcurrent.

This topic is divided into two areas:–

(i) protection against overload current

(ii) protection against short-circuit current.

An OVERLOAD is defined as an excess current in an otherwise healthy circuit and to protect the conductors from damage due to heat the protective device must operate at not more than 1.45 times the lowest current carrying capacity (Iz) of any conductor in the circuit. Hence:–

$$I_2 \leqslant 1.45\ Iz$$

where I_2 is the minimum operating current of the device. However it is stated in the Regulations that a BS88 fuse of nominal rating (In) not exceeding (Iz) may automatically be assumed to comply. The onus here is on the circuit designer to establish the correct cable size taking into account the selection process detailed in Appendix 9. Allowances must be made for ambient temperature, grouping, type of installation and proximity of thermal insulation.

A SHORT-CIRCUIT between conductors of the same circuit must be cleared by the protective device before damage is caused to conductors and connections. Initially the value of prospective short-circuit current at the point of installation of the device must be established. This has given rise to a number of problems in application in that in the absence of detailed information the tendency has been to quote theoretical maximum figures, leading in some cases to over-specification of equipment. Where the load is fed from the consumer's own transformer then the determination of fault level is relatively simple, but in the interconnected systems of the supply authority which may be re-inforced at some future date the problem is more complex. However where the H.B.C. fuse is the protective device there is little difficulty since these are generally rated in excess of 60 kA, which is sufficient for the majority of installations.

It is stated in the Regulations that where the load conductors have been selected in accordance with the requirements for overload protection (see above) then the requirements for short-circuit protection will automatically be met with fuses. However if the fuse is selected for short-circuit protection only, for instance when used for back-up protection, it shall be verified that the energy let-through is less than the limiting value for the conductor, represented by the adiabatic equation

$$t = \frac{K^2\ S^2}{I^2}$$

where
t = duration in seconds
s = cable c.s.a (mm^2)
I = effective rms short-circuit current
K= a factor dependent upon the insulation of the cable e.g. 115 for p.v.c. on copper

At high short-circuit currents with fault clearances as low as a half-cycle of a.c. waveform the 'time' becomes irrelevant and the equation may be transposed to:–

$$I^2 t = K^2\ S^2$$

The manufacturer will supply maximum values of total let-through energy ($I^2 t$) for each fuse which may then be compared to the value $I^2 t$ for the cable size and type to be used.

Co-ordination of Overload and Short-Circuit Protection (Back-up protection)

Short-circuit protective devices may be used to protect from damage due to effects of short-circuit other devices used for overload protection e.g. circuit-breakers, or motor-protection e.g. a motor starter. It is important to establish that such co-ordination is valid by the comparison of device energy withstand capabilities. In the case of miniature and moulded-case circuit breakers the manufactuer's of the circuit-breaker should make recommendations based on actual test results, as reliance on comparison of time/current characteristics may not be valid.

Motor-starter back-up protection is covered in detail in BS 4941: Part 1: 1979 and basically states that the overload-relay shall operate at currents up to 8 times full-load motor current, with the fuse taking over beyond that level. Grades of protection are specified according to whether the starter is required to be operational after short-circuit or not.

Discrimination.

It is required that protective devices in an installation be co-ordinated to provide as far as practicable that the device nearest a fault will operate leaving devices nearer the supply intact. This is checked by comparison of device time/current characteristics (See Fig. 8) for overload and low short-circuit faults and by comparison of $i^2 t$ data (See Fig. 9) for high fault level short-circuits. The pre-arcing $i^2 t$ of the device nearer the supply source must not be exceeded by the total operating $i^2 t$ of the device nearest the fault, taking into account the prosepctive fault levels at the relevant point in the circuit.

Summary.

The paper has attempted to outline the basic design features of currently-available fuse-switchgear equipment and to show how such equipment may be employed to meet the requirements of the 15th Edition of the Wiring Regulations. Essential requirements are:– compliance with the current British Standards, certified test performance, particularly on short-circuit, and provision of adequate application data. In general all this will be readily available from the reputable U.K. manufacturer.

