performance requirements, the actual KVA capacity of the generator exceeds the nameplate KVA rating.

Ratings of generators used in diesel engine-driven electric sets range from 15 KW up to almost any size, singly or in combination. Generators as employed in standby or prime power electric sets have voltage ratings from 120 volts, single-phase, to 4800 volts, polyphase. For most lighting and heating loads, a 120/240-volt, 3-wire, single-phase alternator is recommended.

Mixed power and lighting loads are usually served by a 3-phase, 4-wire alternator, with the single-phase loads divided among the three phases and connected line-to-neutral. A typical generator of this type provides 208-volt, 3-phase power for motors and 120-volt, single-phase power for lights. This combination of voltages results when the generator is wound so that each phase produces 120 volts line-to-neutral. Then line-to-line voltage is $\sqrt{3}(120) = 208$ volts.

If voltage drop is not too great in distribution lines between the generator and the power loads, 208 volts may be adequate for serving motors and other equipment nominally rated at 220 volts but capable of operating with as much as 10% undervoltage. If the equipment won't tolerate undervoltage, or if long distribution lines drop the voltage too much, higher-voltage 3-phase, 4-wire machines are available with ratings such as 127/220 or 139/240. In any of the foregoing arrangements, the single-phase loads should be balanced as much as possible between the three phases.

Where most of the load consists of motors, and the lighting load is small, it can be served by a 240-volt, 3-phase, 3-wire generator, with the lights being supplied from the individual phases through step-down transformers.

Of course, some industrial plants are served by higher voltages such as 2400 or 4800 volts, with distribution at an intermediate voltage such as 480 volts. Generators are available for any of these voltages. Normally a standby electric set is connected on the secondary side of the normal-source transformer and produces the voltage required for internal distribution.

Most generators have a range of voltage adjustment whereby the actual voltage produced may be adjusted to the requirements of the application. Thus voltage may be adjusted to compensate for line drop so that the voltage at the load circuit breaker is the same whether furnished by the utility service or by the standby electric set. The voltage also may be adjusted if load requirements change in the future. Some generators have a "broad range" voltage, providing a greater range of adjustment. Thus, a broad-range generator might offer an adjustment range of 208-240 volts while the range of another generator would be 208-220 volts.

Many generators are wound in such a way that each phase has two windings that may be connected either in series or in parallel. A generator with its stator windings connected in series produces twice as much voltage as one connected in parallel. For example, the windings could be connected in series to produce 480 volts line-to-line or in parallel to produce 240 volts line-to-line. A machine with such dual windings is called a selective-voltage generator. Ordinarily, this does not mean that the user has the choice of two voltages. Actually, for the usual standby or prime power application, the windings are permanently connected to produce the specified voltage.

However, there are applications where the ability to select from two voltages is useful. These include portable electric sets, rented units, military and public utility applications. For these applications, the electric set can be equipped with a switch that permits changing from series to parallel connections. The switch should be of the type that can be locked in position before the generator is connected to the load. There would be no reason to specify this selective-voltage capability in the usual electric-set application.

Effect of Power Factor

The industry standard is to design alternators for 0.8 power factor loads. However, in some applications the load may have a lower power factor, and this raises the question of whether the load should be modified to raise its power factor or the electric set should be designed to accommodate the lower power factor. Good commercial practice indicates that modifying the load to correct power factor is the most economical procedure. If the power factor is lagging (the usual case), it can be raised by adding capacitance to the circuit--for example, substituting a synchronous motor for an induction motor or adding shunt capacitors.

Low power factor is detrimental to a generator and will reduce generator life unless a generator with excess KVA capacity or special winding insulation is specified. When P.F. is less than 1, there is a reactive current component that flows between the generator and the load and adds additional heat to the generator windings. Reactive current is caused by the inherent reactance of some electrical devices, such as motors and induction equipment. Although the reactive current does not represent usable power, the extra heat it develops reduces generator efficiency.

Power factor normally does not affect the size of the engine driving the generator. The engine load is based primarily on the KW output of the generator. However, low power factor reduces generator efficiency and thus adds somewhat to the required HP per KW. In some cases, this could require a jump to the next size of engine.

