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REPORT ON PROPOSED CHANGES TO

BRITISH STANDARD BS 5306-8: 2012

FIRE EXTINGUISHING INSTALLATIONS AND EQUIPMENT ON PREMISES.

PART 8. SELECTION AND POSITIONING OF PORTABLE FIRE EXTINGUISHERS. CODE OF PRACTICE

Prepared by
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On the instructions of Walker Morris Solicitors representing Safelincs Limited

16 May 2021

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1 INTRODUCTION

1.1 I am the Managing Director of Michael Jones Chartered Forensic Fire Electrical Ltd and I am a Forensic Scientist with specialisms in fire investigation and electrical matters. I am a Bachelor of Science in Electrical and Electronic Engineering; I hold the Diploma of the Forensic Science Society in Fire Investigation and have passed the Membership Examination Paper of the Institution of Fire Engineers in Fire Investigation. I am a Chartered Engineer with the Engineering Council and registered by FEANI to practice in Europe, which confers upon me the title Eur Ing; I am also a Chartered Forensic Practitioner. I am a Member of the Institution of Electrical Engineers (now the Institution of Engineering and Technology, IET, but original members can retain the IEE post-nominals), a Member of the Institution of Fire Engineers and a Member of the Chartered Society of Forensic Sciences (formerly the Forensic Science Society, for which I sat on Council from 2010 to 2013). I was a Member of the running committee of the UK Chapter of the International Association of Arson Investigators from 2009 to 2012. I have worked as a Forensic Scientist/Engineer for over thirty years.

1.2 On 09 May 2021, I was instructed in this matter by Walker Morris Solicitors, who represent Safelincs Ltd, to review proposed changes to British Standard BS 5306-8:2012 "*Fire Extinguishing Installations and Equipment on Premises. Part 8. Selection and Positioning of Portable Fire Extinguishers. Code of Practice*" where it refers to the tests in British standard BS EN 3-7 "*Portable fire extinguishers. Characteristics, performance requirements and test methods*" for the resistance to electrical conductivity of water based portable fire extinguishers.

1.3 I understand that BS 5306-8 is being amended by Committee FSH2 of the British Standard Institute and that a new, draft standard has been published for consideration. In particular, clause 7.7.1 of the draft standard states "… Only non-conductive extinguishing media, such as powder, carbon dioxide or clean agent should be used on electrical equipment." The concern for Safelincs Ltd is that this reads as excluding water-based extinguishers for use on fires involving electrical equipment, yet there are some types of water-based extinguishers that can meet an electrical conductivity test set out in BS EN 3-7 and which have previously been considered as safe for use on fires involving electrical equipment. This level of safety has been recognised in the existing standard BS 5306 – 8 (2012) in clause 9.2, note 2 which states "Water-based extinguishers can be marked as being suitable for use on live electrical equipment up to 1000 V AC at a distance of 1 m in accordance with BS EN 3-7." I understand that Committee FSH2 propose to remove this note from the next edition.

1.4 I have not seen any research document or report from the British Standards Institute setting out the reasons for no longer accepting the use of water-based fire extinguishers that pass the requirements of BS EN 3-7 as being safe for use on fires involving electrical equipment. I understand from discussion with Safelincs Ltd that the concerns raised by Committee FSH2 is that while the extinguishers might pass the test for type approval, in use, the smoke of the fire might ionise the water and make it conductive, thereby exposing the operator of the extinguisher to the risk of an injurious electric shock.

2 PHILOSOPHY OF USING WATER SPRAY ON ELECTRICAL FIRES

2.1 I am given to understand from Safelincs Ltd that there are principally two types of water based portable fire extinguisher; one simply emits a stream of water but the other emits a pressurised spray. It is the second type, that can be demonstrated to pass the necessary test in Annex C of BS EN 3-7, which is the subject of discussion in this report.

2.2 The relevant test in BS EN 3-7 is set out in Annex C, and requires that the extinguisher be operated at a distance of 1 m from a metal plate charged with electricity to a voltage of 35,000 V (35 kV). The electricity supply is connected to earth and during the test, measurements are made between earth and the handle and nozzle of the extinguisher for any leakage current. Clause 9.2 in the main body of BS EN 3-7 states that the leakage current should be no more than 0.5 milliamps (mA) at any time during the complete discharge of the portable fire extinguisher. Prior to the test being undertaken, the source resistance of the high voltage transformer being used in the test is assessed by reducing the output voltage to 10% (ie 3.5 kV) and putting a short-circuit across the output terminals of the transformer. The current through the short-circuit is measured and should not be more than 0.1 mA.

2.3 **Figure 1** sets out the calibration circuit from which it can be derived that the source resistance of the transformer must not be less than 35 megohms (MΩ, where 1MΩ = 1 million Ohms). **Figure 2** demonstrates the circuit during the testing of the extinguisher from which it can be seen that the resistance of the water jet must not be less than 665MΩ. In electrical systems, conductivity is the inverse of resistance so in order to pass the test, the conductivity of the water stream must not be greater than 1.5 nano-Siemens/metre (nS/m where 1nS = 0.000 000 001S).

2.4 In pure water, two hydrogen atoms are bonded to an oxygen atom by means of covalent bonds to make a molecule of water. The molecule, therefore, has a net electrical charge of zero. By applying a degree of activation energy to a water molecule it can be broken down to form bonds with ionic material and the resulting compounds are capable of forming charged dipoles which can migrate in the influence of an external voltage to produce a flow of electric current. Principally, the means of making water conductive is to introduce contaminants. A simple review of information available on the internet suggests that high quality deionised water has a conductivity of approximately 0.5 micro-Siemens per centimetre (μS/cm), drinking water 200 to 800 μS/cm per centimetre and seawater, 50 milli-Siemens per centimetre(mS/cm). By summarising the figures in common units of micro-Siemens/metre (μS/m) we get:

Seawater	500 μS/m
Drinking water	2-8 μS/m
De-ionised water	0.005 μS/m
EN3-7 water	0.0015 μS/m

It can be seen that the conductivity of the water used in an extinguisher that passes the test of BS EN 3-7 is a third that of high-quality deionised water so is, arguably, three times safer.

2.5 **Figure 3** explains how a spray of de-ionised water can achieve such a low level of conductivity. It shows that even if the applied voltage is strong enough to produce such a field between each drop of water that the water molecule can be polarised, the water molecules are separated by the spraying action and, therefore, there can be no migration of charge under the influence of the electric field. In the figure, an example of 240 V AC is given during a time in the wave cycle when one end is positive and the other is negative. In the example, five water droplets have been projected from the fire extinguisher nozzle and one is just about to leave, the first drop having reached an exposed, live cable. Ordinarily, there would be a voltage field of 240V/m across all the droplets, but assuming that drops had, somehow, been polarized, then with the drops equally spaced, the strength of the voltage field between each drop is only 48 V over 20 cm, that is, 2.4 V/cm, whereas the electric field strength required to make dry air conductive is 30,000V/cm. Hence, the presence of water droplets cannot distribute the electric field to such a degree as to make intermediate air conductive and instead, conductivity has to be through the water molecules themselves but, because they are in the form of a spray, the molecules are not joined together so there is no continuous stream of water between the two electrodes of the system that could allow the water molecules to become polarised. Hence, the use of water spray makes even polarized water non-conductive, enabling it to be safe for use on fires involving electrical apparatus.

2.6 **Figure 4** shows the situation where the water spray is reaching a cable that is surrounded by free radicals in the smoke of a fire. In the example, the free radicals have allowed a breakdown of air between the last and penultimate droplet of water, which means that the voltage of the system now falls across the remaining droplets, increasing the field strength to 3 V per centimetre; this is still a long way from enabling electricity to track back through the whole treatment droplets. Hence, where the water is in close proximity to the fire some of it might become polarised owing to the presence of polarised free radicals in the smoke of the fire, but the remaining stream still maintains a strong resistance to the flow of electric current.

2.7 **Figure 5** is an extract from the American code of practice NFPA 921 “Guide for Fire and Explosion Investigations” and shows how the process of combustion involves the breaking down and reforming of many different species of molecule. For this to happen, the constituent fuel has to be heated so that its internal chemical bonds are broken, and in this way, the molecules will split into free radicals that are charged: at the same time, the oxygen in the air with which the fuel reacts in order to burn, also has to have its covalent bonds broken down by the heat that starts the fire so that the oxygen can form into O^+ and O^- free radicals. The reaction of the oxygen free radicals with the fuel free radicals is the process of combustion and emits light, but as the fire develops, the heat can generate more free radicals than there is time for the combustion reaction to accommodate and this means that above the reaction zone, there will be free radicals that could ionise water droplets to make them conductive.

