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OPERATION, MAINTENANCE AND REPAIR OF AUXILIARY GENERATORS

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CHAPTER 1

INTRODUCTION

1-1. Purpose.

This manual covers the various types of auxiliary power generating systems used on military installations. It provides data for the major components of these generating systems; such as, prime movers, generators, and switchgear. It includes operation of the auxiliary generating system components and the routine maintenance which should be performed on these components. It also describes the functional relationship of these components and the supporting equipment within the complete system.

1-2. Scope.

The guidance and data in this manual are intended to be used by operating, maintenance, and repair personnel. It includes operating instructions, standard inspections, safety precautions, troubleshooting, and maintenance instructions. The information applies to reciprocating (diesel) and gas turbine prime movers, power generators, switchgear, and subsidiary electrical components. It also covers fuel, air, lubricating, cooling, and starting systems.

a. In addition to the information contained in this manual, power plant engineers, operators, and maintenance personnel must have access to all other literature related to the equipment in use. This includes military and commercial technical manuals and engineering data pertaining to their particular plant.

b. Appendixes B through F provide details related to fuel storage, lubricating oil, coolant, forms and records, and safety (including first aid). Texts and handbooks are valuable tools for the trained engineer, supervisor, and operator of a power plant. The manufacturers of the components publish detailed operating, maintenance, and repair manuals. Instructions, applicable to the equipment, are provided by each manufacturer and should be filed at the plant for safekeeping and use. Replacement copies are available from each manufacturer.

1-3. References.

Appendix A contains a list of references used in this manual. Other pertinent literature may be substituted or used as supplements.

1-4. Explanation of abbreviations and terms.

Abbreviations and special terms used in this manual are explained in the glossary.

CHAPTER 2

EMERGENCY POWER SYSTEMS

2-1. Emergency power.

Emergency power is defined as an independent reserve source of electric energy which, upon failure or outage of the normal source, automatically provides reliable electric power within a specified time.

a. A reliable and adequate source of electric power is necessary for the operation of active military installations. Power must also be available at inactive installations to provide water for fire protection, energy for automatic fire alarms, light for security purposes, heat for preservation of critical tactical communications and power equipment, and for other operations.

b. Power, supplied by either the local utility company or generated on-site, is distributed over the activity. The source of distribution may be subject to brownout, interruption or extended outage. Mission, safety, and health requirements may require an uninterruptible power supply (UPS) or standby/emergency supply for specific critical loads. Justifiable applications for auxiliary generator are:

(1) Hospitals (life support, operating room, emergency lighting and communication, refrigeration, boiler plant, etc.).

(2) Airfields (control tower, communications, traffic control, engine start, security, etc.).

(3) Data processing plant systems.

(4) Critical machinery

(5) Communication and security.

c. It is essential that a schematic showing the loads to be carried by an auxiliary generator be available for reference. Do not add loads until it is approved by responsible authority.

2-2. Types of power generation sources.

a. The critical uses of electric power at a site demand an emergency source of power whenever an outage occurs. Selection of the type of auxiliary generating plant is based on the mission of the particular site and its anticipated power consumption rate during an emergency. The cost of plant operation (fuel, amortized purchase price, depreciation, and insurance) and operation and maintenance personnel requirements must be analyzed. Future load growth requirements of the site must be considered for size selection.

b. Auxiliary power generating plants are designated as either class B or class C. The design criteria for a class B plant is comparable to those of a primary power plant. A primary power plant usually is started manually; a class B plant may have either a manual or an automatic start system. Accordingly, a class B plant is almost as costly to construct and operate as a primary power plant of similar size. Usually, a class B plant is a permanent-type unit capable of operating between 1000 and 4000 hours annually. The class C plant always has an autostart control system (set to start the plant when the primary power voltage varies or the frequency changes more than the specified operational requirements).

(1) A class B plant (considered a standby long-term power source) is used where multiple commercial power feeders are not available or extended and frequent power outages may occur. Total fuel storage must be enough for at least 15 days continuous operation.

(2) A class C plant is used where rapid restoration of power is necessary to feed the load. More than one class C unit is usually used when the technical load exceeds 300 kW at 208Y/120 volts or 600 kilowatts (kW) at 48OY/277 volts. Spare class C units are sometimes provided for rotational maintenance service. The autostart control system ensures that the load is assumed as rapidly as possible. Diesel engine prime movers may be equipped with coolant and lubricating oil heaters to ensure quick starting. Recommended total fuel storage must be enough for at least seven days continuous operation.

c. Emergency generators must provide adequate power for critical loads of a building or a limited group of buildings, heating plants, utility pumping plant, communication centers, or other such installations where interruption of normal service would be serious enough to justify installation of an auxiliary power plant. The plant must be reliable and easily started in all seasons of the year. The plant building should be completely fireproof with heating and ventilation facilities that satisfy the plant's requirements. The space around the units should permit easy access for maintenance and repair. Space should be provided within the building for safe storage of fuel such as a grounded and vented "day" tank. Type and grade of fuel should be identified on the tank. Important considerations for these plants included the following:

(1) Selection of generators (size and quantity, type of prime mover, and load requirements).

(2) Determination of need for instrumentation (meters, gauges, and indicator lights).

(3) Selection of protective equipment (relays and circuit breakers).

(4) Determination of need for automatic starters, automatic load transfer, etc.

