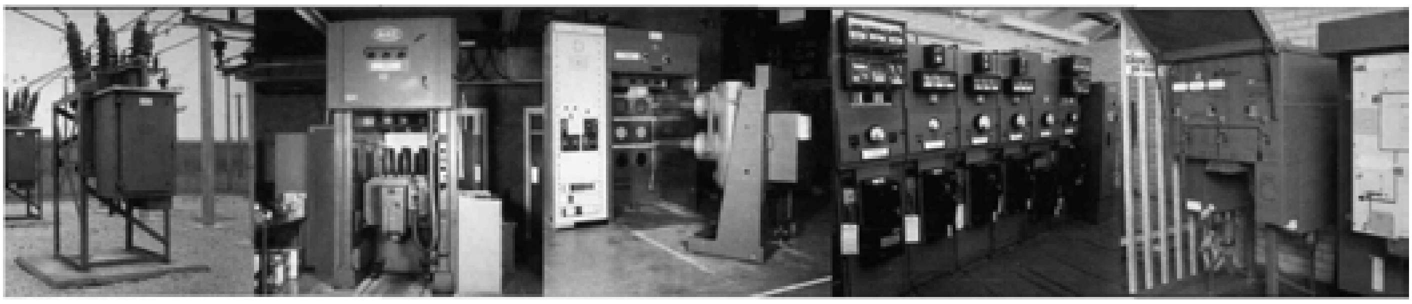
HSG230

Keeping electrical switchgear *safe*



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This guidance is issued by the Health and Safety Executive. Following the guidance is not compulsory and you are free to take other action. But if you do follow the guidance you will normally be doing enough to comply with the law Health and safety inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

Contents

Introduction

1 This book is aimed primarily at owners and operators of electrical switchgear in industrial or commercial organisations. Electricity distribution companies or equipment suppliers may also find the advice useful. It should help managers, engineers and other relevant personnel understand their responsibilities and duties in the selection, use, care and maintenance of high-voltage and low-voltage switchgear.

2 In some circumstances the guidance may not be directly applicable and for interpretation any queries should be directed to the appropriate enforcing authority. Definitions of some of the key terms used in the book are provided in Appendix A.

Scope

3 This book provides guidance on the selection, use, care and maintenance of three-phase electrical switchgear with voltage ratings from 400 V alternating current (ac) up to and including 33 kV ac. It deals with circuit-breakers, switches, switch fuses, isolators and high-voltage (HV) contactors. The types covered embrace switchgear using oil, air, sulphur hexafluoride (SF,) or vacuum as the interrupting medium.

4 The guidance does not address direct current (dc) switchgear, switchgear used on single-phase ac traction systems of any voltage, low-voltage moulded case circuit-breakers, or low-voltage contactors and miniature circuit-breakers.

Background

5 In general, switchgear has a proven record of reliability and performance. Failures are rare but where they occur the results may be catastrophic. Tanks may rupture and, in the case of oil-filled switchgear, can result in the ejection of burning oil and gas clouds, causing death or serious injury and major damage to plant and buildings in the vicinity of the failed equipment.

6 Modern switchgear using sulphur hexafluoride gas or vacuum as the insulating medium has removed the hazard of burning oil but inevitably has introduced other risks that need to be managed. Accident experience has shown that failure usually occurs at, or shortly after, operation of the equipment. So the way switchgear is operated, its condition and the circumstances existing in the system at the time of operation to a large extent determine whether the equipment will function safely.

7 Switchgear of all types and ratings has been manufactured in accordance with British and international standards for over 60 years. As with most equipment, current specifications bear little resemblance to those of earlier years and the previous specifications have been shown, by subsequent experience and by technical developments, to be deficient. Examples of differing requirements between earlier and current standards are those relating to operating mechanisms and fault test sequences.

Legislation

8 The Health and Safety at Work etc Act 1974 (HSW Act), the Management of Health and Safety at Work Regulations 1999 (Management Regulations) and the Electricity at Work Regulations 1989 (EAW Regulations) apply (see Appendix B 'Further reading').

9 The HSW Act contains requirements to the effect that anyone employing people should ensure their safety so far as is reasonably practicable.

10 The Management Regulations require an employer (or self-employed person) to make an assessment of risks to employees or others, taking specialist advice where necessary. The level of detail in the assessment should be broadly proportionate to the risk, whch means it needs to be fairly detailed in the case of switchgear as the risk is one of serious injury or even death.

11 The EAW Regulations require electrical equipment for use at work to be constructed, maintained and operated in such a way as to prevent danger so far as is reasonably practicable.

12 Equipment should not to be used where its strength and capability may be exceeded and it should be protected from excess current. This is discussed in paragraphs 22 and 23 (see also EAW Regulations, regulation 5).

Equipment and its location

13 In any premises that require a high-voltage supply, that incoming supply often passes through switchgear to control dstribution of electricity within the site. Switchgear varies in size, age and appearance. Typical examples are shown in Appendix C. It is important to recognise that the different categories of switchgear, ie switches, isolators, switch fuses, HV contactors and circuit-breakers, have a different switching capability and you need to be familiar with the switchgear types on the site and their purpose.

14 Switchgear is generally located in substations and/or switchrooms, ie areas that are separated from the day-to-day activity of the premises and which, in many instances, are visited on a very infrequent basis. Such rooms are generally locked and access is usually restricted to authorised persons. Periodic inspection of switchrooms is considered good practice to ensure that deterioration is not occurring to either the switchgear or the environment. For example, it is unacceptable for any building damage to cause water or debris build-up on equipment that is for indoor use. Procedures should be in place to detect and rectify such faults as quickly as possible.

15 In some premises, low-voltage switchgear will be located in work activity areas. There will also be cases where high-voltage switchgear and motor starters are found adjacent to the machinery that they control. It is important that the equipment is in good condition. Operatives in the area should be made aware of this and procedures put in place for them to report incidents and/or any damage that occurs.

16 Occasionally switchgear is located outdoors. This can lead to even fewer visits than to switchgear located in switchrooms and again a practice of periodic inspection is necessary, along with procedures to deal with any deterioration that is found.

17 Much of the equipment still in service is some 25 years old or more. Equipment that is 35 or more years old is usually of particularly robust construction. As a result, it is often assumed (incorrectly) that the equipment has an unlimited life in service. Much of the older equipment has a limited operation capability and these limitations are not always understood by operating staff. An example of this is a situation where a defined delay before operation is necessary after a fault clearance to allow time for the arc extinction processes to recover.

Potential problems with switchgear

18 This section highlights a number of potential problems that may be encountered with switchgear. These are particularly relevant to oil-filled electrical switchgear that is more than 25 years old but may well be valid for more modern switchgear, depending on the circumstances of a specific user or site. The following sub-sections provide guidance on dealing with the relevant issues.

Lack of knowledge

19 Switchgear should be operated by trained staff, who are often known as 'authorised persons'. In the past these were generally works' electrical engineers and senior supervisors but due to changing employment patterns this is no longer the case. Some users may not have any 'authorised persons' on their staff and may have chosen to contract out all operational work and maintenance of their switchgear. As a result, there may be no one within the organisation who understands the equipment, its safe operation or the need for maintenance. This should be treated as unacceptable and steps should be taken to remedy the situation.

20 Staff responsible for care, operation and maintenance of switchgear should receive training (or refresher courses) relevant to the duties that are required of them. This is particularly relevant to staff called upon to operate switchgear and such staff should have competency at the 'authorised person' level. Even where all operational and maintenance work is contracted out, it is preferable that there is sufficient technical knowledge within the company to audit the practices of the contractors and to handle abnormal (including emergency) situations that will inevitably arise on the premises. If this is not the case, this role should be given to an independent organisation.

21 A number of organisations (eg electricity distribution companies or specialist training organisations) provide training courses to the varying levels of competency that may be required.

Overstressing

22 Switchgear is described as being 'overstressed' when the potential fault energy of the electrical system (eg from a short-circuit) at the switchgear location exceeds the fault energy rating of the switchgear. When it is operated under fault conditions it is unable to cope with the resulting electrical and thermal stress that can sometimes lead to catastrophic failure, ie total destruction of the switchgear. Such failures are accompanied by arc discharge products, burning gas clouds and oil mist (if oil switchgear). These envelop anyone near the switchgear, resulting in serious burn injuries and often death.

23 While the original installation design may have been adequate, modfications and extensions to the network that feeds the switchgear, or of the network controlled by it, can lead to situations where the switchgear is overstressed. An example is where the infeed capacity has been increased. Also some configurations of the network (eg by paralleling of transformers onto the switchgear busbars) can lead to an overstressing situation. Such situations should be documented and clear operating instructions provided to prevent such a configuration being created. They can result from a response to an abnormal operational situation whereby an incorrect network configuration is inadvertently set up.

Modifications

24 Over the years, manufacturers have issued. details of modifications to existing equipment that should be carried out on switchgear to improve its safety However, the procedures for circulating such information are not perfect and in many cases users are unaware of the need to carry out these modifications. As a result, the equipment may be incapable of performing satisfactorily. It would be wise to carry out an audit, if one has not already been undertaken, of the switchgear for which the user is responsible and liaise with the manufacturers (or other appropriate expert) to identify any outstanding modifications.

25 It is also good practice to catalogue any circulars or instructions that are received relating to modifications and make them readily available to all staff whose duties involve the operation and maintenance of switchgear.

Dependent manual operating mechanisms

26 The operating mechanisms of most switchgear, ie independent manual, dependent power, independent power and stored energy (see Appendix A for definitions), do not result in any particular risks. However, this is not the case where switchgear is of the dependent manually operated (DMO) type. DMO mechanisms were fitted to both high- and low-voltage switchgear but these types of operating mechanism are no longer made.

27 With DMO switchgear, the operator closes or opens the switchgear solely by manual effort. Therefore movement of the contacts is totally dependent upon the speed and actions of the person operating the levers/ handles. Any hesitancy on the part of the operator is likely to lead to a serious and potentially fatal failure of the switchgear, eg operators may not realise that they have failed to close the circuit-breaker completely and release the operating lever/handle, thus drawing an arc within the oil tank which can result in catastrophic failure. It is essential that these levers/handles are operated in a decisive and positive manner without any hesitation and as rapidly as possible, particularly over the latter portion of the closing operation. In addition, should a lever/handle be closed onto a system fault the force needed is significantly greater than when closed onto normal system load current. In some cases it may be physically impossible to close (or open) the device under fault conditions, again this may result in failure. See paragraphs 54-58 for guidance on actions to take in these situations.

Lack of maintenance

28 This is usually the result of oversight, lack of knowledge of the equipment, or pressures to avoid plant shutdowns. Whatever the cause, it will lead to a situation where switchgear has been neglected (this is particularly true of low-voltage devices). The result is that routine servicing such as oil changing, lubrication, contact refurbishment, and verification of contact engagement may not have been carried out for many years and deterioration due to corrosion may also have occurred. In some cases the expertise in maintenance techniques and for handling insulating oil is lacking.

29 Where oil-filled switchgear has been neglected, it is difficult to. assess the actual fault capability of the switchgear in the state in which it is found. An audit of maintenance records should be carried out to establish whether or not there is a problem and, if necessary, a detailed condition assessment should be made.

Anti-reflex handles

30 At one time, a common cause of accident/incidents with high-voltage switches was when an operator carried out an incorrect operation when moving the operating handle (eg switching from OFF to EARTH instead of from OFF to ON) and then immediately attempted to reverse that incorrect operation. As oil switches are not rated for the interruption of fault current, any attempt to open them when fault current is flowing is likely to lead to disruptive failure, with the possibility of the operator(s) being killed.

31 To address this problem, many manufacturers have produced anti-reflex operating handles for their equipment. These handles are one-way operating devices and have to be removed and relocated before carrying out a further operation, thus imposing a time delay between operations. This built-in time delay means that when the incorrect operation is reversed, no fault current is flowing (as the circuit protection will have operated to interrupt the current flow), and there is no likely failure of the switch. The built-in time delay is also important when closing from OFF to ON onto a known fault.

32 A review of the oil switches and oil switch fuses should be undertaken to determine whether an anti-reflex facility exists. Where no such facility exists, action should be taken to retrofit an appropriate modification.

Management of switchgear

33 It is the duty of all users of switchgear to provide management systems that will ensure safe operation and minimise the risk of injury, Such management systems should include the following:

(a) policies and procedures covering the installation, commissioning, operation, maintenance and removal of the equipment;
(b) an appropriate system of records;
(c) definition of responsibilities and training requirements;
(d) auditing of the effectiveness of procedures.

34 An important pre-requisite is to identify all switchgear in service and to ensure that up-to-date records of network diagrams and configurations (including prospective fault level values at every relevant point on the system) are available. From this basic information, any potential risks, eg overstressing or dependent manual operation, should be assessed so that any necessary remedial action can be identified to ensure that the equipment and systems are being operated safely, and that work is put in hand to eliminate or reduce the risks. The basic records for an LV installation may also contain electrical installation certificates and periodic inspection reports. Further information is in BS 7671 (see Appendix B 'Further reading').

35 Sufficient technical expertise may not be available in-house to carry out a risk assessment and decide on the appropriate precautions. In such cases switchgear users should take advice from suitably competent organisations, including:

(a) electricity distribution companies;
(b) switchgear manufacturers;
(c) switchgear maintenance companies with particular expertise in older types of switchgear;
(d) consulting organisations specialising in switchgear.

36 The British Electrotechnical and Allied Manufacturers Association (BEAMA) can provide up-to-date details of manufacturers and the Institution of Electrical Engineers (President's list of experts) may also be able to provide help and guidance as to other sources of information and expertise (see Appendix D for their addresses).

Records

37 All switchgear users should have a record of their switchgear available. Where there are doubts about the accuracy or validity of records then a new inventory should be prepared as a matter of urgency. The basic records that are suggested are discussed below

Network diagrams

38 The diagram is a schematic representation of the network and it is ideal to display the interconnection of the plant items, including the switchgear. This allows the normal and any alternative arrangements of the network to be displayed in a way that is readily understood, bearing in mind that there may be several switchrooms or substations on any one site. In addition, the diagrams can be annotated with the status of the switchgear in a particular network arrangement to avoid any confusion, particularly where overstressing may be an issue.

Asset register

39 An asset register forms the basis of management information providing both basic identification information (location, type etc) and performance/maintenance records. Although some items may not be scheduled to receive any routine maintenance, all items that are likely to receive some kind of attention during their life should be included.

A hierarchical structure is essential to ensure a logical approach to establishing information for asset management purposes. It is possible to develop complex hierarchies, but most asset owners find that a two- or three-level hierarchy is sufficient. A typical structure might involve:

Level 1: Location/cost centre/process or production grouping
Equipment associated with an activity, eg production department.

Level 2: Unit
Collection of plant items that are interdependent and adjacent to each other in Level 1.

Level 3: Item
Distinct item of plant within the unit, usually the smallest discrete piece of equipment from an operational point of view, eg item of switchgear, tripping battery etc.

40 Use of a hierarchical structure allows the straightforward development of an asset numbering system, eg an item can be coded as a combination of the cost centre code, the unit code and its own code to provide a unique code.

41 Along with the structure, the level of information to be recorded against each item needs to be decided. Collecting plant data can be a time-consuming and costly exercise, particularly basic data that does not directly contribute to improvements in performance and safety. Care should be taken not to collect too much basic data and typical information that is required for an item of switchgear at each location includes:

(a) location (may already be defined by the structure);
(b) manufacturer and type reference;
(c) serial number and year of manufacture;
(d) date of installation;
(e) voltage rating;
(4 current rating;
(g) fault rating and whether it is a certified or assessed and assigned rating;
(h) type of operating mechanism (dependent manual, independent manual, dependent power, independent power and stored energy);
(i) details of any modifications, eg fitted anti-reflex handles;
(j) if the equipment is an oil circuit-breaker, whether it is plain break equipment (ie equipment without arc control devices) or not;
(k) type of electrical protection fitted and details of the settings.

