Chapter 2

Generator Selection and Operation Principles

Selecting the generators that can produce the power required by a field unit is an important function. The operator or person responsible for this function must select the number and types of generators that can best meet the unit's needs. The tasks and factors that govern the selection process are described in this chapter. Some basic operations required for power generation in the field also are described. Preliminary tasks that must be completed before power generating equipment is selected are computing the load, computing the cable size, and balancing the load required for the field unit.

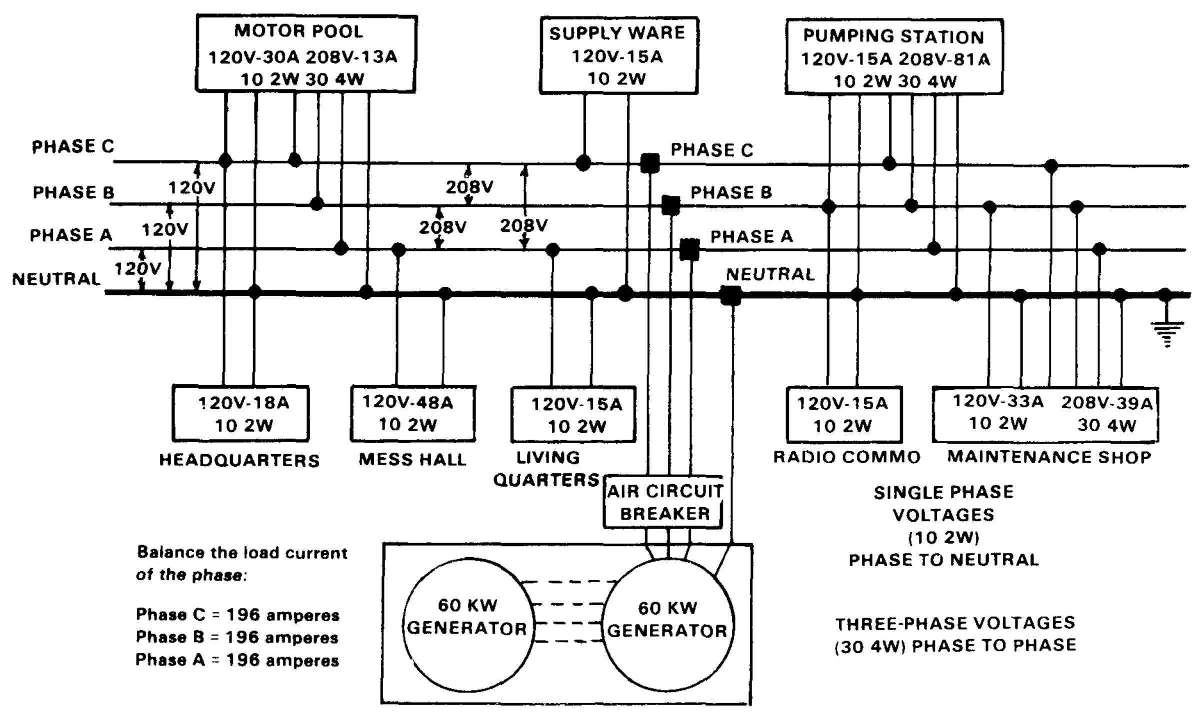
COMPUTING THE LOAD

An accurate estimate of the load requirement is needed before a field unit's power distribution system can be designed properly. The estimated load is determined from the size and location of the load. Complete the following steps to determine the field unit's load requirement:

Map the field unit.
Locate and mark each structure that requires electric power on a map. Identify each structure, such as barrack, recreation hall, or warehouse, as shown in the figure on page 11.

Determine the electrical load for each area.
Electrical loads usually are measured in amperes (amps), kilowatts, or kilovolt–amperes. The total electrical load fluctuates constantly as equipment starts and stops.

Compute the connected load.
The connected load for each structure is computed from the electrical load. The connected load should total the wattage required for all lights and electrical devices plus the total horsepower of all motors. The connected load usually is measured in kilowatt–amperes.



LOAD REQUIREMENTS OF A MILITARY FIELD INSTALLATION

Compute the demand load.
The demand load, computed from the connected load, is the maximum demand required to serve a connected load. The demand load usually is less than the connected load because all equipment in a building, seldom operates at one time. The ratio between the estimated maximum demand load and the connected load is the demand factor. Note that the demand load is never greater than the connected load. The demand and connected loads may be the same if the mission of a tactical shop requires that all electrical equipment be operated simultaneously.

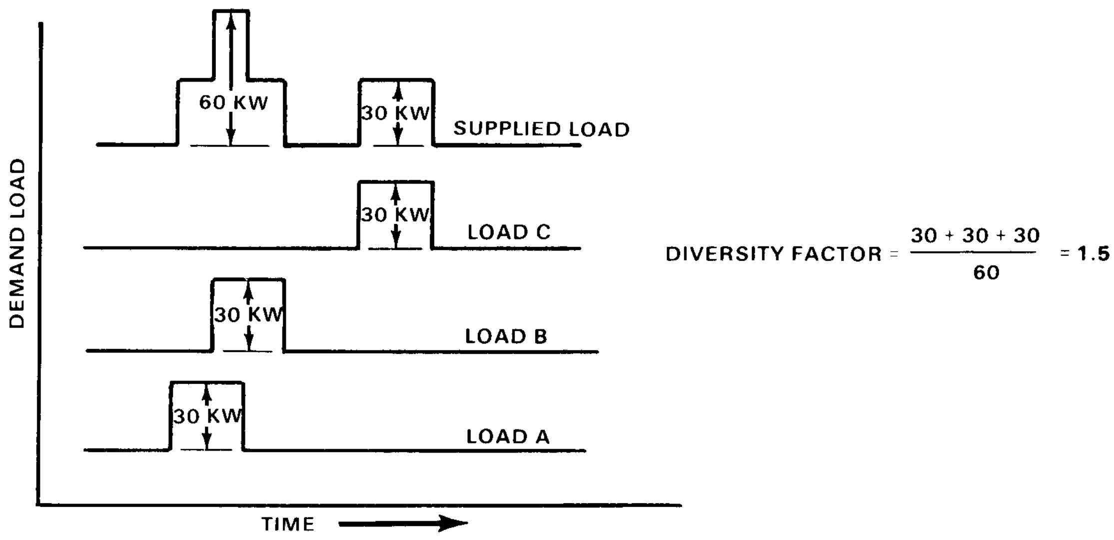
The demand factors established for the design of several types of military structures are listed in the table on page 12. Use the following formula to determine the demand load when the demand factor is known:

Demand load = connected load x demand factor.

Compute the diversity factors.
Measured at the point of supply, the diversity factor is the ratio of the sum of the maximum power demands for the component parts of a system to the maximum demand of the entire system. The diversity factor is similar to the demand factor except that it deals with the actual demand load not the potential demand load. For example, a generator set may serve three

DEMAND FACTORS	
STRUCTURE	DEMAND FACTOR
Housing	.9
Aircraft maintenance facilities	.7
Operation facilities	.8
Administrative facilities	.8
Shops	.7
Warehouses	.5
Medical facilities	.8
Theaters	.5
NAV aids	.7
Laundry, ice plants, and bakeries	1.0
All others	.9

demand sites, each with a maximum demand of 30 kw, as shown in the figure below. In this example, the potential demand load is 90 kw. Because the maximum demands at the three sites do not occur simultaneously, the maximum demand load on the generator set is only 60 kw, not 90 kw. In this example the diversity factor is computed as: $\frac{90}{60} = 1.5$.



DIVERSITY FACTOR

Demand and diversity factors are used in planning the design of electrical facilities. They are used to determine the type and size of generator sets required for a field unit. Demand factors also are used to rearrange existing facilities. For example, additional equipment may greatly increase the connected load for a structure, but it may or may not require a change to the serving generator set.

The diversity factors of significant loads must be considered when they contribute to peak loads. Loads that occur at peak load times may affect the capacity required for a generator set, while loads that occur at nonpeak times may not. For example, a dining facility may contribute about 25 percent of its actual electrical load to the peak load of the system.

