Scottish Hospital Technical Note 5

The Operation and Management of Emergency Electrical Generators in Scottish Healthcare Premises

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Contents

Foreword

This Scottish Hospital Technical Note has been prepared to summarise the important issues relating to the operation and management of emergency electrical generator installations within Scottish healthcare premises.

An emergency generator installation which fails to perform its required function in the event of disruption to the premises' electrical supply may have serious and potentially life threatening consequences. Effective operational management of emergency electrical services is an essential part of the healthcare facilities.

Emergency electrical services in healthcare premises are a management responsibility, with the Chief Executive having the ultimate responsibility for the safety and reliability of their operation. The day to day responsibility for the management of these services will typically lie with healthcare estates/engineering staff who will have a range of maintenance, testing and safety regimes to implement. The intention of this Scottish Hospital Technical Note (SHTN) is to provide the staff having this responsibility with a summary of the technical guidance relevant to the operational management of emergency electrical generator installations. General safety issues are also considered and a risk assessment technique that addresses these particular characteristics is provided.

Scottish Health Technical Memorandum SHTM 2011: *Emergency electrical services* gives comprehensive advice and guidance on legal/mandatory requirements, design applications, maintenance and operation of emergency electrical services in all types of healthcare premises. This document does not supersede SHTM 2011 but should be read in conjunction with it.

This publication is supplemental to current guidance in the Scottish Health Technical Memoranda (SHTM) series and should be read and applied in conjunction with the series.

1. Management responsibilities

Introduction

1.1 The dependency of healthcare premises upon electrical power supplies has increased significantly in recent years. This is due, in part, to the increased use of electrically dependent medical equipment at all stages of patient care. Interruptions of the electrical power supply to medical equipment and clinical areas can seriously disrupt the delivery of effective treatment with life threatening consequences for the patient. There is a requirement, therefore, for those managers with responsibility for healthcare premises to ensure that electrical power is provided for essential services in the event of any disruption to electrical supplies. This requirement is met through the provision of emergency electrical services, which can be in the form of batteries and uninterruptible power supply (UPS) systems, and/or stand-by emergency electrical generator installations.

1.2 Batteries are used in situations where a response time of less than 0.5 seconds is required and applications include emergency power for Theatre and escape lighting and certain equipment. UPS systems are typically used for computer applications and special equipment, where, a 'no break' electrical supply is required. Where a UPS is installed, testing should be undertaken on a regular basis. It is also important to ensure that any failure in a UPS will not disrupt the normal electrical supply to the equipment being served. Stand-by emergency electrical generators are used extensively in healthcare premises to provide essential electrical power primarily to clinical, diagnostic and essential service areas. Considering the criticality of such systems it is important that the operational management arrangements in place are both thorough and effectively implemented.

1.3 The complexity of the emergency electrical services varies across healthcare premises and will very much be dependent on the size of the site and the range of support facilities, clinical diagnostic and essential services undertaken. Battery installations and UPS systems are generally less complex to operate than emergency generator installations and are not dealt with in this document. However, the operation and management of emergency electrical generator installations requires maintenance and testing regimes and it is these aspects which are addressed in this document.

1.4 The guidance herein refers to a typical diesel engine electrical generator installation which is most commonly applied throughout the NHS in Scotland (NHSiS). Additional functions such as peak lopping or combined heat and power (CHP) are not considered in this document. The risk assessment technique that is detailed in Section 3.6 can, however, be applied to most types of installation.

The term ‘emergency generator’ used in this document should be understood to imply emergency electrical generators.

Statutory Requirements

1.5 There is a general duty of care under the Health and Safety at Work etc. Act 1974 and specific duties under the Electricity at Work Regulations 1989, which oblige employers to ensure the provision of safe electrical plant and systems, and to provide adequate maintenance to ensure continued safety. This duty applies to the operation of emergency generators and associated systems. Failure to adequately maintain such systems could therefore result in a failure to comply with the above Act.

Environmental Considerations

1.6 Consideration must be given to the environmental impact of diesel engines including exhaust pollution, methods of exhaust gas cleaning, required stack height, noise and fuel storage arrangements. *This latter element is likely to be subject to change in the near future with the Government intending to introduce new regulations in England which are aimed at reducing the number of oil-related water pollution incidents. The Control of Pollution (Oil Storage) (England) Regulations 2000 will set design standards for all above ground oil storage containers and it is anticipated that similar legislation will be effected in Scotland sometime thereafter.* Management has a responsibility, to ensure that the operation of emergency generator installations do not breach the requirements of relevant environmental legislation such as the Clean Air Act 1993, the Control of Pollution Act 1974 and the Environmental Protection Act 1990. The implementation of GREENCODE and reference to SHTM 2011: ‘Emergency electrical services’ Part 2 ‘Design considerations’ will provide further information.

Operational Responsibilities

1.7 Healthcare estates/engineering personnel will generally have the day to day responsibility for the safe operation and reliability of emergency generator installations. This includes the responsibility for correct implementation of the maintenance and test regimes and supervision of this function where these activities are undertaken by a specialist contractor. Monitoring and recording of the requirements should be followed up by advising the Chief Executive where failures of these have occurred.