(5) Selection of auxiliary generator size is based on satisfying the defined electrical load requirement (expressed as kilowatts).

d. Portable power plants are widely used on military installations because of the temporary nature of many applications. The power plants (including a diesel or gas turbine prime mover) are self-contained and mounted on skids, wheels, or semi-trailers. Although the size of portable units may vary from less than 1 kW to more than 1,000 kW, the most commonly used units are less than 500 kW capacity. Reciprocating prime movers are usually used for portable power plants. Gas turbine engines are frequently employed for smaller units because of their relatively light weight per horsepower.

e. Portable diesel powered generators usually operate at 1200, 1800 or 3600 revolutions per minute (rpm), since high speeds allow a reduction in weight of the generator plant. To keep weight down, such ancillary equipment as voltage regulators, electric starters and batteries are sometimes omitted from the smaller generators. Starting may be done by crank or rope, ignition by magneto, and voltage regulation through air-gap, pole-piece, and winding design. Portable plants usually have a minimum number of meters and gauges. Larger size portable units have an ammeter, a frequency meter, a voltmeter, and engine temperature and oil pressure gauges. Generator protection is obtained by fused switches or air circuit breakers.

2-3. Buildings and enclosures.

a. Auxiliary power generating equipment, especially equipment having standby functions, should be provided with suitable housings. A typical power plant installation is shown in figure 2-l. The equipment should be located as closely as possible to the load to be served. Generators, prime movers, switchboards, and associated switching equipment should always be protected from the environment. Many small units are designed for exterior use and have their own weatherproof covering. Transformers and high-voltage switching equipment can be placed outdoors if they are designed with drip-proof enclosures.

b. The buildings housing large auxiliary power generating systems (see fig 2-1) require adequate ceiling height to permit installation and removal of cylinder heads, cylinder liners, pistons, etc., using chain falls. An overhead I-beam rail, or movable structure that will support a chain fall hoist, is necessary. The building should have convenience outlets and be well lighted with supplemental lighting for instrument panels. Heat for the building should be steam, heat pumps or electric heaters to avoid hazards from explosive vapors.

c. Prime movers require a constant supply of large quantities of air for combustion of fuel. Combustion produces exhaust gases that must be removed from the building since the gases are hazardous and noxious. The air is usually supplied via a louvered ventilation opening. Exhaust gases are conducted to the outside by piping that usually includes a silencer or muffler (see fig 2-l).

d. Precautions must be taken when environmental conditions related to location of the generating system are extreme (such as tropical heat and/or desert dryness and dust). Cooling towers and special air filters are usually provided to combat these conditions. Arctic conditions require special heating requirements.

e. When required for the auxiliary generating equipment, the building or enclosure should be fireproof and constructed of poured concrete or concrete and cinder blocks with a roof of reinforced concrete, steel, or wood supports with slate or other fireproof shingles. Ventilation and openings for installation and removal of materials and equipment should be provided.

(1) *Foundations.* A generator and its prime mover should be set on a single, uniform foundation to reduce alignment problems. The foundation should be in accordance with manufacturer's recommendations for proper support of equipment and dampening of vibrations. Foundation, prime mover, and generator should be mechanically isolated from the building floor and structure to eliminate transmission of vibrations. All mechanical and electrical connections should allow for vibration isolation.

(2) *Floors.* The floors are usually concrete with non-skid steel plates over cable and fuel-line trenches. The floor space should provide for servicing, maintenance, work benches, repair parts, tool cabinets, desks, switchboard, and electrical equipment. Battery bank areas require protection from corrosive electrolytes. Floors must be sealed to prevent dusting, absorption of oils and solvents, and to promote cleanliness and ease of cleanup. Plates and gratings covering floor trenches must be grounded. Rubber matting should be installed in front of and around switchboards and electrical equipment to minimize shock hazard.

2-4. Fuel storage.

Fuel storage space should be provided near the plant, with enough capacity to allow replenishment in economical, reasonable intervals. The total fuel storage capacity should be large enough to satisfy