BS CLASSIFICATION	CAPABILITY	ADDITIONAL OBLIGATORY TESTS				
		M & B	S.T.W.	FUSED S/C	S/C MAKE	ELEC END
(A) SWITCH	MAKING BREAKING O/L, MAKING S/C, CARRYING S/C.	X	X		X	X
(B) DISCONNECTOR (ISOLATOR)	ISOLATION IN OPEN POSITION, CARRYING NORMAL CURRENTS, CARRYING S/C CURRENTS. NOTE NO SWITCHING CAPACITY REQUIRED		X			
(C) SWITCH-DISCONNECTORS	ISOLATION IN OPEN POSITION MAKING AND BREAKING O/L MAKING S/C CARRYING S/C	X	X		X	X
(D) FUSE COMBINATION UNIT	COMBINES FUSE(S) WITH (A),(B), OR (C) ABOVE.			X		X (EXCEPT DISCONNECTORS)

Table: TABLE 1

KEY:- M & B = MAKING AND BREAKING CAPACITY
S.T.W. = SHORT-TIME WITHSTAND CURRENT
FUSED S/C = FUSED SHORT-CIRCUIT CURRENT
S/C MAKE = SHORT-CIRCUIT MAKING CAPACITY
ELEC. END = ELECTRICAL ENDURANCE

TABLE 2

NATURE OF CURRENT	CATEGORY	TYPICAL APPLICATIONS
ALTERNATING CURRENT	AC-20	CONNECTING AND DISCONNECTING UNDER NO-LOAD CONDITIONS
	AC-21	SWITCHING OF RESISTIVE LOADS, INCLUDING MODERATE OVERLOADS
	AC-22	SWITCHING OF MIXED RESISTIVE AND INDUCTIVE LOADS, INCLUDING MODERATE OVERLOADS
	AC-23	SWITCHING OF MOTOR LOADS OR OTHER HIGHLY INDUCTIVE LOADS

FIGURE 3.

SIMPLIFIED SECTION OF CARTRIDGE FUSE

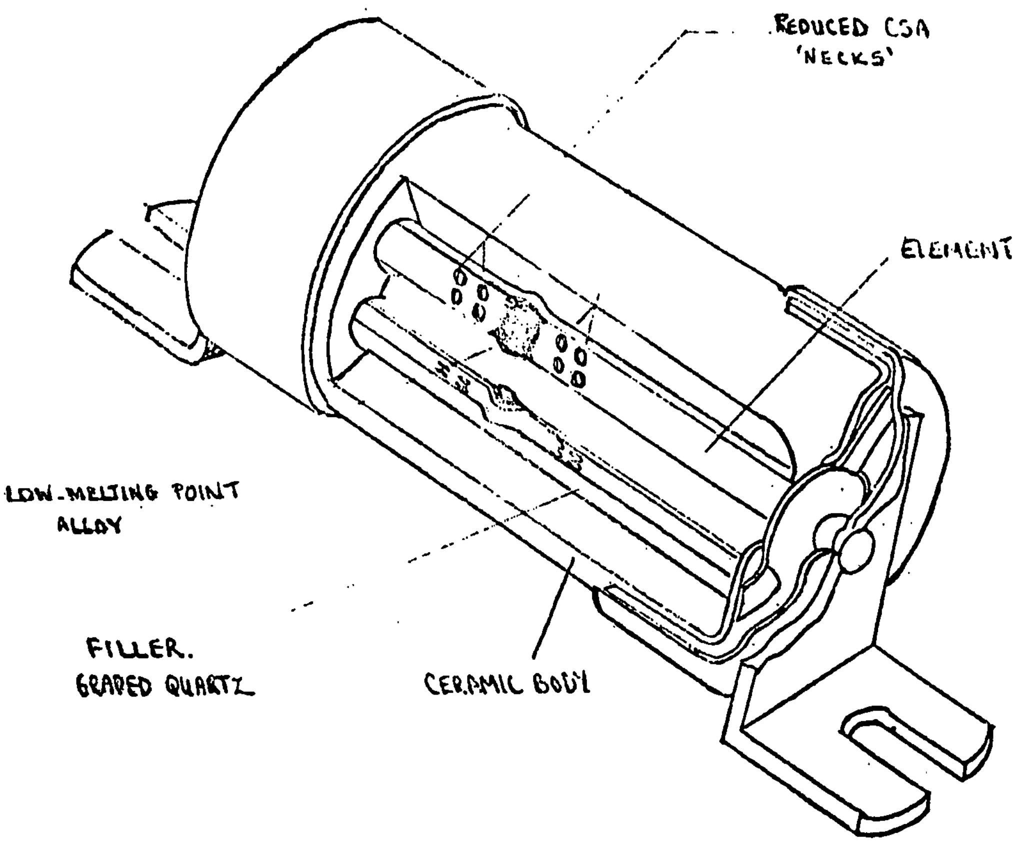

FIGURE 4.