2. Design criteria and typical installation

System Criteria

2.1 The main criteria, as detailed in SHTM 2011, for emergency electrical supplies to essential support services, clinical and diagnostic areas within healthcare premises are as follows:

- **response time typically of 15 seconds or less** – this is generally only achievable through the use of a reciprocating engine which makes the diesel engine ideal for this function;
- **continuous full-load running for a minimum period of 200 hours** – this requires an adequate supply of fuel (diesel), to be stored on site. 200 hours is the minimum period advised for continuous operation of the generator on full load and is dependent largely on location and fuel delivery constraints, for example, this period may have to be extended for rural locations where a prolonged outage could be anticipated together with fuel delivery constraints. The engine room service tank (often referred to as the day tank) should be at least 750 litres or equivalent to 10 hours full load running of the engine.

System Characteristics – Typical Installation

2.2 The essential characteristics of emergency electrical generator installations are that they should be self-contained, with their own fuel supply and run independently of any other system.

A typical emergency electrical generator installation is shown in Figure 1 and consists of the following principal components:

- **fuel system** – this will consist typically of the engine room service tank, a bulk fuel storage tank, associated pipework and safety devices to facilitate the safe transfer of fuel;
- **engine starting batteries** – the capacity of engine starting batteries (expressed in Ampere hours 'Ah') will depend on the size of the engine and should be capable of turning an engine over at constant speed for 60 seconds continuously in an ambient temperature of 0°C. They should also be located as near to the engine as possible to minimise the volt drop in the connecting cables. For very large engines, compressed air starting is often used. Typically, it is necessary to provide three air compressors – two driven by electric motors and the third driven by a petrol or diesel engine to allow for main engine start up difficulties during a black start situation when there is no electric power supply;

- **diesel engine** – this is considered the most effective and economical prime mover as it has a more rapid response time for load acceptance from a cold start than other types. For equal engine speeds and frame sizes, the output of a diesel engine is approximately twice that of a gas engine;
- **alternator** – various types of alternator exist including brushless which are now generally provided for generating sets;
- **control systems** – this will include the automatic voltage regulator (AVR) and systems for governor, excitation and load control. Also alarm and monitoring systems including voltage monitoring for automatic start up.

Key Design Considerations

2.3 This section is intended only to provide a brief summary of the key design considerations for emergency generator installations. Reference should be made to SHTM 2011: *Emergency electrical services,* Part 2 'Design considerations' for further information. The following points, however, may be relevant when considering modifications to existing installations:

- **Segregated or unified circuits** – the demand for essential electrical services within healthcare premises has steadily increased largely due to the complexity and criticality of the services now offered. Non clinical departments, which may have been traditionally supplied by segregated non essential electrical services, may now be considered to be 'essential' to the running of the facility with the disruption and knock on effects of the non availability of such departments now acknowledged. As a result, the decision making process for selecting either a segregated non-essential/essential system or a unified electrical system has changed. The advent of Private Finance Initiative (PFI) projects for healthcare buildings, where the loss of an electricity supply would impact on the ability of the PFI service provider to deliver and thereby affect financial revenue, will have an influence in this process. In this regard, a risk assessment approach is a fundamental requirement to assist in the decision making process. It is likely that further guidance will be issued in respect of this aspect of risk assessment to support the extant guidance available i.e., in the Institution of Electrical Engineers Guidance Note No.7, Chapter 10; Medical Location and Associated Areas, and the Institution of Electrical Engineers Publication 364: Section 710 - Medical Locations which gives guidance on supplies and standby supplies for medical equipment.
- **Power ratings of engine(s)** – engines should be continuously rated as defined in BS 5514 (ISO 3046) and be capable of operating at the rated load for a period of 12 consecutive hours, in which time would be included an overload of 10% for a period not exceeding one hour. This is a detailed design consideration and specialist advice should be sought.

- **Number of generating sets** – the number of generating sets is largely determined by the size of the premises. Whereas a single generator may be sufficient for small premises in terms of functionality and economics, two or more will likely be required for larger premises. In this situation, the generators should be capable of running synchronised and in parallel.
- **Single (island) / parallel running** – in terms of the mode of operation, 'island' running of the generator(s) is the simplest arrangement in that each generator will supply electrical power to a discrete isolated system. Additional costs are incurred for parallel running for the control and protection equipment required. When parallel running with the mains supply is undertaken, this will require agreement with the relevant public electricity supply company.
- **Type of alternator and rated output** – there are several types of alternator, however, the brushless alternator is now generally provided for all generator sets.
- **A control, changeover contactors, relays etc.** – a wide range of controls/automatic changeover switches exists and the complexity will be dependent on the particular requirements of the installation. This is a detailed design consideration and specialist advice should be sought.

3. Operation, maintenance and testing

3.1 The operational management arrangements to ensure generator availability are further detailed in SHTM 2011: 'Emergency electrical services' Part 4 'Operational management'. The criticality of this provision cannot be over emphasised and it is vital, therefore, that the arrangements in place are both thorough and effectively implemented and tested.

Safety

3.2 Only authorised and competent persons who have received suitable training should be appointed to manage the operational aspects of emergency generator installations. These designated staff functions are defined within SHTM 2020: *Electrical safety code for low voltage systems (Escode – LV)* and SHTM 2021: *Electrical safety code for high voltage systems (Escode – HV)*.