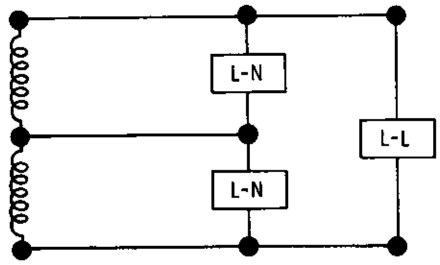


Figure 3-7.1. Single-Phase, 3-Wire Generator Connections

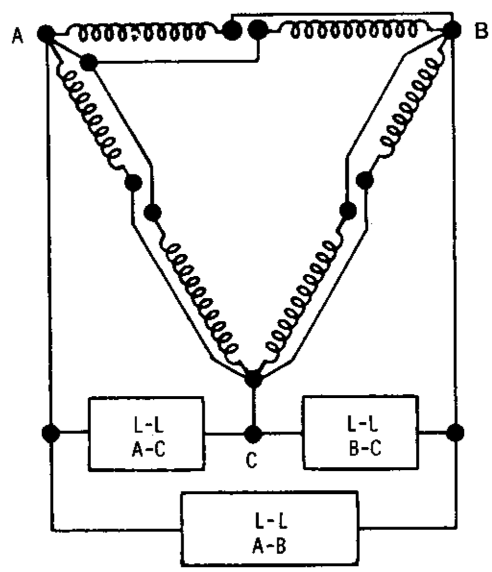


Figure 3-7.2. Parallel-Delta Connected, Line-to-Line, 120-138.5 V.

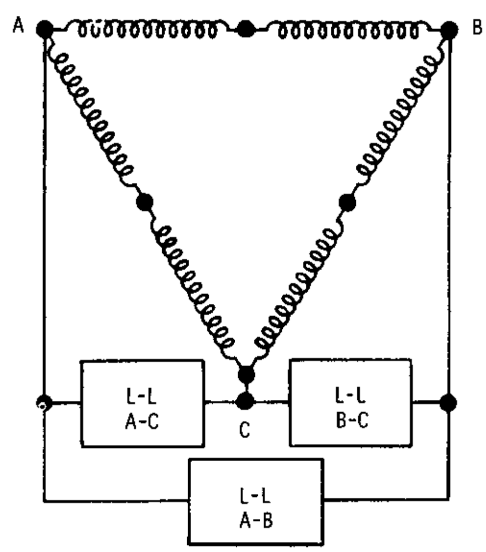


Figure 3-7.3. Series-Delta Connected, Line-to-Line, 240-277 V.

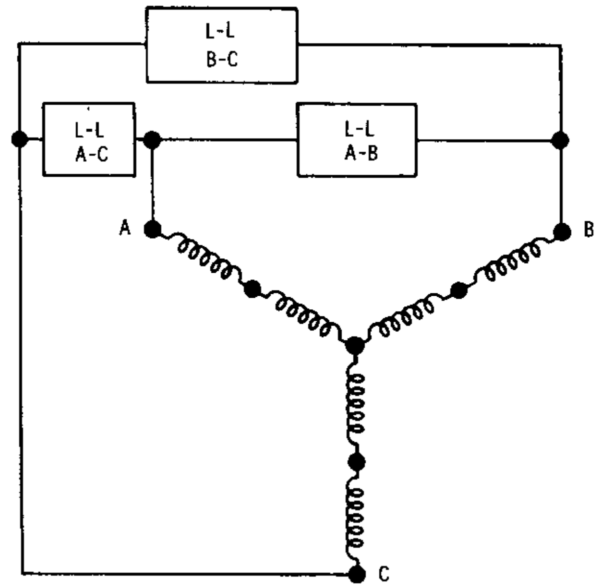


Figure 3-7.4. Series Connected, Line-to-Line, 416-480 V.