2.8 Water in liquid form extinguishes a fire by cooling the fuel and preventing it from reacting with the oxygen in the air. Water droplets cool the fire because they turn the water into a form where it has low mass but high surface area and can, therefore, draw heat from the fire to evaporate. The heat of evaporation that they draw, cools the fire rapidly. In doing so, it can be argued that the hot water vapour can react more readily with remaining free radicals and form an ionised mist; however, this will require a degree of time for the reaction to be completed and during that time, the mist will be drawn away with the smoke of the fire in thermal convection currents. In **figure 6** I show that whether the person holding the fire extinguisher is tackling a fire at high level, mid-level or low-level, they are unlikely to have the nozzle of the extinguisher in close proximity either to the point of reaction in the fire or the hot smoke zone. This is particularly true of extinguishers which passed the EN 3-7 as they are required to be held 1 m away from the fire. It follows that even if there were sufficient time for water droplets at the end of the extinguisher stream be vaporised and react with free radicals in the area, the nozzle of the extinguisher will be away from that zone and will be emitting non charged water droplets. Hence, there will still be an area of non-conductivity in the water spray near the nozzle of the extinguisher.

3 ELECTRIC SHOCK MECHANISM

3.1 The sketch at **figure 7** shows the electric circuit that would be involved if somebody applying a fire extinguisher were to receive an electric shock. The National Grid transformers that supply mains electricity have their star points attached to earth for reasons of operational safety, which means that an electric potential exists between any live conductor and the earth; hence, anyone coming into contact with a live conductor and earth can receive an electric shock. **Appendix A** describes the electricity supply system in more detail; while the nominal single phase electrical supply voltage in the UK is 230V, it used to be 240V and many power stations still generate at that level as it fits within the upper tolerance of the new standard figure. It is often found then, that mains voltages are still in the region of 240V even though they are nominally considered to be 230V. I have, therefore, used 240V for the basis of the calculations in this report. It can also be seen in reference to appendix A, that while three phase electrical systems are classed as operating at 400/415 volts, that is the line-to-line value (ie phase to phase) but the voltage to earth from any of those phases is still only 240V, hence, the maximum phase to earth shock voltage available on a three-phase system is only 240V, not 415. This means that from the point of view of somebody potentially receiving an electric shock while using a fire extinguisher in typical commercial and industrial applications, the maximum shock voltage is only 240V, even at the point of supply (ie the meter position).

3.2 In figure 7 I have shown the connection of the grid supply to earth as resistor R_{E1} and the resistance of the grid supply itself as R_S. The resistance of the water jet is R_J, the resistance of the person's body R_B and the resistance between the person and earth, R_{E2}. The international standard IEC 479-1 "*Effects of current on human beings and livestock – Part 1: General aspects*" describes how the effects of electricity on a human can vary according to the frequency of the waveform, the magnitude of the voltage, the duration of the shock and even the geometry of the source of contact. It is, therefore, very difficult to predict exactly how a particular person might respond to exposure to electricity; however, useful summaries are given in figure 14 of the standard and table 4, which I have reproduced here as **figures 8** and **9**. From these it can be seen that a reasonable estimate of the value of the body resistance, R_B, is 2,000Ω. Measurements of R_S, R_{E1} and R_{E2} combined together are often made during the initial testing of an installation and are typically below 10 Ω and, therefore, not significant compared R_B.

3.3 The data in IEC 479-1 suggests that with values of shock current less than 0.5 mA it is unlikely the recipient will feel anything but will feel tingling at higher levels, then pain at around 10 mA. The next stage in the electric shock experience is involuntary muscle actuation as the pulses of the current stimulate the motor control nerve input of the muscles. This will cause all muscles along the current path to activate and in the minor stages could feel like cramp but can soon develop to a position where the user is unable to control their muscles. If the electric shock travels through the arm, then all muscles will be activated and those with the strongest influence will take precedent in which case, the gripping muscles of the hand will clench. If a person is in contact with a live conductor, they will not be able to let go. If the shock current passes through the legs, all the leg muscles are activated and as the kicking muscles are strongest, the legs will straighten out suddenly, giving the impression that the person has been thrown backwards. If the current travels in the area of the heart, it can interfere with the operation of the heart causing it to be erratic (fibrillation) or even stop. As the path of current flow is important in understanding whether the heart might be affected, it is difficult to establish the level of current that might be dangerous in that respect; however, residual current devices are set to operate, typically, at 30mA. This level will not prevent somebody from experiencing the shock, nor experiencing pain but for the short duration of the shock (30ms) it will not be fatal.

3.4 For the person depicted in figure 7 to receive a shock of 30mA would require the resistance of the water jet, R_J, to be approximately 6,000Ω, which is 110,000 times less than the resistance of the water jet that would pass the test of BS EN 3-7.

3.5 It can be seen from the above that it is extremely unlikely that a jet of water which passes the test of BS EN 3-7 can become so conductive that the operator of the fire extinguisher would receive even the slightest sensation of an electric shock, let alone an injurious shock. What is more likely, is that any conductor that is exposed in the fire will form a short-circuit with other conductors, either through charred insulation, smoke or residual firefighting water, and the ensuing short-circuit will cause a fuse, circuit breaker or residual current device to operate and isolate the electricity: Indeed, if the smoke of the fire is so polarised as to ionise a jet of water, the electricity would much sooner pass through the smoke; if the electricity supply fuse does not operate, the ensuing arcing would likely deter someone from approaching the fire with a portable extinguisher.

3.6 In **Appendix B** I have considered the possibility of a person standing in a pool of residual firefighting water receiving an electric shock and from the results, it can be seen that an extremely high level of conductivity would be required in order to produce a shock voltage of 50V between the legs of the user of the extinguisher. The values of conductivity required to either cause a 20A fuse to blow or a 200A fuse to operate are almost a million times greater than the conductivity of sea water. This would require a great deal of absorption by the pool of water of contaminants from the smoke, which would not only have to react fully with the water but do so while the person is still present. Given that the use of handheld fire extinguishers is for first-aid firefighting, it is far more likely that before such a highly conductive pool of water could be formed (if ever), the electricity will have been isolated, the fire extinguisher spent, or the operator moved away from the fire either because it is extinguished, and the area made safe or it has developed beyond first-aid control.

4 QUESTIONS

4.1 My instructing solicitors have asked me to answer a number of specific questions which I shall repeat below and answer in turn:

4.2 **Question**: Does it pose any safety risk for a user to discharge water-based extinguishers, which were successfully dielectrically tested in line with BS EN 3-7, on live electrical equipment of up to 1000 V AC if a safety distance of 1 m is adhered to?

4.3 **Answer**: In my view it is extremely unlikely that any safety risk would arise under those circumstances. It must be borne in mind that a shock voltage greater than 240V to earth would only be possible on highly specialised equipment, in which case it is likely that first-aid firefighting would only be carried out by highly trained personnel, if at all.

4.4 **Question**: If it does, please assess whether you consider such a safety risk to be of a level to mean that the Standard should be amended in line with the Draft Standard so as not to permit (or to discourage) the use of these products in the circumstances.

4.5 **Answer**: From the discussion given above in this report, I do not consider there to be any risk of danger of electric shock to a person using an extinguisher which complies with the requirements of Annex C of BS EN 3-7. I do not, therefore, see any need for the current standard to be amended; indeed, I am concerned that the amendment to the standard could give rise to a stronger, alternative risk. The alternative is that first-aid firefighting might not be undertaken because the extinguisher is not considered appropriate and that the fire might grow to a point where it presents a risk of danger to the occupiers of the building, or a risk of significant damage. The whole point of portable fire extinguishers is to have a tool readily available to administer first-aid firefighting. The more versatile that tool, the more chance of it being successful. A water-based extinguisher that passed the requirements of Annex C in BS EN 3-7 would, for example, readily extinguish a fire in a printer without any risk of electric shock to the user, and, thereby, eliminating the risk of the office burning down and staff being laid off.

4.6 **Question**: If the answer to [the questions above] is that it does not pose any safety risk (or does not pose an unacceptable safety risk), please confirm whether this applies to:

(a) Foam
(b) Water
(c) Deionised water;

provided each has been successfully dielectrically tested in line with BS EN3-7 seven?