3.3 Safe working practices, as prescribed in SHTM 2020 should be developed for working on emergency generator installations, and method statements for work procedures included in local house rules. This should include the formalised written instructions which detail a safe system of work. On automatically/remote starting plant, a warning sign advising personnel that the plant may start automatically without warning should be prominently displayed. Safety documents, typically in the form of a permit-to-work may also be required for certain activities. Scottish Hospital Technical Note (SHTN) 4; *General Purposes Estates and Facilities Model Safety Permit-to-Work System* may be used for this purpose.

3.4 A typical emergency electrical generator installation with the standard safety features is shown in Figure 1. The following aspects should be considered when planning or reviewing a generator installation:

- consideration of the layout of the engine room and the space available for maintenance operations. Aspects relating to entry into confined spaces may be relevant in some cases;
- discharge of exhaust gases to ensure that these do not escape or re-circulate within the generator room – the location of the final exhaust point is also an important design consideration to ensure that fumes are not drawn into nearby wards or departments;
- avoidance of contact with hot surfaces such as the exhaust, radiator and other components likely to become hot when the generator is running;

- arrangements for lifting items of plant for servicing or replacement – where lifting equipment such as a crane is necessary, the requirements of the Lifting Operations (Lifting Equipment) Regulations 1998 (LOLER) must be observed;
- fire safety risk assessments for engine rooms that consider the means of escape, fire resistance of the engine room construction and doors and general fire precautions should be completed;
- condition of floors and internal walls within the engine room. Floors should be of a suitable non-slip and oil resisting finish and internal walls should have a finish which resists build-up of dirt and can be easily and effectively cleaned;
- adequacy of lighting levels within the engine room – a minimum of 150 lux is recommended in the working area. Good illumination of the control panels is also required. Self contained battery operated luminaires with three hours duration should also be provided;
- provision of rubber or other insulating matting at electrical switchgear/control panels;
- socket outlets with residual current protection at convenient points within the engine room for equipment. Hand tools should be supplied at 110 V from a 240/110 V Class1 isolating transformer with earthed output winding centre taps if a 110 V ring main supply is not available. Class 2, 240/25 V portable FELV isolating transformers made to BS 3535 to supply class 3, 25 V handlamps should always be available;
- the temperature within the engine room should be prevented from falling below 10^{o}C through the provision of thermostatically controlled heating;
- adequacy of ventilation for ensuring a satisfactory air supply to the engine and for preventing an undue temperature rise in the engine room when the engine is running;
- consideration of the noise levels within the engine room when the generator is running. Personal protective equipment (PPE) in the form of ear protection has to be provided where the noise level equals or exceeds the first action level – 85dB(A) as defined in the Noise at Work Regulations 1989. The noise levels presented to adjacent wards and departments must also be considered.

Maintenance

3.5 The faults most widely stated by health service estates/engineering professionals as being prevalent in emergency electrical generator installations are detailed as follows:

- failure of the generator due to electrical loads being in excess of the generator capacity – essential busbar loads can generally creep up over the years. This can sometimes out-strip the capacity of the generator and lead to overload tripping;
- drop-out contactors being 'jammed' in position through non-use. This highlights the need to regularly test the whole system and not merely the generator supplying a dummy load;
- failure of starting batteries due to poor condition. Connections, electrolyte level and specific gravity should all be checked at recommended frequencies;
- fuel contamination due to water, fuel 'bug' and age. This problem can be largely overcome by good housekeeping practices;
- lack of ventilation and overheating of the generator set – air inlets and outlets should be kept clear of any obstructions to ensure adequate air flows to and from the generator room. Where motorised louvers are installed on air inlets and outlets and are thermostatically controlled, this operation should be verified by means of testing;
- blocked filters and failure of fuel transfer systems which should be connected to the essential electrical supply circuit;
- failure of engine heaters in extreme cold ambient temperature conditions;
- poor design features which include essential equipment not being connected to essential supplies, mains sensing circuits in the wrong location and incorrect displays on instruments.

3.6 The proper application of a good maintenance regime will generally overcome many of the above fault conditions. The nature and frequency of maintenance operations will largely depend upon the age and condition of the equipment and the particular operating conditions under which it is required to function. Whether a specialist contractor, generator manufacturer, or 'in-house' estates engineering staff perform maintenance operations, the Trust management has a legal responsibility to ensure that these operations are appropriate for the circumstances and carried out in a safe and efficient manner. Management through informed analysis of maintenance records and the logbook specific to the installation should achieve this. *The issue of job instructions for maintenance operations and training for staff performing maintenance on generator installations will also assist in securing the reliability of the plant.*

3.7 Complete “as-fitted” drawings, circuit diagrams, charts and the manufacturer/suppliers maintenance instructions, should be available and used as the foundation for the maintenance programme. The terms used in relation to maintenance and their definition are as follows:

Examine: To make a careful and critical scrutiny of an item without dismantling, by using the senses of sight, hearing, smell and touch, to verify that the plant or equipment is in working order.

Check: To make a thorough inspection for damage, wear or deterioration and to ascertain that the plant or equipment is correctly adjusted to conform to the required standards and recommendations.

Test: To operate the plant or equipment and/or use the appropriate testing instruments to ensure that plant or equipment is functioning correctly.

3.8 The actual frequency of maintenance routines should be established from the maintenance manuals for the equipment. Practical experience with equipment of different manufacturers, and information from plant history logs, may advise the need to vary the frequencies and tasks in particular installations.