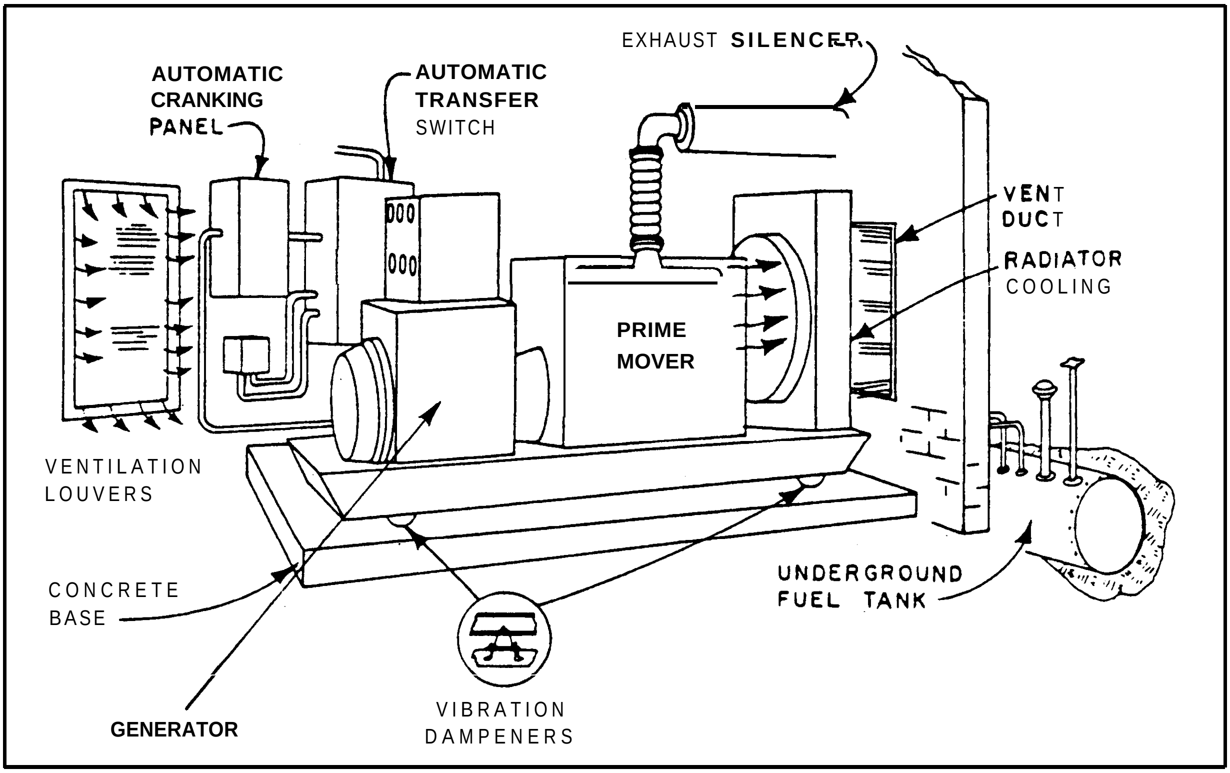

Figure 2-l. Typical installation of an emergency power plant.

the operational requirements of the class B or class C generating plants that are used. Fuel logistics should be considered when sizing fuel storage capacity

a. Fuels for the equipment described herein (refer to app C) are combustible substances that can be burned in an atmosphere of oxygen. Two categories of fuel storage are discussed: liquids and gases. In either case, fuel storage tanks, associated pumps and piping systems must be grounded and protected from galvanic, stray current or environmental corrosion.

b. Liquid fuel for auxiliary power generating systems is usually stored in buried tanks equipped with vent pipes and manholes. Above-ground tanks may be used for storage at some locations. These tanks usually have provisions for venting, filling and cleaning. A gauge with indicator is used to determine tank contents. Two tanks are necessary to ensure a continuous supply during tank cleaning (every two years) and maintenance operations. Provisions must be made to use a gauge stick to positively determine depth of tank contents. Storage tanks should be checked for settled water accumulated through condensation and the free water drained periodically.

c. Gaseous fuel is stored in tanks either as a gas or a liquid, depending on the type of fuel. Natural gas is stored as a gas. Butane and propane are cooled and kept under moderate pressure for storage as liquids. Methods to determine tank contents are covered in paragraph 5-7*b*(8).

d. Day tanks. A grounded and vented day tank, having not more than 275 gallons capacity, is installed within the power plant building. The tank is normally filled by transfer pump from the installation's main storage tank. Provision should be made to fill the day tank by alternate means (or directly from safety cans or barrels) if the transfer system fails.

2-5. Loads.

Most electrical plants serve a varied load of lighting, heating equipment, and power equipment, some of which demand power day and night. The annual load factor of a well-operated installation will be 50 percent or more with a power factor of 80 percent or higher. Equipment and controls must be selected to maintain frequency and voltage over the load range.

2-6. Distribution systems.

a. The load determines direct current (DC) or alternating current (AC), voltage, frequency (DC, 25 Hertz (Hz), 50 Hz, 60 Hz, 400 Hz), phases and AC configuration (delta or wye). Voltage and other parameters of the distribution system will have been selected to transmit power with a minimum of conversion (AC to DC), inversion (DC to AC), (AC) transformer, impedance, and resistance loss. For a given load; higher voltage, unity power factor, low resistance/impedance, and lower frequency generally result in lower distribution losses. Use of equipment to change or regulate voltage, frequency or phase introduces resistance, hysteresis and mechanical losses.

b. A lagging power factor due to inductive loads (especially under-loaded induction motors) results in resistive losses (I^2R) because greater current is required for a given power level. This may be corrected by the use of capacitors at the station bus or by "run" capacitors at induction motors to have the generator "see" a near-unity but yet lagging power factor.

c. Overcorrection, resulting in a leading (capacitive) power factor must be avoided. This condition results in severe switching problems and arcing at contacts. Switching transients (voltage spikes, harmonic transients) will be very damaging to insulation, controls and equipment. The electronics in radio, word and data processing, and computer arrays are especially sensitive to switching and lighting transients, over/under voltage and frequency changes.

d. The distribution system must include sensing devices, breakers, and isolation and transfer feed switches to protect equipment and personnel.

2-7. Frequency.

The frequency required by almost all electrical loads is the standard 50 or 60 Hz. Most electrical equipment can operate satisfactorily when the frequency varies plus or minus ten percent ($\pm 10\%$). Steady state frequency tolerance (required for frequency-sensitive electronic equipment) should not exceed plus or minus 0.5 percent of design frequency. Since some equipment are sensitive to frequency changes, operators must closely monitor frequency meters and regulate frequency when necessary.

2-8. Grounding.

Grounding implies an intentional electrical connection to a reference conducting plane, which may be earth (hence the term ground) but more generally consists of a specific array of interconnected electrical conductors referred to as grounding conductors. The term "grounding" as used in electric power systems indicates both system grounding and equipment grounding, which are different in their objectives.

a. System grounding relates to a connection from the electric power system conductors to ground for the purpose of securing superior performance qualities in the electric system. There are several methods of system grounding. System grounding ensures longer insulation life of generators, motors, transformers, and other system components by suppressing transient and sustained overvoltages associated with certain fault conditions. In addition, system grounding improves protective relaying by providing fast, selective isolation of ground faults.

b. Equipment grounding, in contrast to system grounding, relates to the manner in which noncurrent-carrying metal parts of the wiring system or apparatus, which either enclose energized conductors or are adjacent thereto, are to be interconnected and grounded. The objectives of equipment grounding are:

(1) To ensure freedom from dangerous electric shock-voltage exposure to persons.