4.7 **Answer**: My view is that any extinguisher that passes the test in Annex C of BS EN 3-7 is safe for use on low-voltage (less than 1000 V AC) mains fed electrical apparatus.

4.8 **Question**: Do you consider the BS EN 3-7 dielectric test to be safe practice and fit for purpose?

4.9 **Answer**: Yes, as well as the foregoing discussion, the standard has been adopted from a Europe standard approved by the Comité Européen de Normalisation (CEN) and developed by the French standards body, ANFOR. Hence it has International application throughout the European community and other countries that adopt BS EN or ANFOR standards.

4.10 **Question**: How big is the safety margin with regards to maximum conductivity permitted in BS EN 3-7 in relationship to the maximum safe exposure of humans?

4.11 **Answer**: These issues have been addressed in the text above but in summary, it is my view that the safety margins are so great as to consider the risk to be negligible.

4.12 **Question**: Do you consider the BS EN 3-7 dielectric test to be safe practice and fit for purpose?

4.13 **Answer**: Yes.

4.14 **Question**: Do you consider the current BS 5306-8 Standard to set out safe advice in relation to water-based extinguishing liquid which has been tested in line with BS EN 3-7 and their use?

4.15 **Answer**: Yes.

4.16 **Question**: If the answer to [the question above] is “no”, please confirm what additional advice you consider could be added to the Standard to provide sufficient safety advice?

4.17 **Answer**: Not applicable, but perhaps the marking to put on extinguishers that meet the requirements of Annex C of BS EN 37 could give more practical advice, such as “Suitable for use on mains supplied electrical equipment from a distance of no less than 1 meter” as this would deal with all the equipment that might reasonably be expected to be encountered in domestic, commercial and industrial premises in the UK other than specialised equipment. As only extinguishers that comply with Annex C of BS EN 3-7 can use this marking, compliance is implicit.

4.18 **Question**: Do you have any experience or knowledge of any safety related incidents caused by the use of water-based extinguishing liquid which has been tested in line with BS EN 3-7 on live fires involving electrical equipment since 2000 (when we understand the first iteration of the Standard is issued)?

4.19 **Answer**: No, I have never been asked to investigate any such matter nor have I heard any report of such a matter in all the 3,000 or so fires I have investigated, nor at any Institute Conferences, informal working groups or other such events that I have attended.

4.20 **Question**: Do you consider the use of water-based extinguishing liquid which has been tested in line with BS EN 3-7 on live equipment to be less safe than any of the other extinguishers the use of which is recommended in the Draft Standard (e.g. Class F extinguishers)?

4.21 **Answer**: No. The purpose of a standard is to set a datum by which equipment or systems can be compared; hence, any extinguisher that passes the relevant test in BS EN 3-7 is as safe as any other for the risk being addressed.

4.22 **Question**: Are you able to identify any other types of fire extinguishers which require a user to take specific steps or actions to prevent other risks from occurring prior to or during the discharge of the extinguisher? If so, please provide details of those other extinguishers, the steps that user is required to take and the other risks that those steps are designed to eliminate or mitigate to a tolerable level.

4.23 **Answer**: Yes. Ordinary water stream fire extinguishers which do not pass the test in BS EN 3-7 should not be used on electrical fires because they can present the risk of a continuous stream of conductive material forming a bridge between exposed electrical conductors and the user and, therefore, present the risk of electric shock. Carbon dioxide extinguishers can generate extremely cold temperatures on the nozzle so the user must not hold the nozzle except by means of a good, thermally insulating glove, otherwise they can receive third-degree burns. Fire extinguishers that use halon gas or other oxygen suppressants should not be used in confined spaces otherwise occupiers can become unconscious or suffocate. Powder extinguishers, which use chemicals to neutralise the free radicals in the fire, can cause extreme irritation to the user so should not be used in confined spaces. Users also have to consider whether the fire extinguisher is appropriate for the material involved in the fire so for example, water-based fire extinguishers should not be applied directly to oil-based fires as they can disperse the oil and thereby spread the fire, although water mist extinguishing systems, which use the latent heat of evaporation to cool the fire, can be employed in fixed firefighting equipment installed in for example, kitchens.

5 CONCLUSIONS

5.1 In my view, any portable fire extinguisher that passes the test in Annex C of BS EN 3-7 is safe for use on low-voltage, (less than 1000 V AC) mains fed electrical apparatus from a distance of not less than 1m.

5.2 In my view, there is no requirement, and I have seen nothing that demonstrates any need, to change the advice given in the current version of BS 5306-8 relating to the application of fire extinguishers that meet the requirements of Annex C of BS EN 3-7 on fires that involve live electrical apparatus at voltages less than 1000 V AC.

6 EXPERT'S DECLARATION

6.1 As a Chartered Engineer I am bound by the Code of Conduct of the Engineering Council and hereby affirm that I have complied with that Code of Conduct in the preparation of this report.

6.2 Amongst other things, the Engineering Council's Code of Conduct requires that;

> Engineering professionals have a duty to acquire and use wisely the understanding, knowledge and skills needed to perform their role. They should:
>
> - always act with care
> - perform services only in areas in which they are currently competent or under competent supervision
> - keep their knowledge and skills up to date
> - assist the development of engineering knowledge and skills in others
> - present and review theory, evidence and interpretation honestly, accurately, objectively and without bias, while respecting reasoned alternative views
> - identify, evaluate, quantify, mitigate and manage risks not knowingly mislead or allow others to be misled

6.3 I understand that should this matter proceed to litigation, my overriding duty will be to assist the Court in matters within my expertise, and that this duty overrides any obligation to those instructing me or by whom my fees are paid. I confirm I have complied with that duty and will continue to do so. I am aware of the requirements set out in Part 35 of the Civil Procedure Rules and the accompanying Practice Direction, the Protocol for the Instructions of Experts to give Evidence in Civil Claims, and the Practice Direction for Pre-action Conduct.

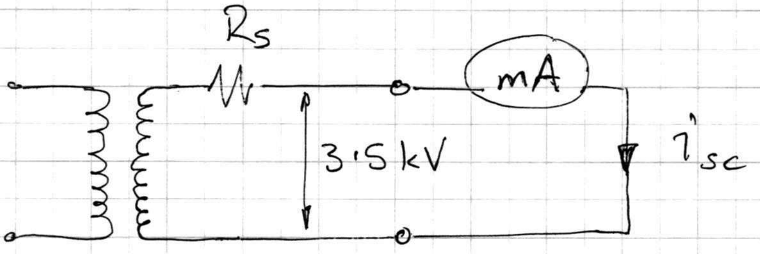
6.4 I confirm that I have made clear which facts and matters referred to in this report are within my own knowledge and which are not. Those that are within my own knowledge I confirm to be true. The opinions I have expressed represent my true and complete professional opinions on the matters to which they refer.