Maintenance records

42 A minimum requirement would be to record:
(a) the date of the last maintenance/oil change (where applicable);
(b) in the case of a circuit-breaker, the number of fault operations since it was last maintained (if known).

43 This provides a record that maintenance schedules are being adhered to and also provides planning for the next maintenance. As will be seen in later sections, some measurements are taken during the maintenance and it is valuable to record such data in order to determine trends in performance and what problems are emerging. Such records should be retained as a history and the information should not overwrite the previous record.

Operational issues

Fault level and ratings

44 For each item of switchgear identified in the site inventory (in particular the DMO switchgear) you need to take the following steps:
(a) Identify the British Standards or other standards relevant to the individual switchgear.
(b) Calculate fault energy levels at the output

terminals of each item of switchgear. In some cases it will be necessary to include the fault energy contribution from rotating plant such as large induction motors, synchronous motors and generators. The electricity supply company is required to provide, on request, the maximum short-circuit current at the incoming supply terminals (Electricity Supply Regulations 1988 regulation 32 or Electricity Safety, Reliability and Continuity Regulations 2002, regulation 27).

(c) Determine the switchgear rating. Where switchgear is in use that was designed to obsolete British Standards (see Appendix B), reassessment of the rating by manufacturers or specialists may be necessary.

(d) Compare the fault energy levels calculated in (a) with the certified or assigned switchgear fault energy rating determined in (c) to establish whether the equipment is overstressed.

45 It is recommended that the procedures are applied to both high-voltage (ie 3.3 ky 6.6 ky 11 ky 22 kV and 33 kv) systems and low-voltage (230/415 V) systems as separate exercises. It may be easier to deal with each individual system at each voltage separately as the individual system may have very different problems.

46 Other than for the simplest of system configurations, the calculation of fault levels is a specialist topic requiring support from people experienced in undertaking and interpreting such calculations.

Effect of on-site generation and other large rotating machines

47 On-site generating plant and other large rotating machines have an impact on the operational duty of switchgear, especially in terms of fault current handling, connection of the generators and synchronous motor drives to the network and on the protection requirements. The following actions need to be taken:

(a) Check that the fault energy levels at the circuit-breaker(s) controlling the generators and other large rotating machines are within the capability of the circuit-breaker, paying particular attention to older switchgear. If this is not the case, then treat the circuit-breaker as overstressed. (The review of fault levels discussed in the previous section should have included the on-site generation.)

(b) Provide measurement equipment to ensure that generator or synchronous motors are synchronised before closing the controlling circuit-breaker(.$, since attempting to close a circuit-breaker or switch onto networks that are not synchronised can lead to overstressing.

(c) Estimate the effects on the transient recovery voltage across the controlling circuit-breaker(s) when opening on a fault being fed by the generator and other large rotating machines. If this exceeds the rating of the circuit-breaker(s), then treat the circuit-breakers as overstressed. A problem that may arise with older switchgear is relating the original test requirements for establishing rating against the conditions on-site. In these cases expert advice should be sought.

(d) Confirm whether the protection settings in use are appropriate for the situations when the generation is operating and when it is not operating. For guidance refer to Electricity Association Engineering Recommendations G59/1,1991 and G75,1996.

Precautions for reducing the risk of switchgear failure and injury

48 The need for precautions to be taken and how quickly they should be implemented will depend on whether the equipment is overstressed, whether it has been modified in accordance with manufacturer's instructions, the type of operating mechanism, the maintenance condition etc.

Overstressed switchgear

49 Where the switchgear fault energy rating is less than the potential fault energy levels, the following actions should be taken immediately, regardless of the type of operating mechanism:

(a) Prohibit all live operation and disable automatic tripping of the switchgear. This action will necessitate readjustment of electrical protection further back towards the source of supply so that the electrical protection at the switchgear can be made non-operative. The readjustment is needed to ensure adequate levels of electrical protection for the system.

(b) Prevent people gaining access to the switchgear while it is live.

(c) The switchgear should be maintained in accordance with manufacturer's advice by trained personnel. Particular attention should be paid to insulating oil, solid insulation, contact assemblies, operating mechanisms, seals and gaskets, as applicable.

(d) Reduce the fault energy levels, if possible. In some cases changing system operating conditions will achieve this, for example operating transformers as single feeders to switchboards and not in parallel with other transformers. These changes should be made as soon as possible to reduce the fault energy level to as low as practicable.

(e) Longer-term measures that can be taken to reduce fault energy levels include fitting reactors or network reconfiguration. These measures may be used to reduce fault energy levels to values less than the fault energy ratings of switchgear. Such actions are normally only a solution for high-voltage installations. It should be noted these measures will not overcome the problems associated with switchgear that has no fault energy rating.

50 Where the actions (d) and (e) above reduce the fault energy levels below the rating of the switchgear, then electrical protection and live operation can be restored, after necessary measures (eg interlocks) have been provided to prevent the rating being exceeded at any time.

51 If the actions (d) and (e) in paragraph 49 do not reduce the fault energy levels below the ratings of the switchgear, and it is sited in open workshop areas, the provision of blast protection should be considered. This may take the form of suitable walls or enclosures, the purpose of which is to contain any failure of the switchgear while it is energised. However, this is a complex matter and it is often more practicable to make the switchgear dead and provide alternative electrical supplies.

52 Where high-voltage and low-voltage switchgear share the same switchroom and only one set of switchgear is overstressed, it will be necessary to either:

(a) keep personnel out until the overstressed switchgear is made dead; or

(b) where space permits, erect a suitable blast wall around that switchgear, thus permitting personnel access to the other switchgear.

53 In addition to these immediate actions, arrangements should be made to replace the overstressed switchgear as soon as possible.

Dependent manually operated (DMO) switchgear

54 Dependent manually operated (DMO) mechanisms are generally only found on older types of oil and air circuit-breakers.

55 All operation and maintenance of DMO switchgear should be restricted to those personnel trained in the operation of the switchgear concerned. They should also be aware of the dangers of operating the equipment incorrectly, the construction of the switchgear and the manufacturer's maintenance requirements. The personnel will need to be familiar with the safe system of work outlined in paragraph 56. It is essential that the actions listed to allow continued use of DMO switchgear be treated as short-term measures only.

56 Where the switchgear is not overstressed (ie ratings are greater than the actual fault energy levels), the following precautions are needed to reduce the risks that result from the fact that it has dependent manual operation:

(a) All DMO switchgear should be maintained in accordance with the manufacturer's advice. This should include, where applicable, the checking of seals and gaskets, which should be properly installed and in good condition. An annual maintenance schedule for this equipment should be prepared and be implemented.

(b) Power closing mechanisms should be fitted as a matter of urgency to all high-voltage DMO switchgear (ie 3.3 kV and above). However, this should only be carried out in accordance with the manufacturer's advice. It may not be possible to obtain the necessary guidance and advice where the original manufacturer no longer exists and there are no agents. In these cases it is not advisable to fit power closing mechanisms.

(c) A phased replacement programme should be prepared and implemented for all DMO switchgear manufactured prior to 1960 and for those high-voltage systems manufactured and installed after 1960 that cannot be fitted with power closing mechanisms. In some cases it is possible to obtain replacement circuit-breakers of modern design (often called cassettes), which can be used to replace old high- and low-voltage units and can use the existing switchgear busbar housings and support arrangements. This approach can mitigate the cost of replacement. Advice should be sought from the manufacturer regarding this approach – see also the section on 'Selection of new, replacement or refurbished switchgear' (paragraphs 163-175).

(d) When DMO switchgear is to be closed, the preferred method of operation is as follows (in order to achieve this preferred method of operation it may be necessary to change system running conditions and adjust the electrical protection accordingly):
   - make the system dead upstream using a suitably rated independent operated switch or circuit-breaker;
   - check, where practicable, the system beyond the DMO switchgear to ensure that it is fault-free. This will mean applying various electrical tests to the system;
   - if the system is healthy, close the DMO switchgear to ON; and
   - energise the system from the remote point, ensuring that no personnel are in the vicinity of the DMO switchgear.

   The following can, however, be operated with the system live:
   - bus-section and bus-coupler circuit-breakers on a fully energised system (ie live both sides); and
   - circuit-breakers controlling circuits that have been tested immediately before closure.

(e) Where the DMO switchgear has recently been operated for the purpose of routine isolation, it may be reclosed manually, providing the electrical circuit it feeds has not been disturbed.

57 Where work has been undertaken on the electrical system normally made live by DMO switchgear, the circuit should be tested comprehensively prior to operation of the switchgear.

58 Where DMO switchgear is also overstressed the precautions in paragraph 49(a) and (b) are particularly important.

Modifications

59 Where possible, details of any modifications recommended by the switchgear manufacturer to improve safety should be identified and implemented and suitable records kept.

Fault clearance

60 If a circuit-breaker shows any signs of abnormal condition (see paragraph 68) following a fault clearance operation, it needs to be examined and assessed before a decision is made to reclose it. The circuit-breaker may need to be maintained before being reclosed. On some designs of oil circuit-breakers it is normal for small quantities of oil to be ejected via the tank venting arrangement.

Care and maintenance of oil switchgear

General advice

62 Examples of typical oil switchgear arrangements are shown in Appendices C1, C2, C4, C5 and C6. The main failure modes for oil switchgear, together with their implications, are listed below.

(a) **Faults within oil compartments**
These are invariably catastrophic with explosion/fire and often involve personal injury or fatality and serious damage to the building.

(b) **Failure of oil circuit-breaker to trip (mechanism and protection faults)**
This usually results in an extended disconnection time due to upstream circuit-breaker tripping.

(c) **Solid insulation faults (external to oil compartments)**
These can cause extensive damage to equipment, injury to people and damage to the building.

62 A major concern is the risk of catastrophic failure resulting from failures within the oil compartment and these can result from:

(a) contaminated insulating oil;
(b) poor maintenance of arc interruption system (contacts and arc control devices);
(c) breakdown of solid insulation;
(d) breaking fault current above rated capability (in the case of a circuit-breaker);
(e) internal component failure.

63 Various actions can be taken to minimise these risks of catastrophic failure and these are set out below, together with the problem areas they address:

(a) **Inspection (non-intrusive)**
An external inspection will address obvious signs of abnormal condition that are detectable by sight, smell and sound.

(b) **Maintenance (intrusive)**
Maintenance under outage conditions will address problems due to mechanism defects, insulating oil contamination and deterioration, erosion of contacts and arc control devices.

(c) **Condition monitoring/assessment by partial discharge techniques**
These techniques can be used to detect and locate deterioration of solid insulation.

(d) **Refurbishment/replacement**
This approach can be taken to address problems caused by inadequate rating, inadequate operating mechanism or arc interruption system, or deteriorated or defective insulation.

64 The sections below look at the inspection and maintenance actions in detail. There is information on condition monitoring and assessment techniques in paragraphs 146-152 and on refurbishment and replacement options in paragraphs 163-175.

Inspection

65 A regular substation inspection is recommended. At the time of the inspection any remedial work should be prioritised, so that it is carried out:

(a) immediately (this should always be the case when security of the substation enclosure has been interfered with);
(b) at the earliest possible opportunity; or
(c) at the next scheduled maintenance.

66 An inspection schedule would be expected to include the following items.

Switchgear environment

67 An inspection sequence for the switchgear environment should include the following aspects:

(a) switchroom access and surrounds (including fence and external walls, if outdoors);
(b) signs of trespass and/or interference;
(c) presence and legibility of warning notices;
(d) switchroom internal fabric;
(e) firefighting equipment;
(f) general housekeeping;
(g) signs of water ingress/dampness in switchroom.

Signs of abnormal condition

68 A check for any abnormal conditions should be carried out immediately on entering the substation and if any danger is suspected then the inspection should be aborted. Typical warning signs are:

(a) high temperature in switchroom;
(b) presence of smoke;
(c) smell of 'hot' substances (oil, compound etc);
(d) audible discharges or arcing;
(e) smell of ozone;
(f) signs of leaked oil in vicinity of oil circuit-breaker tank;
(g) signs of fresh compound leaks;
(h) distortion and evidence of sooting on enclosures.

Switchgear general condition

69 The external visual inspection of the switchgear should include the following items:

(a) general condition of exposed busbars and air break switches (where present);
(b) general condition of the switchgear (rust, oil leaks, oil level gauge etc);
(c) compound leaks from cable boxes, busbar chambers, band joints and end caps;
(d) ammeters, voltmeters, operation indicators, protection equipment;
(e) labelling, padlocks and key exchange interlocks.

70 In addition to the visual inspections above, the use of limited and non-intrusive diagnostic screening should be considered for inclusion in an inspection schedule. The information provided allows users to have confidence in the continuing safety and reliability of the switchgear until the next maintenance by the detection of incipient faults before they happen. Details of the techniques that can be considered are provided in the 'Condition monitoring' section (paragraphs 146-152).

71 A similar external inspection should be carried out on associated equipment, such as batteries and chargers, control panels and other ancillary equipment.

Maintenance

72 Detailed guidance on the maintenance of electrical switchgear can be found in BS 6423: 1983 and BS 6626: 1985 (see Appendix B 'Further reading').

Time-based preventive maintenance

73 Oil-filled switchgear was designed and introduced at a time when the predominant maintenance philosophy consisted mainly of equipment overhauls at fixed intervals. Time-based maintenance has been and continues to be applied to such switchgear. Manufacturers' recommendations are available to determine the maintenance programme and advice can be sought from specialist organisations.

74 Rigorous application of such schedules has provided high levels of reliability, whereas neglecting maintenance can lead to a switchgear condition where its ability to perform all its duties safely and satisfactorily is not easy to ascertain. So it is essential that oil-fled switchgear is properly maintained and the application of a correctly implemented time-based maintenance programme is a well-proven route.

Condition-based maintenance

75 In recent years attention has focused on condition-based maintenance where maintenance is dictated by need as revealed by inspections and condition monitoring techniques or predictive maintenance methods. Some users have moved to this approach but only after careful assessment of the parameters to be monitored, techniques for acquiring the condition data and, most importantly, an understanding of the degradation mechanisms affecting the switchgear and the criteria on which the decisions to take action are based.

76 When considering moving to a condition-based maintenance approach, the options available need to be carefully assessed. This should be done preferably with the assistance of organisations with experience in this area, since the performance of switchgear is influenced by the electrical and environmental conditions under which it operates. Simply applying techniques and criteria from another industry section may not be appropriate.

Reliability-centred maintenance (RCM)

77 RCM can assist in the process of determining the maintenance policy because it analyses maintenance tasks in a structured way to determine the maintenance requirements of any item of equipment in its operating context. It does so by taking account of plant usage and condition, the causes and consequences of failure, and the required performance standards of the organisation. See Appendix B 'Further reading' for details of publications which provide more background information on RCM.

Maintenance procedures

78 Whatever the approach used to determine when maintenance is required, it is important that the intrusive maintenance work is undertaken in a structured manner in accordance with a documented procedure/ checklist.

79 Maintenance of oil-filled switchgear should comprise a thorough internal examination, paying particular attention to the following items, where they apply:

(a) the inspection items listed in paragraph 69;
(b) examination and cleaning of the tank interior, internal mechanism, contacts, arc control devices, bushings, phase barriers and tank lining;
(c) dressing, refurbishing or replacing main/arcing contacts (including contact alignment check using oil circuit-breaker slow-close facility);
(d) cleaning of arc control devices or replacement if burnt or worn beyond acceptable tolerances (cross-jet pots, turbulators etc);
(e) replacement of insulating oil with new, reclaimed or reconditioned oil;
(f) lubrication of operating mechanism and adjustment where required;
(g) replacement of seals and gaskets, clearing vents and checking indicator windows;
(h) examination of primary isolating contacts for damage, burning, corrosion - cleaning and refurbishing (as necessary);
(i) checking and lubrication of the oil circuit-breaker isolating mechanism;
(j) checking correct function of position indicators and interlocks;
(k) checking shutter operating mechanisms (as appropriate);
(l) examining inside of cable termination chambers and current transformer chambers (as appropriate);
(m) examining and checking voltage transformer (as required);
(n) secondary injection testing on circuit-breaker protection system (or, if this is not scheduled, carry out manual trip-test);
(o) on fuse switche/switch fuses, trip-testing with an appropriate fuse trip-testing device;
(p) examination of secondary contacts, wiring and auxiliary switches;
(q) checking the truck goes fully into position and switchgear is level as appropriate when putting back into service.