(2) To provide current-carrying capability during faults without creating a fire or explosive hazard.

(3) To contribute to superior performance of the electric system.

c. Many personal injuries are caused by electric shock as a result of making contact with metallic members that are normally not energized and normally can be expected to remain non-energized. To minimize the voltage potential between noncurrent-carrying parts of the installation and earth to a safe value under all systems operations (normal and abnormal), an installation grounding plan is required.

d. System grounding. There are many methods of system grounding used in industrial and commercial power systems (refer to fig 2-2), the major ones being:

(1) Ungrounded.

(2) Solidly grounded.

(3) Resistance grounding: low-resistance, high-resistance.

(4) Reactance grounding.

e. Technically, there is no generally accepted use of any one particular method. Each type of system grounding has advantages and disadvantages. Factors which influence the choice of selection include:

(1) Voltage level of the power system.

(2) Transient overvoltage possibilities.

(3) Type of equipment on the system.

(4) Cost of equipment.

(5) Required continuity of service.

(6) Quality of system operating personnel.

(7) Safety considerations, including fire hazard and others

f. An ungrounded system is a system in which there is no intentional connection between the neutral or any phase and ground. "Ungrounded system" literally implies that the system is capacitively coupled to ground.

(1) The neutral potenial of an ungrounded system under reasonably balanced load conditions will

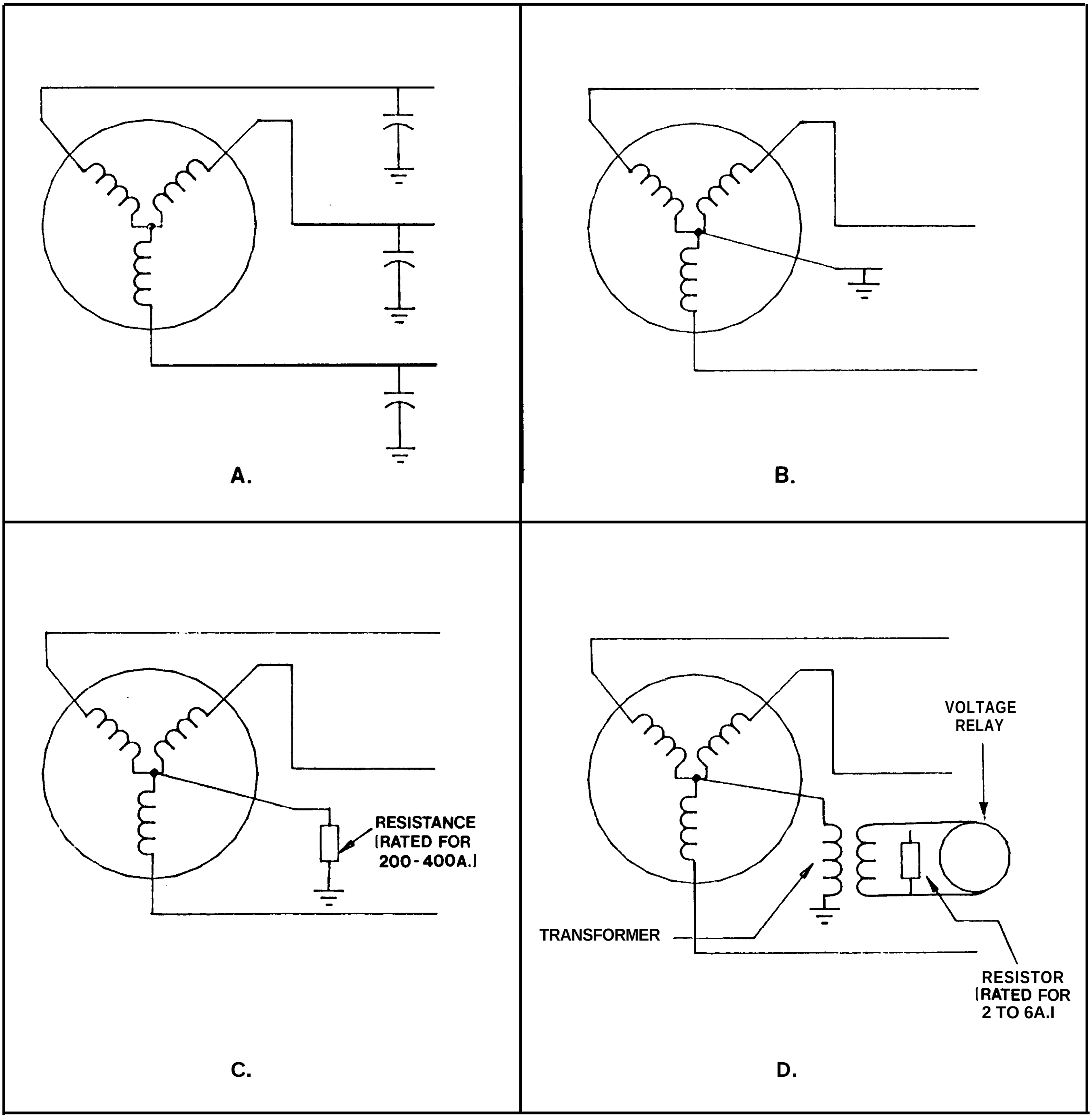

Figure 2-2. Types of system grounding.
A) UNGROUNDED GENERATOR, B) SOLIDLY GROUNDED, C) LOW RESISTANCE GROUNDING, D) HIGH RESISTANCE GROUNDING

be close to ground potentials because of the capacitance between each phase conductor and ground. When a line-to-ground fault occurs on an ungrounded system, the total ground fault current is relatively small, but the voltage to ground potential on the unfaulted phases can reach an unprecedented value. If the fault is sustained, the normal line-to-neutral voltage on the unfaulted phases is increased to the system line-to-line voltage (i.e., square root of three (3) times the normal line-to-neutral value). Over a period of time this breaks down the line-to-neutral insulation and results in insulation failure. Ungrounded system operation is not recommended because of the high probability of failures due to transient over-voltages (especially in medium voltage i.e., 1 kilovolt (Kv)-15 Kv) caused by restriking ground faults.

