Health and Safety Executive OC 482/2

Field Operations Division

To

Factory Inspectors (Construction Groups)

FCG Specialist Inspectors (Elec)

ELECTRICAL SAFETY OF INDEPENDENT LOW-VOLTAGE AC

PORTABLE AND MOBILE GENERATORS AND CONNECTED SYSTEMS

1 The attached information document examines the effects of various modes of operation of single-phase and 3-phase generators with their connected systems and makes appropriate safety recommendations. It may be copied and given to interested persons outside HSE. It is emphasised that it deals only with ac systems.

2 An earlier draft of the paper was submitted by the HSE representative to BSI Technical Subcommittee GEL/107 and used as a guide for the section on portable and mobile low voltage generators in the revision of BS CP 1013, now due for publication before the end of 1991.

3 The proposed advice on this subject in the revised British Standard is presented in an abridged form as the Standard mainly deals with the earthing requirements of fixed power distribution and utilisation systems and the means to achieve low earth resistances. It was also the opinion of BSI that some of the detailed advice was more appropriate to an HSE publication.

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HSE 482/2

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PORTABLE AND MOBILE GENERATORS AND CONNECTED SYSTEMS

INTRODUCTION

1 This document contains internal guidance which has been made available to the public. The information may not be applicable in all circumstances and any queries should be directed to the appropriate enforcing authority.

2 It covers the use of low-voltage ac generators which supply electrical systems, usually temporary systems for short-term needs, that cannot be fed conveniently from a mains supply.

3 Low voltage conventionally means a voltage 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. For the purpose of this document, the generators addressed are those which supply output voltages of 110 V ac, 220 V ac, 230 V ac or 240 V ac single-phase, and 415 V ac 3-phase.

GENERAL

4 Generator users should operate their equipment in accordance with the manufacturer's instructions. Generators are frequently hired from plant-hire companies which are in turn responsible for providing the hirer with information for the safe use of their equipment. On no account should users interfere with the internal electrical connections of hired equipment. If questions arise about the operation of the equipment or its safety, users should refer to their suppliers in the first instance.

5 Besides other controls and instruments associated with a generating set, efficient means should be provided for the following.

(1) Stopping the prime mover.

(2) Connecting the load to the generator terminals (eg at an enclosed terminal box or by a suitable socket outlet). Terminal boxes, if metallic, should be electrically continuous with the generator enclosure. Socket outlets should be suitable for their environmental exposure. BS 4343 sockets are recommended. BS 1363 sockets, sometimes fitted to small machines intended for domestic use, are unsuitable for use in wet conditions.

(3) Protecting the connected system against excess currents.

(4) Switching off the connected load.

(5) Connecting the generator enclosure to earth when necessary, depending on the mode of operation of the generator and its connected system.

6 Generators have metallic enclosures with windings which are not usually referenced internally to the enclosure. With independent generators, it is important to distinguish between protective and system earthing, and also to consider the effects of other chosen reference points. Protective conductors and equipotential bonding relate to ways in which external metallic enclosures are connected to limit simultaneously accessible voltages under fault conditions and to enable fault currents to flow to operate electrical protection. The referencing of an electrical system to earth or other chosen reference point primarily limits the potential of system conductors with respect to that reference point but will also provide a path for fault currents.

LOW-VOLTAGE, SINGLE-PHASE PORTABLE AND TRANSPORTABLE GENERATORS

7 These are generally machines ranging in size from 0.3 to 10 kVA. Winding connections are brought out to a socket, in which the third or protective conductor socket tube is usually connected internally to the generator enclosure but may in some cases be referenced internally to one pole of the generator winding. A voltage-selector switch may be fitted to enable 240 V or 120 V outputs to be obtained from BS 4343 sockets of the appropriate type.

8 Where there is no path for earth fault currents to return to the 'separated' winding of a generator (cf the secondary winding of an isolating transformer), it is acceptable for these small generators and their loads to be run without deliberately connecting either external metallic parts or one pole of the single-phase electrical system to earth, subject to the following conditions.

(1) Only cables which are suitable for their environmental exposure should be used to connect the generator to its load. The use of PVC-insulated and sheathed cables with flexible, braided wire armour and a PVC over-sheath is recommended.

(2) The generator enclosure should be bonded to all other metallic enclosures which form part of the system (eg to the metallic braid of flexible cables and the load enclosures if metallic), by correct termination of the protective conductors and braids.

(3) If flexible cables without a continuous metallic braid are used, suitable 3-core cables should be selected with an extruded over-sheath capable of high resistance to abrasion or damage.

(4) All cables require frequent inspection. Users should be alert to risks which arise from damaged cables which should be replaced and not repaired, and from

defective terminators at plugs, sockets and couplers.

(5) Load cables supplied from unearthed single-phase generator windings should be kept as short as practicable and supply compactly located loads which are not widely dispersed. With extensive unearthed or 'floating' systems, there is a higher probability of the development of undetected earth faults caused by damaged cables.