80 During the maintenance of oil switches, fuse switches and ring main units, the tank cover should be removed for the minimum time necessary and replaced immediately after the required work is completed. This will ensure that the risk of contamination of the tank interior by moisture, airborne particulates, dust, insects and vegetation (if out doors) is minimised.

Frequency of maintenance

81 Switchgear should be maintained at a frequency appropriate to the equipment. The manufacturer, or others, may be able to give advice on this but difficulties exist in defining the frequency. These are affected by operating policies, types of switchgear and the reliability requirements. An industrial user whose activities depend on the reliability of power supply may institute more frequent maintenance as a means of guarding against power failures than (say) a distribution company where the duplication built into the network allowing alternative supplies means that a higher risk of malfunction may be acceptable.

82 Overstressed and/or DMO switchgear needs special attention. If any such switchgear has not been maintained within the past three years, then maintenance should be carried out immediately and thereafter on a frequent basis.

83 Trip-testing of oil circuit-breakers provides an operational test and 'exercises' the mechanism. It can be carried out more frequently than the internal maintenance, within operational constraints. Annual trip-testing is considered a suitable frequency by many users and, if combined with tripping via the protection scheme, also confirms that satisfactory (or otherwise) operation of the complete tripping system will occur under fault conditions.

84 Periodic testing of the protection relay scheme is a separate consideration, which may or may not be undertaken at the same time as maintenance of the switchgear. Further guidance is provided in the 'Protection' section (paragraphs 153-156).

85 Carrying out intrusive maintenance on oil switchgear introduces risks:

(a) errors can be made in the maintenance procedure, leaving the equipment at greater risk of failure than if the maintenance had not been carried out;

(b) switching is required in order to release the equipment for maintenance - the risk of a failure is greatest during a switching operation.

86 So carrying out maintenance too frequently can increase risk and optimising the maintenance schedule is needed to minimise the overall risk. A suitable method to establish the correct maintenance interval involves laboratory analysis of oil samples taken during normal maintenance combined with a thorough inspection by experts to establish the extent of degradation that has occurred during the maintenance interval. This can be done on the total population or by sampling. The validity of the maintenance interval can therefore be established, ie if the degradation is negligible then the maintenance period can be increased and vice versa if the degradation is significant. By repeating the procedure at the subsequent maintenance, after the revised interval, the optimum interval can be derived.

Oil circuit-breakers subject to special duty

87 Oil circuit-breakers that regularly interrupt large load currents, eg those controlling arc furnaces or frequently operated motors, will require more frequent maintenance attention than circuit-breakers on normal distribution duty.

88 The level of attention will depend on the nature of the duty being performed in relation to the rated capability (electrical and mechanical) of the circuit-breakers. Particular focus will need to be put on monitoring the rate of contact/arc control device deterioration, oil carbonisation and mechanism wear. In general, the manufacturer's guidance should be sought and implemented.

Insulating oil

89 The reliable performance of oil-filled switchgear depends on the maintenance of certain basic characteristics of the mineral insulating oil. It is essential that any new, reclaimed or reconditioned insulating oil is tested prior to being introduced into equipment to ensure that it meets the required level of performance.

90 Sampling of oil in service can provide valuable information on the deterioration of the oil and of the switchgear itself and the materials contained within it. Laboratories with long experience of testing oil samples can provide assessments of the state of a user's switchgear and of the validity of the maintenance programme. Guidance on the monitoring and maintenance for mineral insulating oils in electrical equipment is provided in BS 5730 (see Appendix B 'Further reading'). This includes values and significance of standardised oil tests and uniform criteria for the evaluation of test data, along with practical details on:

(a) sampling techniques;
(b) testing procedures and assessment criteria;
(c) handling and storage of oil samples.

Cleaning and inspection of oil-filled chambers

91 Oil-filled chambers should only be cleaned using appropriate cleaning materials, eg suitable proprietary wipes or synthetic sponges. It is suspected that several serious accidents have been caused by the presence of fibres from wipes used in oil-filled distribution equipment. It is therefore extremely important that any wipe that is used should not release fibres. Similarly, care is needed when using sponges to avoid tearing, which can allow small sponge fragments to be introduced into chambers.

92 There are wide variations in the performance of proprietary wipes on the market and advice on the appropriate types to use should be obtained from suppliers and specialist organisations. Using disposable gloves and overalls also minimises the possibility of any contamination by fibres from clothing. The use of chamois leather cloths rinsed out in clean insulating oil is not recommended for the cleaning of oil-filled chambers.

93 In the presence of trace contaminants in insulating oil, eg acids, peroxides and moisture, the plating metals such as zinc and cadmium used in switchgear can form metal salts and soaps, resulting not only in the degradation of the plating surfaces but also in the degradation of the oil.

94 In particular circumstances, zinc and tin platings can degrade and form a large number of small 'whiskers'. For switchgear with tin and/or zinc plated components, particular care should be taken to check all such components for whiskers immediately following the removal of the oil. Remove any whiskers with an oil-soaked wipe and then dispose of the wipe.

95 The phosphated coatings of steel components in switchgear are known to degrade in service, resulting in the presence of loose, phosphorous-rich particles contaminating the oil and coming to rest on the horizontal surfaces of the tank and other components including bushings and insulators. Switches that contain phosphated components should be subject to rigorous cleaning to remove contamination from insulating surfaces. Coated components should also be thoroughly cleaned to reduce the rate of recontamination of the oil.

96 Cadmium from the plating of mechanism metalwork can react with oil and moisture to form a cadmium soap, leading not only to the degradation of the plating surfaces but also to the degradation of the oil. Cadmium soaps on the surface of solid insulation may lead to electrical degradation of the solid insulation. To prevent such a degradation, insulator surfaces should be cleaned with an appropriate solvent.

However, because cadmium and cadmium compounds are highly toxic substances, they need to be handled correctly Advice on the general handling of cadmium can be obtained from the HSE leaflet *Working with cadmium: Are you at risk?* (see Appendix B 'Further reading'). For guidance on the dealing of oil contaminated by cadmium or cadmium sludge during tank cleaning see paragraphs 100-102 and for advice on disposal see paragraphs 191-194.

97 Any switchgear in which there is evidence that the oil is particularly contaminated should be subjected to rigorous inspection of all components to check for signs of corrosion, tracking, delamination or other degradation. Degraded components should be replaced. Of the insulating materials used in switches, densified wood laminate and pressboard are most susceptible to degradation in wet environments. As close examination of these components may not indicate when they have a high moisture content, insulation resistance measurements are recommended to establish their fitness for continuing in service. You will need to seek expert advice to establish a test method and recommended pass levels.

98 Fungal growth can occur in insulating oil that contains free water. The growth occurs at the interface between water from below and the carbon compounds from above. The most common fungal growth identified in insulating oil is *Cladosporium Resinae.* While it is rare to find fungal growth in insulating oil, any occurrence needs to be dealt with because as the fungus grows the oil is degraded, producing more water and various volatiles and acidic conditions that can cause corrosion of materials. The production of water and resultant corrosion of materials in contact with the oil will also reduce the insulating properties of the oil.

99 The spores of *Cladosporium Resinae* are airborne. They can lay dormant for periods of time and germinate when adequate moisture becomes available. Growth of the fungus from germinated spores can occur in a temperature range of -25°C to 40°C. Biocides can be used to lull the spores and it is important to eradicate them because if they are not destroyed the fungal growth is likely to reoccur.

Tank cleaning techniques

100 In order to clean the inside of switchgear tanks to a satisfactory level, it is recommended that once the used oil has been removed, the tanks are sprayed/vacuumed out to remove dirty oil and any particulate contamination from the tank base and other surfaces. The tanks should be sprayed down with clean oil under pressure, ensuring all accessible components are sprayed. This oil should then be removed using a liquid vacuum cleaner. The procedures should be repeated at least one further time. Examination of the interior of the tank should be completed to ensure all the contamination has been removed from the tank.

101 Application of the spraying technique can create an oil mist in the immediate vicinity of the switchgear so suitable personal protective equipment should be provided and used to prevent inhalation of the oil mist. Where the residual oil in the tank is known or is suspected to contain cadmium contamination or cadmium sludge, there is a health risk to personnel carrying out the cleaning process. The main risks are from inhalation and ingestion. It is recommended that oil-resistant, disposable overalls and gloves are used, along with the use of fitted chemical safety goggles. Respirators that prevent the inhalation of the oil mist need to be used at all times. Personnel need to be made aware of the hazards of ingestion and that contact with the mouth is to be avoided, along with the need for good personal hygiene after handling the substances and before eating.

102 A pump dedicated to oil is preferred, with the clean oil pumped using a separate pump, which should be used exclusively for this purpose. Two separate hoses, one for clean oil and one for dirty oil, should also be used to ensure no contamination of the clean oil occurs.

Post-fault maintenance of oil circuit-breakers

103 It is strongly recommended that all oil-filled circuit-breakers are maintained as soon as possible after they have either been closed onto a fault or have operated automatically to disconnect a fault from the system. This maintenance should essentially consist of:

(a) inspection and cleaning of all insulation within the tank to eliminate carbon, metal vapour/particle contamination;

(b) restoration of the contacts and arc control devices to an acceptable condition (including a check on contact alignment by slow-closing the oil circuit-breaker);

(c) replacement of the insulating oil;

(d) inspection of the tank, tank gaskets and tank internal mechanism for signs of damage or distortion.

104 Where provision is made in the design for venting, this should be checked to ensure that it is not obstructed and any seal is intact and functioning. Further guidance on maintenance can be found in manufacturers' manuals and in the relevant British Standards.

Care and maintenance of non-oil switchgear

General advice

105 Non-oil switchgear makes use of air, sulphur hexafluoride (SF_6) or vacuum as the interrupting medium, the remainder of the switchgear often being air-insulated. In some designs the vacuum interrupter bottles are housed within sulphur hexafluoride chambers. The appropriate parts of this section also apply to contactors.

106 An example of an arrangement of a vacuum circuit-breaker is given in Appendix C3, a sulphur hexafluoride-insulated vacuum circuit-breaker in Appendix C8 and an air circuit-breaker in Appendix C7.

107 The sealed envelopes of sulphur hexafluoride and vacuum switchgear improve the reliability by removing the potential degradation of the interrupting medium to adverse environments such as dust, moisture etc. This has led to the introduction of the terms 'low maintenance' or 'reduced maintenance' for such switchgear, but this does not mean that such equipment is maintenance-free. Failures do occur and inspection/maintenance procedures are required for such equipment. Two issues should be noted:

(a) With sulphur hexafluoride switchgear a significant proportion of reported problems are associated with loss of gas through defective/worn seals.

(b) With vacuum switchgear, X-rays may be generated when the open contact gap is stressed at high-voltage. There are no harmful emissions at normal service voltage but if a high-voltage pressure test is carried out with the switchgear in an open position then X-rays may be generated. Guidance should be sought from the manufacturer on the maximum voltage that can be applied to ensure that the maximum level of radiation generated is less than that permitted for unclassified workers in the Ionising Radiation (Sealed Sources) Regulations 1969.

108 As with oil switchgear, actions can be taken to minimise the risks of catastrophic failure, eg:

(a) inspection;

(b) maintenance;

(c) condition monitoring/assessment;

(d) refurbishment/replacement (more likely to be relevant for air-insulated switchgear as sulphur hexafluoride and vacuum types are modern designs).

Inspection

109 A regular substation inspection is recommended, as discussed for the oil-filled switchgear in paragraphs 65-71. This should cover:

(a) switchgear environment;
(b) signs of abnormal condition;
(c) switchgear general condition (for sulphur hexafluoride equipment the gas pressure gauge should be checked, a pungent smell indicates gas leakage);
(d) checks on all the plant items in the substation.

Maintenance

110 Detailed guidance on the maintenance of electrical switchgear can be found in BS 6423: 1983 and BS 6626: 1985 (see Appendix B 'Further reading').

111 Sulphur hexafluoride and vacuum switchgear is designed to be low maintenance but that does not mean that maintenance *can* be ignored. Maintenance using a time-interval approach, based on manufacturer's recommendations, may be applied to such switchgear. Rigorous application of such schedules should provide high levels of reliability.

112 Condition-based maintenance is an option where maintenance is dictated by need as revealed by inspections and condition monitoring techniques or predictive maintenance methods. As with oil-filled switchgear, this requires careful assessment of the parameters to be monitored, techniques for acquiring the condition data and, most importantly, an understanding of the degradation mechanisms affecting the switchgear and the criteria on which the decisions to take action are based. Before a user considers moving to a condition-based maintenance approach, the available options should be carefully assessed, preferably with the assistance of organisations with experience in this area. The performance of switchgear is influenced by the electrical and environmental conditions under which it operates and simply applying techniques and criteria from another industry sector may not be appropriate.

113 Reliability-centred maintenance (see paragraph 77) can assist in the process of determining the maintenance policy because it analyses maintenance tasks in a structured way to determine the maintenance requirements of any item of equipment in its operating context. It does so by taking account of plant usage and condition, the causes and consequences of failure, together with the required performance standards of the organisation.

Maintenance procedures

Sulphur hexafluoride switchgear

114 The maintenance work should essentially include:

(a) inspection of the external condition;
(b) checking of gas pressure;
(c) if 'topping up' of the gas is necessary, then refer to precautions in paragraph 130;
(d) inspection, adjustment and lubrication of mechanisms (including shutters where appropriate);
(e) on withdrawable equipment, examination of primary isolating contacts for damage, burning, corrosion - cleaning and refurbishing (as necessary);
(f) on withdrawable equipment, checking and lubrication of circuit-breaker isolating mechanism;
(g) checking correct function of position indicators and interlocks;
(h) examining inside of cable termination chambers and other chambers as appropriate, removal of surface contamination from accessible solid insulation (where applicable);
(i) examining and checking voltage transformer (as required);
(j) secondary injection testing on circuit-breaker protection system (or, if this is not scheduled, carry out manual trip-test);
(k) examination of secondary contacts, wiring and auxiliary switches.

Vacuum switchgear

115 The maintenance work should essentially include:

(a) inspection of the external condition;
(b) measurement of contact wear where a measurement method is available;
(c) a check on the vacuum integrity, eg by a high-voltage pressure test (see warning on X-rays in paragraph 107);
(d) inspection, adjustment and lubrication of mechanisms (including shutters where appropriate);
(e) on withdrawable equipment, examination of primary isolating contacts for damage, burning, corrosion - cleaning and refurbishing (as necessary);
(f) on withdrawable equipment, checking and lubrication of circuit-breaker isolating mechanism;
(g) checking correct function of position indicators and interlocks;
(h) examining inside of cable termination chambers and other chambers as appropriate - removal of surface contamination from accessible solid insulation (where applicable);
(i) examining and checking voltage transformer (as required);
(j) secondary injection testing on circuit-breaker protection system (or, if this is not scheduled, carry out manual trip-test);
(k) examination of secondary contacts, wiring and auxiliary switches.