(2) Overvoltage limitation is particularly important in systems over 1 Kv, because equipment in these voltage classes are designed with less margin between 50/60 Hz test and operating voltages than low voltage equipment. The remaining various grounding methods can be applied on system grounding protection depending on technical and economic factors. The one advantage of an ungrounded system that needs to be mentioned is that it generally can continue to operate under a single line-to-ground fault without significant damage to electrical equipment and without an interruption of power to the loads.

g. A solidly grounded system refers to a system in which the neutral, or occasionally one phase, is connected to ground without an intentional intervening impedance. On a solidly grounded system, in contrast to an ungrounded system, a ground fault on one phase will result in a large magnitude of ground current flow but there will be no increase in voltage on the unfaulted phase.

(1) On low-voltage systems (1 Kv and below), the National Electrical Code (NEC) Handbook, article 250-5(b) requires that the following class of systems be solidly grounded:

(a) Where the system can be so grounded that the maximum voltage to ground on the ungrounded conductors does not exceed 150 volts.

(b) Where the system is 3 phase, 4 wire wye connected in which the neutral is used as a circuit conductor.

(c) Where the system is 3 phase, 4 wire delta connected in which the midpoint of one phase winding is used as a circuit conductor.

(d) Where a grounded service conductor is uninsulated in accordance with the exceptions to NEC articles 230-22, 230-30, and 230-41.

(2) Solid grounding is mainly used in low-voltage distribution systems (less than 1000 volt (V) system) and high-voltage transmission systems (over 15 Kv). It is seldom used in medium-voltage systems (1 Kv to 15 Kv). Solid grounding has the lowest initial cost of all grounding methods. It is usually recomrrended for overhead distribution systems supplying transformers protected by primary fuses. However, it is not the preferred scheme for most industrial and commercial systems, again because of the severe damage potential of high-magnitude ground fault currents.

(3) In most generators, solid grounding may permit the maximum ground fault current from the generator to exceed the maximum 3-phase fault current which the generator can deliver and for which its windings are braced. This situation occurs when the reactance of the generator is large in comparison to the system reactance. National Electrical Manufacturers Association 1-78 places a requirement on the design of synchronous generators that their windings shall be braced to withstand the mechanical forces resulting from a bolted 3-phase short circuit at the machine terminals. The current created by a phase-to-ground fault occurring close to the generator will usually exceed the 3-phase bolted fault current. Due to the high cost of generators, the long lead time for replacement, and system impedance characteristics, a solidly grounded neutral is not recommended for generators rated between 2.4 Kv and 15 Kv.

(4) Limiting the available ground fault current by resistance grounding is an excellent way to reduce damage to equipment during ground fault conditions, and to eliminate personal hazards and electrical fire dangers. It also limits transient overvoltages during ground fault conditions. The resistor can limit the ground fault current to a desired level based on relaying needs.

h. Low-resistance grounding refers to a system in which the neutral is grounded through a considerably smaller resistance than used for high-resistance grounding. The resistor limits ground fault current magnitudes to reduce the damage during ground faults. The magnitude of the grounding resistance is selected to detect and clear the faulted circuit. Low-resistance grounding is used mainly on medium voltage systems (i.e., 2.4 Kv to 15 Kv), especially those which have directly connected rotating apparatus. Low-resistance grounding is not used on low-voltage systems, because the limited available ground fault current is insufficient to positively operate series trip units.

(1) Low-resistance grounding normally limits the ground fault currents to approximately 100 to 600 amps (A). The amount of current necessary for selective relaying determines the value of resistance to be used.

(2) At the occurrence of a line-to-ground fault on a resistance-grounded system, a voltage appears across the resistor which nearly equals the normal line-to-neutral voltage. of the system. The resistor current is essentially equal to the current in the fault. Therefore, the current is practically equal to the line-to-neutral voltage divided by the number of ohms of resistance used.

i. High-resistance grounding is a system in which the neutral is grounded through a predominantly resistive impedance whose resistance is selected to allow a ground fault current through the resistor equal to or slightly more than the capacitive charging current (i.e., $I_R > 3I_{co}$) of the system. The resistor can be connected either directly from neutral to ground for wye type systems where a system neutral point exists, or in the secondary circuit of a grounding transformer for delta type systems where a system neutral point does not exist. However, because grounding through direct high-resistance entails having a large physical resistance size with a continuous current rating (bulky and very costly), direct high-resistance grounding is not practical and would not be recommended. High-resistance grounding through a grounding transformer is cost effective and accomplishes the same objective.

(1) High-resistance grounding accomplishes the advantages of ungrounded and solidly grounded systems and eliminates the disadvantages. It limits transient overvoltages resulting from single phase to ground fault, by limiting ground fault currents to approximately 8 A. This amount of ground fault current is not enough to activate series over-current protective devices, hence no loss of power to downstream loads will occur during ground fault conditions.

(2) Special relaying must be used on a high-resistance grounded system in order to sense that a ground fault has occurred. The fault should then be located and removed as soon as possible so that if another ground fault occurs on either of the two unfaulted phases, high magnitude ground fault currents and resulting equipment damage will not occur.