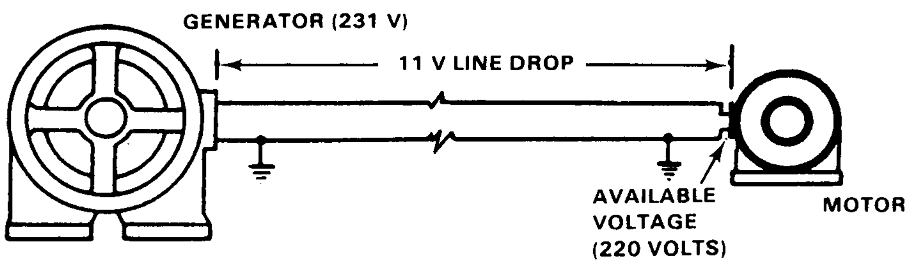
Compute the power factors.
The power factor of an anticipated load must be determined before the amount of power required for an area can be estimated accurately. All AC power estimates are calculated using equipment power factor ratings whenever possible. Noninductive loads such as lights, heaters, and soldering irons are computed at a power factor of 1.0. Inductive loads such as partially loaded transformers and induction motors produce a power factor less than 1.0 because they introduce inductive reactance. The sum of the inductive and noninductive loads is the connected load for the entire installation.

The power factor of an AC circuit is the ratio of the true power (watts) to the apparent power (volt-amperes), as shown in the following formula:

$$\text{Power factor} = \frac{\text{watts}}{\text{volt-amperes}}.$$

The power delivered by a DC generator set (in watts) is the product of the current multiplied by the voltage. There is no inductive reactance in a DC circuit regardless of the character of the load.

Compute the voltage drop.
A voltage drop is the difference between the amount of voltage at the input and output ends of a transmission line. A voltage drop, sometimes called the line loss, is caused by the resistance of the line.



TYPICAL LINE VOLTAGE DROP

Line loss is expressed either as a percentage of the voltage required at the receiving end or as a percentage of the voltage applied by the generator to the line. The example in the figure on page 13 shows a generated voltage of 231 volts, a receiving end voltage of 220 volts, and a line loss of 11 volts. The voltage loss or drop expressed as a percentage of the voltage at the receiving end is 11/220 or 5 percent. The voltage loss, expressed as a percentage of the voltage from the generator end in this example, is 11/231 or 4.8 percent of the sending end voltage. The percentage loss or drop is usually shown as a percentage of the voltage required at the receiving end.

The maximum allowable drop for lighting and power loads, as stated in the National Electrical Code, is 5 percent. This allows no more than a 3-percent loss in the branch lines and no more than a 2–percent loss in the main and feeder lines.

To increase the voltage at the receiving end of the distribution system, increase the voltage output from the generator set. However, the output should never exceed the voltage rating of the generator set. Operators must monitor the voltage throughout the distribution system periodically to identify and correct malfunctions in electrical equipment connected to the lines.

A calculated voltage drop is used to plan a distribution system. A system that does not produce enough voltage may cause unexpected results. For example, the heat produced by resistive heating equipment varies as the voltage varies. Thus, a system operating at 10 percent below the rated voltage will produce 19 percent less heat. The heat loss is absorbed by the conductors supplying the power and may cause conductor failure.

Allow for growth.
Expect the power demands on an electrical circuit to increase in the future. Allow a growth of at least 50 percent of the initial load. When installing a wiring system for electric power, ensure the circuit can accommodate at least 50 percent more than the actual connected loads.

COMPUTING THE CABLE SIZE

A cable connects the generator set to the load. The size of this cable affects the efficiency of the generator. Power losses will occur along the transmission line if the cable is too small. The load current carried by the cable and the distance between the generator set and the load are used to determine the correct cable size.

When a conductor is too small in diameter to carry the current demanded, the cable may overheat and cause the insulation to burn. If the cable wires melt, the circuit will break. The amount of resistance to current flow that occurs along the cable is determined by the distance between the generator set and the load.

Complete the following steps in sequence to determine the cable size required:

1. Use the following tables to compute the total current demand for each phase:

LOAD CONVERSION FACTORS

TO FIND	DIRECT CURRENT	ALTERNATING CURRENT	
		SINGLE PHASE	THREE PHASE
Amperes when horse-power is known	$\frac{HP \times 746}{E \times Eff}$	$\frac{HP \times 746}{E \times Eff \times PF}$	$\frac{HP \times 746}{1.73 \times E \times Eff \times PF}$
Amperes when kilo-watts are known	$\frac{KW \times 1000}{E}$	$\frac{KW \times 1000}{E \times PF}$	$\frac{KW \times 1000}{1.73 \times E \times PF}$
Amperes when kilovolt-amps are known		$\frac{Kva \times 1000}{E}$	$\frac{Kva \times 1000}{1.73 \times E}$
Kilowatts when-amperes are known	$\frac{I \times E}{1000}$	$\frac{I \times E \times PF}{1000}$	$\frac{I \times E \times 1.73 \times PF}{1000}$
Kilowatts when horse-power is known	$\frac{HP \times 746}{1000 \times Eff}$	$\frac{HP \times 746}{1000 \times Eff}$	$\frac{HP \times 746}{1000 \times Eff}$
Kilovolt-amps when amperes are known		$\frac{I \times E}{1000}$	$\frac{I \times E \times 1.73}{1000}$
Kilovolt-amps when horsepower is known		$\frac{HP \times 746}{1000 \times Eff \times PF}$	$\frac{HP \times 746}{1000 \times Eff \times PF}$
Horsepower output when amperes are known	$\frac{I \times E \times Eff}{746}$	$\frac{I \times E \times Eff \times PF}{746}$	$\frac{I \times E \times 1.73 \times Eff \times PF}{746}$
Load power factor when rated horsepower and kilovolt-amps are known		$\frac{HP \times 746}{100 \times Kva \times Eff}$	$\frac{HP \times 746}{100 \times Kva \times Eff}$

I = amperes; E = volts; Eff = Efficiency (as a decimal); PF = power factor (as a decimal); KW = kilowatts; Kva = kilovolt-amperes; HP = horsepower.

Three phase, AC lines are assumed to be feeding balanced, three-phase loads.

For three-phase loads, input current is per phase.

WATTAGE CONSUMPTION OF ELECTRICAL APPLIANCES

APPLIANCE	AVERAGE WATTAGE	APPLIANCE	AVERAGE WATTAGE	APPLIANCE	AVERAGE WATTAGE
Clock	3	Grill	600	Refrigerator	500
Coffeemaker	1000	Hotplate	1250	Radio	100
Fan, 8-inch	30	Humidifier	500	Soldering iron	200
Fan, 10-inch	35	Iron	1000	Television	300
Fan, 12-inch	50	Mixer	200	Toaster	1200
Heater (radiant)	1300	Phonograph	40	Washing machine	1200
Griddle	450	Range	8000	Water heater	4500

FULL-LOAD CURRENTS OF MOTORS

HP	120V	240V
1/4	2.9	1.5
1/3	3.6	1.8
1/2	5.2	2.6
3/4	7.4	3.7
1	9.4	4.7
1 1/2	13.2	6.6
2	17	8.5
3	25	12.2
5	40	20
7 1/2	58	29
10	76	38
15		55
20		72
25		89
30		106
40		140
50		173
60		206
75		255
100		341
125		425
150		506
200		675

These values of full-load current are average for all speeds, and are in accordance with the National Electrical Code.

HP	115V	230V
1/8	4.4	2.2
1/4	5.8	2.9
1/3	7.2	3.6
1/2	9.8	4.9
3/4	13.8	6.9
1	16	8
1 1/2	20	10
2	24	12
3	34	17
5	56	28
7 1/2	80	40
10	100	50

These values of full-load current are in accordance with the National Electrical Code, and are for motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torques may requre more running current, in which case the nameplate current rating should be used.

For full-load currents of 208- and 200-volt motors, increase the corresponding 230-volt motor full-load current by 10 and 15 percent, respectively.

FULL-LOAD CURRENTS OF MOTORS (CONTINUED)

INDUCTION TYPE SQUIRREL-CAGE AND WOUND MOTOR AMPERES					SYNCHRONOUS TYPE UNITY POWER FACTOR† AMPERES				
HP	110V	220V	440V	550V	2300V	220V	440V	550V	230V
½	4.0	2.0	1.0	0.8					
¾	5.6	2.8	1.4	1.1					
1	7.0	3.5	1.8	1.4					
1½	10.0	5.0	2.5	2.0					
2	13.0	6.5	3.3	2.6					
3		9.0	4.5	4.0					
5		15.0	7.5	6.0					
7½		22.0	22.0	9.0					
10		27.0	14.0	11.0					
15		40.0	20.0	16.0					
20		52.0	26.0	21.0					
25		64.0	32.0	26.0	7.0	54.0	27.0	22.0	5.4
30		78.0	39.0	31.0	8.5	65.0	33.0	26.0	6.5
40		104.0	52.0	41.0	10.5	86.0	43.0	35.0	8.0
50		125.0	63.0	50.0	13.0	108.0	54.0	44.0	10.0
60		150.0	75.0	60.0	16.0	128.0	64.0	51.0	12.0
75		185.0	93.0	74.0	19.0	161.0	81.0	65.0	15.0
100		246.0	123.0	98.0	25.0	211.0	106.0	85.0	20.0
125		310.0	155.0	124.0	31.0	264.0	132.0	106.0	25.0
150		360.0	180.0	144.0	37.0		158.0	127.0	30.0
200		480.0	240.0	192.0	48.0		210.0	168.0	40.0

These values of full-load current are in accordance with the National Electrical Code, and are motors running at speeds usual for belted motors and motors with normal torque characteristics. Motors built for especially low speeds or high torque may require more running current, in which case, the nameplate current rating should be used.