Air-break switchgear

126 The maintenance work should essentially include:

(a) inspection of the external condition;
(b) examination of main/arcing contacts for excessive burning/damage - recondition or renew as required, taking account of manufacturer's requirements for different contact construction and materials;
(c) checking/adjusting spring contact force and contact alignment as required;
(d) removal, examination and cleaning of the arc chutes - renew if damaged or eroded;
(e) inspection, adjustment and lubrication of mechanisms (including shutters where appropriate);
(f) on withdrawable equipment, examination of primary isolating contacts for damage, burning, corrosion - cleaning and refurbishing as (necessary);
(g) on withdrawable equipment, checking and lubrication of circuit-breaker isolating mechanism;
(h) checking correct function of position indicators and interlocks;
(i) examining inside of cable termination chambers and other chambers as appropriate - removal of surface contamination from accessible solid insulation (where applicable);
(j) examining and checking voltage transformer (as required);
(k) secondary injection testing on circuit-breaker protection system (or, if this is not scheduled, carry out manual trip-test);
(l) examination of secondary contacts, wiring and auxiliary switches.

Frequency of maintenance

117 Switchgear should be maintained at a frequency appropriate to the equipment and its duty. The manufacturer, or others, may be able to give advice on this but difficulties exist in defining the frequency. These are affected by operating policies, types of switchgear and the reliability requirements. An industrial user whose activities depend on the reliability of power supply may institute more frequent maintenance as a means of guarding against power failures than (say) a distribution company where the duplication built into the network allowing alternative supplies means that a higher risk of malfunction may be acceptable.

118 For non-oil circuit-breakers subject to special industrial load duties, the manufacturer's guidance should be sought on the level of maintenance required.

119 Trip-testing of circuit-breakers provides an operational test and 'exercises' the mechanism. It can be carried out more frequently than the internal maintenance, within operational constraints. Annual trip-testing is considered a suitable frequency by many users and, if it is combined with tripping via the protection scheme, it also confirms whether satisfactory operation of the complete tripping system will occur under fault conditions.

120 Periodic testing of the protection scheme is a separate consideration which may or may not be undertaken at the same time as the maintenance of the switchgear. Further guidance is provided in the 'Protection' section (paragraphs 153-156).

Sulphur hexafluoride gas handling and safety precautions

121 Under normal conditions, the sulphur hexafluoride gas remains inside the switchgear in a sealed system and any decomposition products formed during interruptions are neutralised by molecular sieves, as well as by natural recombination processes. However, sulphur hexafluoride can be released at all stages of the equipment life cycle and procedures for handling it are required. In order to advise personnel that a substation contains sulphur hexafluoride equipment it is advisable to post a notice within the substation that clearly states this.

122 It remains up to an individual user to determine the extent to which they wish to handle the gas in sulphur hexafluoride-filled switchgear. This can range from, at one extreme, a decision to make use of external contractors or manufacturers to deal with all aspects of managing and operating the switchgear, through to the other extreme of handling it completely in-house. Companies need to ensure adequate training of personnel and that the required equipment and facilities are available to proceed with the policy they adopt. Particular attention will need to be paid to adopting the correct procedures during maintenance, refilling, condition testing and end-of-life disposal. Expert advice, training and support on these issues can be obtained from manufacturers, sulphur hexafluoride gas suppliers, electricity distribution companies and specialist organisations.

Release of sulphur hexafluoride

123 Sulphur hexafluoride is a greenhouse gas and, although the global warming effect is likely to remain small compared to other greenhouse gases for the foreseeable future, control over its use is essential. The European electricity industries have agreed a set of actions with the manufacturers of sulphur hexafluoride-filled electrical equipment to reduce emissions of the gas to atmosphere and recommend good housekeeping by the electricity utilities in line with the following aims:

(a) sulphur hexafluoride should not be deliberately released into the atmosphere;
(b) sulphur hexafluoride should be recycled and reused to the maximum possible extent;
(c) losses of sulphur hexafluoride from electrical equipment should be minimised;
(d) all new sulphur hexafluoride equipment should allow for recycling;
(e) standardising recycling procedures should be formulated.

Hazards

124 Procedures for safe handling of sulphur hexafluoride are available from a number of authorities (see, for example, IEC Technical Report 1634, EA Engineering Recommendation G69) and from manufacturers. These also give guidance and safety recommendations on the handling of sulphur hexafluoride due to leaks from equipment and from any arc by-products. It is generally accepted that, when properly managed, sulphur hexafluoride does not represent a greater danger for the user than the other materials (metals, plastics etc) used in any other type of switchgear whether it is air-insulated, oil-insulated, solid-insulated or vacuum switchgear.

125 Sulphur hexafluoride in its pure state is inert, colourless, tasteless, non-flammable and non-toxic. However, like nitrogen, it will not support life and a large volume in the atmosphere may cause personnel to suffer from lack of oxygen. Sulphur hexafluoride gas is about five times heavier than air, and thus will tend to accumulate on lower levels such as cable trenches and tunnels.

126 All switchgear containing sulphur hexafluoride used for both insulating and arc extinction purposes shall be deemed to be contaminated if it has previously been in electrical service. By-products are generated by sulphur hexafluoride decomposition due to the energy released during electrical switchgear operations, such as switching, internal short circuit, partial discharge etc, and these decomposition products are acidic and corrosive. Users will need to have procedures to call in appropriate and trained personnel together with the required equipment (which may include personal protective equipment) to deal with:

(a) emergency situations - release of contaminated sulphur hexafluoride gas;
(b) scheduled maintenance of contaminated sulphur hexafluoride equipment involving access to the sulphur hexafluoride compartment;
(c) testing sulphur hexafluoride gas and filling procedures;
(d) possible contamination in areas surrounding the switchgear;
(e) storage, transport and disposal of contaminated gas.

127 It should be noted that the presence of small quantities of gaseous decomposition products is accompanied by clear warning signals in the form of a pungent and unpleasant odour. Irritation occurs within seconds, well in advance of any dangers arising from poisoning.

128 Where there is any work on equipment which involves contact with sulphur hexafluoride or its decomposition products, then the staff should observe the following precautions:

(a) use disposable protective overalls;
(b) maintain a high standard of personal hygiene;
(c) do not eat, drink or smoke;
(d) avoid cleaning nose, eyes or face other than with clean paper tissues;
(e) clean off any decomposition products from the work area, clothing and equipment;
(f) dispose of protective overalls in an approved manner;
(g) wash all exposed parts of the body as soon as possible after leaving the working area.

Sampling

129 The majority of modern switchgear up to 33 kV uses sealed containment with the sulphur hexafluoride gas at a small, positive gauge pressure (typically 0-1 bar gauge). This type of equipment is completely assembled, filled with sulphur hexafluoride and tested in the factory and no further handling of the gas is required during its expected operating life. However, there may be occasions where sampling and testing of the gas is required. As indicated above, care must be taken not to release gas into the atmosphere and also to treat it as contaminated gas. Guidelines for assessing the quality of the gas are available in BS 5207 and BS 5209. These also provide guidance on quality of new gas and gas to be used for topping-up switchgear.

Topping-up

130 It may be necessary to 'top-up' the quantity of sulphur hexafluoride within switchgear if the pressure is found to be below the optimum pressure for that type of equipment. It is essential that the additional sulphur hexafluoride used be of a known and satisfactory quality and tested for quality before it is introduced. Where recycled gas is to be used then specialist equipment isavailable.

Care and maintenance of ancillary equipment

Test probes

131 A number of serious incidents have occurred involving shortcomings with portable test probes. As a result, it is essential that these items should be inspected on a regular basis. Including them in an asset register (see paragraph 39) will allow a regular inspection instruction to be generated and ensure that this is not overlooked. Use of, for example, a safety colour-coding procedure to indicate the current period of use will ensure that probes that are outside that period are not inadvertently used. The checks and actions carried out should include:

(a) inspection of general condition, damage and deterioration;
(b) inspection for correct and legible identification;
(c) cleaning to remove oil films and loose dirt. It is important that only wipes that do not release fibres should be used;
(d) inspection of contacts for wear, burning or other signs of abnormal condition and to ensure they are securely attached;
(e) inspection of bushings for cracks, damage, burning etc;
(f) inspection of any guide pins, interlocking tabs and locking bolts to ensure they and any other parts are securely attached;
(g) measurement of the insulation resistance using an insulation tester and comparison against an agreed pass figure;
(h) for those probes that are shown to be in satisfactory condition, mark with the correct code for the current period of use;
(i) removal of any damaged or defective probes from use and initiation of repair or replacement.

132 It is strongly recommended that all test probes be stored in clean, dry containers when not in use.

Earthing equipment

133 The earthing equipment for switchgear can be categorised as:

(a) integral - part of the permanent operating mechanism of the switchgear;
(b) extensible - a system of probes that are attached to a circuit-breaker truck which can then be racked into an earth position;
(c) portable - a system of probes for insertion into the switchgear spouts and leads for connection to a suitable earth point.

134 This section is concerned with the care and maintenance of the latter two types (extensible and portable) since these are separate, removable items unlike the integral types, which will be dealt with as part of the maintenance regime of the switchgear itself.

135 Portable and extensible types of earthing equipment are vital pieces of safety equipment and so it is essential that these should be inspected on a regular basis. Including them in an asset register (see paragraph 39) will allow a regular inspection instruction to be generated and ensure that this is not overlooked. Use of, for example, a safety colour-coding procedure to indicate the current period for use will ensure that equipment that is outside that period is not inadvertently used.

136 The checks and actions carried out should include:

(a) inspection of general condition, damage and deterioration;
(b) inspection for correct and legible identification;
(c) cleaning as required;
(d) inspection of contacts, connections and leads for wear, burning or other signs of abnormal condition and to ensure they are securely attached;
(e) inspection of all insulation components for damage;
(f) inspection of any guide pins, interlocking tabs and locking bolts to ensure they are

functional and secure;

(g) for earthing equipment that is shown to be in satisfactory condition, mark with the correct colour code for the current period of use;

(h) removal of any damaged or defective earthing equipment from use and initiation of repair or replacement.

Testing

Tests to be undertaken during commissioning

137 The commissioning of new (or refurbished) switchgear requires detailed testing to confirm the functionality of the switch or circuit-breaker, secondary wiring, protection, indications etc. This requires a detailed checklist of all relevant items and is beyond the scope of this document. Commissioning should normally be carried out by the manufacturer or main contractor installing the switchgear, who will have the necessary experience and expertise to cover all the necessary actions.

Tests to be undertaken during and following maintenance

138 Before being returned to service, the switchgear should be subjected to an operational check to ensure correct close and open operations. This should include checks on any interlocks, indicator lamps, local (and remote if applicable) trip indications, trip counters etc.

139 Automatic circuit-breakers should be tripped using the protection system to test the complete tripping circuit. Trip-timing tests are valuable to confirm satisfactory tripping mechanism performance and as a condition-monitoring tool.

140 Also, by reference to the manufacturer's maintenance requirements, carry out any additional testing relating to specific switchgear types.

Diagnostic testing

141 A number of diagnostic tests, both intrusive and non-intrusive, can be applied to switchgear throughout its life. Such tests may be undertaken during commissioning in order to establish a baseline for regular testing, eg mechanism timing/trip profiles. The baseline measurements may then be used as a basis for a condition-based maintenance strategy.

142 Later in the asset life cycle, diagnostic testing can be carried out to provide information on the condition of the asset, eg partial discharge measurements on solid insulation.

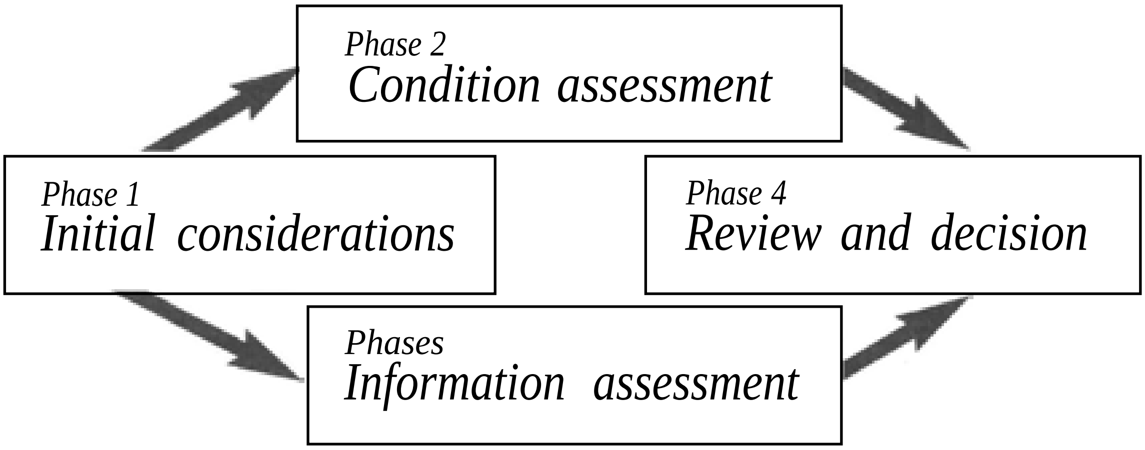
143 Where a particular type of switchgear has a known defect affecting its electrical integrity, diagnostic techniques such as partial discharge detection can provide effective screening.

144 Further information on available diagnostic techniques is provided in the 'Condition monitoring' section (paragraphs 146-152).

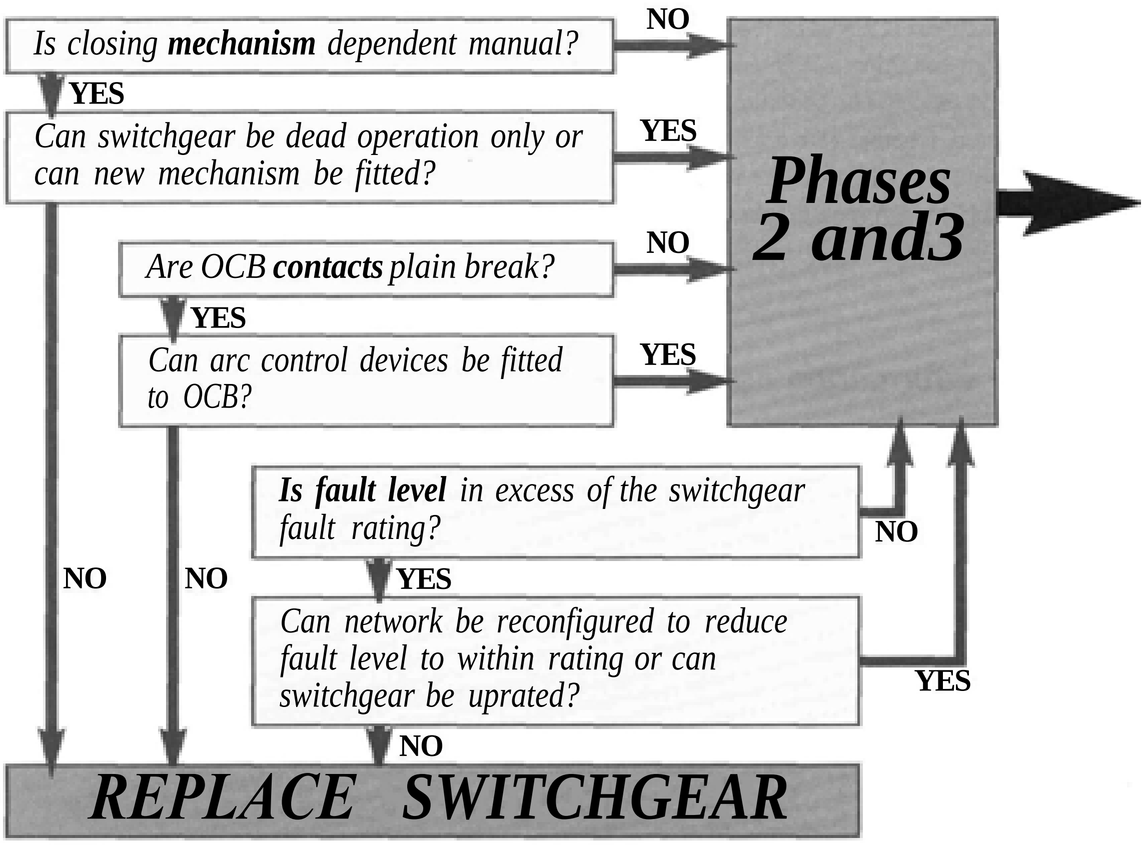
Assessment of aged switchgear

145 The risk of catastrophic failure (particularly in the case of oil switchgear) increases with age and so a process of assessment is needed in order to decide on the appropriate action for dealing with aged switchgear in service. Such an approach should incorporate condition assessment where appropriate. Application of this process will enable rational decisions to be made on whether to retain, refurbish or replace each switchboard and allow investment to be directed to best effect. The decisions are made on the basis of condition and on the potential risk of leaving individual switchboards in service. The decision-making process follows the assessment actions displayed in the following flowcharts.