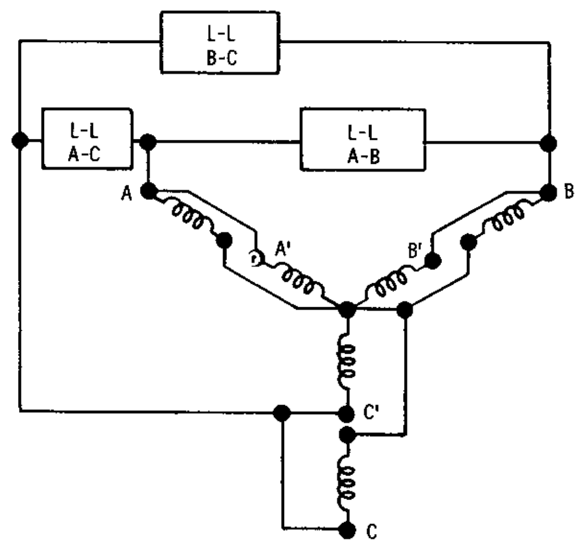


Figure 3-7.5. Parallel Connected, Line-to-Line, 208-240 V.

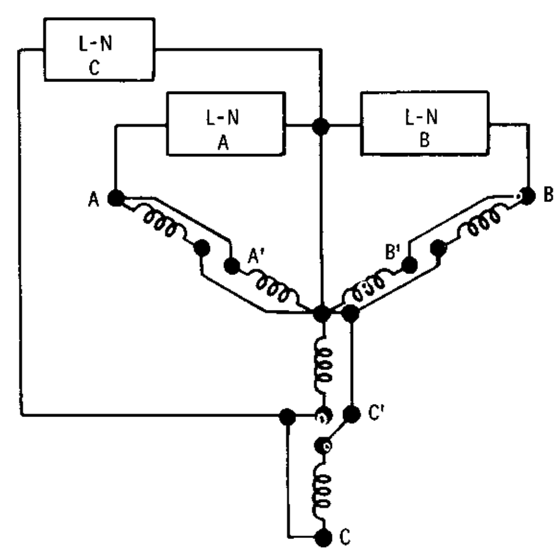


Figure 3-7.6. Parallel Connected, Line-to-Neutral, 120-138.5 V.

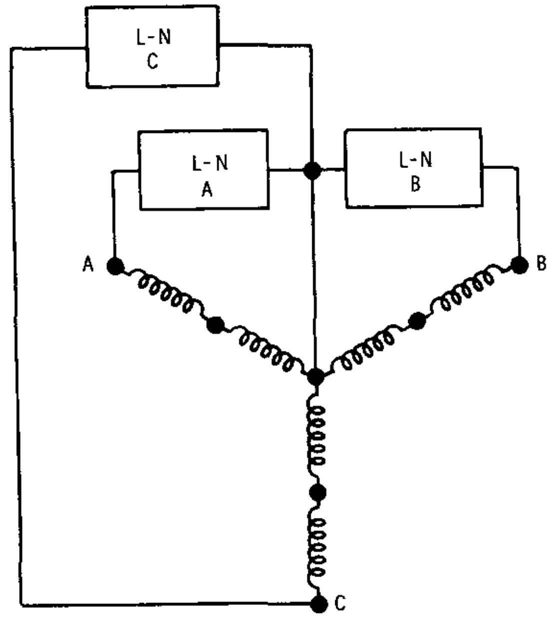


Figure 3-7.7. Series Connected, Line-to-Neutral, 240-277 V.