Application of supplementary protection by an external residual current device (RCD)

9 If supplementary personal protection of this type is desired, an RCD cannot operate as intended unless one pole of the single-phase electrical system is connected to a reference point so that fault current can return to the generator winding, so causing the RCD to trip. The chosen reference point is generally earth except in the case of a system which is totally contained within equipotentially bonded metalwork which should then be the chosen reference point. The RCD then acts as a sensitive insulation monitor which trips the supply when a first fault occurs between a live conductor and the enclosing metalwork, resulting in a very safe system.

10 Electric shock can result if unarmoured single-phase generator cables are damaged and touched after the integrity of an unreferenced system has already been destroyed by a first undetected earth fault. In this case inclusion of an RCD will minimise the resulting danger to persons making contact between a live conductor and earth. For all applications which involve personal protection by minimisation of danger from electric shock, an RCD should have a rated tripping current of 30 mA and comply with BS 4293: 1983.

11 It is unusual for small, single-phase generators to have built-in RCDs, so when this form of supplementary protection is desired, a separate RCD assembly has to be provided. The system will require installation by a competent person and should then include the following features:

(1) a suitable enclosure for the RCD, all insulated or metallic and, if the latter, bonded to the protective conductor;

(2) connections by BS 4343 plugs and sockets;

(3) an internal connection in the RCD enclosure to reference one pole of the generator winding to the protective conductor, unless the generator supplier has already provided this connection internally; and

(4) earthing of the generator enclosure to enable the RCD to operate on occurrence of the first fault to true earth (see para 23).

12 The possible gains from deliberately earthing a small single-phase system, for correct operation of what is at best supplementary protection, are unlikely to outweigh the safety and economic advantages of using the system as a simple floating system in the first place. This observation must always be subject to great care by the user in selecting cables suitable for their working environment or special processes, choosing cable routes which offer protection against accidental damage and frequent inspection of insulation integrity throughout the system which should be compact and not extensive.

LOW-VOLTAGE, 3-PHASE MOBILE GENERATORS

13 These units may be mounted on trolleys, skids or other vehicles and have outputs from about 15 kVA upwards at 415V. As supplied, the generator winding may not be connected to the machine frame. Instead the 3 phases and the neutral connection are brought out to the generator terminal box or, on smaller units, to a BS 4343 socket outlet.

14 The neutral point of 3-phase windings should be connected to a reference point in order to prevent the possibility of neutral inversion and to enable protection to operate correctly on single-phase faults. This reference point should be electrically continuous with the generator enclosure, subframe and load-circuit protective conductors. In the case of 3-phase generators, it should also be connected to true earth when reasonably practicable (see para 23).

15 A generator terminal box provides a universal means for a user to connect separate neutral and protective conductors as well as the 3-phase conductors. A BS 4343 socket for a 5-pin plug provides the same facility but some 3-phase generators are fitted with sockets for 4-pin plugs, the connections to neutral and frame having been already combined internally at the socket. This has implications if single-phase loads are supplied by a 3-phase generator, and reinforces the need for users to know exactly how winding and frame connection have been brought out to the generator terminal assembly, whether terminal box or socket.

Selection of cables for 3-phase service

16 The effect of drawing single-phase loads from a 3-phase generator with 4 terminals is that the fourth connection will carry unbalanced load current, acting as a combined neutral/protective conductor. This is undesirable in systems supplied by independent 3-phase generators. Four conductors (3 phases and a protective conductor) should only be used when the 3-phase load is known to be balanced (ie when the fourth or protective conductor is not required to carry residual current from unbalanced single-phase loads).

17 For 3-phase and neutral supplies from independent generators, 5 load connections are required, either from the 4 or 5-pin plug which mates with the generator socket or from the generator terminal box, namely 3 phases, an insulated neutral and a protective conductor. This is particularly important if it is subsequently wished to fit a separate 3-phase RCD unit in the output connections as fault current which may flow in the protective conductor must not be "summed" by the RCD. The use of 5 connections to a 4-pin plug requires that neutral and protective conductor connections are commoned (ie connected together) within the plug, the matching socket connection on the generator forming the winding neutral/frame reference point. In practice, no problems are likely if 4-core cables with PVC-sheathed, flexible metallic braid or 3-phase and neutral insulated PVC/steel wire armoured PVC over-sheath cables are used.

18 When cables are selected for connection to any system, it should be noted that the choice between flexible metallic braid, standard steel wire armour or pliable wire armour will depend upon loads, availability of cable types and the possible need for flexing of cables in service.

SUPPLEMENTARY PROTECTION OF 3-PHASE GENERATORS

BY A RESIDUAL CURRENT DEVICE

19 Some 3-phase generators are supplied with built-in RCDs and the neutral point of the winding is internally connected to the generator frame and protective

conductor terminal. Otherwise a separate 3-phase RCD may be installed in the load circuit, close to the generator, by a competent person. The RCD then provides fast-acting, first-fault protection if a fault develops anywhere in the load circuit between a phase conductor and metallic enclosures which are bonded by the protective conductor (ie an insulation-monitoring function).

20 When the reference point defined in para 14 is earthed, the RCD should also operate if a fault occurs between a phase conductor and true earth, for example by insulation breakdown or by personal contact between damaged unarmoured cables and true earth.