For full-load currents of 208- and 200-volt motors, increase the corresponding 220-volt motor full-load current by 6 and 10 percent, respectively.

† For 90 and 80 percent power factor the above figures should be multiplied by 1.1 and 1.25, respectively.

2. Use the table below to determine the wire size capable of carrying the total current.

ALLOWABLE CURRENT CAPACITIES OF CONDUCTORS, IN AMPERES, FOR NOT MORE THAN THREE CONDUCTORS IN A RACEWAY OR CABLE						
A	B (Note 2)	C	D	E	F	G
Size AWG or MCM	Rubber types R, RW, RU, RUW (14-2) Type RH-RW (Note 1) Thermoplastic types T, TW	Rubber type, RH type RH-RW (Note 1) type RHW	Paper Thermoplastic asbestos type TA Var-Cam type V Asbestos Var-Cam type AVB MI Cable	Asbestos varnished cambric types AVA, AVL	Impregnated asbestos types AI (14-8) AIA	Asbestos types A (14-8) AA
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
0	125	150	155	190	200	225
00	145	175	185	215	230	250
000	165	200	210	245	265	285
0000	195	230	235	275	310	340

Note 1: If type RH-RW rubber-insulated wire is used in wet locations the allowable current carrying capacities will be that of column C, and if used in dry locations, the current carrying capacities will be that of column D.

Note 2: Insulation type and description.

Type	Description
R	code-grade rubber compound
RW	moisture-resistant rubber compound
RU	latex-rubber compound
RUW	latex-rubber, moisture-resistant compound
RH-RW	heat- and moisture-resistant rubber compound
RH	heat-resistant rubber compound
RHW	heat- and moisture resistant compound
T	thermoplastic-covered for dry locations
TA	thermoplastic- and asbestos-covered for switchboard wiring
TW	thermoplastic-covered for moist locations
MI	mineral-insulated, copper-sheathed for general use and special high-temperature locations
A	non-impregnated, all-asbestos, w/o asbestos outer braid
AA	non-impregnated, all-asbestos, with asbestos outer braid
AI	impregnated, all-asbestos, w/o asbestos outer braid
AIA	impregnated, all-asbestos, with asbestos outer braid
AVA	impregnated-asbestos and varnished-cambric with asbestos braid
AVB	impregnated-asbestos and varnished-cambric, flame-resistant cotton braid
AVL	impregnated-asbestos and varnished-cambric, outer asbestos braid, lead sheathed
V	varnished cambric

If the wire size determined from the table on page 18 is not available, use parallel runs of smaller wires or use the next larger size. Substitute sizes based on the current–carrying capacities of the wires are listed in the table below. The wire substitutions in the table should not produce excessive voltage drops along the distribution line. However, operators must monitor the voltage at the receiving end to ensure the size substituted carries the current efficiently.

SUBSTITUTE WIRE SIZES						
WIRE SIZE	CURRENT CARRYING CAPACITY (AMPS)	NUMBER AND SIZE OF WIRES THAT MAY BE SUBSTITUTED FOR A SINGLE WIRE OF THE SIZE SHOWN IN THE FIRST COLUMN				
		2	3	4	5	6
1,000,000	455	300,000	000	0	2	3
900,000	435	300,000	00	1	2	3
800,000	410	250,000	00	1	2	4
750,000	400	250,000	00	1	3	4
700,000	385	0000	00	1	3	4
600,000	355	0000	0	2	3	4
500,000	320	000	1	3	4	6
100,000	280	00	2	4	—	6
300,000	240	0	3	4	6	8
250,000	215	1	3	6	—	8
0000	195	1	—	6	8	—
000	165	2	6	—	8	10
00	145	3	6	8	10	—
0	125	4	6	8	10	—
1	110	6	8	10	—	12
2	95	6	8	10	12	—
3	80	8	10	12	—	14
4	70	8	10	12	14	—
6	55	10	12	14	—	—
8	40	12	14	—	—	—
10	30	14	—	—	—	—

3. Use the table below to determine the total resistance of the cable when it is connected between the generator set and the load.

PHYSICAL AND ELECTRICAL PROPERTIES OF CONDUCTORS

STANDARD RUBBER CONDUCTOR		I.P.C.E.A. CLASS B STRANDING	AT 77°F (25°C)	
SIZE AWG	CIRCULAR MILS	NO. OF WIRES	BARE COPPER	TINNED COPPER
18	1,624	7	6.64	7.05
16	2,583	7	4.18	4.43
14	4,107	7	2.63	2.69
12	6,530	7	1.65	1.72
10	10,380	7	1.04	1.08
9	13,090	7	.824	.856
8	16,510	7	.654	.679
7	20,820	7	.519	.538
6	26,250	7	.410	.427
5	33,100	7	.326	.339
4	41,740	7	.259	.269
3	52,640	7	.205	.213
2	66,370	7	.162	.169
1	83,690	19	.129	.134
0(1/0)	105,500	19	.102	.106
00(2/0)	133,100	19	.0811	.0842
000(3/0)	167,800	19	.0642	.0668
0000(4/0)	211,600	19	.0509	.0525

Ampacity (amperes plus capacity) affects the size of wire required for a distribution cable. Ampacity is the current-carrying capacity of a cable or wire expressed in amperes. If the ampacity load is great and the wire length from the generator set to the load is short, ampacity considerations will require a larger wire size than the size normally required. When power requirements are low and the length of the line is long, the voltage drop criteria will require a larger wire size than the size normally required. The criteria resulting in the larger size wire govern the design of the distribution system.

NOTE: When a cable is installed overhead, use a minimum size of Number (No) 8 American wire gage. An overhead cable must meet the voltage-drop requirement and be strong enough to support its own weight plus any additional weight caused by fallen branches, ice, or snow.

BALANCING THE LOAD

The final task before selecting generator sets for a field unit is to balance the load among the phases. When balancing a load, the operator must ensure each phase carries an equal share of the load.

Loads may be connected between a power carrying conductor (live wire) and a ground (neutral) wire, or they may be connected between several live wires. When an operator connects a load between a live wire and a ground wire, any unbalanced current (power) in the line conductors is supplied through the ground wire. A load connected between two or more live wires is distributed equally among the live wires.

An installation fed by a three-phase, four–wire generator set can have a single-phase load attached to each of the three phases. Regardless of the number of loads supplied or how the loads are arranged, the generator supplies the total load on each phase. The generator attempts to supply the power required to satisfy the load in each phase. The power must be balanced so that each phase receives an equal amount of current from the generator set. The operator can ensure the loads are balanced by connecting the loads so that each phase receives an equal load.

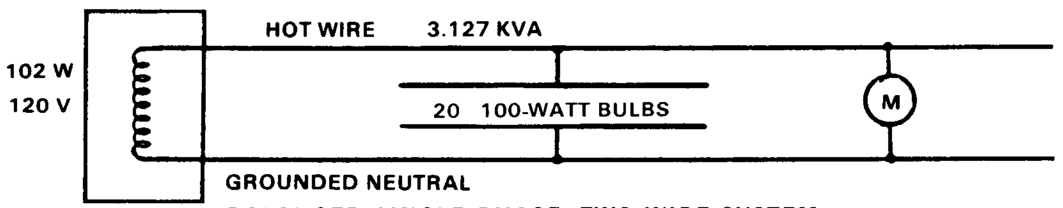
An unbalanced load has two adverse effects:

- Unbalancing causes high voltage on the lightly loaded phase and low voltage on the other phase or other two phases. This causes poor voltage regulation throughout the system.

- A load that is unbalanced for a long time damages the generating equipment.