(3) High-resistance grounding is normally applied on electrical systems rated 5kV and below. It is usually applied in situations where:

(a) It is essential to prevent unplanned system power outages.

(b) Previously the system has been operated ungrounded and no ground relaying has been installed.

(4) NEC Articles 250-5 Exception No. 5 and 250-27 have specific requirements for high impedance grounding for system voltages between 480 and 1000 V. For those system voltages the following criteria apply:

(a) The conditions of maintenance and supervision assure that only qualified persons will service the installation.

(b) Continuity of power is required.

(c) Ground detectors are installed on the system.

(d) Line-to-neutral loads are not served.

(5) Depending on the priority of need, high resistance grounding can be designed to alarm only or provide direct tripping of generators off line in order to prevent fault escalation prior to fault locating and removal. High-resistance grounding (arranged to alarm only) has proven to be a viable grounding mode for 600 V and 5 kV systems with an inherent total system charging current to ground ($3I_{co}$) of about 5.5 A or less, resulting in a ground fault current of about 8 A or less. This, however, should not be construed to mean that ground faults of a magnitude below this level will always allow the successful location and isolation before escalation occurs. Here, the quality and the responsiveness of the plant operators to locate and isolate a ground fault is of vital importance. To avoid high transient overvoltages, suppress harmonics and allow adequate relaying, the grounding transformer and resistor combination is selected to allow current to flow that is equal to or greater than the capacitive charging current.

j. Ground fault current can be reduced in distribution systems which are predominantly reactive through reactance grounding. A reactor is connected between the generator neutral and ground. The magnitude of the ground fault is directly related to the reactor size. The reactor should be sized such that the current flow through it is at least 25 percent and preferably 60 percent of the three phase fault current. Because of the high level of ground fault current relative to resistance grounded systems, reactance grounded systems are only used on high reactance distribution systems.

k. Whether to group or individually ground generators is a decision the engineer is confronted with when installing generator grounding equipment. Generators produce slightly non-sinusoidal voltage waveforms, hence, circulating harmonic currents are present when two or more generating units with unequal loading or dissimilar electrical characteristics are operated in parallel.

(1) The path for harmonic current is established when two or more generator neutrals are grounded, thus providing a loop for harmonic circulation. Because of the 120” relationship of other harmonics, only triple series (3rd, 9th, 15th, etc.) harmonic currents can flow in the neutral. Harmonic current problems can be prevented by: eliminating zero sequence loops (undergrounding the generator neutrals); providing a large impedance in the zero sequence circuit to limit circulating currents to tolerable levels (low or high resistance grounding the generator neutrals); connecting the generator neutrals directly to the paralleling switchgear neutral bus and grounding the bus at one point only; or, grounding only one generator neutral of a parallel system.

(2) An effective ground grid system in power plants or substations is highly important and one that deserves careful analysis and evaluation. The primary function of a ground grid is to limit voltages appearing across insulation, or between supposedly non-energized portions of equipment or structures within a person’s reach under ground fault conditions. Reducing the hazard ensures the

safety and well being of plant personnel or the public at large. A ground grid system should also provide a significantly low resistance path to ground and have the capability to minimize rise in ground potential during ground faults.

(3) The conductive sheath or armor of cables and exposed conductive material (usually sheet metal) enclosing electrical equipment or conductors (such as panelboards, raceways, busducts, switchboards, utilization equipment, and fixtures) must be grounded to prevent electrical shock. All parts of the grounding system must be continuous.

(4) Personnel should verify that grounding for the system is adequate by performing ground resistance tests.

(5) The ground grid of the plant should be the primary system. In some cases a metallic underground water piping system may be used in lieu of a plant ground grid, provided adequate galvanic and stray current corrosion protection for the piping is installed, used and tested periodically. This practice is not acceptable in hazardous areas and is not recommended if the piping system becomes sacrificial.

(6) The plant ground grid should have a system resistance of 10 ohms or less. Ground grid system resistance may be decreased by driving multiple ground electrode rods. A few rods, deeply driven and widely spaced, are more effective than a large number of short, closely spaced rods. Solid hard copper rods should be used, not copperplated steel. When low resistance soils are deep, the surface extension rods may be used to reach the low resistance stratum. Bonding of ground conductors to rods should be by permanent exothermic weld (preferred) or compression sleeve, and not by bolted clamp (corrosion results in high resistance connection). Resistance at each rod in a multiple system should not exceed 15 ohms.

(7) Reliable ground fault protection requires proper design and installation of the grounding system. In addition, routine maintenance of circuit protective equipment, system grounding, and equipment grounding is required (refer to ground resistance testing, chap 7).

(8) Equipment grounding refers to the method in which conductive enclosures, conduits, supports, and equipment frames are positively and permanently interconnected and connected to the grounding system. Grounding is necessary to protect personnel from electric shock hazards, to provide adequate ground fault current-carrying capability and to contribute to satisfactory performance of the electrical system. Electrical supporting structures within the substation (i.e., metal conduit, metal cable trays, metal enclosures, etc.) should be electrically continuous and bonded to the protective grounding scheme. Continuous grounding conductors such as a metallic raceway or conduit or designated ground wires should always be run from the ground grid system (i.e., location of generators) to downstream distribution switchboards to ensure adequate grounding throughout the electrical distribution system. Permanent grounding jumper cables must effectively provide a ground current path to and around flexible metallic conduit and removable meters. Shielded cables must be grounded per manufacturers' requirements. Shielded coaxial cable requires special grounding depending on use and function. A voltmeter must be used for detecting potential differences across the break in a bonding strap or conductor before handling.