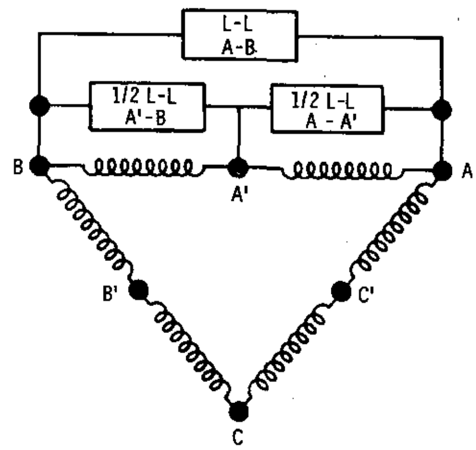


Figure 3-7.8. Delta Connected

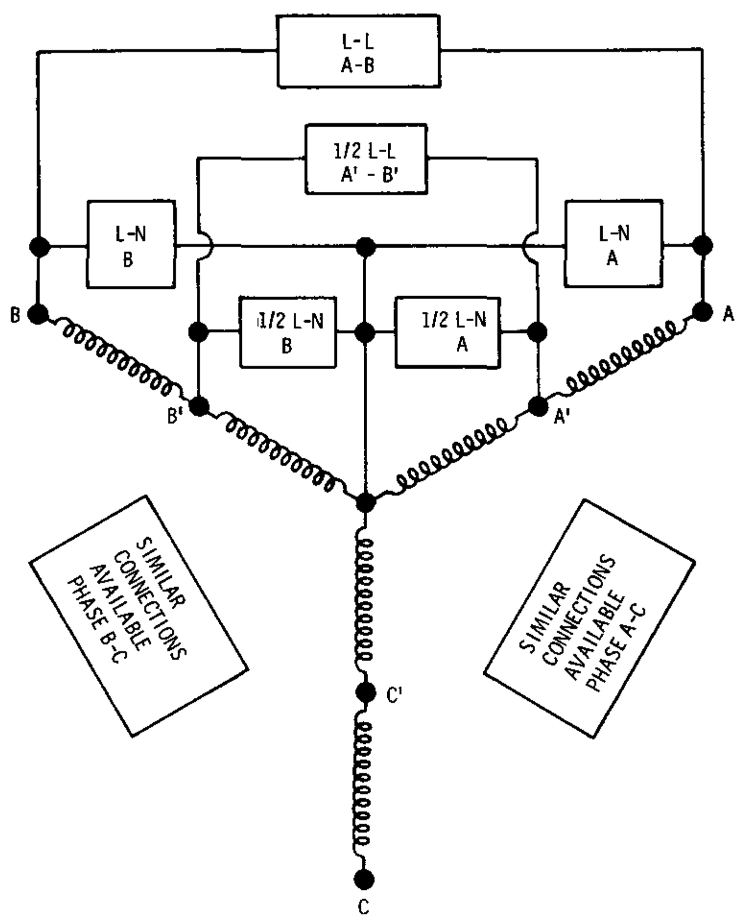


Figure 3-7.9. Wye Connected

Determining Power Factor

For existing installations, power factor can be measured by a power factor meter or can be calculated from the readings of a voltmeter, ammeter and wattmeter. It also can be determined by use of a 3-phase wattmeter, or two single-phase wattmeters, or a wattmeter and a KVAR meter, or a watthour meter and an ammeter. Recording meters are preferable to indicating meters.

For a new installation, full-load power factor can be calculated by totalling both KW and KVA for all elements of the load. Divide the total KW by the total KVA to obtain power factor.

Temperature Rise

Current flowing in the windings of a generator raises the temperature of the windings. Over a period of time, the heat tends to break down the winding insulation. Generators built to N.E.M.A. standards have an insulation design life of 30,000 hours based on continuous-duty rating. Operation of a generator at current levels above rated values accelerates winding insulation degradation.

The temperature shown on the generator nameplate is not the actual winding temperature but is a "temperature rise", which is the difference between the ambient temperature and the average temperature in the windings after the generator has warmed up and its temperatures have stabilized while operating at rated load and power factor. The winding temperature is the sum of the room air temperature and the temperature rise. As long as the room air temperature does not exceed a specified nominal value (usually 40°C), the total temperature will not exceed the limit for the class of insulation used in the generator windings, and the design life of the insulation will be achieved.

If the air is cooler than 40°C, a greater temperature rise can be tolerated, which means that greater power could be generated without shortening insulation life; or, conversely, a smaller generator might be used for the same load. If the ambient temperature is higher or if operating conditions tend to generate more heat (for example, low power factor), then the power output must be reduced, or a larger generator must be used, or the generator windings must have a better class of insulation.

The nominal 40°C ambient temperature refers to room air in the vicinity of the generator. After the electric set starts, radiation from engine and generator will raise the room temperature until it stabilizes at some level that depends on outdoor temperature and the capacity of the room ventilating system. This room temperature should be calculated for the worst condition—i.e., electric set operating at peak load and maximum anticipated outdoor temperature. The calculated room temperature should be included in the Specification as a guide for the electric set manufacturer, especially if it exceeds 40°C.