Assessmentprocess overview



Phase 1 - Initial considerations



Notes:

(a) If the switchgear has either a dependent manual operating mechanism or, in the case of oil circuit-breakers, plain break contacts (ie no arc control system), then it is strongly recommended that it be scheduled for early replacement (or upgrading if practicable).

(b) If the calculated fault level at the switchboard exceeds the switchgear fault rating and there is no possibility of reconfiguring the network to reduce the fault level, then usually the only viable option will be to replace the switchgear with modern equipment of an adequate rating.

Phase 2 - Condition assessment procedures

Visual inspection of switchgear and its environment
+
Sample internal examinations
+
Assessment of condition of insulation by partial discharge detection/ monitoring (and/or other appropriate diagnostics)

Notes:

(a) If the switchgear is not to be replaced as a result of the Phase 1 considerations, it will be necessary to carry out condition assessment in order to establish the suitability of the switchgear for continuing service. The condition assessment should embrace a mixture of external and internal examination, together with appropriate diagnostic tests to ascertain the condition of HV insulation.

(b) Information on diagnostics for assessing insulation condition is provided in the 'Conditioning monitoring' section (paragraphs 146-152).

Phase 3 - Information assessment

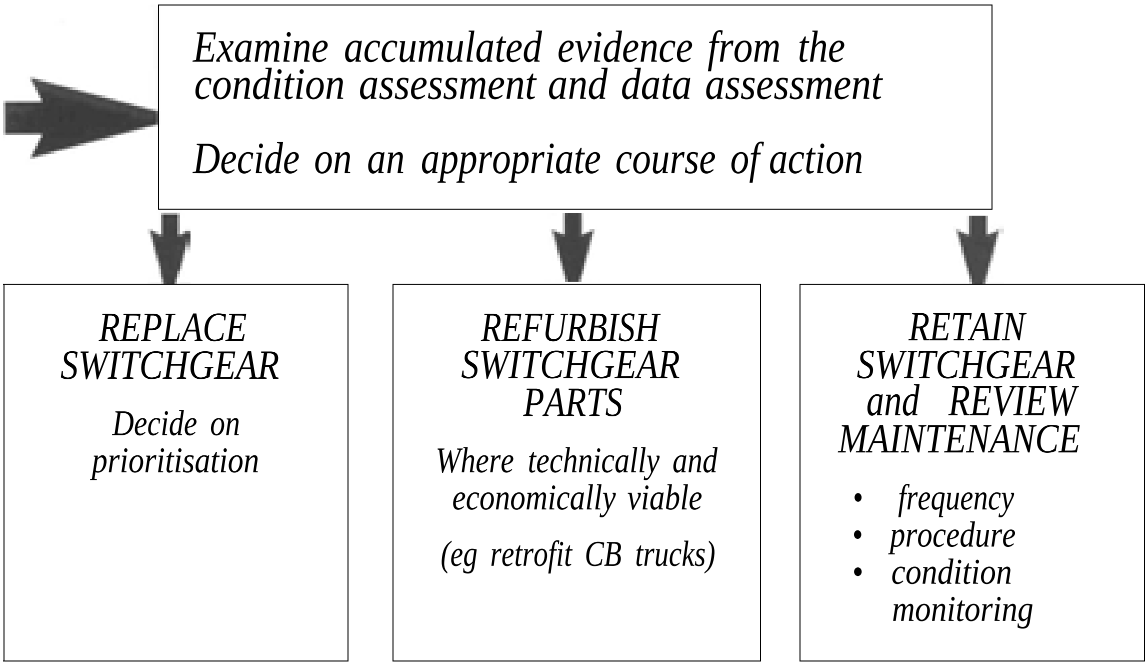
Consideration of

- *Fault and defect history*
- *Maintenance records/policy/costs*
- *Condition of enclosure*
- *Spares availability*
- *Operational and network planning issues*
  - *additional capacity requirements*
  - *redundant circuits*
  - *remote control requirements*
  - *presence of other plant*

Note:

The above information needs to be acquired from the appropriate sources and assessed.

Phase 4 - Review and decision



Note:
If it is decided to retain the switchgear in service, an estimate of remaining life should be made and the maintenance regime modified to include regular condition monitoring.

Condition Monitoring

Available techniques

Partial discharge detection

146 Partial discharge (PD) measurements provide a powerful technique to diagnose the condition of insulation in high-voltage plant. A number of specialist service companies are able to undertake PD measurements and provide interpretative guidance on the significance of specific measurements. The following non-intrusive techniques are available using portable instruments:

(a) measurement of transient earth voltages (TEVs);
(b) ultrasonic detection;
(c) radio frequency interference (RFI) detection.

147 Some surface discharges are best detected using ultrasonic detection equipment and in practice a combination of 'TEV and ultrasonics is generally used on indoor, metal-clad switchgear. RFI can also be used to detect some advanced partial discharge activity but the technique is limited in application. Where necessary, the partial discharge measurements are supplemented with intrusive tests (PD, loss angle and capacitance) and visual inspection to pinpoint the precise nature of a problem.

148 On strategically important switchboards, permanent partial discharge monitoring can be considered based on the TEV principle.

Thermographic surveys

149 Infra-red techniques use either thermal imaging equipment or non-contact thermometers. The techniques are useful for detecting overheated conductors, connections and fuses on open-fronted, low-voltage distribution boards or on other low-voltage switchgear where live parts can be safely exposed and remotely scanned. These techniques are not particularly useful for indoor high-voltage, metal-clad switchboards but can detect overheating bushings and connections on open terminal switchgear.

Mechanism timing tests

150 Many problems in circuit-breakers are attributable to distortion or damage of the metal parts or 'stiction' in the mechanism causing failure to open or close, or slow opening of the circuit-breaker. Detection of a problem in a mechanism may not be fully dealt with by invasive maintenance and in fact may be more effectively dealt with by incorporating timing tests into the periodic trip-tests which *can* be carried out at the time of, or independently of, maintenance activities. As well as straightforward timing, the use of trip-profile instruments provides a more detailed appreciation of the mechanism performance and is potentially a valuable additional test that *can* be incorporated into the routine trip-testing procedure.
A number of instruments are available on the market and specialist organisations can provide a testing and assessment service.

Strategies for application

151 The application of diagnostic techniques, whether non-intrusive or intrusive, assists users by providing:

(a) confidence in the continuing safety and reliability of the switchgear;
(b) a sound engineering basis for making investment decisions on plant replacement or refurbishment;
(c) the basis of a cost-reduced maintenance strategy, ie incorporating condition .monitoring.

152 Switchgear that is not to be replaced as a result of a condition assessment programme, and is found suitable for further service, will require a maintenance regime modified to include some form of ongoing condition monitoring. Non-intrusive diagnostic techniques can form a part of that condition-monitoring programme.

Protection

Protection relay schemes

153 The protection relays and associated systems should be subjected to regular inspection and diagnostic testing in addition to routine maintenance actions. Diagnostic testing will give an indication of the condition and comparison of test results with records of previous results will provide a guide to possible deterioration and assist in determining the appropriate testing/maintenance interval. This procedure is valuable for estimation of trends.

154 Insulation resistance testing should be carried out on the secondary wiring associated with the protection, including any pilot wires if they form part of the protection circuitry. This is important since current leakage across the wiring will affect the characteristics of the protection scheme and may have a detrimental effect on the operation and discrimination of the protection scheme.

155 The checks and actions carried out for protection relay schemes should include:

(a) ensuring relay settings are correct;
(b) inspection for condition, damage and deterioration. For an electromechanical-type relay this should include checks that:
  - relay movement runs freely;
  - magnet gaps and induction disc are clean;
  - contacts are not burnt or pitted (refurbish as necessary);
  - induction disc resetting time (electromechanical IDMT relays);
  - flag mechanisms and reset knobs operate correctly;

- front cover glass and seals are satisfactory;
- current transformer shorting contacts operate satisfactorily;

(c) secondary injection tests to check operating characteristics. These tests will be dependent on the protection type (instantaneous and IDMT overcurrent/earth fault, directional, auto-reclose, unit, distance, motor protection etc) and whether time-limit fuses are used. Guidance on the test procedure can be obtained from manufacturers or specialist testing companies;

(d) checking the correct operation of load ammeters and any other instruments;

(e) insulation resistance testing.

(f) trip-testing of the circuit-breaker from the protection;

(g) inspection of the associated current and voltage transformers where appropriate.

Fuse protection

156 For switchgear where the protection is dependent on fuse operation (eg switch fuses and fuse switches) then the operation tests involve carrying out fuse trip-testing (a test-trip fuse can be used if available) to ensure that:

(a) single fuse operation causes all other phases to operate;

(b) the manual ON/OFF trip mechanism operatescorrectly.

Batteries and chargers

157 Batteries for circuit-breaker tripping and closing supplies play a vital role in the overall performance of the switchgear. The batteries and associated chargers need an appropriate maintenance regime in order to ensure consistent and reliable performance.

158 The battery/charger installation should be regularly inspected, tested and maintained. The level of maintenance attention will depend on the type of battery and type of charger system in use. The battery manufacturer's operation and maintenance instructions should be followed, and in particular, the recommended charging rates should be adhered to.

159 All work on substation batteries needs to be carried out in accordance with the safety rules applicable to the work and only insulating tools complying with BS EN 60900 (see Appendix B 'Further reading') and other suitable equipment are to be used.

160 Care needs to be taken to ensure that removal of connections does not inadvertently immobilise the switchgear or associated equipment.

162 Smoking or the use of naked flames should not be allowed in the proximity of battery installations and the production of sparks should be avoided due to inadvertent short-circuiting ofcells.

162 When batteries are replaced it is important that the existing battery charger is compatible with the new batteries and old batteries are disposed of, observing the relevant environmentallegislation.

Selection of new, replacement or refurbished switchgear

General advice

163 A completely new switchboard installation will utilise the latest designs on offer from manufacturers. However, where a decision has to be taken to replace switchgear in an existing installation, then a number of options are available:

(a) replace the switchboard in its entirety;

(b) replace the individual switchgear units (moving and fixed portion);
(c) refurbish the switchboards or individual switchgear units;
(d) retrofit the switchgear (this usually applies to circuit-breakers).

164 A major factor in such a decision is to obtain some technical confidence that the high-voltage insulation components of the busbar system, current transformer chambers, cables and terminations etc have adequate remaining life to justify any proposed expenditure on partial replacement, refurbishment or retrofitting. For this reason it is essential that an overall assessment of the switchgear is carried out before evaluating the economics of refurbishmendretrofit against replacement. This should include condition assessment of the high-voltage insulation using partial discharge measurement techniques. Included in this process is the evaluation of available test data and relevant standards. Where circuit-breakers are under consideration, it is also important to consider:
(a) the condition of the secondary wiring, protection and control equipment;
(b) interlocking and earthing arrangements in relation to current safety standards;
(c) short-circuit ratings;
(d) venting arrangement (where appropriate).

165 The availability of spares plays a role in the decision process. Consideration should be given to the availability of both strategic items (eg bushings, current transformer chambers, cable boxes, mechanisms) and routine maintenance items (eg arcing contacts, turbulator inserts, gaskets, tripping and closing coils). Confirmation should be sought as to whether spares are available from the original equipment manufacturer (OEM), or the OEMs successor companies, or from small 'specialist' engineering companies.

Ratings

166 The load rating and the short-circuit rating of any new/refurbished/retrofit switchgear should be assessed relative to that of any of the fixed portion and ancillary equipment such as the current transformers that are to be retained. It is not unknown for users to overlook the fact that where there is a mismatch between the replaced/refurbished equipment and the existing equipment then the lowest load and short-circuit rating apply. Consequently, they may install uprated switchgear that cannot be utilised to its full rating.

Replacement installations

167 Where a complete new switchboard is to be installed, the opportunity exists to consider whether direct replacement is necessary or whether the switchboard arrangement can be simplified. You also need to take account of the possible additional capacity benefits and the reduced maintenance costs associated with the new switchgear. Also, less space will generally be required and the opportunity given to modernise the protection and control schemes.

168 Where only individual switchgear panels are to be replaced, then the decision is one of a like-for-like replacement, if it is still available, or of a modern equivalent (see also circuit-breaker retrofit option described in paragraphs 172-174).

169 It should be noted that old paper/lead cables can be internally damaged by significant disturbance and appropriate measures need to be taken to avoid this.

Refurbished/retrofitted switchgear

170 Users should only embark on the refurbishment and/or retrofit route after an overall assessment of those parts of the switchgear to be retained has been carried out. This is necessary to confirm that the retained parts have adequate rating and sufficient remaining life to justify the expenditure on refurbishment/retrofitting. The options available are refurbishment of switchgear or retrofitting of circuit-breakers.

Refurbishment of switchgear

171 This can be viewed as a major overhaul of the switchgear with replacement of parts deemed to be time-expired, eg operating mechanisms, insulation components etc.

Retrofit circuit-breakers for withdrawable switchgear

172 Retrofitting involves updating the existing moving portions of switchgear, generally to incorporate vacuum or sulphur hexafluoride technology, for use with the existing fixed portions. Two options can be considered:

(a) replacing the complete circuit-breaker truck; or

(b) modifying the existing truck to incorporate a vacuum or sulphur hexafluoride circuit-breaker.

173 Retrofit systems can be obtained either from switchgear manufacturers or specialist retrofit suppliers. When selecting a system, particular attention should be paid to the mechanical compatibility between the fixed portion and the new moving portion. Problems can be experienced due to mechanical mismatch between the mating portions, shutter actuation, racking mechanisms and physical clearances. These are better addressed at the planning stage rather than attempting to cure them at the installation stage. Such problems can be minimised by close liaison between the user and supplier at all stages of a retrofit operation.

174 It is good practice to carry out a partial discharge survey of the switchboard, prior to installation of the retrofit units, to establish the integrity of the existing equipment and repeat the survey after installation to ensure that problems have not been exacerbated or introduced.

Second-hand equipment

175 It is possible to purchase second-hand switchgear from companies specialising in the recovery of redundant switchgear and in its refurbishment for re-sale. If second-hand switchgear is being considered, it is important to only deal with reputable and experienced organisations. Such organisations are required to provide documentation on the use and maintenance of the equipment. This would include information originating from the OEM. An audit of the contract by an independent consultant can be a worthwhile safeguard against purchase of equipment that might not be fit for purpose. The companies supplying the refurbished equipment though should ensure all relevant items are dealt with during overhaul, upgrades, modifications etc.

Measures to limit fires

176 Failure of switchgear can lead to fires and where oil-filled equipment is involved the incident can be a major one. A serious incident not only poses potential fire and smoke risks to people in the vicinity and to the building fabric but may also affect other plant, thus escalating the primary event. There are a number of techniques that can be used singularly or in combination to mitigate the effects of a fire and limit smoke spread.

Compartmentation

177 Substation plant items *can* be separated by fire-resisting barriers to limit the extent of any fire to the item of fire origin. If automatic extinction or control is required (see paragraphs 178-180), then compartmentation is useful. However, there may be contradictory requirements between fire safety and explosion safety, for example where venting may be required to safeguard against explosion. Compartmentation needs to be carefully designed so that it can contain a fire but not inhibit any venting required for explosion control.

Control and extinction

178 Fire-extinguishing systems use extinguishing mediums such as halon and carbon dioxide

(CO_2). Halon is not a favoured medium due to environmental considerations but its use may be necessary in areas where fire hazards are particularly severe and could affect adjacent plant.