Time current characteristic curves — 2–800A general purpose fuse links

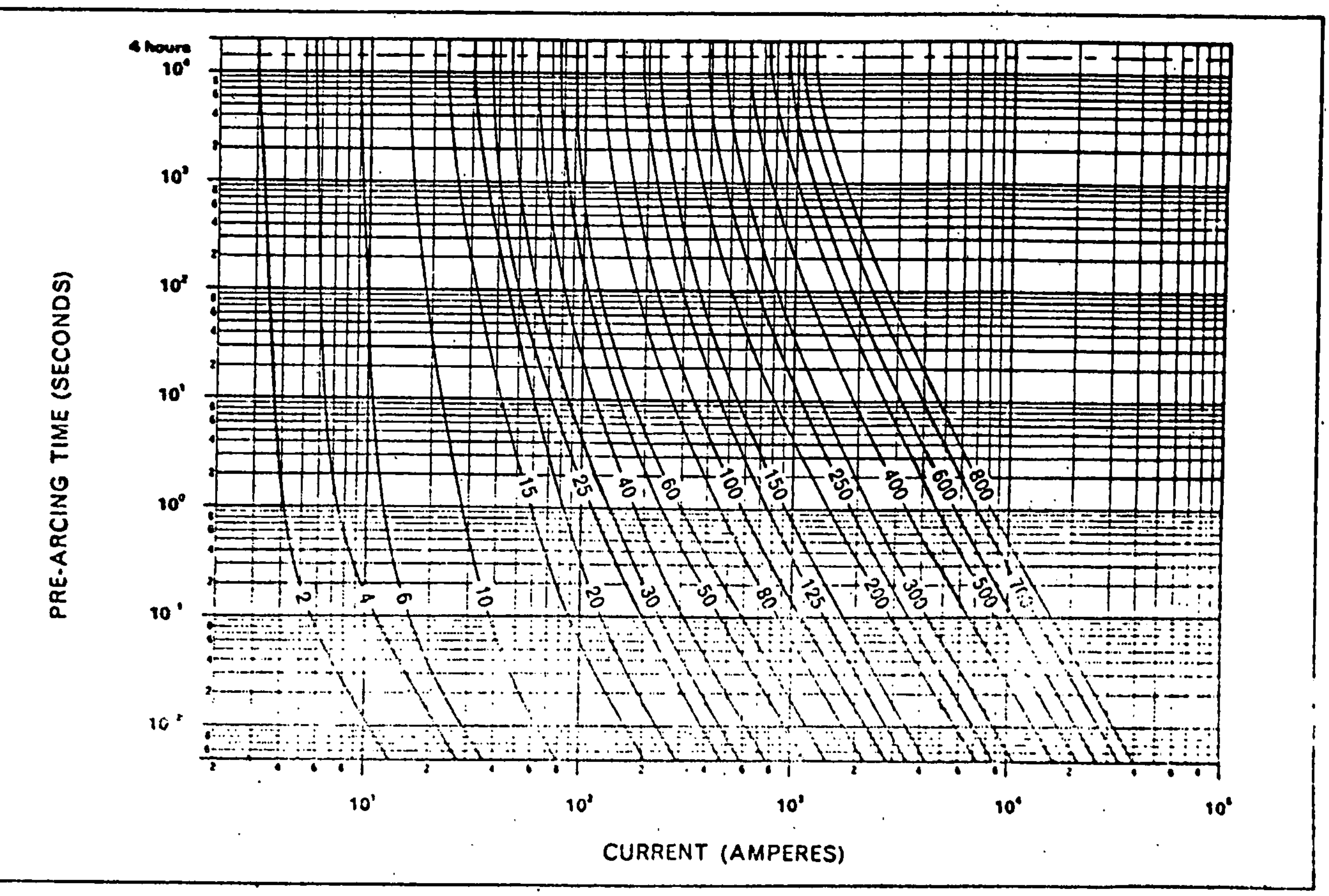

FIG 8 FUSE CHARACTERISTICS