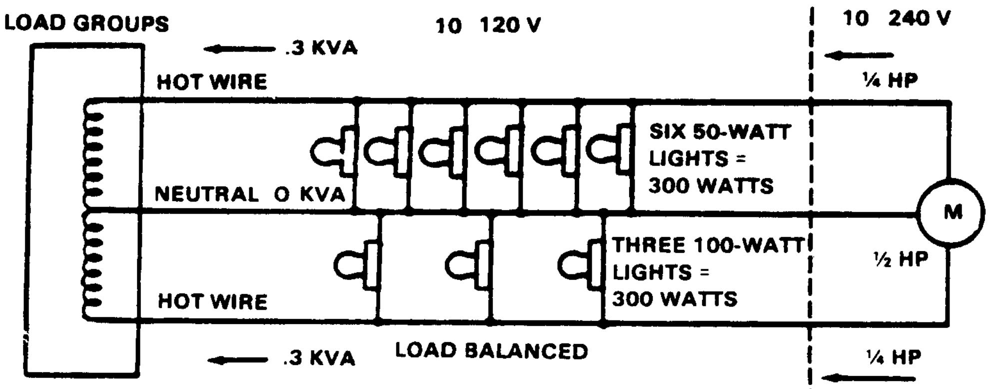
Single-Phase Systems

A single-phase, two-wire, 120–volt system cannot be unbalanced because the two wires are connected to one load. This basic load-carrying circuit is connected so that one–half of the total load is supplied by one live wire, and the other one–half of the load is supplied by the other live wire.



BALANCED SINGLE-PHASE, TWO-WIRE SYSTEM

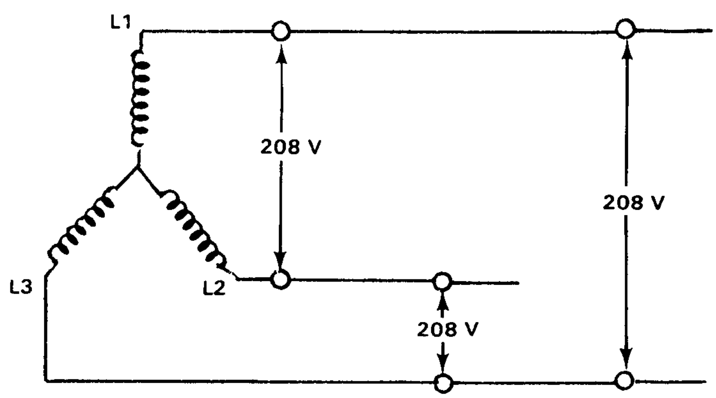
A single-phase, three–wire, 120/240–volt system has two live wires and one ground wire. It can supply power for two single–phase, 120–volt loads and one single-phase, 208/220-volt load group.



BALANCED SINGLE-PHASE, THREE-WIRE SYSTEM

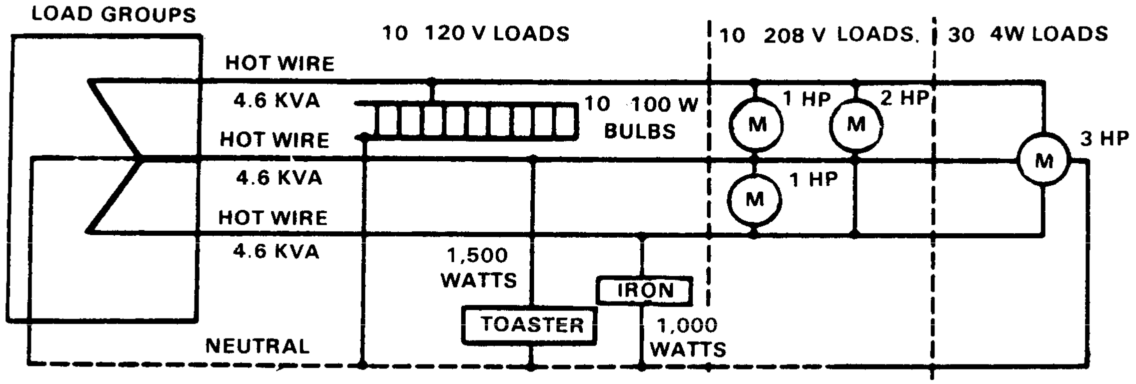
Three-Phase Systems

A three-phase, three-wire, 208-volt system has three live wires. It can supply three single-phase, 208–volt loads or one three–phase, 208-volt load. Divide the total load equally between the three live wires for a single-phase connection.



BALANCED THREE-PHASE, THREE-WIRE SYSTEM

A three-phase, four-wire, 120/208-volt system (figure on page 23) has three live wires and one ground wire. This system can supply power for a single-phase, 120-volt load; a three-phase, 208-volt load; and a single–phase, 208-volt load.



BALANCED THREE-PHASE, FOUR-WIRE SYSTEM

When the total load is balanced, the operator marks the voltage and number of phases needed on a site diagram. The voltage and phase requirements are marked plainly on most AC and DC motors.

SELECTING THE GENERATOR

After the distribution system is designed and the load is balanced, the operator can select the generating equipment to produce the power needed for the field unit. The following factors govern the selection process:

- Electrical loads to be supplied.
- Kilowatt rating requirements.
- Operating voltages required.
- Number of phases required.
- Frequency requirements.

In addition to these factors, the availability of fuels, the expected life of the field unit, the availability of skilled maintenance personnel, and the probable load deviation must be considered when selecting generating equipment for a field unit.

The electrical systems at most military field units supply power day and night for various lighting, heating, and power equipment. The annual load factor of a well–operated, active field unit is 50 percent or more of the capacity of the generator sets. The annual load has a power factor of 80 percent or more of the average power factor. Therefore, all of the above criteria must be considered when selecting generating equipment.

The layout of the field unit must be considered when selecting generating equipment. For example, if the load is more than a few hundred feet from the generator set, a high-voltage distribution system may be needed. If the power plant serves a primary distribution system, the generator set must be rated at the distribution system's voltage. This eliminates the need for a transformer at the sending end. Also, the number of phases required by the load may differ from that of the generators on hand. Because most loads can be divided and balanced between phases, most medium- and large-sized generator sets are designed for three-phase operation.

Most electrical loads in the United States require a frequency of 60 cycles. Although equipment operators try to maintain a constant frequency throughout the electrical system, deviations sometimes occur. Most electrical equipment operates satisfactorily when the frequency drifts approximately 5 cycles above or below 60 cycles. Equipment such as teletypewriters and electric clocks are sensitive to frequency changes. The operator must consider frequency drift when selecting generator sets that supply power to equipment sensitive to frequency changes.

Operators must select generator sets that are the proper size and type for the field unit's needs. If a central generating station is needed but there is not enough time to build one, the operator must install a generator set at each work site that requires power. The size of the generator set selected for each work site will depend on the needs of the site. For example, the electrical load at a headquarters building that consists of lights and single–phase motors can be supplied by a small, single-phase generator set. A maintenance shop that uses large amounts of single-phase and three-phase power requires a three-phase generator set.

The choice of generator set must be coordinated with the maintenance and supply facilities at the field unit. Maintenance skills and the necessary tools and spare parts required for the selected generator must be available at the field unit.

Power and Voltage Requirements

The power and voltage requirements of the load determine the size of the generator set used. For example, a two–wire, 120-volt generator set with an output rating of 1.5 kw produces enough electricity for equipment rated at 120 volts, single-phase, with a combined power load of less than 1.5 kw (1,500 watts). A 5-kw, AC generator set produces enough electricity for equipment requiring between 1.5 kw and 4.5 kw.

If motors are part of the load, the capacity of the generator set must be increased above the capacity normally required. The increased capacity is needed to compensate for reduced terminal voltage when large motors are started and when frequency surges occur during motor acceleration. These power drains may adversely affect the performance of electronic systems and other equipment fed from the same generator set. Also, motors already running may stall when large motors are started. Operators can avoid these and similar problems by removing the existing load when starting a large motor. Place the small loads back on the generator set after the large motor has reached its required speed.

Some single-phase loads contain equipment rated at both 115 and 230 volts. These loads require a generator set with a single–phase, three-wire, 120/240-volt output.

The size of the load is a primary consideration when selecting a generator set. Determine the capacity needed to support the load before selecting a generator set. Sets with capacities ranging from 0.5 kw to 500 kw are available.

Selection Guides

Use the following guides to select a generator set:

- Single-phase equipment provides power for small lighting, AC and DC motors, special equipment such as radial (arc) electric welders, and some furnace loads. Either a two- or a three-wire system may be used, depending on the size of load and the area serviced.