3.9 In addition to the examination, checks and tests previously described, arrangements should be made for a general overhaul of the generators at the manufacturers’ recommended frequency. This may involve a temporary provision of emergency stand-by generators during the overhaul, which is best facilitated by the provision of interlocks on the switchboard specifically for this purpose.

Appendix 1 displays an example of a servicing and maintenance checklist, which could be applied to a typical installation.

3.10 The principal components of a typical installation, as detailed in Section 2, and the maintenance criteria that are likely to apply are detailed as follows:

A. Fuel System

Checks should be made in relation to the engine room service/day tank, the bulk fuel storage and fuel transfer facilities and associated valves and pipework. This would include checking for leaks at all connections, checking fuel levels, high/low alarms and operation of the fuel transfer pump. The security of the electrical bonding connections from both service/day and bulk fuel storage tanks to the engine generator set should also be verified. The following points should be noted:

- the fuel tank should be refilled after use or at the end of the day's operation as this will exclude the moisture-laden air in the tank;
- the sediment and water from the fuel tank and filter should be drained weekly;

- change the fuel filters at recommended service intervals;
- sufficient fuel filtering equipment should be installed on the engine to thoroughly filter the fuel;
- change to the correct fuel and lubricating oil for winter operation.

Fuel quality is another important aspect of the management of emergency generator installations and it is essential that fuels are stored using ‘good housekeeping’ techniques and free from water contamination. It is almost impossible to totally eradicate water from stored fuels and water can accumulate as a result of natural water content settlement, ingress from pipe flushing or repairs and from tank sweating/condensation due to outside air temperature fluctuations. Water is the major requirement for microbiological contamination of fuels (‘fuel’ bug) which can in turn cause fuel system fouling, fuel degradation and corrosion. The contamination begins when micro-organisms multiply at the interface between water on the bottom of the tank and the fuel. The micro-organisms, present in the air at all times, enter the tanks through the breathers or fillers and form a layer of algae. When the tank is refilled, the algae become broken and dispersed throughout the fuel. Carried in the fuel, the algae then block the engine fuel filters to the extent that the engine may stop because of fuel 'starvation'.

Tanks and fuel water traps should be kept free from water with the tank and water traps being drained of water at regular intervals. While the addition of fuel biocides will kill micro-organisms in the fuel, their addition will not dissolve or remove the debris they form. Heavily contaminated systems must therefore be physically cleaned and a biocide added on refilling to kill any remaining organisms. Biological contamination of diesel fuel is more prevalent in areas where a lot of moisture is present in the surrounding air, for example wet tropical areas and coastal areas. Further information on fuel quality and management can be obtained from fuel suppliers who will advise and provide guidance on this subject.

B. Engine Starting Batteries

The capacity of engine starting batteries generally relates to the generator kW rating and they should be located as near to the engine as possible in order to minimise the volt drop in the connecting cables. Regular servicing of battery equipment is necessary to maintain the integrity of the installation. Battery neglect, the purchase of unsuitable batteries or incorrect interpretation of battery test results have been attributed to a large proportion of failures associated with engine starts. Batteries must be recharged at current/time values recommended by their manufacturer and engine batteries should be recharged immediately after use. The battery charger should also be subject to regular checks to ensure that the trickle current recharge rate is correct.

The following starting aids are commonly found on generator installations to facilitate engine starting during cold weather:

Jacket water heater(s)
In extreme cold ambient temperature conditions, besides changing to the correct grade of lubricating oil, the engine may be fitted with a mains supply jacket water immersion heater(s). Fitting a jacket water heater(s) caters for easier starting by keeping the engine water temperature between 27 - 38°C (80 - 100°F).

Sump heater(s)
Sump heater(s) have been used in emergency generator installations to aid engine starting. However, certain manufacturers (e.g. Dorman Diesels Ltd) do not recommend a sump heater(s) because of localised overheating. This is due to the oil not circulating by convection currents causing oxidation of the oil and breakdown. This will result in inefficient lubrication to moving parts causing engine failure.

C. Diesel Engine

Modern diesel engines are capable of extensive use and will be capable of operating for several years, when their use is confined to an emergency generating role, before cylinder and crankshaft overhaul is necessary. Servicing and overhaul will generally be influenced by the quality of fuel and lubricating oils used as well as the pattern of operation and programme of test runs. Routine servicing and maintenance will generally consist of checks concerned with the lubrication system and scheduled replacement of the lubricating oil and oil filter(s), the fuel system and replacement of fuel filter(s) if fitted and the replacement of air filters. The exhaust system should also be subject to checks, as should the cooling radiator fluid to ensure there is sufficient anti-freeze and corrosion inhibitor and that no fluid leakages have occurred. Appendix 2 shows a typical engine manufacturers' maintenance schedule for a midrange engine series.

Where large engines are started by compressed air, particular maintenance arrangements will apply to the associated compressor plant.

Checks should also be performed on engine instrumentation and alarm facilities which monitor the running condition of the engine and generator.

D. Alternator

The brushless alternator routine maintenance checks should include a visual inspection of the generator windings/ventilation grilles and power cable connections.

E. Control Systems

The automatic voltage regulator (AVR) is the central feature of the generator output control. Detailed testing arrangements, taking into account the advice of the manufacturer/installer, should be implemented. Monitoring and alarm systems should also be examined, checked and tested.