(9) A typical grounding system for a building containing heavy electrical equipment and related apparatus is shown in figure 2-3. The illustration shows the following:

(a) Grounding electrodes (driven into the earth) to maintain ground potential on all connected conductors. This is used to dissipate (into the earth) currents conducted to the electrodes.

(b) Ground bus (forming a protective grounding network) which is solidly connected to the grounding electrodes.

(c) Grounding conductors (installed as necessary) to connect equipment frames, conduits, cable trays, enclosures, etc., to the ground bus.

(10) Radio frequency interference (RFI) is interference of communications transmission and reception caused by spurious emissions. These can be generated by communications equipment, switching of DC power circuits or operations of AC generation, transmission, and power consumers. The frequencies and sources of RFI can be determined by tests. Proper enclosures, shielding and grounding of AC equipment and devices should eliminate RFI. RFI can be carried by conductive material or be broadcast. Lamp ballasts, off-spec radio equipment and certain controls may be the prime suspects. The radio engineer or technician can trace and recommend actions to eliminate or suppress the emissions. Pickup of RFI can also be suppressed by increasing the separation distance between power and communication conductor runs.

2-9. Load shedding.

Load shedding is sometimes required during emergency situations or while operating from an auxiliary power source in order to ensure enough power gets to the critical circuits (such as the circuits required for classified communications or aircraft

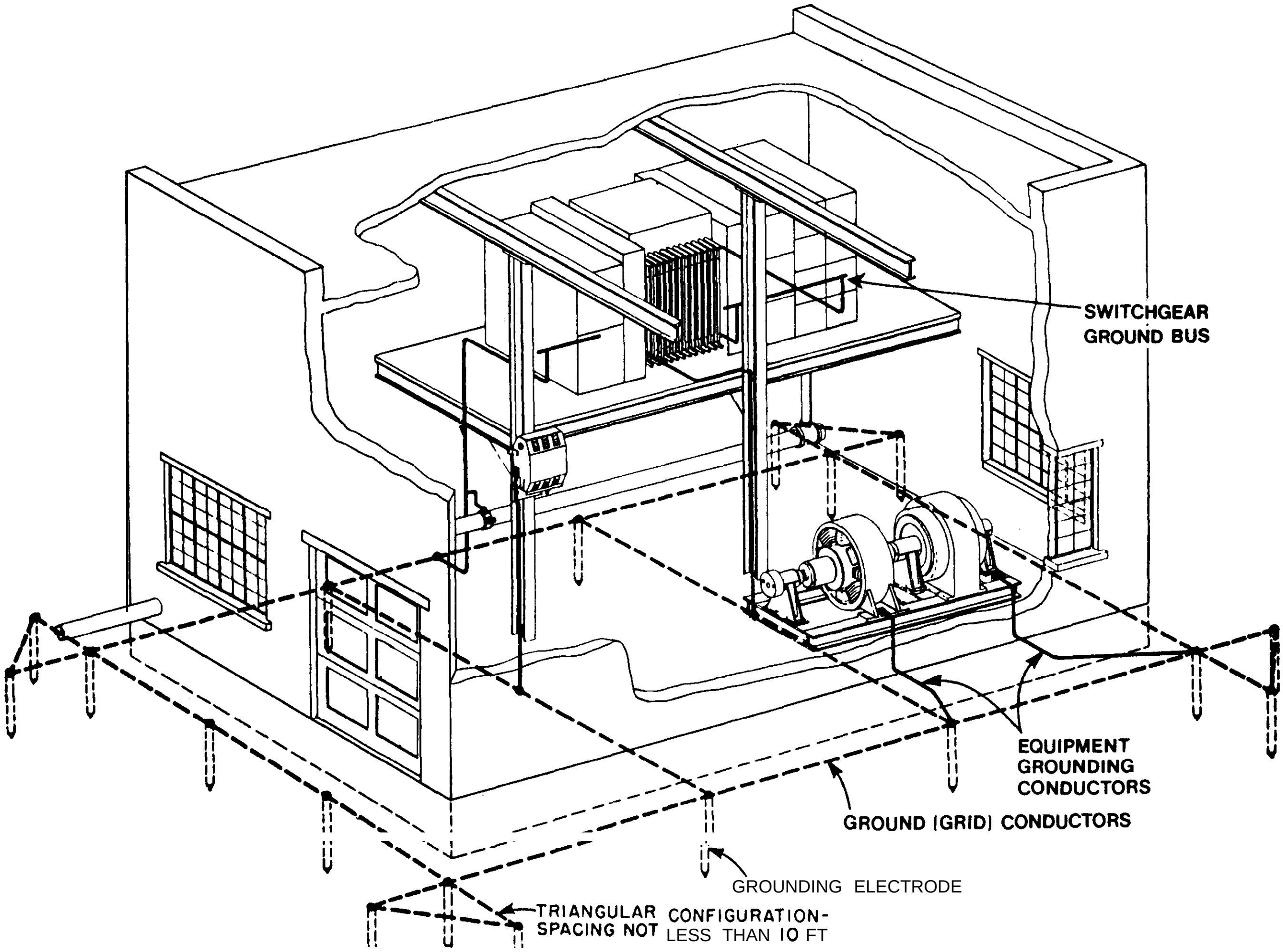

Figure 2-3. Typical grounding system for a building.

flight control). Emergency situations include the handling of priority loads during power "brown-outs" and sharing load responsibilities with prime power sources during "brown-outs". Usually load shedding consists of a documented plan that includes a method for reducing or dropping power to noncritical equipment. This plan should include an updated schematic for load shedding reference and "Truth Table" to ensure correct sequencing of dropping and restoring loads on the system. Plans for load shedding are part of the emergency operating instructions and vary from one facility to another. The extent of load shedding and the sequence of dropping loads and restoring to normal are also contained in the plan.