MJones

Eur Ing M Jones BSc FSSocDip CEng ChFP MIEE MIFireE MCSFS

FIGURES 1 TO 9

Calibration Circuit



R_s = source resistance of transformer windings

i_{sc} = short circuit current

By Ohm's Law, $V = IR$ hence $i_{sc} R_s = 3{\cdot}5\,\text{kV}$

$$R_s = \frac{3{\cdot}5\,\text{kV}}{i_{sc}}$$

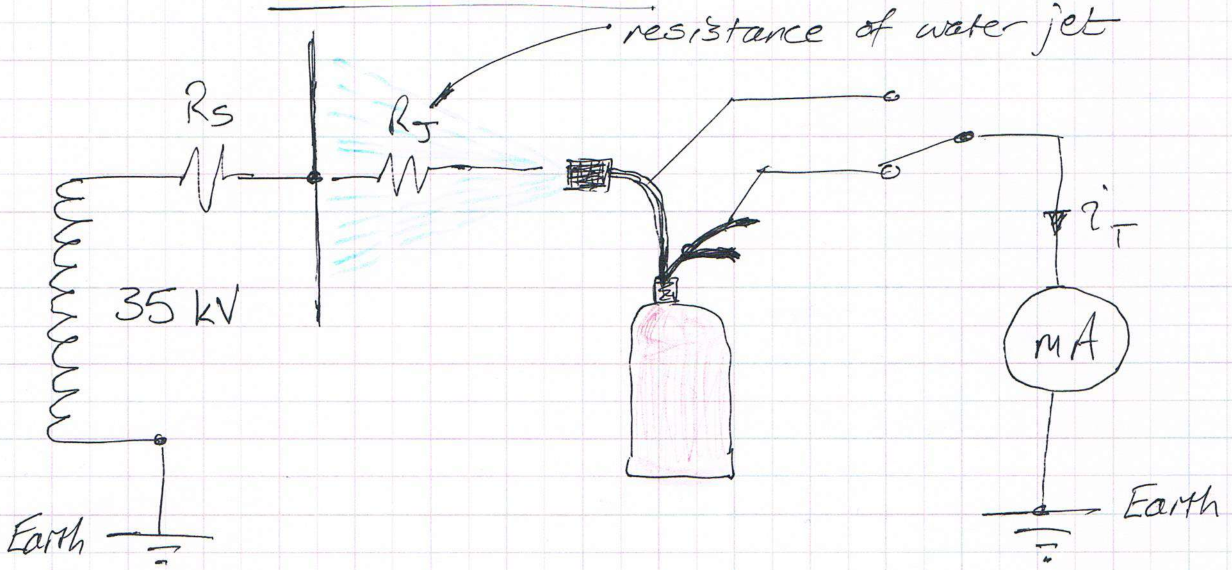
$i_{sc} \not> 0{\cdot}1\,\text{mA}$ $(1 \times 10^{-4}\,\text{A})$ so

$$R_s \not< \frac{3{\cdot}5 \times 10^{3}}{1 \times 10^{-4}} = 3{\cdot}5\ 10^{7}$$

Hence the source impedance of the test transformer must not be less than $35\,M\Omega$

Figure 1
Calibration circuit for test in Annex C of BS EN 3-7

Test Circuit BS EN 3-7



To pass the test $i_T \not> 0.5\,\text{mA}\ (5\times10^{-4}\,\text{A})$

$$\text{Hence } (R_S+R_J) > \frac{35\times10^{4}}{5\times10^{-4}} = 7\times10^{8}$$

$$R_S+R_J > 700\ M\Omega$$

$$\text{and } R_S \not< 35\ M\Omega$$

$$\therefore R_J \not< 665\ M\Omega.$$

The resistance of the water jet must not be less than 665 Mega-Ohms.