With respect to spares, SHTM 2011: Part 4 ‘Operational management’ suggests the following spares are readily available for equipment operating in an emergency role only:

- one complete set of cylinder gaskets, special seals and packings etc.;
- one set of renewable parts for oil fuel and air inlet filters;
- two complete cylinder fuel oil injectors;
- one automatic voltage regulator (AVR) replacement unit;
- one set of rotating diodes for brushless generators;
- one set of engine control relays.

Testing

3.11 The difficulty in testing generator installations on load within the acute healthcare setting has often proven problematic. However, it is emphasised that a programme of test runs is required to ensure reliable engine start-up. A summary of the test run requirements is shown in Table 1. Further detail can be found in SHTM 2011: *Emergency electrical services*, Part 4, ‘Operational management’.

Table 1: Test run requirements for emergency generator installations

Test	Frequency	Purpose
Turn the engine over with the fuel isolated.	Weekly	To purge the cylinders of water deposits that may have entered from leaking gasket seals from the water jacket or water condensed from previous running.
No-load run of up to 15 minutes duration.	Fortnightly	To test the reliability of the engine start up and the electrical control system. **Extended no-load running is not advised – refer to section 3.4**
Operational run with loads in excess of 70% full load for periods of at least two hours.	Monthly	Removes carbon deposits accumulated during the no-load runs. **Note:** Trip tests on load should only be attempted at loads less than 25% full load.
Operation of the overspeed governor – should be carried out prior to the load test with the circuit breaker open.	Monthly	Proves the operation of the overspeed governor.

On conclusion of load tests, engines should be allowed to run for five minutes at no-load before final shutdown to assist natural cooling of the engine and remove cylinder hot spots resulting from sudden load shut-down.

Additional tests to those detailed above may be required for particular situations and conditions, and possibly at the recommendation of specific suppliers / manufacturers of emergency generator equipment.

Where test runs are conducted by a specialist contractor, management must satisfy themselves that these are being conducted correctly and at the appropriate frequencies. Results of the test runs should be recorded in the log book specific to the generator installation.

Light Load Operation

3.12 If an engine is operated on a load of less than 25-30% of its rated output, this is generally considered to be light load operation. The usual results of such operation are heavier than normal lubricating oil consumption and oil leaks from the air and exhaust manifolds. This can occur due to:

a. the fact that turbocharger oil seals are not fully effective on light load which can result in oil being delivered together with the air into the engine air manifolds and;

b. the cylinder temperatures being too low to ensure complete burning of all the fuel delivered.

A further result is that of abnormal carbon build-up on the valves, piston crowns and exhausts ports which can lead to the normal service interval between top overhauls being reduced.

3.13 Running on light load, therefore, should not exceed the 15 minute no-load test run which SHTM 2011: *Emergency electrical services* states should be undertaken fortnightly. The engine manufacturers' recommendations should also be sought in this regard. Running the generator monthly with loads in excess of 70% of the full load for periods of at least two hours (also required by SHTM 2011) will burn off carbon deposits in the engine and exhaust system.

Troubleshooting

3.14 Most engine manufacturers/suppliers produce their own Troubleshooting Guide which would generally be contained within issued maintenance and service documentation. This can prove a useful aid for healthcare estates/engineering staff in relation to fault finding on emergency generator installations. The 'Troubleshooting Guide' shown in Table 2 has been prepared to reflect the most common problems in relation to the operation of emergency generator installations. Table 3 displays a further typical troubleshooting guide which uses the engine exhaust smoke colour to assist with the identification of engine fault finding.

Table 2: Troubleshooting guide

Fault and Possible Cause	Remedy
Engine will not start – no fuel at atomisers:	
Stop control in ‘no fuel’ position.	Turn control to ‘run’ position.
Insufficient fuel in tank, air has been drawn into the system.	Replenish fuel tank, then ‘bleed’ system.
Fuel lift pump inoperative.	Remove lift pump and rectify or fit replacement pump.
Fuel filters choked or fuel feed pipe blocked.	Check fuel feed to fuel pump and filters, rectify as necessary.
Fuel pump not delivering fuel to the atomisers.	Remove pump for attention of specialised workshop and fit replacement.
Engine will not start – fuel at atomisers:	
Atomisers require servicing.	Service or fit replacement set.
Wrong type of thermostat unit fitted.	Check that correct type is fitted.
Thermostat unit inoperative.	Visually check unit, fit new unit if unserviceable.
Valve and/or pump timing incorrect.	Check and reset if necessary.
Engine will not start – cranking speed too low:	
Battery not in well-charged condition.	Fit fully charged replacement.
Incorrect grade of lubricating oil.	Check oil viscosity against approved lists in manual for temperature range.
Poor electrical connections between battery and starter motor.	Check and tighten or remake connections if necessary.
Starter motor faulty.	Examine and rectify if necessary.
Engine will not start - poor compression	
With poor compression, starting may just be difficult in normal weather, but in cold weather the engine may just refuse to start altogether, dependent on how much compression there is and the cranking speed. The causes are numerous, and include worn liners, piston rings and leaking valves.	There is no quick remedy for this condition; generally, the engine will have been in service for some time. At least a top overhaul or probably a complete overhaul would be indicated to restore the lost compression, which is so vital for the efficient running of a diesel engine.