2-10. Components.

Standards for selection of components for an auxiliary power plant are usually based on the electrical loads to be supplied, their demand, consumption, voltage, phase, and frequency requirements. Also to be considered are load trend, expected life of the project and of the equipment, fuel cost and availability, installation cost, and personnel availability and cost. Factors related to prime movers must also be considered: the diesel because of its relatively low cost and good reliability record, as well as its ability to use liquid or gaseous fuel; the gas turbine for permanent standby plants because it is relatively compact in relation to its high generating capacity (desirable if the anticipated power consumption rate is high). The components of the typical power systems are briefly described in the following paragraphs.

a. Prime movers are reciprocating engines, gas turbines, or other sources of mechanical energy used to drive electric generators.

b. Governors control and regulate engine speed. A governor must be capable of regulating engine speed at conditions varying between full-load and no-load and controlling frequency.

c. Generators are machines (rotating units) that convert mechanical energy into electrical energy.

d. Exciters are small supplemental generators that provide DC field current for alternating current generators. Either rotating or static-type exciters are used.

e. Voltage regulators are devices that maintain the terminal voltage of a generator at a predetermined value.

f. Transfer switches are used to transfer a load from one bus or distribution circuit to another, or to isolate or connect a load. The rating of the switch or breaker must have sufficient interrupting capacity for the service.

g. Switchgear is a cabinet enclosure containing devices for electric power control and regulation, and related instrumentation (meters, gauges, and indicator lights).

h. Instrumentation senses, indicates, may record and may control or modulate plant electrical, thermal and mechanical information essential for proper operation. It may also provide an alarm to indicate an unacceptable rate of change, a warning of unsatisfactory condition, and/or automatic shutdown to prevent damage.

CHAPTER 3

PRIME MOVERS

3-1. Mechanical energy.

A prime mover is an engine that converts hydraulic, chemical, or thermal energy to mechanical energy with the output being either straight-line or rotary motion. Rotary mechanical energy is used to drive rotary generators to produce electrical energy. Over the last 125 years, the internal combustion engine, steam turbine and gas turbine have displaced the steam engine. Auxiliary electrical generators are today usually driven by either reciprocating engine or gas turbine. These are available in wide ranges of characteristics and power rating, have relatively high thermal efficiency and can be easily started and brought on line. In addition, their speed can be closely regulated to maintain alternating current system frequency.

a. *Fuel is burned directly in the internal combustion engine.* The burning air/fuel mixture liberates energy which raises the temperature of the mixture and, in turn, causes a pressure increase. In the reciprocating or piston engine this occurs once for each power stroke. The pressure accelerates the piston and produces work by turning the crankshaft against the connected load.

(1) Reciprocating spark ignition (SI) engines. These engines operate on the Otto Cycle principle typical for all reciprocating SI engines. The events are:

(a) Intake stroke. A combustible fuel/air mixture is drawn into the cylinder.

(b) Compression stroke. The temperature and pressure of the mixture are raised.

(c) *Power (expansion) stroke.* Ignition of the pressurized gases results in combustion, which drives the piston toward the bottom of the cylinder.

(d) Exhaust stroke. The burned gases are forced out of the cylinder.

(2) Four strokes of the piston per cycle are required (four-stroke cycle or four-cycle). One power stroke occurs in two revolutions of the crankshaft.

(3) The output o fan engine can be increased with some loss in efficiency by using a two-stroke (two-cycle) Otto process. During the compression stroke, the fuel/air mixture is drawn into the cylinder. During the power stroke, the mixture in the cylinder is compressed. Near the end of the power stroke, burned gases are allowed to exhaust, and the pressurized new mixture is forced into the cylinder prior to the start of the next compression stroke.

(4) In the Otto cycle, the fuel/air mixture is compressed and ignited by a timed spark. The exact ratio of fuel to air is achieved by carburization of a volatile fuel. Fuel injection is also in use in the Otto cycle to achieve more precise fuel delivery to each cylinder.

(5) Four-cycle SI gasoline engines are used as prime movers for smaller portable generator drives (see fig 3-l). The advantages are:

(a) Low initial cost.

(b) Light weight for given output.

(c) Simple maintenance.

(d) Easy cranking.

(e) Quick starting provided fuel is fresh.

(f) Low noise level.

(6) The disadvantages of using four-cycle SI gasoline engines are:

(a) Greater attendant safety hazards due to use of a volatile fuel.

(b) Greater specific fuel consumption than compression ignition (CI) engines.

(7) Reciprocating CI engines. These operate on the Diesel Cycle principle typical for all CI engines. The-events are:

(a) Intake stroke. Air is drawn into the cylinder.

(b) Compression stroke. Air is compressed, raising the pressure but ‘also raising the temperature of the air above the ignition temperature of the fuel to be injected.

(c) *Power stroke.* A metered amount of fuel at greater-than-cylinder-pressure is injected into the cylinder at a controlled rate. The fuel is atomized and combustion occurs, further increasing pressure, thus driving the piston which turns the crankshaft.

(d) Exhaust stroke. The burned gas is forced from the cylinder.

(8) As with the SI four-cycle engine, the four cycles of the CI engine occur during two revolutions of the crankshaft, and one power stroke occurs in every two revolutions.

(9) The CI or diesel engine may also use two-cycle operation with increased output but at lower engine efficiency.

(10) In the Diesel cycle, only air is compressed and ignition of the fuel is due to the high temperature of the air. The CI engine must be more stoutly constructed than the SI engine because of the higher pressures. The CI engine requires high-pressure fuel injection.