SUPERIMPOSED ON MCB CHARACTERISTICS

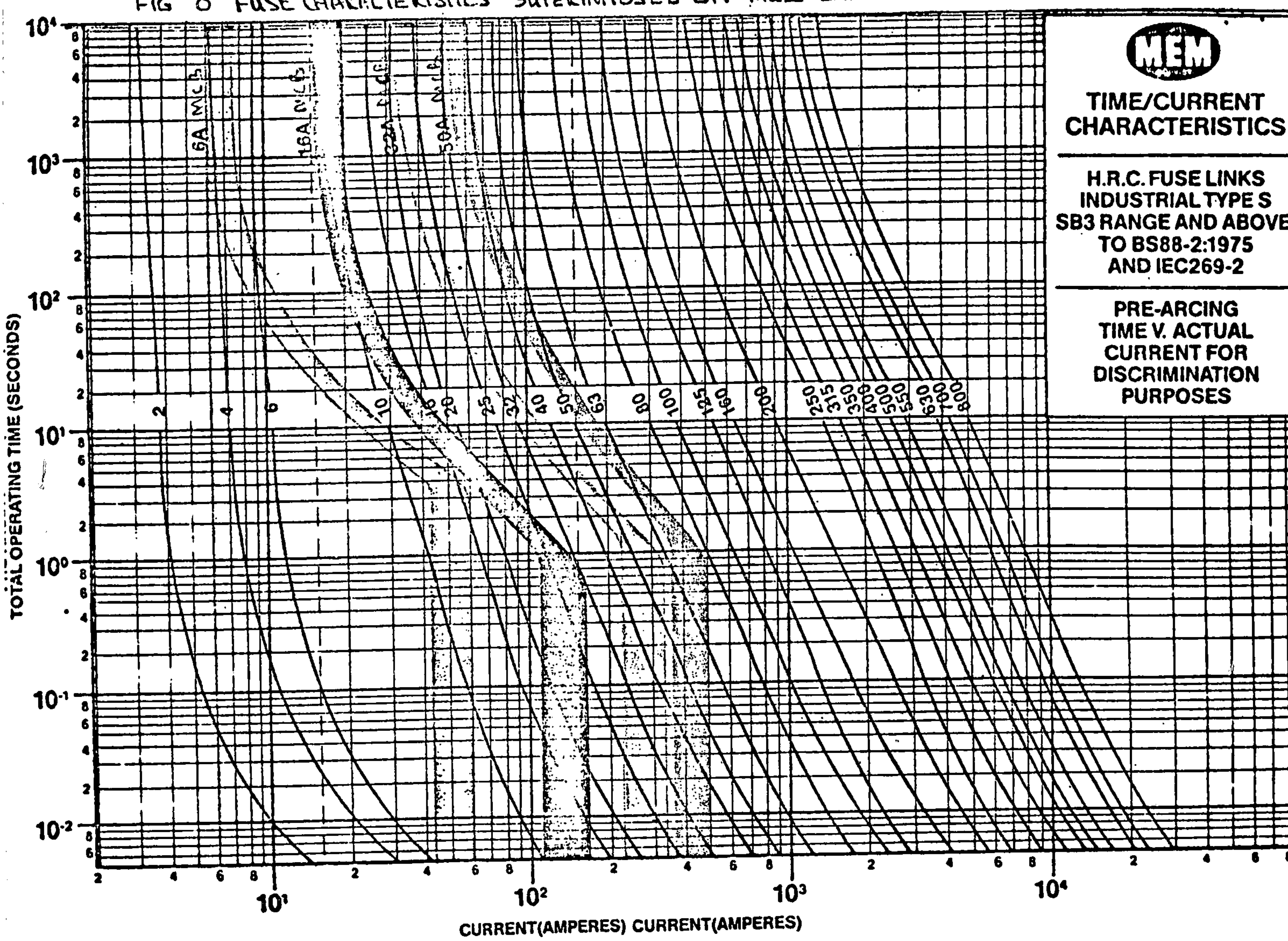

FIGURE 9.

I²t characteristics — 10–800A general purpose fuse links