$$\text{Conductivity} = \frac{1}{\text{Resistance}}$$

Hence conductivity of water spray must not be greater than $1/R_J$

Hence, conductivity $\not> 1.5\times10^{-9}$ Siemens/meter

ie $\not> \underline{1.5\,\text{nS/m}}$

Figure 2
Test circuit of Annex C of BS EN 3-7

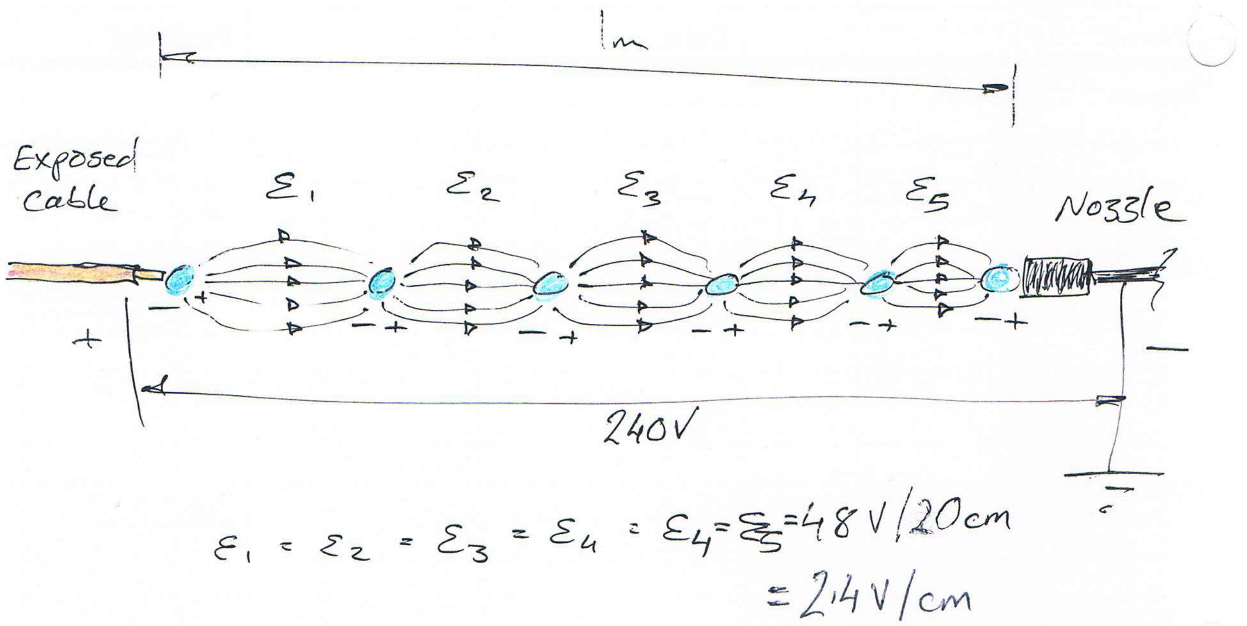


Figure 3
Electric field dispersion in a stream of charged droplets

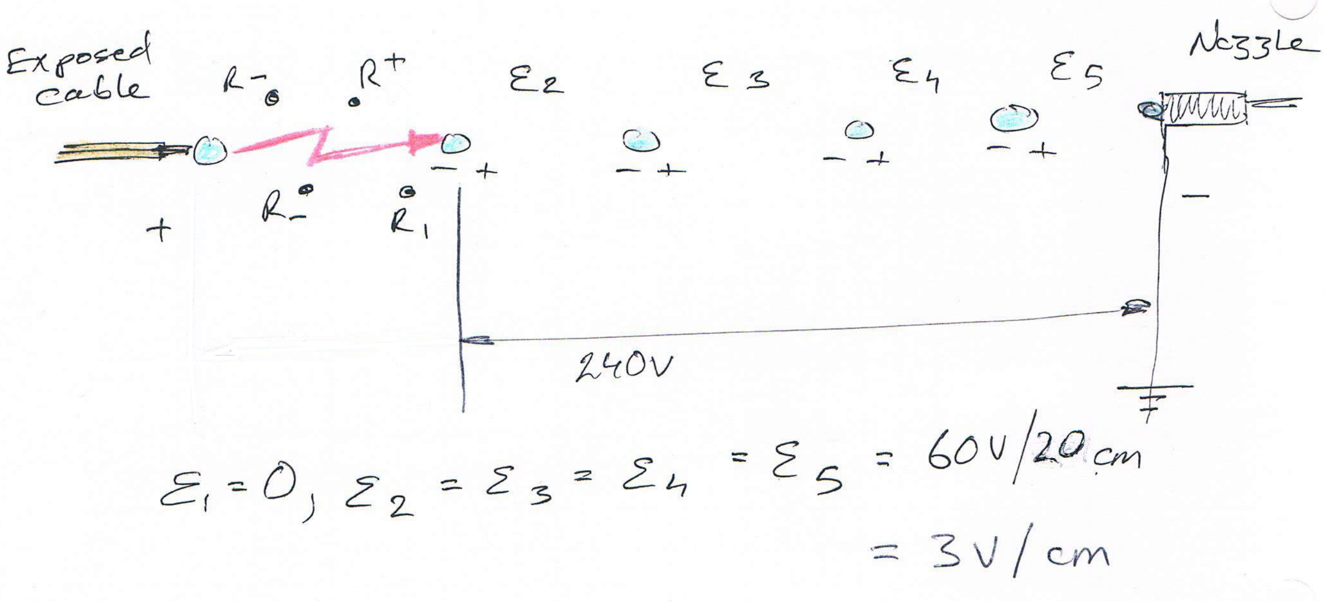


Figure 4
Charged droplet stream entering a charged smoke zone

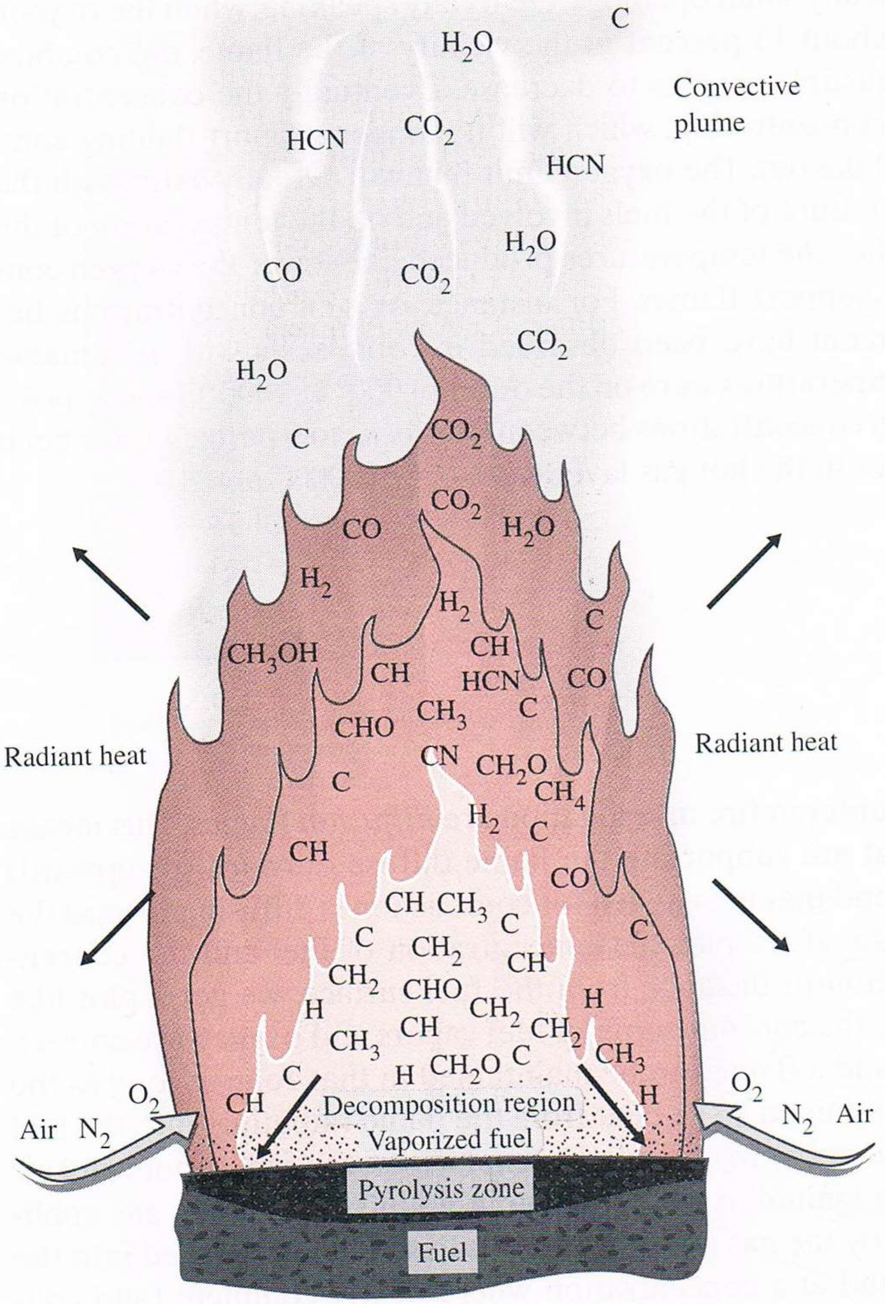
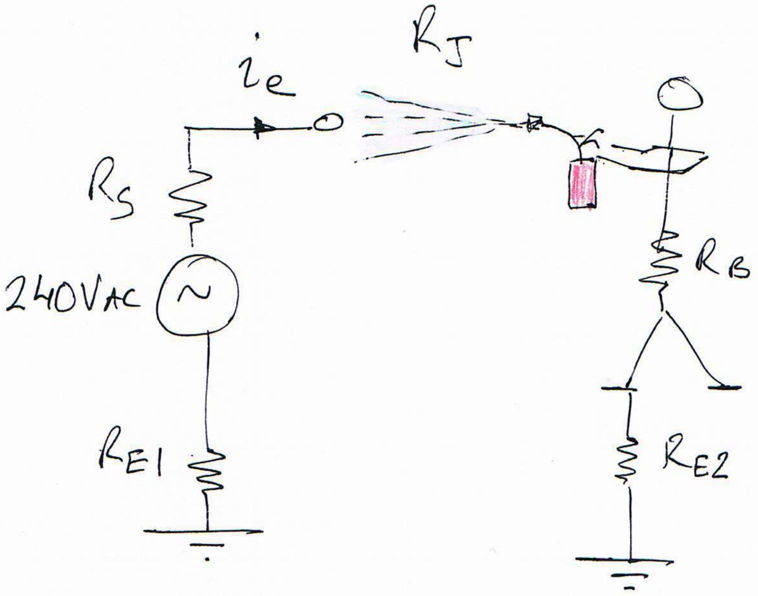


FIGURE 3.1 ◆ Typical flaming combustion of organic fuel showing decomposition region where volatized fuel decomposes to simpler species before combustion and intermediate products are formed.

Figure 5
Extract from NFPA 911 showing species development in a fire

Figure 6
Typical applications of a fire extinguisher



$$i_e = \frac{240}{R_S + R_J + R_B + R_{E2} + R_{E1}}$$

But as $R_J \simeq R_B$ and $R_B \gg R_{E1}, R_S$ and R_{E2}

$$i_e \simeq \frac{240}{R_B + R_J}$$

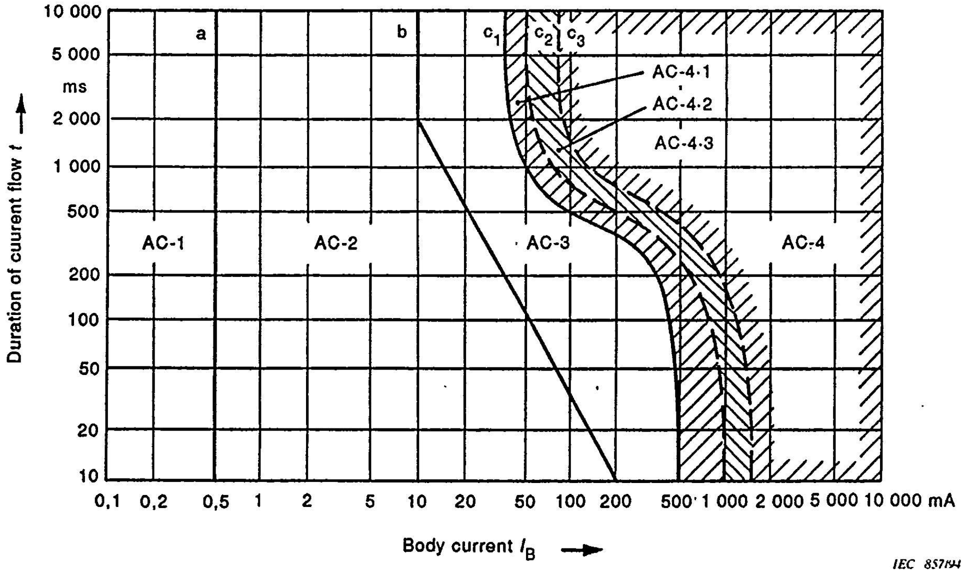
For $i_e < 30mA$ and $R_B \simeq 2{,}000\Omega$