Fault and Possible Cause	Remedy
Engine starts, runs for a few moments, then stops:	
Partially choked fuel feed pipe or filter.	Trace and rectify.
Fuel lift pump not giving adequate delivery.	Check output of lift pump and rectify or replace as necessary.
Fuel tank vent hole blocked.	Check and clear if necessary.
Restriction in induction or exhaust systems.	Check and rectify if necessary.
Air leaking into supply or return fuel pipes.	Check and trace.
Engine misfiring or running erratically:	
Atomiser(s) require attention.	Isolate offender(s), remove and test; if faulty, service or fit replacement(s).
Air in fuel system.	Check for air in fuel pump; if present prime the fuel system.
Water in fuel pump.	Thoroughly check fuel system for signs of water; remove if present, then prime with clean fuel.
Valve and/or pump timing incorrect.	Check and reset if necessary.
Valve clearances incorrect.	Check and reset if necessary.
Fuel leaking from high pressure pipe.	Observe with engine running and replace pipe if necessary.
Engine runs evenly but suffers from loss of power:	
Atomiser(s) require servicing.	Remove and service or fit a replacement set.
Loss of compression.	Refer to previous remarks on poor compression.
Pump not delivering sufficient quantity of fuel to meet engine requirements.	Observe throttle linkage for unrestricted travel; if satisfactory, pump should be checked for correct output in specialist workshop.
Air cleaner causing restriction to the flow of air.	Check that correct type is fitted and that it has been serviced in accordance with the instructions given in manual.
Fuel pump timing incorrect.	Check and reset if necessary.

Fault and Possible Cause	Remedy
Engine runs but with a smoky exhaust:	
Incorrect air-fuel ratio.	Check diaphragm and adjustment of air-fuel ratio control. Check for any restriction to the airflow; if satisfactory, have the fuel pump maximum fuel output checked.
Cold starting aid (thermostat) valve leaking.	Replace with a serviceable unit.
Valve and/or fuel pump timing incorrect.	Check and reset if necessary.
Atomiser(s) require servicing.	Remove and service or fit a replacement set.
Excessive oil consumption.	Generally consistent with poor compression and long engine life; workshop examination required to give precise details.
Engine knocking:	
Faulty atomiser (nozzle needle sticking).	Fit replacement atomiser.
Fuel pump timing too far advanced.	Check timing and reset if necessary.
Piston striking a valve.	Check valve timing, piston topping and valve head depth relative to cylinder head face.
Incorrect fuel.	Check that the tank has been filled with diesel fuel and not petrol by mistake.
Worn or damaged bearings.	Engine overhaul required.
Engine overheating (most common fault in hospitals):	
Generator Room – Poor Ventilation.	Check air supply and exhaust ducts to generator room.
Coolant level in system too low.	Replenish and check if leakage is taking place, if so, rectify at once.
Radiator or system partially blocked.	Flush system through thoroughly in accordance with manufacturers instructions.
Blockage or restriction due to ice formation.	Locate trouble spot and take any action necessary to prevent recurrence.
Fan belt slipping or incorrect type of fan fitted.	Check fan belt tension and fan type.
Valve and/or fuel pump timing(s) incorrect.	Check and reset if necessary.
Thermostat stuck in the closed position.	Check and replace with a new one if found unserviceable.

Fault and Possible Cause	Remedy
Low oil pressure:	
Oil level in sump too low.	Replenish to correct level.
Incorrect grade or inferior grade oil being used.	Change to approved grade.
Oil leaking externally from engine.	Rectify immediately.
Pressure gauge or oil warning light switch inaccurate.	Check either against a master unit.
Oil pump worn or pressure relief valve. sticking open.	Remove and examine.
Suction pipe to oil pump allowing air to be drawn in.	Rectify leak or renew pipe as necessary.
Worn main or big end bearings.	Engine overhaul required.
High oil pressure:	
Incorrect grade of oil being used.	Change to approved grade.
Pressure gauge inaccurate.	Check against a master unit.
Pressure relief valve sticking closed.	Remove and examine.
Excessive crankcase pressure:	
Partially choked breather pipe.	Check pipe for any obstruction.
Worn or sticking piston rings.	Engine examination required.
Pipework or tank on vacuum side of exhauster allowing entry of air into the system (only where exhauster is fitted).	Check system for leaks and rectify if necessary.

Table 3: The use of exhaust-smoke colour in engine fault finding

Colour of Smoke	Symptom	Probable Diagnosis
Black or Dark Grey	Smoke at full load at any engine speed but particularly highest and lowest speeds, and power at least normal.	Maximum fuel setting of injection pump too high. Excess fuel device not tripping automatically to normal after starting.
	Smoke at full load, particularly at high and medium speeds, engine quieter than normal.	Pump timing retarded (or advance device not correctly fitted).
	Smoke at full load particularly at low and medium speeds, engine noisier than normal.	Pump timing too advanced.
	Smoke at full load particularly at high and medium speeds, probably with loss of power.	Injector nozzle holes (or some of them) wholly or partially blocked.
	Smoke at full load at higher speeds only.	Air cleaner restricted due to blockage with dirt or damage.
	Intermittent or puffy exhaust smoke, sometimes with white or blue tinge, usually coupled with knocking.	Injector nozzle valve struck open intermittently.
	Smoke at full loads at high speed, engine running faster than normal when on governor.	Governor speed setting considerably above engine makers maximum.
	Smoke at full loads at high speed, engine running slower than normal on governor (vacuum type).	Governor venturi throat partially choked with carbon.
	Smoke at most speeds and loads, tending to blue or white when cold and when starting.	Nozzle sprays impinging on cylinder head, due to incorrect fitting of injector into cylinder head.
	Smoke at higher loads and speeds, not necessarily at maximum.	Injector nozzle valve lift excessive, due to repeated valve or seat refacing, without lift correction.
	Smoke at all speeds at high loads, mostly low and medium speeds and probably coupled with poor starting.	Loss of cylinder compression due to stuck rings, bore wear, valve wear or burning, sticking valves, incorrect valve setting.
	Smoke at full load, either at high or low speeds only, but in some cases at all speeds.	Incorrect nozzle type fitted, or mixed types, or out-of-date type, or type for different duty.
	Smoke at full load, mostly at medium and high speeds coupled with low power.	Injection high-pressure pipes of incorrect length or bore, or having badly closed-in bore at ends, or due to sharp bends.