N.E.M.A. or A.B.S. temperature rise standards are based on continuous-duty service with a life expectancy of 30,000 hours. Standby ratings are based on operation for a few days or hours at well spaced intervals. Under these conditions, restricting temperature rise of a standby generator to continuous-duty levels would provide an unrealistically long life expectancy. By accepting an increase of temperature rise, the standby generator can be rated to deliver more KVA than continuous-duty machines. Accordingly, generator ratings for standby service are based on a greater temperature rise, typically 25°C greater than N.E.M.A. standards for continuous-duty service. Of course, a generator should not be operated at its standby rating in continuous-duty service.

Class of insulation should not be specified. Rather, specify load, type of duty (standby, prime power, continuous, etc.), maximum ambient temperature, altitude, and power factor. Include information on climate or environment, if unusual. A better class of insulation may permit a smaller generator to be used. The generator manufacturer can determine the most economical trade-off between generator size and class of insulation.

Required Generator Capacity

Basically, the generator must have enough KVA capacity to serve the peak KW load at the load power factor. In some cases, a 3-phase generator may need additional capacity to serve the peak load because of the way loads are connected to the phases. The capacity then would be based on an "equivalent total 3-phase load."

Motor starting can affect the required generator capacity in two ways. Depending on whether motors might start near the peak demand period of the day, the extra KW drawn by motors when starting could make the peak demand greater than the maximum steady load. The other effect is that the extra current draw, when a motor is started, causes a momentary dip in generator voltage; and thus the generator must have enough KVA capacity to start the largest motor without excessive voltage dip. Where large motors are started across the line, this effect can actually be the controlling factor in establishing required generator capacity.

The generator size based on peak load is compared with the size of generator required to avoid excessive voltage dip, and whichever is larger becomes the required generator KVA capacity.

Capacity Based on Peak Load

The total connected load is a summation of all loads connected to the generator. It may be the total building load, or it may be a separate emergency or critical circuit. The maximum steady load is a summation of all the loads that will operate simultaneously during the maximum demand period. Thus, if all connected loads will operate simultaneously at some period, the maximum steady load is equal to the total connected load. However, if there are never periods when all loads are operating at full power, the maximum steady load is less than the total connected load.

The peak load may be the maximum steady load or it may be the steady load plus the extra KW drawn by motors when starting if the motors actually will start at or near the peak demand period of the day. The peak load can be determined in an existing building by measuring the demand over a period of time. Where this is not possible (as in a new installation), peak load can be estimated by totalling all of the loads connected to the electric set and multiplying by a demand factor or diversity factor that represents the maximum proportion of the total connected load that ever will be operating at one time.

Of course, if demand is measured by a demand meter, any effect that motor starting KW may have in increasing the peak demand will automatically be included in the recording. But, if demand is estimated, it must be determined whether starting loads add to the maximum steady load.

If the generator is serving both single-phase and 3-phase loads, the single-phase loads should be distributed as nearly equal as possible among the three phases. If it is not possible to divide the single-phase loads equally, causing one phase to carry extra load, the generator must be sized as if all phases were carrying as much load as the most heavily loaded phase. Otherwise, one phase would be overloaded. Since the distribution of loads probably varies throughout the day, the demand profile should be examined to see if there is ever a load condition in which the total load on one phase is more than one-third of the peak load.

Capacity Based on Voltage Dip Limits

Where quality of lighting is important, or where critical equipment is in operation--in hospitals, laboratories or radio stations, for example--voltage dips must be limited. Industrial plants, warehouses, gas stations and other places where customers or workers are not as concerned with lighting quality can accept much larger voltage dips.

Most industrial equipment can tolerate large voltage dips (up to 35% in some cases) as long as the dip does not cause motor contactors to drop out or automatic brakes to set. However, some machines, such as seam welders, will not operate properly if voltage fluctuations on the line exceed 5%. In addition, while many machines may not be affected by large voltage dips, the controls or instruments for those machines may be.