Effect of fortuitous earthing of metallic enclosures

of 3-phase systems

21 Electrical equipment used on systems supplied by generators is likely to be metal clad and some degree of fortuitous earthing of metal enclosures, for example by reasons of their location on the ground or on structural steelwork, is possible but not quantifiable. In this case, an RCD may serve to provide supplementary protection even in systems which are neither totally metal clad nor deliberately earthed at the generator neutral. If fault current which could cause personal injury can flow, it should be detected by the RCD. If, on the other hand, conditions are such that there is no fortuitous earthing of metal enclosures, frames or mountings, then no fault current capable of causing personal injury can flow via true earth.

22 In order to obtain the full benefit from an RCD, either one pole of a single-phase generator or the neutral terminal of a 3-phase generator, together with the relevant metallic enclosures and protective conductors, should be connected to true earth.

Connections to true earth

23 The following are examples of feasible methods, using:

(1) an earth rod driven to a depth of not less than 1 metre;

(2) the earth terminal of an adjacent fixed installation;

(3) permanent structural steelwork;

(4) exposed reinforcement bars in concrete foundations or structures; and

(5) a suitable metallic structure known to be earthed.

LOW-VOLTAGE, 3-PHASE GENERATORS

WITH REFERENCE POINT UNEARTHED

24 These are not strictly 'floating' systems as precautions should already have been taken to prevent neutral inversion (see para 14). If all live conductors of the interconnecting cables and the load are contained within bonded metallic enclosures, the first fault will cause an internal short circuit which should be rapidly cleared by the generator protection without risk externally. If an RCD is included in that system, it will act as a sensitive insulation monitor resulting in even faster fault clearance.

25 If the load cables are unarmoured or other system component enclosures are non-metallic, then safety will depend primarily on the integrity of insulation. If exceptionally it is not reasonably practicable to earth the generator neutral reference point and fit an RCD, it is only acceptable to run the system subject to:

(1) the location of the generator close to its load;

(2) the use of short interconnecting cables between the generator and the load;

(3) a load which is a single, compact item of plant (eg a pump or air compressor);

(4) regular examination by a competent person of those parts of the system which depend solely on insulation integrity for safety (eg non-armoured cables) in order to maintain that integrity at all times.

26 Experience has shown that extensive temporary distribution and subdistribution systems using unarmoured cables are more likely than compact systems to suffer insulation damage. This then creates a subsequent risk to persons because of the possibility of fortuitous earthing of metallic enclosures and therefore, also of the generator neutral connection.

LOOP IMPEDANCE OF SYSTEMS SUPPLIED BY SINGLE OR 3-PHASE INDEPENDENT GENERATORS

27 For single-phase floating systems, loop impedance is inapplicable but circuit impedance should be low enough to ensure the operation of excess current protection within 5 seconds.

28 For 3-phase systems, whether referenced to true earth or not, phase/ protective conductor loop impedance should be low enough to ensure the operation of excess current protection within 5 seconds.

29 When RCDs are fitted to single-phase or 3-phase systems for the purpose of personal protection from contact with a live conductor and true earth (not for insulation-monitoring purposes on totally metal-clad systems), the loop impedance between a phase conductor and true earth should be sufficiently low to ensure operation of the RCD at its rated tripping current. The product of the rated residual operating current in amperes and the earth fault loop impedance in ohms should not exceed 50.

SUMMARY OF ADVICE

30 Floating systems, particularly when limited in extent and under close supervision, do not introduce possible consequential hazards which may arise from deliberately earthing an initially separated single-phase generator winding.

31 Cables with metallic armour or braid, and a plastic over-sheath, are safer than cables with extruded plastic insulation and over-sheath, as the latter are more likely to be damaged.

32 Residual current devices may be used for 2 purposes on systems supplied by independent single-phase and 3-phase generators, namely:

(1) for insulation-monitoring of a system which has complete metallic enclosure of circuit conductors; or

(2) for personal protection in case of contact between a live conductor and true earth or metallic enclosure.

33 Application (32)(2) above demands that the electrical system is referenced to true earth to enable an RCD to operate correctly on the first fault to true earth.

34 Three-phase generator windings always require a neutral reference point, namely enclosure and protective conductors and in general the connection of that reference point to true earth, particularly if the system includes an RCD used for personal protection and not solely for insulation-monitoring purposes.

35 The condition of all connected equipment should be regularly examined by a competent person. Portable and transportable equipment of all types is more likely than a fixed installation to suffer damage which could lead to danger.

36 Composite 3-phase and single-phase loads supplied from 3-phase generators require 4 circuit conductors and a protective conductor.

37 Integrity of insulation is the prime safeguard against shock risk from independent unearthed systems which are not entirely contained within electrically continuous metallic enclosures.

38 When RCDs are fitted, their tripping-time characteristics should be regularly monitored by the use of a suitable proprietary test instrument. Test buttons should be operated frequently to minimise the possibility of maloperation caused by release mechanism friction.

39 Experience proves that temporary cables and associated components, if not carefully selected, fitted and maintained, are more likely to be sources of danger than the generators themselves and their loads.

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