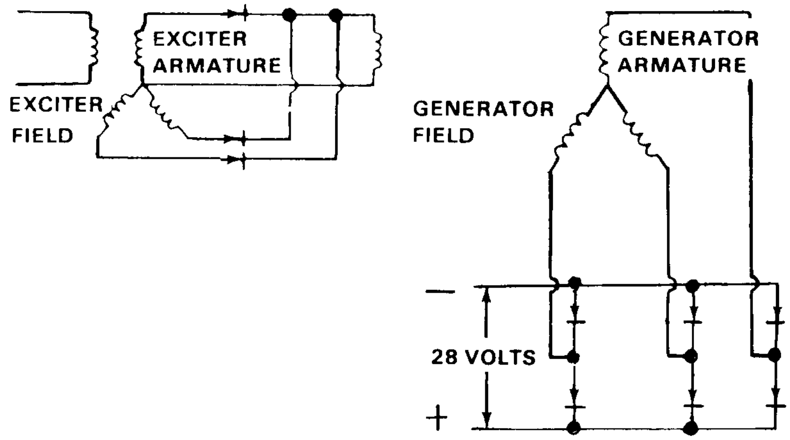
- Three-phase equipment provides power for almost everything except small loads. The generation and transmission lines usually are three-wire systems, but the distribution circuits may be three- or four-wire. When single-phase power is obtained from three-phase circuits, operators must balance each phase at the generator set.

- To determine the voltage required for a generator set, consider the distribution circuits; the size, character, and distribution of the load; the length, capacity, and type of transmission lines; and the size, location, and connection of the generator sets.

- Lighting is universally rated at 120 volts in the United States. The voltage required for lighting can be obtained from a single-phase, two-wire, 120/240-volt circuit or a three-phase, four-wire, 120/208–volt circuit. The general use of combined lighting and small motor circuits increases the use of 120/208 volts for general power application.

- Small motors of less than 5 horsepower are supplied by DC or single–phase AC systems at 120 volts. Large three-phase motors, 5 horse–power or more, usually operate satisfactorily between 200 and 240 volts.

- The DC generator sets are used for specific tasks, and selection is based on the task to be performed. Battery charging is the main use of DC generators. A practical wiring diagram of a two–wire, DC generator set is shown in the figure on page 26.



TYPICAL WIRING DIAGRAM OF A TWO-WIRE, DC GENERATOR SET

- The use of a single generator set is the least desirable method for obtaining continuous electricity. A single generator set is used when the set is isolated from the distribution system and when equipment failure will not seriously affect the field unit's mission. Sometimes a single generator set is used to power extremely large loads that cannot be tied into a limited distribution system.

Generator sets have gasoline, diesel, or gas turbine engines. Fuel is a major factor to consider when selecting a generator set. For example, fuel availability may limit the choice of engines in advanced or isolated areas. Use the following guides to select the type of engine for a generator set:

- Most gasoline engine–driven generator sets are similar to small automotive engines. Therefore, maintenance problems on these sets may be easier to correct than maintenance problems on other, less known, engines.

- Diesel engine-driven generator sets usually operate for longer periods and under greater strains than the gasoline engine–driven generator sets. Also, diesel engines usually require less maintenance than gasoline engines because of their construction and lack of an ignition system.

- Gas turbine engine-driven generator sets consume a lot of fuel, but they offer some advantages. Because these generators have a minimal warm-up time, a load can be applied almost immediately. Also, these sets are not limited to a specific fuel--they have multifuel capability.

Load Classification Requirements

The operator must properly match the load to the generator set at the field unit. Loads are classified as inductive or resistive. The load classification partly determines the amount of load a generator can support. The generator set rating information is in amperes, kilovolt-amperes, kilowatts, power factors, or all of these. If the only data available on a generator set are the kilovolt-amperes, power factor, and voltage output rating, the operator must determine the load classification.

A generator can support its kilovolt-amperes rating if the major portion of a load is inductive. For example, a model MEP-017A generator set rated at 6.25 kilovolt-amperes can support a 6.25 kilovolt-amperes inductive load.

A generator with a load that is entirely resistive may easily be overloaded because it can support only 80 percent of its kilovolt-amperes rating. For example, a model MEP-017A generator set rated at 6.25 kilovolt-amperes can support only a 5-kw load (6.25 x 0.80 = 5). A generator set with a rating of 0.8 power factor cannot support that rating in kilovolt-amperes if the load is purely resistive (a power factor of 1.0). If the ampere rating is known, calculate the total amperes required to support the load but do not exceed the rating of the generator set.

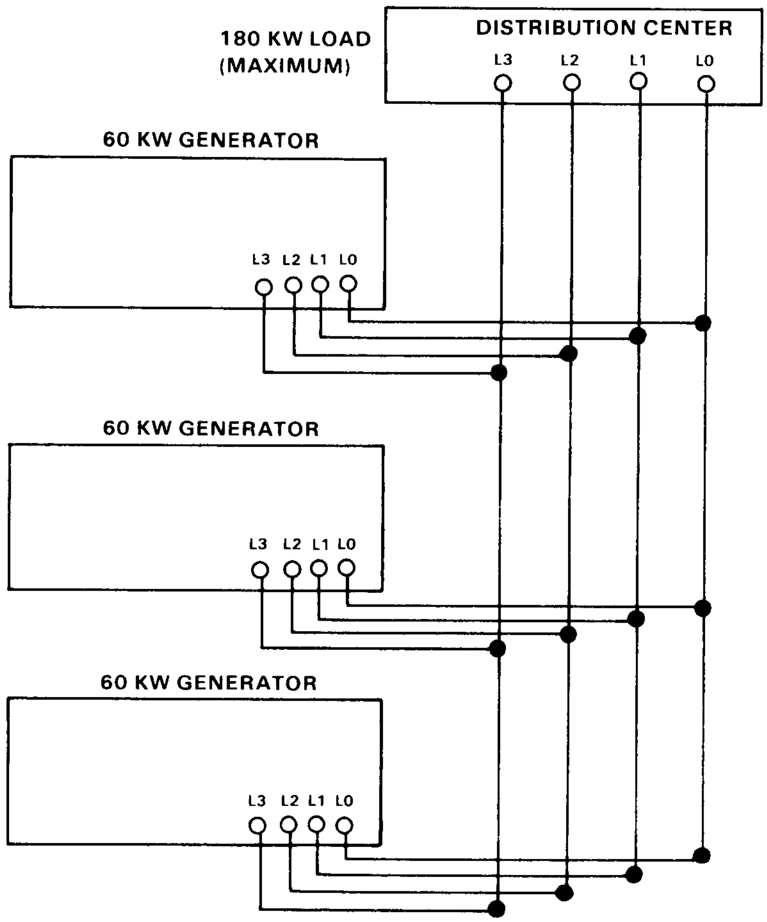
Many generator sets are designed so the operator can select one of several voltages. The ampere rating changes as the voltage output changes. Thus, a model MEP-018A, 5-kw generator set can supply any of the following voltages and amperes:

Phase	Voltage	Amperes
Single	120	104
Single	240	52
Three	120	34.7 (per phase)
Three	208	17.3 (per phase)

Generator set rating information is on the alternator data plate and in the tabulated data section of the technical manual for each generator set.

PARALLELING THE GENERATOR SETS

Sometimes a field unit with only small- and medium-sized generator sets needs a large quantity of power. The operator can accomplish this by connecting and operating two or more generator sets in parallel. When generator sets are connected in this way, their combined kilowatt rating is equal to the sum of the kilowatt ratings for each set. Parallel connected generator sets are shown in the figure below.



PARALLEL CONNECTED GENERATOR SETS

The two main reasons for connecting generator sets in parallel are to provide continuous power and to allow shutdown time for servicing equipment. Installations that require continuous power, such as surgical hospitals, use parallel connected generator sets to avoid power outages. Generator sets are shut down and serviced periodically. When they are connected in parallel, one set can be shut down and serviced while the others continue to operate. Thus, an installation can receive continuous power with no time lost for maintenance and repair.

Operators must synchronize the parallel generator sets before they are connected to the load. Complete the following steps in sequence to synchronize a base set and an incoming set:

1. Close the main circuit breaker on the base set.

2. Ensure the voltmeter indicates the frequency required for the load.

During the synchronizing process, the base (operating) generator set may be connected to the load and operating or it may be disconnected from the load and operating. After steps 1 and 2 are completed, the incoming generator set may be synchronized with the base unit.

3. Open the circuit breaker on the incoming generator set.

4. Ensure the voltage output and the frequency output of the incoming generator set are the same as those of the base set.

5. Place the paralleling switch on the control panels of the base and incoming generator sets in the on position. When the paralleling switches are on, the two paralleling lamps on the control panel of the incoming set will begin to blink on and off. Both lights must become bright and then dark at the same time. If they do not, the generator sets are connected incorrectly.