$$R_J > \frac{240}{30\times10^{-3}} - 2\times10^{-3}$$

$$R_J > 8{,}000 - 2{,}000$$

$$\underline{R_J > 6{,}000\ \Omega}$$

Figure 7
Circuit diagram when fighting a fire with exposed, live conductors

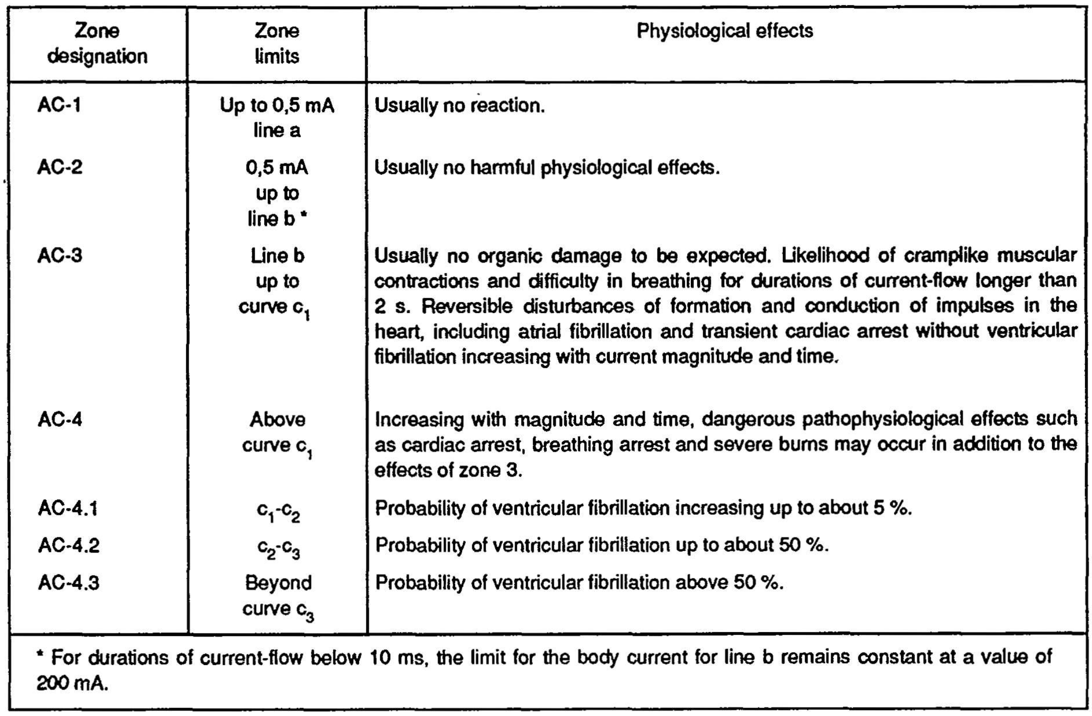


NOTE – As regards ventricular fibrillation, this figure relates to the effects of current which flows in the path left hand to both feet. For other current paths, see 3.6 and table 5. The threshold values for durations of current flow below 0,2 s apply only to current flowing during the vulnerable period of the cardiac cycle.

Figure 14 – Time/current zones of effects of a.c. currents 15 Hz to 100 Hz
(For explanations, see table 4)

Figure 8
Extract from IEC 479-1

Table 4 – Time/current zones for a.c. 15 Hz to 100 Hz



Zone designation	Zone limits	Physiological effects
AC-1	Up to 0,5 mA line a	Usually no reaction.
AC-2	0,5 mA up to line b *	Usually no harmful physiological effects.
AC-3	Line b up to curve c_1	Usually no organic damage to be expected. Likelihood of cramplike muscular contractions and difficulty in breathing for durations of current-flow longer than 2 s. Reversible disturbances of formation and conduction of impulses in the heart, including atrial fibrillation and transient cardiac arrest without ventricular fibrillation increasing with current magnitude and time.
AC-4	Above curve c_1	Increasing with magnitude and time, dangerous pathophysiological effects such as cardiac arrest, breathing arrest and severe burns may occur in addition to the effects of zone 3.
AC-4.1	c_1-c_2	Probability of ventricular fibrillation increasing up to about 5 %.
AC-4.2	c_2-c_3	Probability of ventricular fibrillation up to about 50 %.
AC-4.3	Beyond curve c_3	Probability of ventricular fibrillation above 50 %.

* For durations of current-flow below 10 ms, the limit for the body current for line b remains constant at a value of 200 mA.

Figure 9
Extract from IEC 479-1

APPENDIX A

THREE PHASE ELECTRICITY EXPLAINED

(6 pages)

THREE PHASE ELECTRICITY AND EARTHING

To make most efficient use of generators, three sets of coils are fitted instead of one. **Figure 1** illustrates how electricity is generated from each coil producing a "phase" or "live" supply. As each coil passes through the magnetic field in the generator it produces electricity which will peak in voltage as it passes through the pole of the magnetic field. Hence there are 120˚ of rotation between each phase reaching its peak voltage. There will therefore be a voltage differences between each phase which allows current to flow between them. Where one phase is used by itself to supply a load (e.g. a socket or lighting circuit) then current must return to the generator along a "neutral" conductor.

It is the European standard that the voltage between each pair of phases is 400V. The voltage between any phase and neutral is 230V. By connecting the central point of the generators to earth this ensures that no phase will be at more than 230V above earth under normal conditions.

The three phases can be used by themselves to supply an equally balanced load. Figure 1 shows a three-phase motor connected to the supply. The currents drawn by each coil of the motor will balance out. There will always be one or two phases feeding current into the motor and two or one being used as a return conductor but as each voltage (and current) varies sinusoidally, the resultant load on each phase will be equal and constant.

Where one phase is used by itself to supply a load (e.g. a socket or lighting circuit) then current must return to the generator along a "neutral" conductor otherwise it is not possible for electric current to flow. Hence a neutral connection is made to the central point, or "star point", of the generator. Single phase electricity is commonly supplied to domestic premises by taking phase and neutral cables from the local distribution transformer and connecting them to each house in a 'daisy chain', such that, for example, each third property is connected to the same phase.

If a single-phase load is connected to each phase, then, because they are connected to the neutral bar, the current going through a load connected, say, to the red phase could return via the neutral and via a load connected to the blue phase. If each connected load drew the same amount of peak current, there would be virtually no current flowing through the neutral. If, however, one load draws far more current than the other two, the imbalance of current would return via the neutral.

It is therefore sensible when arranging single phase loads for connection to a three phase supply, to ensure that each phase will supply the same amount of current. This prevents any of the phases or the neutral, being overloaded.

The centre point of the generator is connected to earth (see **Figure 2**) for reasons of transmission system protection. The benefit of this is that the voltages in the system are referenced to earth so it is always known that a single-phase supply will be at 230V (with respect to earth) and two phases at 400V (with respect to each other). The disadvantage is that if a cable is damaged and a person comes into contact with an exposed conductor, current can flow through them to earth and give them an electric shock. It is therefore important to ensure that exposed metalwork is connected together and to a firm earth connection so that in the event of a fault, the current will prefer to flow through the earth conductors rather than the person. Rather than relying on the ground to provide the return path from the consumer’s premises to the supply transformer/generator, a cable is run from the star point of the generator/transformer to ensure a good route to ‘earth’ (ie, the star point) is always available. This can be seen in **Figure 3** where there is a cable from the start point running alongside the power supply cables to the consumer’s ‘earth’ terminal. If the ‘earth’ conductors are arranged so has to have a very low resistance, the earth fault current will be large and cause rapid operation of protective fuses or circuit breakers thereby ensuring rapid removal of the fault from the system.

From the above it can be seen that when a load is connected to a three-phase supply, the current will circulate through each phase and back through the others. When a load is connected to a single phase, the current will circulate through the phase and back to the point of supply along the neutral. If there is a fault such that a cable comes into contact with earthed apparatus, the current will flow through the phase, through the fortuitous circuit to earth then back through the earth to the generator. This path is known as the ‘earth loop’ and the resistance (impedance) of the earth loop is an important parameter in the operation of circuit protection. The earth loop impedance is a measure of the resistance to current flow of the whole circuit, including the distribution cables from the electricity sub-station to the premises and back through the earth path. The earth loop is the circuit through which earth fault current will flow; the red dotted line in Figures 2 and 3 illustrate the earth fault loop for the single-phase appliance connected to the blue phase of the electricity supply.

The above descriptions discuss electricity flow from the generator, through the circuit and back to the generator. In practise, the electricity is transmitted over long distances at very high voltages then reduced at a local distribution transformer in a local sub-station. The transformer has three windings arranged in the same way as Figure 2, hence the above discussions about voltage and current still apply.