179 Such systems require the flooding of fire compartments and measures should be put in place to ensure that the system can be made non-automatic before entry to cater for occasions when personnel need to work in the area (see paragraphs 183-185).

180 A review of the use and provision of portable fire-extinguishers and procedures for checking these and any permanent systems should also be carried out. Where problems are identified either in the design, operation or during inspections, then corrective actions such as replacement, recharging and relocation etc should be taken.

Prevention

181 The most appropriate control measure is that of prevention. The following strategies can be considered:

(a) good management of the plant items, eg careful control of workmanship, as there is a greater likelihood of an incident occurring after replacement or maintenance of equipment;

(b) careful monitoring of any degradation of oil and dielectric insulation;

(c) reduction of possible ignition sources;

(d) good housekeeping.

Detection

182 The use of an appropriate automatic tire detection system could provide the electrical plant room or area with early fire detection and alarm features which could also be linked with a control/extinction system to provide fast response fire suppression or control.

Safety issues

183 Where automatic fire protection systems are installed there are risks to people in the protected area when the system operates. These include:

(a) asphyxiation by the gases or chemical extinguishants used;

(b) poisoning if extinguishants are toxic;

(c) physical injury (falling, striking objects etc) due to poor visibility after release of the gases or chemical extinguishants;

(d) effect of low temperature due to release of the gases or chemical extinguishants.

184 Precautions should therefore be taken if people are to enter an area fitted with automatic fire protection equipment. These include:

(a) the automatic control to be rendered inoperative before entry;

(b) caution notices indicating that the control is on 'non-automatic' to be fitted to the automatic/non-automatic selector;

(c) precautions taken to render the automatic control inoperative to be noted in any safety documents issued for work in the protected area;

(d) instructions issued to staff to ensure that the system is restored to automatic control as soon as all staff have withdrawn from the area.

185 Notices requiring the above actions should be prominently displayed at the point(s) of access to the area.

Training

General advice

186 It is the duty of all users of switchgear to provide necessary training in order that staff involved in the operation and maintenance of switchgear are able to carry out their duties in safety and without risk to health. Many organisations offer a full range of training courses, from general appreciation of site access and responsibilities through to detailed courses on operations, safety, maintenance practice etc. Such organisations include:

(a) electricity distribution companies;

(b) training companies;
(c) switchgear manufacturers;
(d) technical services companies.

187 The use of a set of safety rules and a system of safety documents (see paragraph 188 for definitions) that clearly and unambiguously state what actions are required to ensure safe working is essential, particularly at high voltage. To ensure that the different levels of activity associated with switchgear are performed competently and the safety rules are strictly adhered to, it is also important to define different categories of staff. This means you can clearly define the duties that are expected of them and, just as important, those they are not authorised to carry out. Typical categories are as follows (training courses can be prepared to meet the requirements of these categories):

(a) competent person - a person recognised as having sufficient technical knowledge and/or experience to enable them to avoid danger when carrying out their duties and who may be nominated to receive and clear specified safety documents;
(b) authorised person - a competent person who has been appointed in writing to carry out specified duties, including the issue and cancellation of safety documents, eg a permit-to-work or sanction for test.

Operational safety documents

188 The activities needed to operate, inspect, repair, maintain and test the switchgear will be designated to the appropriate category of person. In all cases, knowledge of the safety rules and application of the safety documents will be required, whether this be general understanding or detailed knowledge, plus an appreciation of the issues raised in this book. The implementation of a safety documents scheme is fundamental to safety in the use, care and maintenance of plant. The correct use of the following documents is essential. The naming of the documents varies between organisations - here are some suggested ones.

(a) Limitation of access - defines the limit within which work or testing (on LV switchgear and systems) may be carried out and specifies necessary precautions.
(b) Permit-to-work - specifies the equipment to be worked on, the work to be carried out and the actions taken to achieve conditions which safeguard people working on the equipment from the dangers that are inherent in the system.
(c) Sanction for test - specifies the HV equipment to be tested, making known the conditions under which the testing is to be carried out and confirming actions taken to achieve conditions which safeguard persons testing the equipment from the dangers that are inherent in the system.

189 Operational safety documents are not intended (and should not be used) for work control purposes.

Inspection and maintenance

190 Personnel engaged on the inspection and maintenance of switchgear will need to be made familiar with the procedures, safety rules and safety documents under which they work and their responsibilities to ensure safety and safe working. They will also need training in the technical aspects of their work.

Disposal issues

191 Anyone who produces, treats, keeps, stores, transports or disposes of waste is subject to a duty of care under seasion 34 of the Environmental Protection Act 1990. This makes holders of waste responsible for its fate even after it has left their hands.

Insulating oil

192 Much of the used oil from switchgear is returned to oil companies and is subject to a process to generate reclaimed oil (which is sold back to the users for reuse). Within the reclaiming and refining processes, the oil companies have their own quality assurance/quality control procedures, which should ensure that the quality and performance of the reclaimed oil being supplied back to users is satisfactory. It is standard practice within the oil companies to check the quality of batches of oil returned for reclaiming and reject those that are severely degraded. Users with known batches of badly degraded oil should keep it as separate waste oil for disposal by the oil companies in an appropriate manner.

293 Switchgear oil may contain polychlorinated biphenyls (PCBs), so the procedures for handling used oil should take account of the approved handling procedures for PCB-contaminated materials or substances as laid down by:

(a) EU Directive 96/59/EC *The Disposal of Polychlorinated Biphenyls and Polychlorinated Triphenyls;*

(b) Statutory Instrument SI 2000 No 1034 *The Disposal of Polychlorinated Biphenyls and Other Dangerous Substances Regulations (England and Wales)* May *2000.*

194 As discussed in paragraphs 91-99, used switchgear oil may contain cadmium or cadmium sludge. Where this situation arises, the oil, cadmium sludge and all material containing it needs to be treated as 'special waste' and the disposal needs to be carried out as laid down by The Special Waste Regulations 1996. This includes all oil containing the cadmium and any new oil or solvents used to clean and rinse the components within the tank. Any wipes, gloves or clothing that have come into contact with the cadmium should be collected and sealed in boxes. All of this should then be appropriately labelled as special waste.

Capacitors

195 Some capacitors contain PCBs and therefore the procedures for disposal of capacitors should take account of approved handling procedures for PCB-contaminated materials or substances - see the documents referred to in paragraph 193.

Sulphur hexafluoride switchgear

196 As stated previously, there is a need to reduce emissions into the atmosphere and so procedures need to be in place to deal with the reclamation or disposal of sulphur hexafluoride gas removed from switchgear and for the disposal of switchgear containing sulphur hexafluoride. Advice on procedures can be obtained from the switchgear manufacturers and from specialist disposal companies. Guidance on the safe handling and final disposal is available from:

(a) CIGRE Technical Brochure No 117, 1997 *SF_6 recycling guide. Re-use of SF_6 gas in electrical power equipment and final disposal;*

(b) IEC Technical Report 1634, 1995 *High-voltage switchgear and controlgear - use and handling of sulphur hexafluoride in high-voltage switchgear and controlgear.*

197 Transportation by road of sulphur hexafluoride in gas bottles or equipment containing it is subject to national and local regulations. Information can be obtained from the European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) and protocol of significance.

Appendices

Appendix A:

Technical definitions

Low voltage

Normally exceeding 50 V ac or 120 V dc but not exceeding 1000 V ac or 1500 V dc between conductors, or 600 V ac or 900 V dc between conductors and earth.

High voltage

Normally exceeding 1000 V ac or 1500 V dc between conductors, or 600 V ac or 900 V dc between conductors and earth.

'Medium voltage'

Some companies and persons use the term 'medium voltage' to describe distribution voltages in range 3.3 kV to 72.5 kV to distinguish these from the higher values of voltage associated with transmission systems. There is no International Electrotechnical Vocabulary (IEV) meaning which specifies values; all that is stated is that the upper value lies between 30 kV and 100 kV. The term has not been used in the UK to prevent confusion with the widely understood use of the term for 415 V three-phase systems.

Switchgear

A combination of one or more switching devices together with associated control, measuring, signal, protective, regulating equipment etc completely assembled under the responsibility of the manufacturer with all the internal electrical and mechanical interconnections and structural parts.

Switching devices

It is possible to separate switching devices into the following groups and to define the type of switching device. It should be noted that they are all electromechanical devices.

Isolator
A switching device which is used to open (or close) a circuit either when negligible current is interrupted (or established) or when no significant change in the voltage across the terminals of each pole or phase of the isolator will result from the operation.

Switch
A switching device suitable for making or closing a circuit under normal and abnormal conditions, such as those of short-circuit, and capable of breaking or opening a circuit under normal conditions.

Circuit-breaker
A switching device capable of making and breaking, or closing and opening, a circuit under normal conditions and under abnormal conditions such as those of short-circuit.

Switch fuse
A switching device that is an integral assembly of switch and fuses in which a fuse is connected in series with the switch.

Fuse switch
A switching device in which a fuse link or fuse carrier constitutes the moving contact.

Operating duties

The operating duties of the above switching devices may be summarised as follows:

- An isolator has no rated making or breaking capability, ie these devices can only be used for OFF-LOAD or DEAD switching.
- A switch is a FAULT MAKE/LOAD BREAK device.
- A circuit-breaker is a FAULT MAKE/FAULT BREAK device.

Operating mechanism

The types of operating mechanisms used for these switching devices are defined as follows:

- **Dependent manual operation** (of a mechanical switching device) (IEV Definition 441-16-13)
  An operation solely by means of directly applied manual energy such that the speed and force of the operation are dependent upon the action of the operator.
- **Independent manual operation** (of a mechanical switching device) (IEV Definition 441-16-16)
  A stored energy operation where the energy originates from manual power, stored and released in one continuous operation, such that the speed and force of the operation are independent of the action of the operator.
- **Dependent power operation** (of a mechanical switching device) (IEV Definition 441-16-14)
  An operation by means of energy other than manual, where the completion of the operation is dependent upon the continuity of the power supply (to solenoids, electric or pneumatic motors etc).
- **Independent power operation** (of a mechanical switching device) (IEV Definition 441-16-6)
  A stored energy operation where the stored energy originates from an external power source and is released in one continuous operation, such that the speed and force of the operation are independent of the action of the operator.
- **Stored energy operation** (of a mechanical switching device) (IEV Definition 441-16-15)
  An operation by means of energy stored in the mechanism itself prior to the completion of the operation and sufficient to complete it under predetermined conditions. This kind of operation may be subdivided according to:
  (a) the manner of storing the energy (spring, weight etc);
  (b) the origin of the energy (manual, electric etc);
  (c) the manner of releasing the energy (manual, electric etc).

Appendix B:

Further reading

General advice (including HSE publications)

The Health and Safety at Work etc Act 1974 The Stationery Office 1974 ISBN 0 10 543774 3

Management of health and safety at work. Management of Health and Safety at Work Regulations 1999. *Approved Code of Practice and guidance* L21 (Second edition) HSE Books 2000 ISBN 0 7176 2488 9

Memorandum of guidance on the Electricity at Work Regulations 1989 HSE Books 1989 ISBN 0 7176 1602 9

Occupational exposure limits: Containing the list of maximum exposure limits and occupational exposure standards for use with the Control of Substances Hazardous to Health Regulations 1999 Environmental Hygiene Guidance Note EH40 (revised annually) HSE Books 2002 ISBN 0 7176 2083 2

Working with cadmium: Are you at risk? Leaflet MSA7 HSE Books 1995 (also available on the HSE website at http://www.hse.gov.uk/pubns/msa7.htm)

Switchgear general

CH Flurscheim *Power circuit-breaker theory and design* Peter Peregrinus Ltd 1985 ISBN 0906048702

R T Lythall *The J and P Switchgear Book: An outline of modern switchgear practice for the non-specialist user* 1972 edition Newnes/Butterworth-Heinemann ISBN 0408000694

BS 3078: 1959 *Isolators (including selectors) for alternating current systems*

BS 4752: 1977: Part 1 *Switchgear and control gear for voltage up to and including 1000 Vac and 1200 V in dc circuit-breakers*

BS 5311: 1976: Parts 1 to 5 *AC circuit-breakers* of *rated voltage above 1 kV*

BS 5311: 1996 *High-voltage alternating-current circuit-breakers*

BS 5463: 1977 *AC switches of rated voltage above 1 kV*

BS 60947: *Specification for low-voltage switchgear and controlgear - general requirements and circuit-breakers*

BS 6423: 1983 *Code of Practice for maintenance of electrical switchgear and controlgear for voltages up to and including 1 kV*

BS 6626: 1985 *Code of Practice for maintenance of electrical switchgear and controlgear for voltages above 1 kV and up to and including 36 kV*

British Standards relating to oil switchgear

BS 116: 1937 Part 1 *Oil circuit-breakers, oil switches and oil isolating-switches for alternating current circuits (three-phase oil circuit-breakers with breaking capacity ratings between 25 and 500 MVA)*

BS 116: 1952 *Oil circuit-breakers for ac systems*

BS 936: 1940 *Oil circuit-breakers for medium voltage ac systems (up to 660 V)*

BS 936: 1960 *Oil circuit-breakers for medium voltage ac systems (up to 660 V)*

BS 2631: 1955 *Oil switches* for *alternating current systems*

BS 5730: 1979 *Monitoring and maintenance guide for mineral insulating oil electrical equipment* (under review based on IEC 60422)

Handling and use of sulphur hexafluoride

BS 5207: 1975 *Specification for sulphur hemfluoride for electrical equipment*

BS 5209: 1975 *Code* of *Practice for the testing of sulphur hemfluoride taken from electrical equipment*

SF_6 recycling guide: Re-use of SF_6 gas in electrical power equipment and final disposal CIGRE Technical Brochure No 117 1997

Guidance on the safety aspects of work on sulphur hexafluoride-filled distribution equipment up to 145 kV EA Engineering Recommendation G69 1988

IEC 376: 1971 *Specification and acceptance of new sulphur hexafluoride*

IEC 480: 1974 *Guide to checking of sulphur hexafluoride (SF_6) taken from electrical equipment*

IEC 694: 1995 *High-voltage switchgear and controlgear. Use and handling of sulphur hexafluoride (SF_6) in high-voltage switchgear and controlgear*

High-voltage switchgear and controlgear - use and handling of sulphur hexafluoride in high-voltage switchgear and controlgear IEC Technical Report 1634 (First edition) 1995. Reference No CEI/IEC 1634:1995.

LV installations

BS 7671: 2001 *Requirement for Electrical Installations (IEE Wring Regulations)* Seventeenth edition

Disposal of hazardous materials

EU Directive 96/59/EC *The Disposal of Polychlorinated Biphenyls and Polychlorinated Triphenyls* European Commission

The Disposal of Polychlorinated Biphenyls and Other Dangerous Substances Regulations (England and Wales) SI 2000/1034 The Stationery Office May 2000

The Special Waste Regulations 1996 The Stationery Office

European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR) and protocol of significance The Stationery Office

RCM background

Smith A M *Reliability-centred maintenance* Wiley New York 1992

Moubray J *Reliability-centred maintenance* Buttenvorth-Heinemann Oxford 1991

Generator protection settings

Recommendations for the connection of embedded generating plant to the public electricity suppliers' distribution systems Electricity Association Engineering Recommendation G59/1 1991

Recommendations for the connection of embedded generating plant to public electricity suppliers' distribution systems above 20 kV or with outputs over 5 MW Electricity Association Engineering Recommendation G75 1996

Insulating tools

BS EN 60900 1994 *Hand tools for live working up to 1000 Vac and* 1500 *V dc*

Ordering HSE publications

Please see inside back cover for details of how to order HSE publications.