NOTE: Turn off all power before reconnecting the generator sets.

The lamps must go on and off together. If the base set is under a power load, observe the kilowatt meter (percent of power meter) on the base set. Then go back to the incoming set and observe the paralleling lamps. Adjust the throttle (on utility sets) or the frequency adjust rheostat (on precise sets) until the lamps go on and off at 3- to 5–second intervals. When the lights are completely dark, close the main circuit breaker on the incoming set. Adjust the frequency rheostat of the incoming set until the kilowatt meter indicates one-half of the power of the base set. Adjust the voltage rheostats on both sets, if necessary, to eliminate crosscurrents.

If the current meter on either set indicates excessive current and the voltage rheostat will not balance the current, do not operate the generators in parallel. Refer to the next higher level of maintenance.

When the synchronizing lamps blink in unison, the two sets are operating in parallel as one base unit. Complete steps 3 through 5 for each additional incoming set. The percent of power meter on the third set should indicate one–third of the load on the base set.

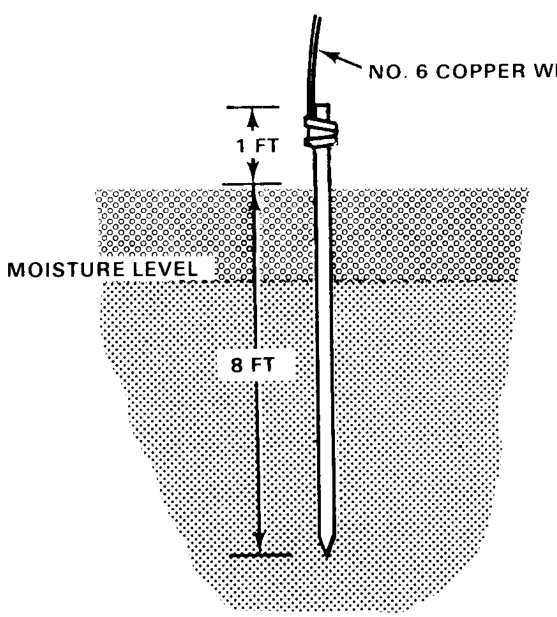
6. After all the generator sets are operating in parallel, divide the load equally among them. To do this, adjust the voltage and frequency outputs of each set. This step completes the paralleling process.

GROUNDING SYSTEMS

Electric power generating equipment must be grounded as a safety precaution. Stray electric current within the generator set or in the distribution system can injure or kill the operator and damage the equipment. Portable field power generating equipment may be grounded with a grounding rod, grounding pipe, or a grounding plate.

Grounding Rod

The standard grounding rod used by military units is a 5/8-inch copper rod with three, 3–foot sections. To install a grounding rod, drive it at least 8 feet into the soil. The rod must be buried below the moisture level. If this cannot be done, replace the grounding rod with an 8–foot electrode. Bury the electrode in a horizontal trench that is at least 2 1/2 feet deep. The electrode must be placed below the moisture level, as shown in the figure below.

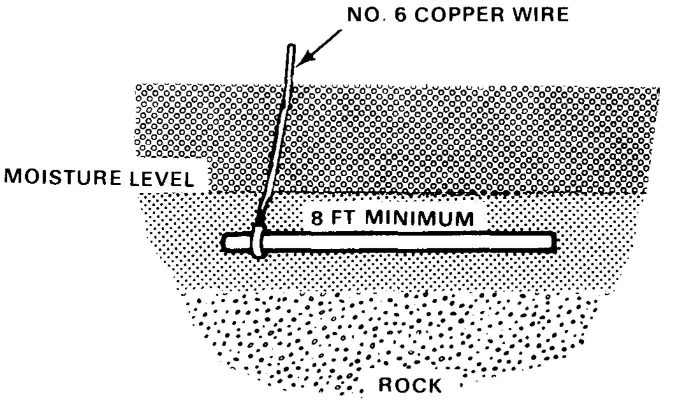


TYPICAL ROD OR PIPE GROUND ELECTRODE

If one grounding rod does not produce a good grounding system, the operator can form a network with three or more rods. Install the rods about 6 feet apart. If three rods form the network, place them in a straight line or in a triangular pattern. Install more than three rods in a straight line. Connect the grounding cable from the generator set to each grounding rod so they are in series.

Grounding Pipe

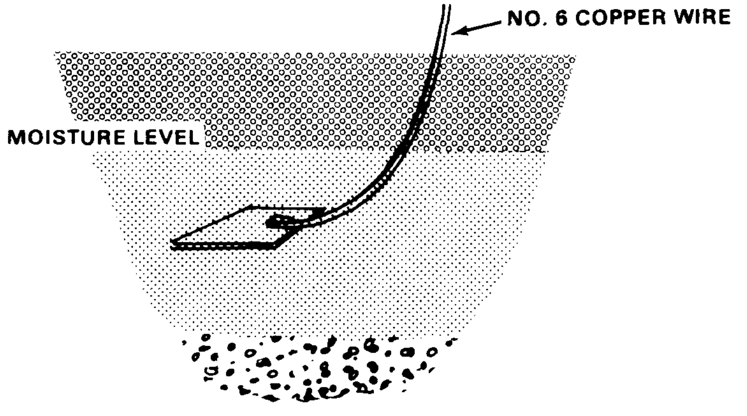
Use a clean, metallic pipe of 3/4-inch trade size or larger to make a grounding pipe. Pipes made of iron or steel must be galvanized or coated for corrosion protection. Drive the pipe at least 8 feet into the soil. If this cannot be done, replace the pipe with an 8-foot long electrode. Bury the electrode in a horizontal trench that is at least 2 1/2 feet deep. The pipe must be placed below the moisture level.



GROUNDING PIPE

Grounding Plate

A buried grounding plate (plate electrode) may be used as a ground. The plate must be at least 36 inches in width and length (9 square feet). An iron or steel plate may be substituted for a plate electrode if it is at least l/4-inch thick and coated for corrosion protection. Grounding plates must be buried below the moisture level.



GROUNDING PLATE ELECTRODE

Attach the grounding system with No 6 American wire gage or a larger cable. Connect one end of the cable to the grounding terminal of the generator set. Tighten the nut securely, as described in the appropriate technical manual. Connect the other end of the cable to the grounding electrode with a special grounding clamp.

Soil Conditions

Contact with the earth does not guarantee a good grounding system. The soil type, moisture content, and soil temperature affect the efficiency of the grounding system. The characteristics of four types of soils are described in the table below.

SOIL CHARACTERISTICS	
TYPE OF SOIL	QUALITY OF GROUND
Fine soil granules with high moisture content	Very good
Clay, loam, shale	Good
Mixed (clay, loam, shale mixed with gravel or sand)	Poor
Gravel, sand, stone	Very poor

Soil is divided into two distinct layers. Topsoil, the first layer, usually ranges from 1 to 6 inches deep. Because it is often dry and loosely packed, topsoil is not a good electrical conductor. Subsoil, the second layer, usually is tightly packed, retains moisture, and provides the best electrical ground. Wet soil passes electric current better than dry soil and allows the grounding system to work efficiently.

A chemical solution is used on soils to improve a poor or very poor grounding system. To make this solution, mix 5 pounds of sodium chloride (common table salt) with 5 gallons of water (1 pound of salt to 1 gallon of water). Dig a hole that is about 1 foot deep and 3 feet wide. Pour the solution into the hole and allow it to seep into the soil. Install the grounding rod in the hole, connect the grounding strap, and fill the hole with soil. Keep the soil around the rod moist at all times.

Frozen soil is a poor conductor of electric current. When the soil temperature drops below 32 degrees Fahrenheit (32°F) or 0° Celsius (C) and the soil moisture freezes, the effectiveness of the grounding system decreases. To compensate for low soil temperatures, locate the grounding system near a source of heat, such as a generator set or vehicle exhaust. When it is difficult to install an effective grounding system because the soil is frozen, connect the grounding strap to something that is already grounded. The grounding strap can be attached to a metal building or an underground pipe. Attach the strap with a grounding clamp if possible; if not, attach it with a bolt.

Another alternative is to drive several grounding stakes into the soil at different locations to form a grounding network. Drive the stakes to the greatest depth possible. If necessary, drill, dig, or blast a hole in the soil, and use the salt solution described previously. A temporary ground may be made by driving a spike deep into a large tree.

The extremely dry and loosely packed desert soils provide a very poor electrical grounding system. Increase the efficiency of whichever grounding system is used in desert soils with the chemical solution described previously. Keep the soil around the grounding system moist at all times. Locate the equipment near an oasis or subterranean water if possible.