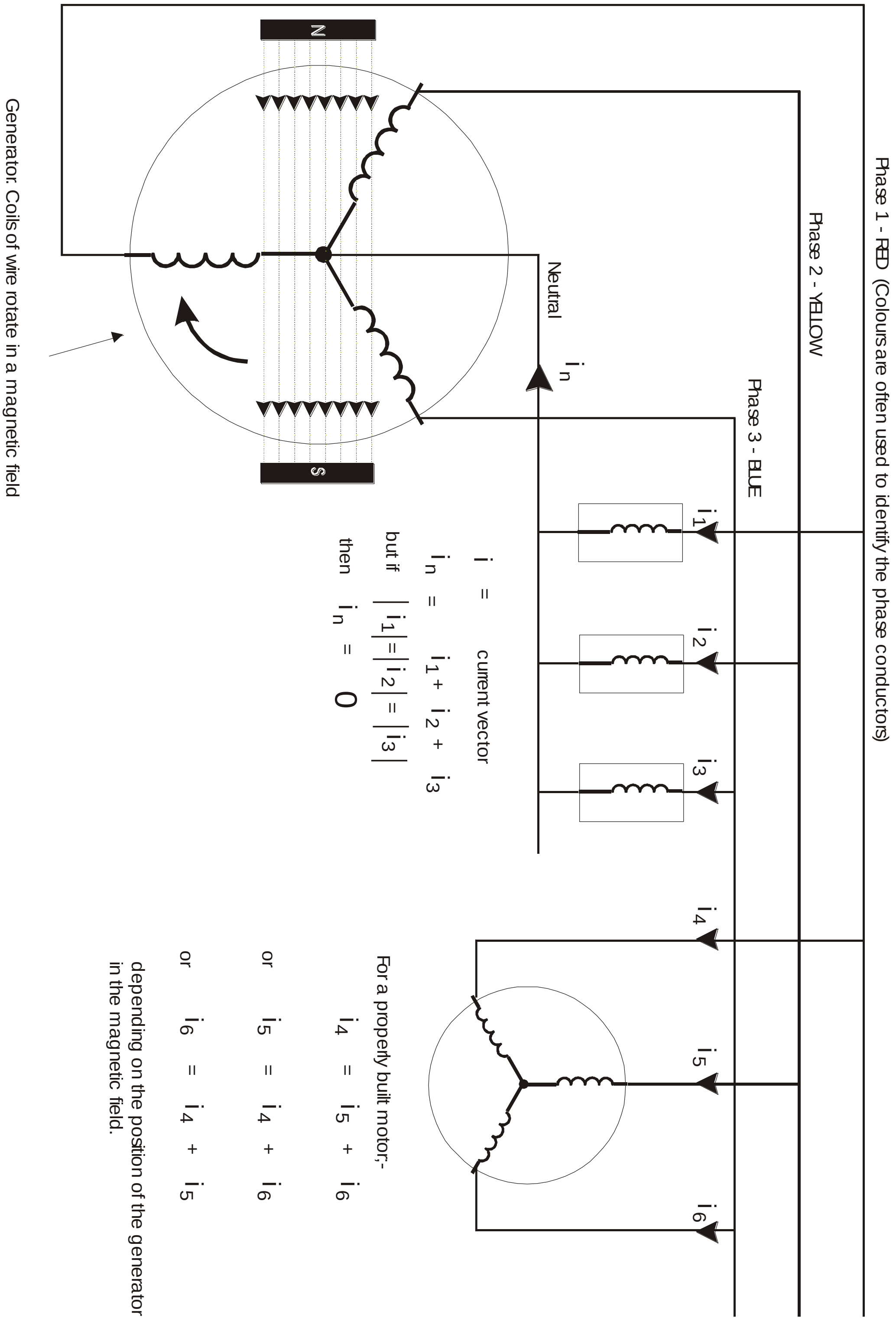


Figure 1.Generation and utilisation of electricity

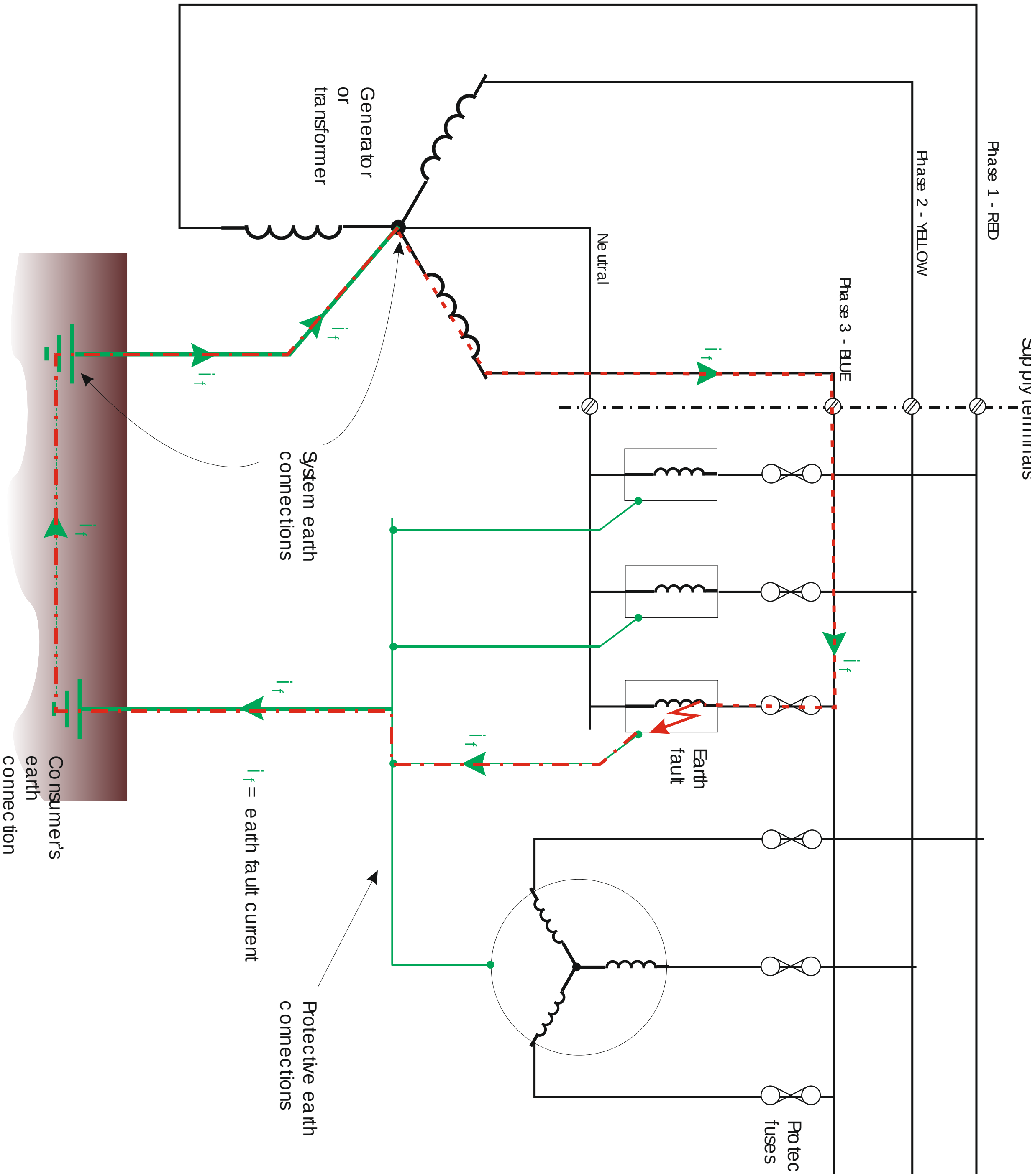


Figure 2. Fortuitous earth protection

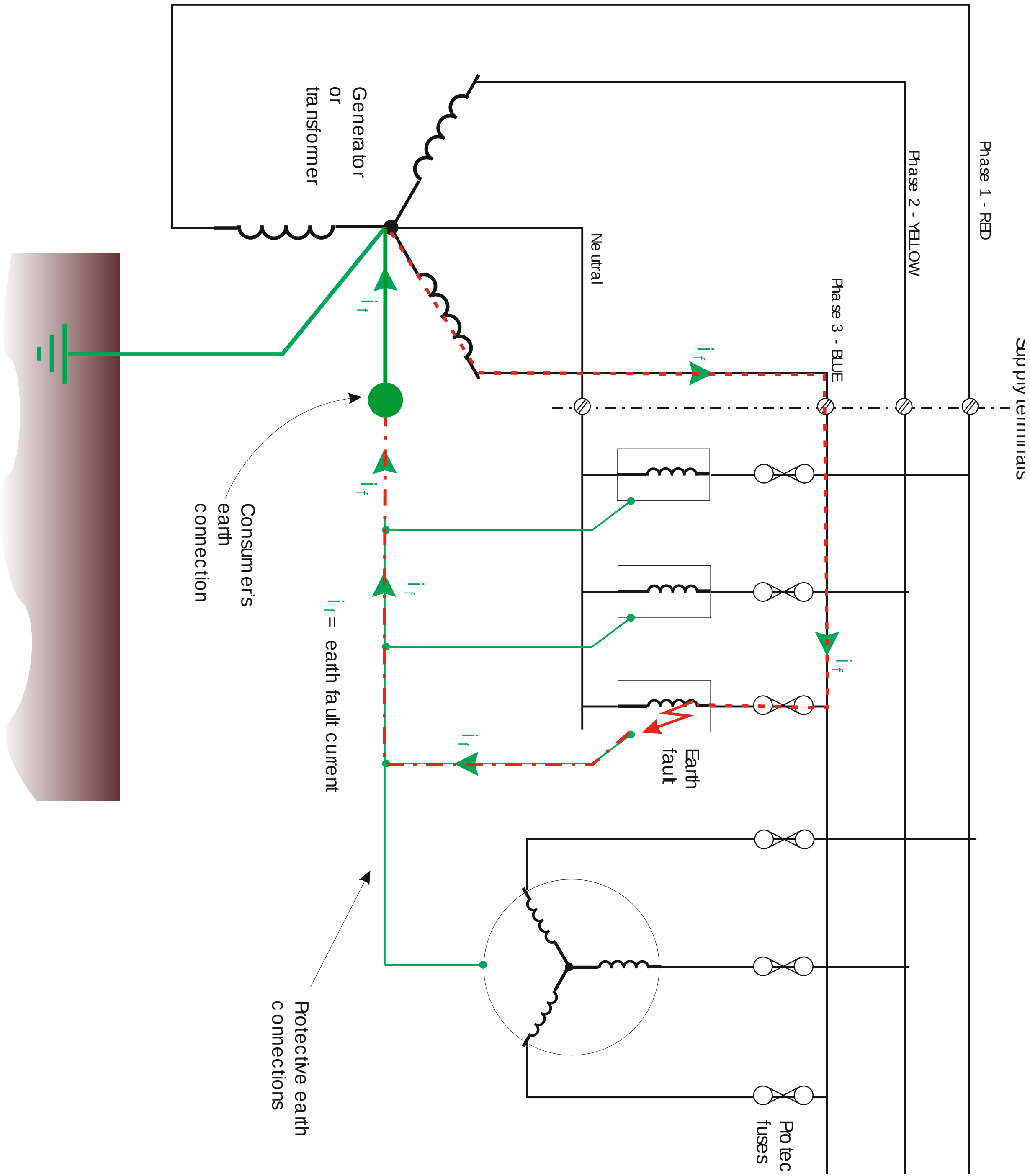


Figure 3. Designed earth protection

APPENDIX B

POOL VOLTAGE EQUATION

(3 pages)

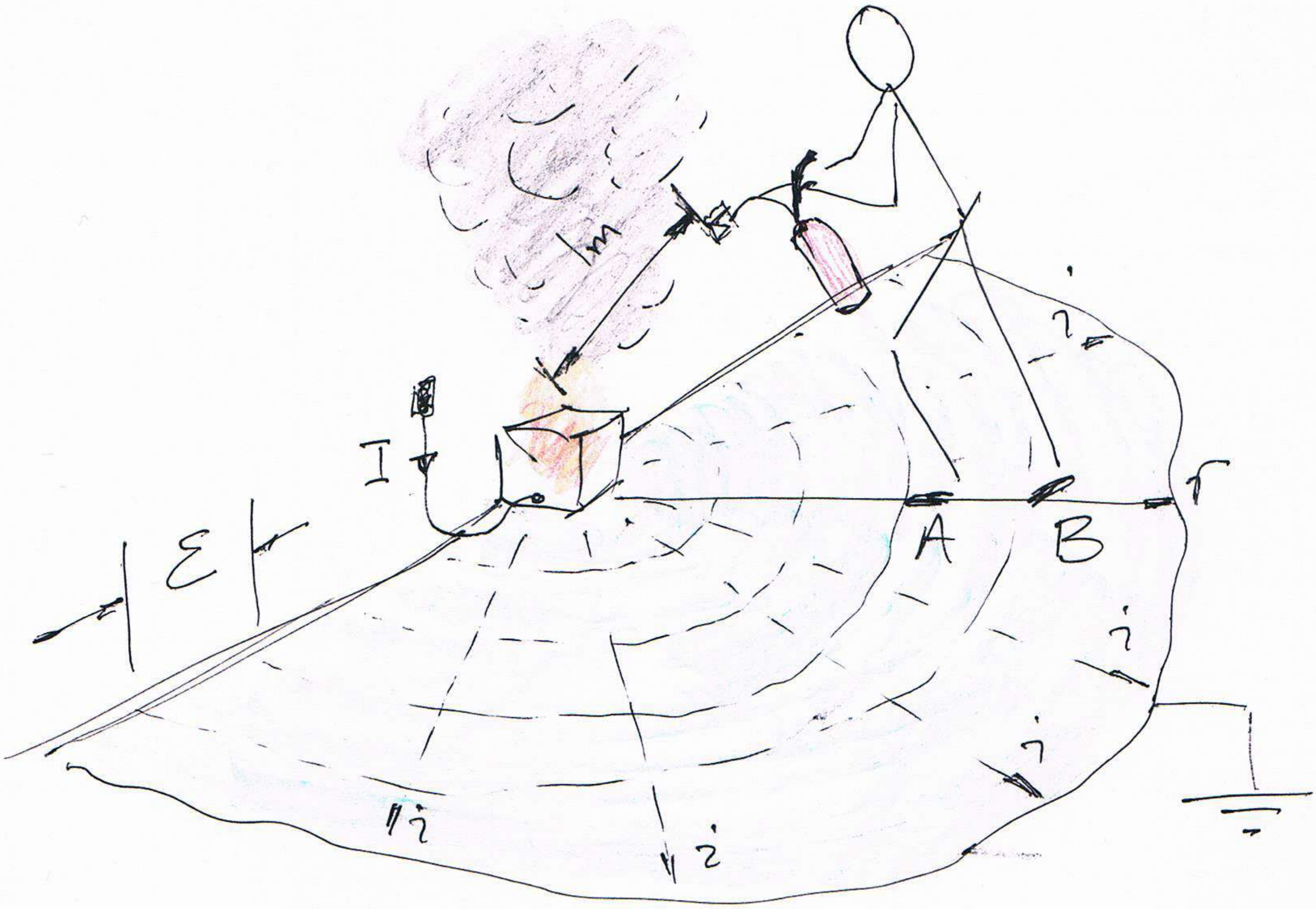


Figure A1
Electric field and current distribution through a pool of fire-fighting water.

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Pool voltage equation

E – Electric field is radial from source (refer fig.

J – Current density, is sum of currents radiating through pool

Hence $J = \frac{\sum i}{\text{area}} = \frac{I}{\frac{1}{2}\pi r^2} = \frac{2I}{\pi r^2}$

$E = \rho J$ where ρ is resistivity of pool water

$\therefore$ $E = \frac{J}{S}$ where S is conductivity of pool water

To find the voltage between feet at positions A,B

$$V = -\int_A^B E\,dr \Rightarrow -\int_A^B \frac{J}{S}\,dr.$$

$$V = -\frac{1}{S}\int_A^B \frac{2I}{\pi r^2}\,dr$$ assuming constant conductivity throughout pool (worst case)

$$\therefore V = -\frac{1}{S}\int_A^B \frac{2I}{\pi r^2}\,dr = -\frac{2}{S\pi}\int_A^B I r^{-2}\,dr.$$