British Standards

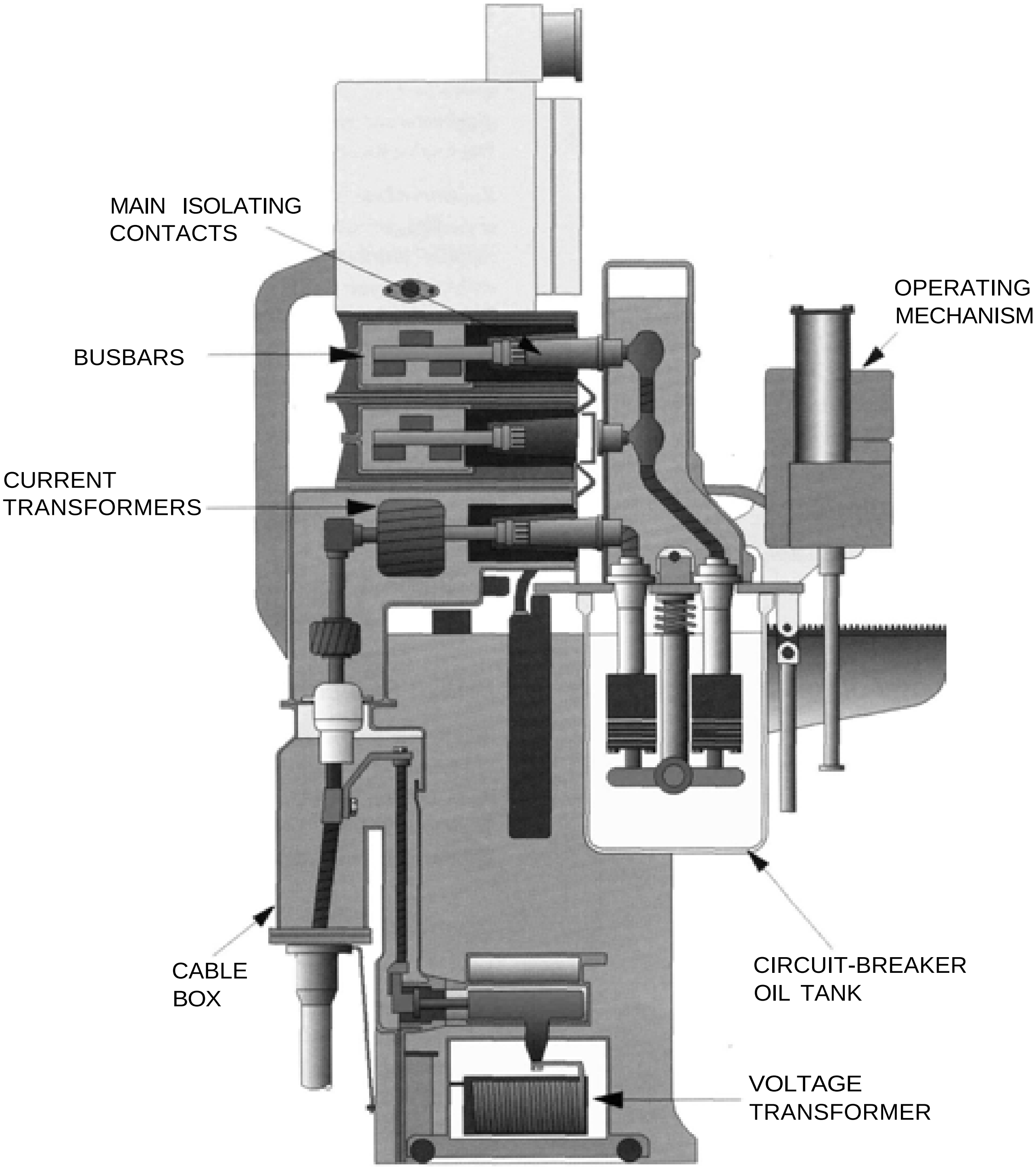
British Standards are available from
BSI Customer Services, 389 Chiswick High Road, London W4 4AL
Tel: 020 8996 9001 Fax: 020 8996 7001
Website: www.bsi-global.com

Publications *from the Stationery office*

The Stationery Office (formerly HMSO) publications are available from
The Publications Centre, PO Box 276, London SW8 5DT
Tel: 0870 600 5522 Fax: 0870 600 5533
Website: www.tso.com
(They are also available from bookshops.)

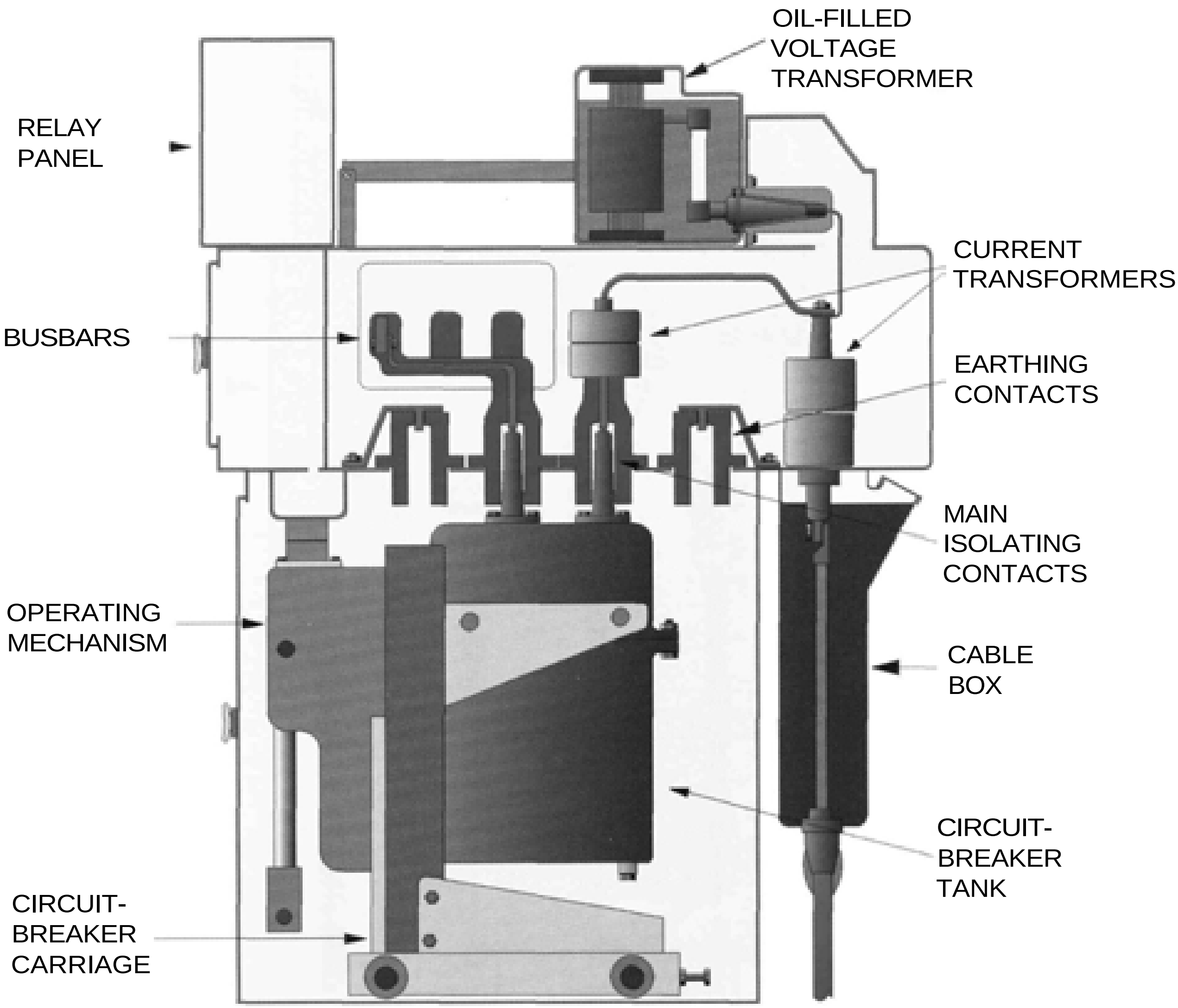
Appendix C:
Examples of switchgear configurations

Appendix C1:
Typical arrangement of a horizontal isolation duplicate busbar 11 kV oil circuit-breaker



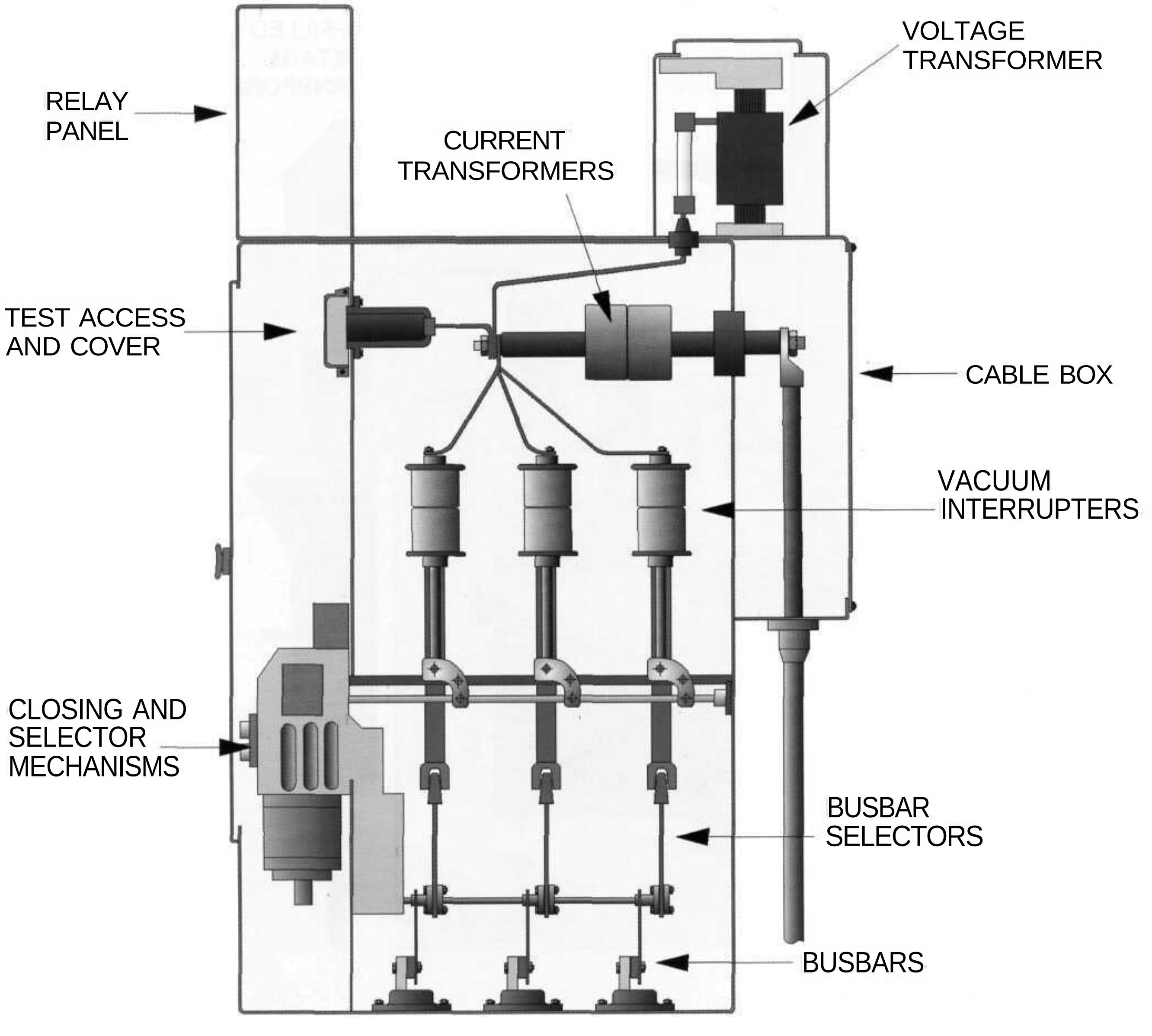
Appendix C2:

Typical arrangement of a vertical isolation 11 kV oil circuit-breaker panel (single busbar with feeder earthing via circuit-breaker transfer)



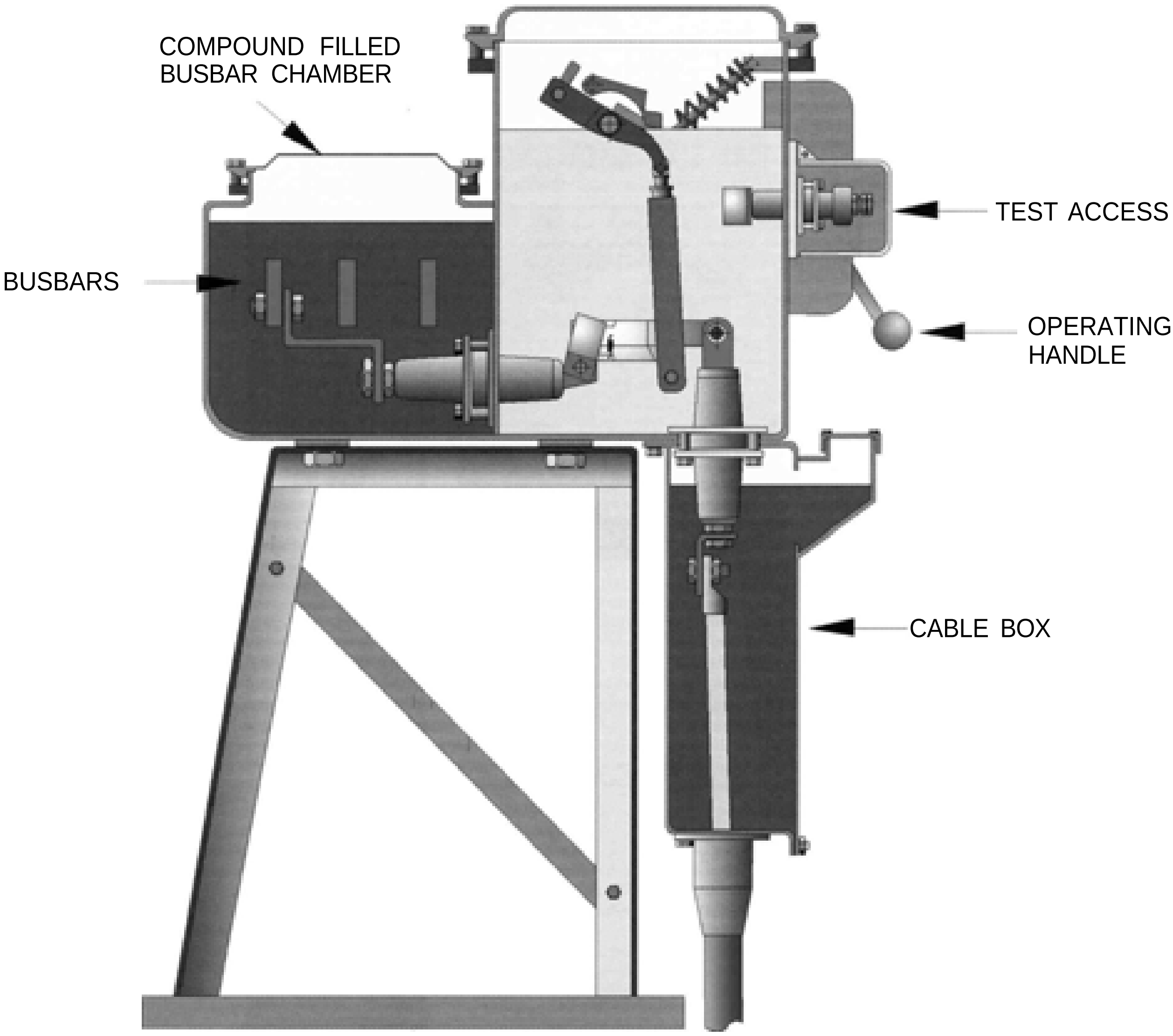
Appendix C3:

Typical arrangement of a single selector fixed pattern 11 kV vacuum circuit-breaker