In the rocky terrain typical of mountainous areas, site selection is the key to providing a good grounding system. Try to locate the equipment near a streambed.

Use a slip hammer to drive a grounding rod into packed, rocky, or frozen soil. This tool can be made locally (garrison) and used to install and remove a grounding rod (figure on page 34). Order a slip hammer through normal supply channels as a driver/puller, national stock number (NSN) 5120-01-013-1676.

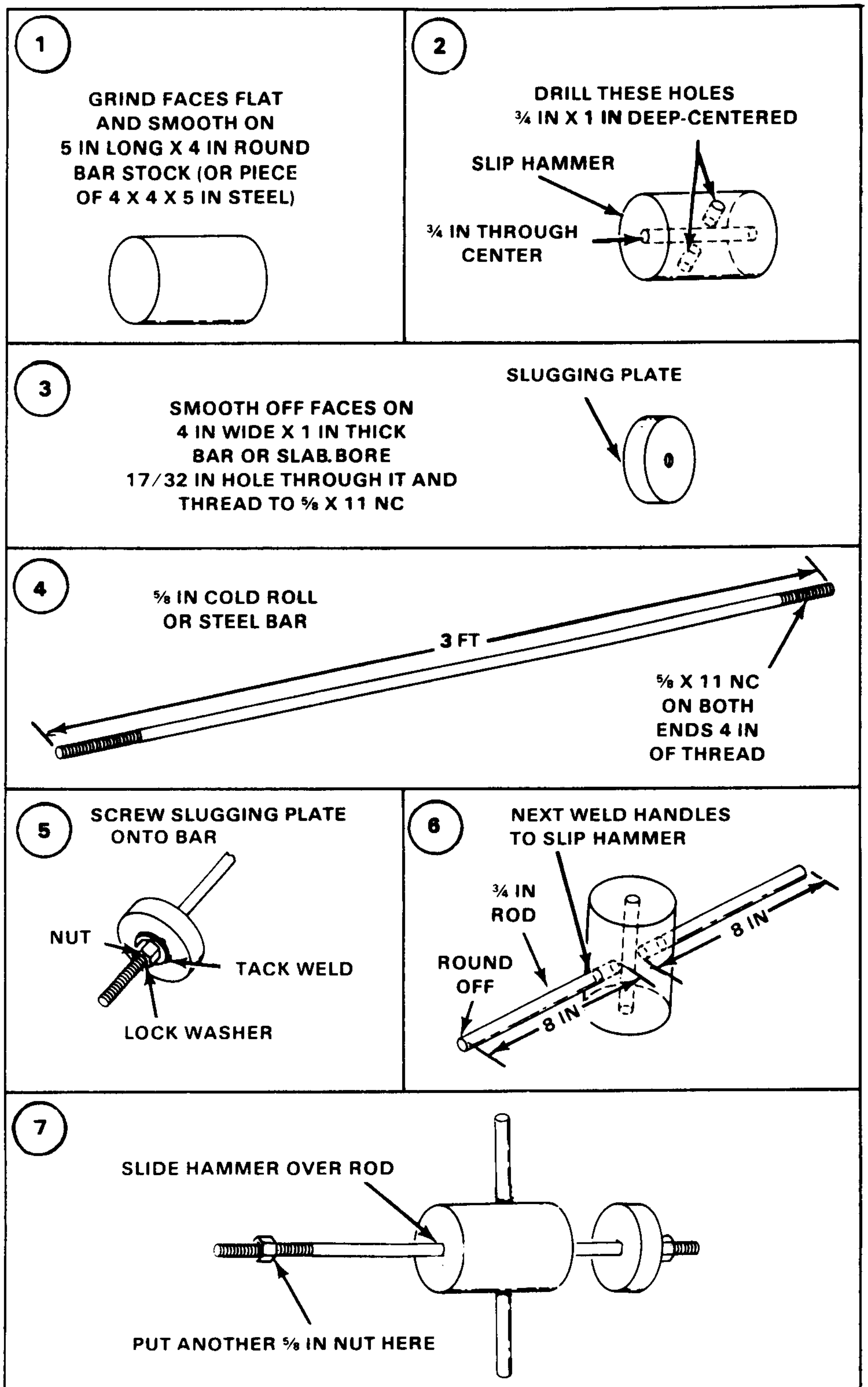
Soils in tropical areas, such as jungles or rain forests, provide good electrical ground for the grounding rod assembly issued with the generator set. Grounding rods are easily installed in these moist soils. The fast buildup of corrosion is a problem in the tropics. To ensure a good electrical path, apply waterproof tape at the connection of the grounding strap and keep the grounding rod clean and dry.

Perform the following checks and services to establish a good grounding system:

Grounding rods.
Remove paint, oil, and grease. Keep the rods clean. Ensure the rods are as straight as possible. Keep the points sharp enough to penetrate the soil.

Grounding straps.
Remove paint, oil, and grease. Keep the straps clean. Ensure the straps and cable are the proper length.

Connections.
Remove paint, corrosion, oil, and grease. Use the proper clamps and connections for the grounding system selected. Tighten the terminal screw and the grounding clamp screws properly.



MAKING A SLIP HAMMER

SELECTING THE GENERATOR SITE

The location of the generator set affects the efficiency of the power system. The individual demands for electric power and the area to be serviced govern the site selected. Generator sets usually are located near the large demands.

The operator must determine where the large demands are located. To do this, the operator studies the map on which the individual demands are plotted. If additional sets are needed for parallel operations, plot them on the map. All the power demands must be plotted on the map before the site is selected and prepared for the generator set.

Place the generator sets near the largest loads. This practice reduces the size of wire cable required, minimizes the line voltage loss, and provides voltage control at the demand end of the line.

Operators should provide shelter for the generator set. Although the equipment is weather-resistant, it needs protection from inclement weather and enemy fire. A revetment type of shelter, described on page 37, provides protection from weather and enemy fire, and it also controls noise levels. Revetment shelters are used for air–cooled generator sets that produce from 0.5 kw through 10 kw of electricity. The shelter should provide ventilation to maintain a reasonable temperature around the generator and allow heated air and exhaust fumes to escape. If the generator set operates in a closed structure, the exhaust gases must be piped outside.

WARNING

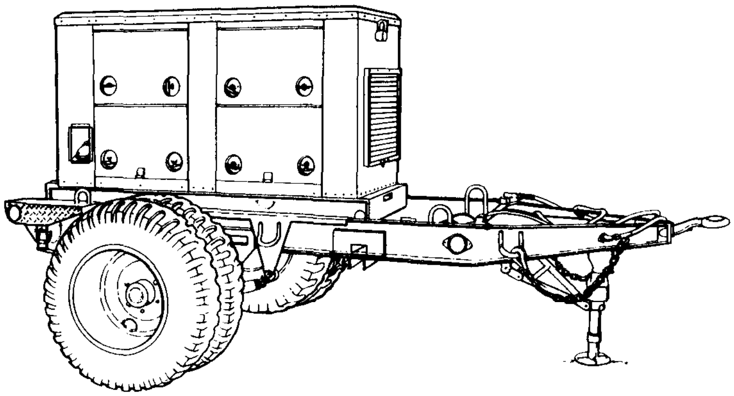
> Never operate an air–cooled, gasoline engine–driven generator set inside a closed building unless forced ventilation can remove the engine heat and exhaust gases outside. Exhaust gases contain carbon monoxide--a poisonous, odorless, and colorless gas.

The pipe used to remove exhaust gases must be installed properly. The pipe should be as short as possible and have no more than one 90-degree bend. Keep combustible materials 6 inches or more from the exhaust pipe. Wrap the pipe with insulation if personnel may touch it accidentally.

Use the following guides to select a site for power generating equipment:

- Provide enough clearance around the generator set to perform maintenance procedures.
- Locate generator sets away from areas where noise may be a problem. Most mobile generator sets produce high noise levels.

- Mount the generator set in an area that is clean, level, dry, well ventilated, and well drained. Use planks, timbers, logs, ammunition boxes, or other material to prevent the skids or frame from sinking into soft earth. Keep the set level, preferably within 5 degrees, for proper lubrication. Never tilt the set more than 15 degrees in any direction. Cargo trucks sometimes are used for mounting generator sets, but more often they are mounted on two–wheeled trailers for greater maneuverability and ease of maintenance. When the set is mounted on a trailer, it is called a power unit.



TRAILER MOUNTED GENERATOR SET

- Mount the generator set on a surface that can support the weight of the equipment.