If we assume I is constant because S is constant and consider only the magnitude as the current is alternating:

$$V = -\frac{2I}{S\pi}\Big[-r\Big]_A^B \qquad V = \frac{2I}{S\pi}\Big[r\Big]_A^B$$

Note of: Water pool shock voltage calculations

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Pool Voltage Equations

Refer to figure

If we consider that foot A is below the nozzle of the extinguisher then $r_A = 1.0$. Assume foot B is 600 mm behind for a strong stance, $r_B = 1.6$

Hence
$$V = \frac{2I}{S\pi}\left[1.6 - 1\right] = \frac{1.2\,I}{S\pi}$$

from which
$$S = \frac{1.2\,I}{\pi V}$$

If we assume the fire is in an appliance connected by a 13A plug containing a typical BS 1361 fuse then with a fuse factor of 1.5, the operating current is 19.5 Amps, say 20A.

At the limit of Safety Extra Low voltage, 50V

$$S = \frac{1.2 \times 20}{\pi \times 50} = \frac{24}{157} = 0.153\ \text{S/m}.$$

If we assume the fire is in 3φ equipment supplied by a BS 88 fuse with a 1.4 fuse factor then, at 200A rating,

$$S = \frac{1.2 \times 200 \times 1.4}{\pi \times 50} = 2.14\ \text{S/m}$$