Fault Tree Analysis

3.15 In support of the Troubleshooting Guide it is advised that Trusts create their own guide using the risk management technique of Fault Tree Analysis (FTA). This will be beneficial where a system has been modified in some way since the time of the original installation. The methodology used in applying this technique also facilitates a good understanding of the entire system when adopted.

The main features of FTA can be summarised as follows:

- it actively seeks out failure events deductively;
- it provides a visual display of how a system can malfunction;
- it points out the critical aspects of the system behaviour;
- it provides reference for the evaluation of system modifications;
- it provides a systematic basis for quantitative analysis.

3.14 The principles and methodology used for Fault Tree Analysis can be referenced in any authoritative text on Risk Management. FTA is a risk assessment technique that provides a systematic description of the combinations of possible occurrences in a system which can result in failure or an undesired event. The analysis starts with a list of potential causes and then works through the system to identify what equipment failure modes and/or human errors could cause that particular event to occur.

3.15 In applying this technique, a ‘Top Event’ has to be selected which is usually the most serious consequence of component or equipment failure. In this context, the top event has been selected as the generator failing to supply its designed electrical power output. The actual ‘Fault Tree’ is now constructed by properly relating all possible combinations and sequences of events that could result in the top event. Possible causes are then placed in a logical and sequential order downward toward the root of the tree. Logic gates, likened to digital logic gates, are then used to connect events and basic causes to subsequent failure events.

3.16 To demonstrate the principles of this technique, the fault tree shown in Appendix 3 has been constructed. The generator failing to supply its' designed electrical power output is taken as the 'top event' with seven intermediate events listed as follows:

(i) engine not turning;

(ii) engine turns but will not fire;

(iii) engine fires but fails to pick up speed;

(iv) engine misfires;

(v) low power output;

(vi) overheating;

(vii) electrical system failure.

3.17 The resulting tree construction then relates all possible combinations and sequences of events that could result in the top event. Basic events are then added to the tree, such as a faulty starter motor or fuel pump, which could result in the top event (actual failure of the stand-by generator in supplying it's designed electrical power) becoming a reality. From carrying out such an analysis, the steps required to either reduce the chance of a basic event occurring or to assist in remedying an operational fault can become clearer.

3.18 This method of analysis is proposed to assist those healthcare estates/engineering staff with the responsibility for maintaining emergency generator installations in carrying out their duties and gaining an understanding of a particular installation. The principles involved in FTA should be applied generally and the analysis validated by the competent personnel for the installation.

4. Records and documentation

Operational Plan

4.1 An operational plan for emergency generator installations is required by SHTM 2011 which states clearly that this is a management responsibility. The operational plan should comprise the following elements:

- a list and description of the main emergency plant and electrical equipment;
- the identification of qualified personnel with adequate training;
- instructions to start, operate, control and shut down the plant and associated switching devices;
- a schedule of possible emergency incidents, with remedial operational procedures, which may cause a loss of normal electrical supplies;
- contingency plans for the use of alternative generating plant;
- implementation of regular staff training for the basic operational procedures required during an emergency.

Contingency Plans

4.2 Contingency plans must be in place which consider the non-availability of the emergency generator installation for whatever reason. This would typically extend to the prompt provision of alternative generating plant. SHTM 2011 also recommends that an emergency exercise, independently adjudicated, is arranged twice a year. General guidance in relation to the formulation of contingency plans can be found in HTM 2070; *Estates emergency and contingency planning*.

Records

4.3 A log-book should be kept for each emergency generator installation and stored in a safe and convenient location together with drawings and circuit diagrams of the system. The log-book should be used to record the following details:

- all work that is carried out on the emergency generator installation including details of any parts that are renewed – this should include a brief note of any defects or failures and rectifying action taken to reinstate defective items of equipment. Servicing and maintenance records such as that shown in Appendix 1 should also be retained within the log book;
- details of the generator itself including the manufacturer, contact details for agents, model, rating, fuel/oil and water capacities and other relevant details such as the spares kept on site;
- the actions taken in respect of any applicable Safety Action Notice (SAN) or Hazard Notice (HAZ). Notices (or copies of) should also be filed within the log-book for ease of reference;
- details of the generators' running should also be recorded including test runs, runs caused by mains failure and runs due to scheduled mains interruptions or due to specific maintenance purposes;
- battery and charger histories including any weekly tests of specific gravity and cell voltages;
- operation of the fuel transfer system and details of fuel levels.