- Provide a Supply of clean fuel that is sufficient for all requirements planned for the life of the installation. For a long–term installation, consider placing the fuel tanks underground.

- Locate the auxiliary fuel tanks for generator sets that produce less than 10 kw as near the shelter as possible. The bottoms of the tanks must be less than 4 feet below the fuel pump on the installed generator set. The fuel tanks for sets producing 15 kw or more must be located less than 12 feet below the fuel transfer pumps. Connect the fuel line between the auxiliary fuel tank and the fuel selector valve. Ensure no dirt or moisture gets into the fuel lines.

- Enclose auxiliary fuel supply tanks that are above ground with engineer tape to rope off the area. Place NO SMOKING signs at each entrance to the fuel supply area, at least 50 feet from fuel supply and the generator set. If possible, construct a shelter to protect the auxiliary fuel supply from direct sun rays and rain. Install a fire point that includes a fire extinguisher (monobromotric–fluoromethane type), shovel, and pickax.

- Provide adequate shelter for generators that will be in service at one location for a long period of time. Use noncombustible material for the shelter if possible. Allow a clearance of 4 to 6 feet if combustible materials are used. A lean-to, shack, or shed can shelter generating equipment adequately.

- Provide a suitable foundation so the generator set can be bolted to the floor. This will eliminate unnecessary vibrations. Do not use the portable, totally enclosed, and winterized type of generator set in a permanent, indoor installation.

CONSTRUCTING A REVETMENT

Air-cooled, engine-driven generator sets are designed to operate in the open with unrestricted ventilation. However, a revetment may be needed to protect the equipment from extreme weather and enemy attack (figure on page 38).

NOTE: Use revetments only for air-cooled, engine–driven generator sets.

The revetment described in this section is designed to shelter one generator set. Install only one generator set within each revetment. Also, do not place other heat generating equipment in a revetment with a generator set. Anything inside a revetment that creates heat will adversely affect the cooling of the set.

Dimensions

The minimum allowable inside dimensions for a revetment for generator sets rated from 1.5 kw through 10 kw are 7.5 feet long, 5.5 feet wide, and 4.0 feet high. The height includes l.O-foot openings around the top of walls that are 3.0 feet high. The entrance into the revetment should be 2.0 feet wide. The height of the sill at the bottom of the entrance should be 1.0 foot or less.

A revetment with these dimensions is also suitable for generator sets that produce 0.5 kw of electricity. However, to economize, the width and length can be reduced to 4.0 feet and 5.0 feet, respectively.

The above minimum dimensions are based only on engine cooling and ventilation considerations. They allow the minimum space required for servicing and maintaining equipment.

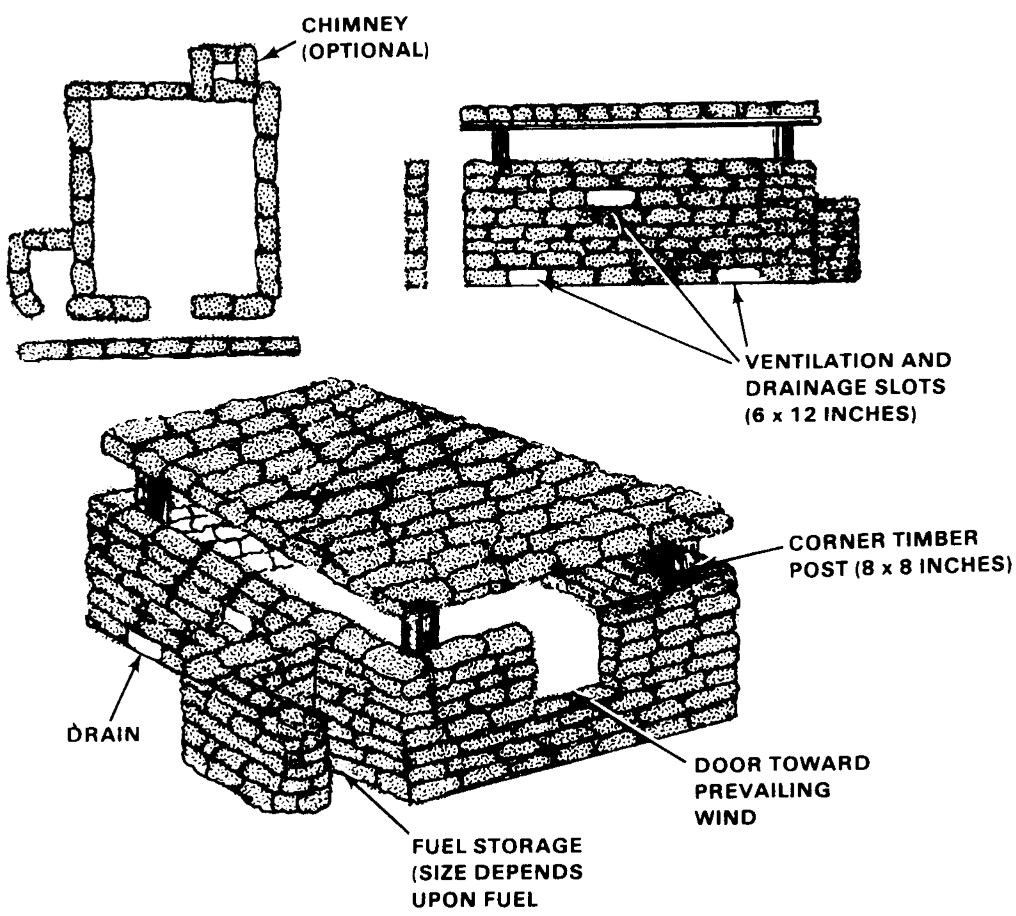
Foundation and Drainage

Generator sets require an adequate foundation. If the generator set is attached to a shipping pallet, the pallet provides an adequate foundation. If the set is not attached to a pallet, use planks, timbers, logs, ammunition boxes, or other materials to prevent the skids of the frame from sinking into soft earth. The foundation must be less than 6 inches high.

A drainage system is required to ensure runoff flows away from the generator set and out of the revetment. Locate all drain holes at the inside ground level. Install a sump and drainage trench for each drain hole if the water does not drain away from the revetment naturally. Locate the sump and drainage trench outside the revetment.

Wall Construction

The walls of the revetment may be constructed with sandbags, ammunition boxes filled with sand or dirt, or any other materials.



REVETMENT CONSTRUCTION

Roof Construction

The roof can be supported by any means possible, but it must be at least 1.0 foot above the wall of the revetment. Allow as much open space between the top of the walls and the roof as possible for ventilation. Roof construction usually consists of two pieces of lumber (4 inches by 4 inches) or logs (4 inches in diameter), about 10 feet long, and enough cross pieces of lumber, logs, or steel planking to cover the entire roof. The cross pieces should be about 8 feet long. If the above materials are not readily available, use any available material.

The amount and type of protection desired determines the thickness of the roof. When adding roof protection, be sure the roof can support the additional weight.

Miscellaneous Construction

Construct a compartment outside the revetment for fuel storage, as shown in the figure on page 38. The size of this storage area depends on the size of the fuel containers. The fuel supply is stored outside the revetment to minimize the hazards associated with fuels at high temperatures. Air temperatures within the revetment increase considerably above the ambient temperature outside when the generator set operates. Some generators are equipped with integral fuel tanks. Do not use the integral fuel tanks in a revetment because of the hazards associated with fuels at high temperatures.

The exhaust from the engine may or may not be ducted out of the revetment. This decision is left to the commander. Install a flexible pipe (chimney) similar to the one shown in the figure at the top of page 60 if the exhaust is ducted outside. If a flexible pipe is not available, use a piece of exhaust pipe or similar material. The point where the exhaust discharges through the revetment wall depends on the type of generator set and exhaust pipe. The exhaust may or may not be discharged into an external exhaust chimney. However, a chimney is preferred because it helps duct the exhaust gases away from the revetment and reduces the noise level.

Construct a revetment doorway shield that is similar to a revetment wall (figure on page 38). The shield is a wall that prevents projectiles and fragments from entering directly into the revetment. The doorway shield must be 3.0 feet high and 7.5 feet long.

Alignment Instructions

When constructing the revetment, align the structure so that the door faces into the direction of the prevailing wind. Install the generator set so its long axis is parallel with the long axis of the revetment. Center the set within the revetment walls. Use the following information to orient the generator set:

ENGINE-DRIVEN GENERATOR SET ORIENTATION

Generator set Output (kw)	Orientation
1.5	Generator end toward the door.
3.0	Engine end toward the door.
4.0	Generator end toward the door.
10.0	Generator end toward the door.