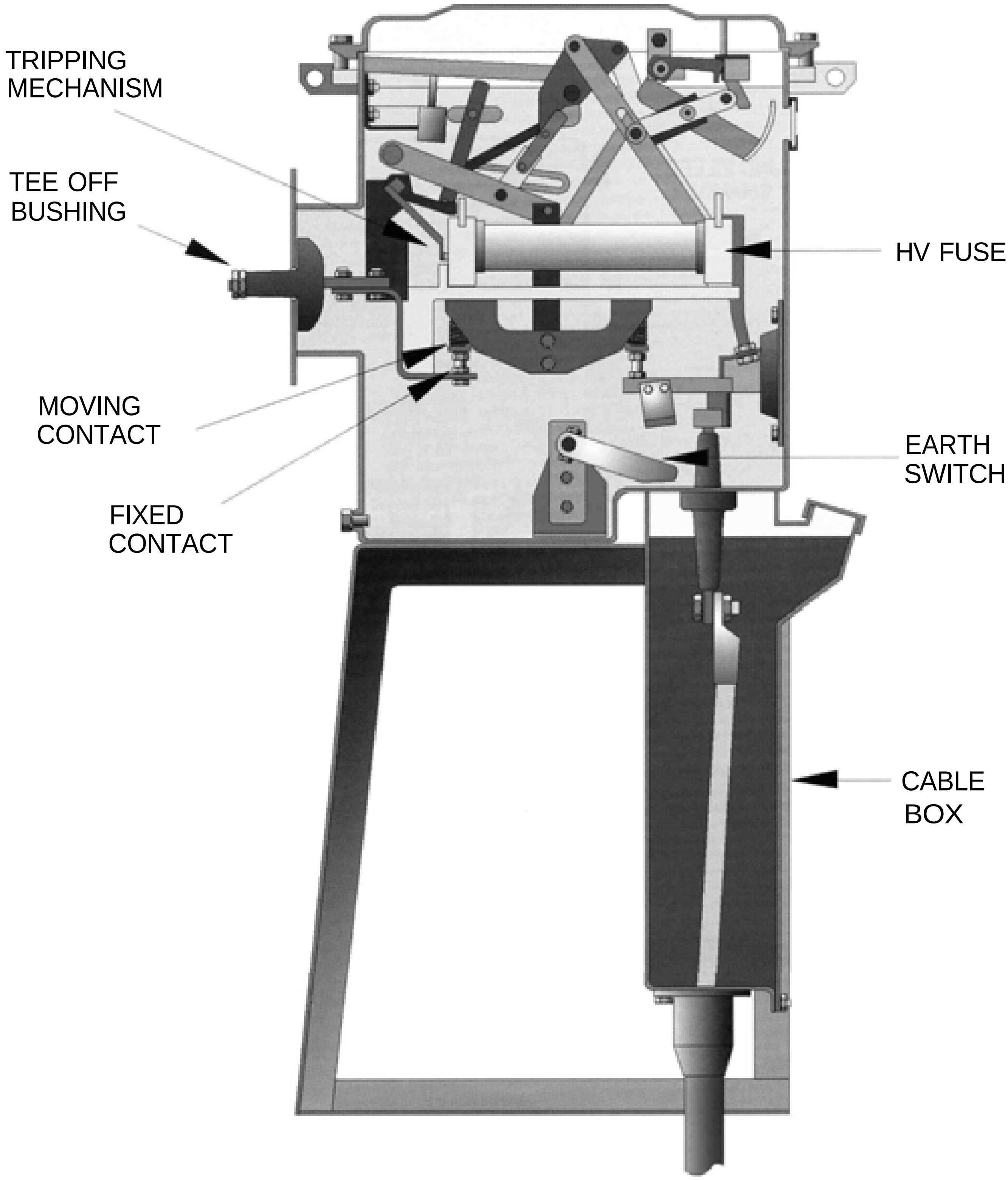
Appendix C4:

Typical arrangement of an 11 kV oil switch



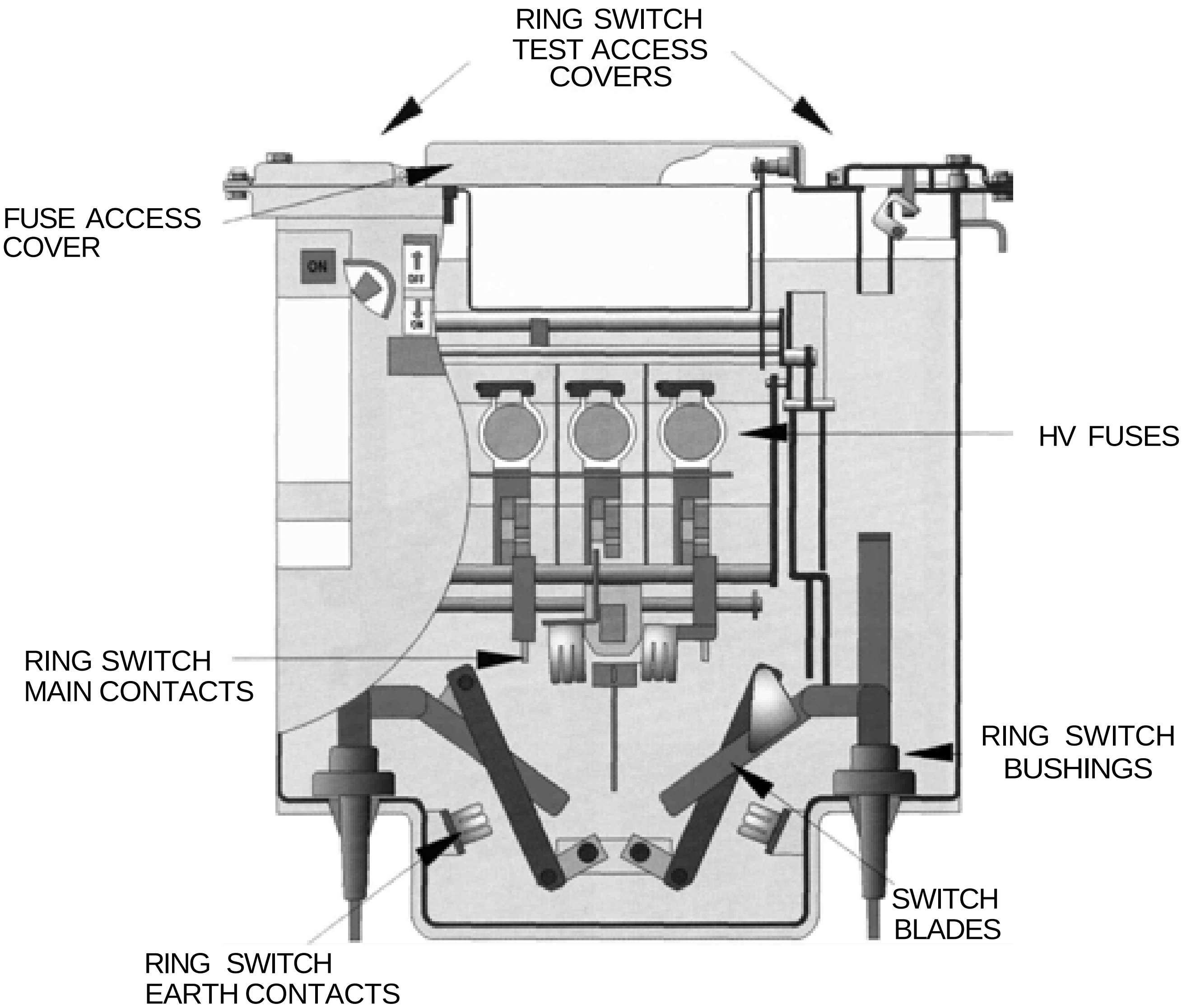
Appendix C5:

Typical arrangement of an 11 kV oil fuse switch



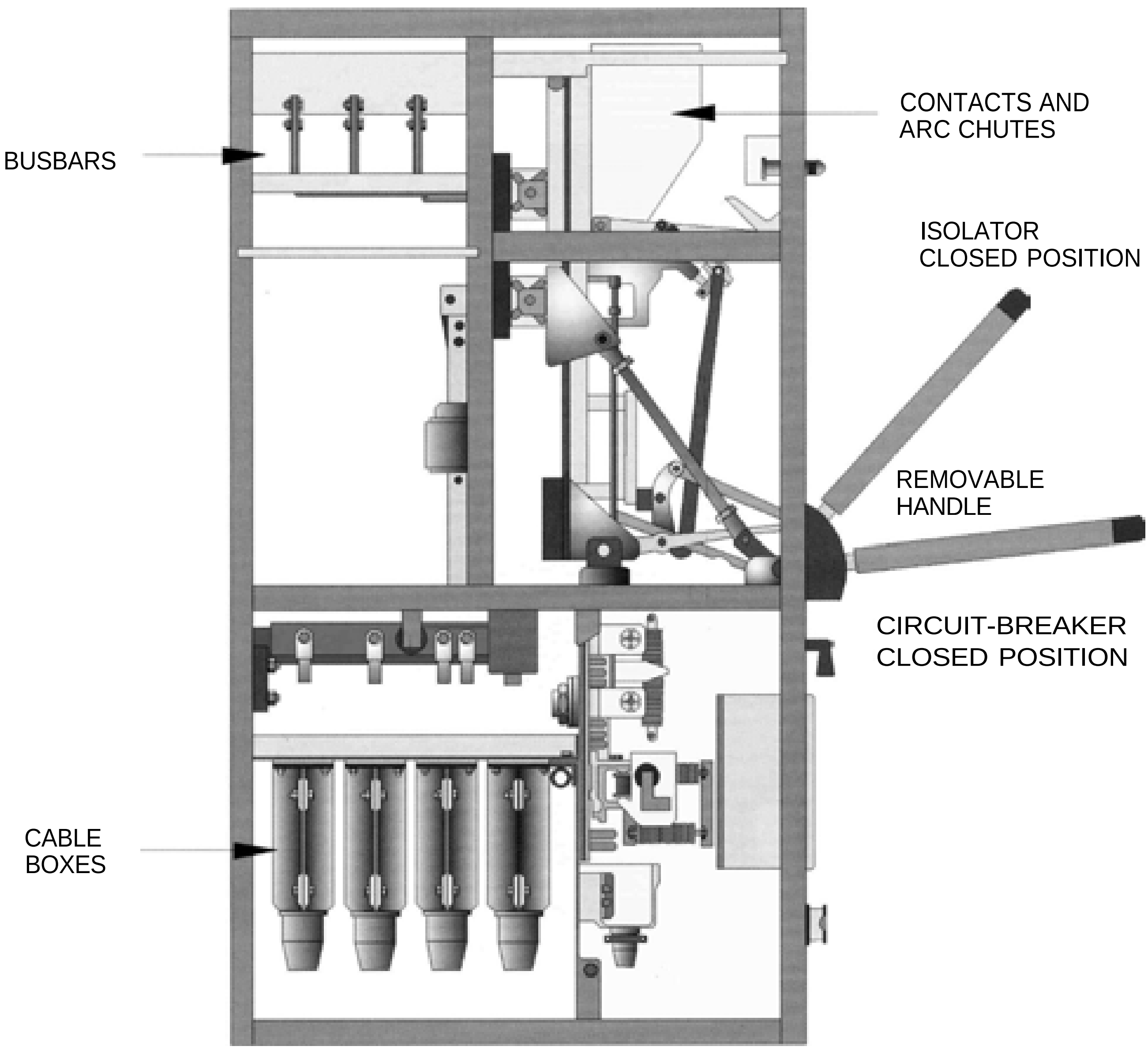
Appendix C6:

Typical arrangement of an 11 kV oil-filled common tank ring main unit (incorporating two ring switches and one fuse switch)



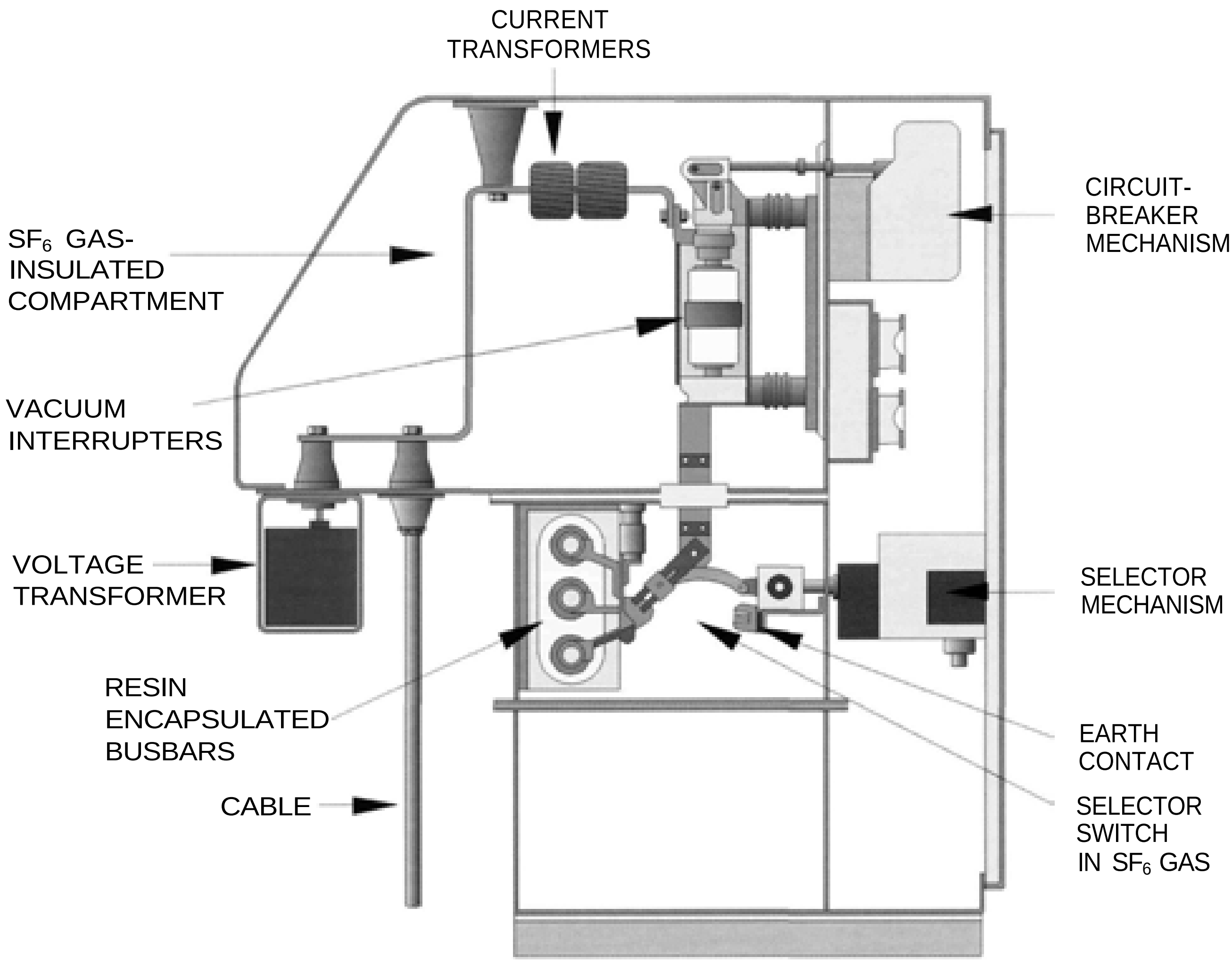
Appendix C7:

Typical arrangement of a 415 V air circuit-breaker



Appendix C8:

Typical arrangement of a 33 kV fixed-pattern vacuum circuit-breaker with sulphur hexafluoride (SF_6) gas insulation



Appendix D:

Other sources of information

British Electrotechnical and Allied Manufacturers Association (BEAMA)
Westminster Tower
3 Albert Embankment
London
SE1 7SL
Tel: 020 7793 3000

The Institution of Electrical Engineers (IEE)
Savoy Place
London
WC2R 0BL
Tel: 020 7240 1871

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