References

NOTE:

Where there is a requirement to address a listed reference, care should be taken to ensure that all amendments following the date of issue are included.

LEGISLATION

Health and Safety at Work etc. Act 1974

Management of Health and Safety at Work Regulations 1999

Electricity at Work Regulations 1989

Provision and use of Work Equipment Regulations 1998 (PUWER)

Environmental Protection Act 1990

The EMC Directive 89/336/EEC.

The LV Directive 73/23/EEC.

The Machinery Directive 89/392/EEC.

STANDARDS

The generator and its control system has been designed, constructed and tested generally in accordance with the following Standards where applicable:

BS 4999	General requirements for rotating electrical machines.
BS 5000	Rotating electrical machine of particular types or for particular applications.
BS 5514	Reciprocating internal combustion engines: performance.
BS 7671	Requirements for electrical installation. IEE Wiring Regulations (16th Edition).
BS 7698	Reciprocating internal combustion engine driven alternating current generating sets.
BS EN 50081	Electromagnetic compatibility. Generic emission standard.
BS EN 500812	Electromagnetic compatibility. Generic immunity standard.
BS EN 60439	Specification for low-voltage switch gear and control gear assemblies.
BS EN 60947	Specification for low voltage switchgear and control gear.

GUIDANCE

SHTM 2007	Electrical services – supply and distribution
SHTM 2011	Emergency electrical services
SHTM 2014	Abatement of electrical interference
SHTM 2020	Electrical Safety Code for low voltage systems (Escode-LV)
SHTM 2021	Electrical Safety Code for high voltage systems (Escode-HV)

Appendix 1: Example – servicing & maintenance checklist

System	Check / Activity		Comments
Lubrication	Check all hose connections	☐	
	Change lubricating oil	☐	
	Change lubricating oil filter(s)	☐	
	Check protective device	☐	
Fuel	Change fuel filter(s) if fitted	☐	
	Check all connections for leaks	☐	
	Check fuel level	☐	
	Check fuel transfer system operation	☐	
	Check high/low alarms	☐	
	Check fire valves	☐	
Air	Check air filter pipework	☐	
	Check vent piping and connections	☐	
	Check air flap and solenoid (if fitted)	☐	
Water	Check condition of fan belts – adjust/replace	☐	
	Check antifreeze – replace if 12 months old	☐	
	Check remote fans and pumps (if applicable)	☐	
	Check radiator core and tanks for leaks, dirt etc.	☐	
	Check protection device operation	☐	
	Check protective guards	☐	
	Check hoses – tighten or replace	☐	
DC system	Check alternator belts – adjust/replace	☐	
	Check acid level of battery(s) – top up	☐	
	Check lugs and terminals – clean and tighten	☐	
	Check charging alternator guards	☐	
Alternator	Visually inspect windings/ventilation grilles	☐	
	Check power cable connections – loosen and reconnect	☐	
	Check circuit breaker and control cable connections	☐	
	Check automatic voltage regulator fixing and wiring	☐	
Heater	Check hoses – tighten or replace	☐	
	Check operation	☐	
Exhaust	Check operation of rain and/or water ingress protection	☐	
	Check exhaust pipe, connections and silencer for leaks	☐	
	Check exhaust pipe insulation for integrity	☐	
	Check system for proximity to combustible material	☐	

System	Check / Activity		Comments
Control Panel	Check cable connections	☐	____________
	Check battery charger (if fitted)	☐	____________
Valve/Injector	Check and adjust tip clearances (if applicable)	☐	____________
General	Check generator/canopy/container/attenuators/ louvres for corrosion, insecure loose items etc.	☐	____________

Appendix 2: Engine manufacturers' maintenance schedule

Daily

Check Operator report
Check oil level
Check coolant level
Check drive belt
Drain water and sediment from fuel – water separator
Check engine for oil/coolant leaks, leaks to the air intake system, damage to belts/hoses.

250 hours running

Replace lubricating oil	Inspect air filter restriction
Replace lubricating filter	Inspect air intake system
Drain water and sediment from fuel tank(s)	

500 hours running

Replace lubricating oil	Inspect air filter
Replace lubricating filter	Inspect air intake system
Replace Fuel filter	Inspect antifreeze freeze point
Replace Coolant filter	
Drain water and sediment from fuel tank(s)	

1,000 hours running

Replace lubricating oil	Inspect air filter
Replace lubricating filter	Inspect air intake system
Replace Fuel filter	Inspect antifreeze
Replace Coolant filter	Inspect fan hub/bearings
Adjust valve clearances	Inspect belt tensioner bearing
Drain water and sediment from fuel tank(s)	Inspect belt tension
	Inspect charge air cooler

2,000 hours running

Replace lubricating oil	Inspect air filter
Replace lubricating filter	Inspect air intake system
Replace Fuel filter	Inspect antifreeze
Replace Coolant filter	Inspect fan hub/bearings
Adjust valve clearances	Inspect belt tensioner bearing
Replace antifreeze	Inspect belt tension
Drain water and sediment from fuel tank(s)	Inspect charge air cooler
	Inspect vibration damper

Appendix 3: Fault tree analysis

This diagram is presented as *fault_tree.pdf*

Appendix 4: Typical emergency generator installation

Please note that the paper size for this diagram is A3: *storage tank.pdf*