When a motor starts, there is a current inrush. Not being an infinite bus, an electric-set generator cannot supply this current inrush without a momentary voltage fall-off while voltage regulator is reacting to increase excitation and reestablish the voltage level. The magnitude and duration of the voltage dip depends on the size of the motor and its inrush KVA, the KVA capacity of the generator, the performance characteristics of the voltage regulator and generator, and the amount of load already on the line.

Table 3-8 shows running KW and KVA and inrush KVA for a range of motor sizes. The inrush KVA shown are typical of N.E.M.A. designs B, C and D, which are the types of motors commonly used. Motor nameplates usually include a "starting code" letter (A, B, C, etc.) which denotes a starting current classification and is unrelated to N.E.M.A. design letter designations. The starting code denotes an average starting KVA/HP as shown in Table 3-9. The inrush KVA of either Table 3-8 or 3-9 assume full-voltage, across-the-line starting. The inrush KVA shown in Table 3-8 normally is applicable, but in some cases the starting code letter shown on the motor nameplate will denote a higher starting KVA/HP. In the latter case, the starting KVA/HP from Table 3-9 should be multiplied by the motor's horsepower rating to determine the inrush KVA.

Detroit Diesel Allison Distributors can supply performance data or curves relating required generator KVA capacity to motor horsepower and inrush KVA for different voltage dip limits. There are different sets of data, ranging from one for a generator equipped with a voltage regulator of normal performance to those for generators equipped with voltage regulators having extra features that enable them to respond more quickly to load transients.

Economy dictates examining the "normal performance" data first. Using the horsepower rating of the largest motor or its inrush KVA from Table 3-8 or 3-9, and knowing the maximum temporary voltage dip that is acceptable in the circuit, the required generator KVA capacity can be selected. If this does not exceed the KVA capacity previously determined for the peak load, then the required generator size will be that determined by the peak load. However, if the KVA established by the voltage dip limit exceeds that required for the peak load, a new KVA should be selected from a "higher performance" set of data for a generator and regulator having better transient response. Then it becomes a matter of economic comparison between the larger, normal-performance generator and the smaller generator with a more expensive, better-performance voltage regulator.

In the foregoing procedure, the maximum motor starting condition must be examined. Usually this means starting of the largest motor unless it is possible for two or more motors to start together. In the case of starting the largest motor alone, either its horsepower rating or inrush KVA may be used along with the appropriate generator performance data to determine required generator KVA capacity. In the case of starting two or more motors together, the sum of their inrush KVA must be used. If a motor will start with other load on the line, then a new factor is introduced that increases required KVA capacity. Detroit Diesel Allison Distributors provide data that relate a correction factor to the amount of load on the line when the largest motor is started. This factor is multiplied by the inrush KVA of the motor, and the corrected inrush KVA is used to establish the required generator KVA capacity.

The foregoing procedure can be followed to determine the size of generator required. Or specify motor ratings, starting conditions, and voltage dip limit, and the supplier will determine the most economical generator and voltage regulator that will meet the performance requirements.

Reducing Generator Size

When the generator KVA capacity established by the peak load is not adequate to meet the voltage dip requirement, the choice is either a larger generator or employing means to limit the size of generator required. One method is to add features to the voltage regulator (such as field forcing) that cause it to respond more promptly to load transients. Prompt and substantial increase in field excitation reduces the voltage dip and keeps it within the specified limit. Thus, a generator capacity equal to the peak load requirement or only slightly larger may achieve the transient performance required.

Another method of limiting the size of generator is to find ways to lessen the effects of motor starting. The large motors could have reduced-voltage starting, or they could be powered by motor-generator sets to cushion load changes. The loads could be divided between two electric sets, one for motors and one for loads that can't abide severe voltage dips. Thus isolated, the critical load would not be affected by motor starting.

The cost of such measures should be weighed against the cost of a larger generator having the excess KVA capacity necessary to minimize voltage dip when these measures are not employed. Not only first cost, but operating cost and maintenance should be considered. A generator with much excess capacity for motor starting will be lightly loaded during normal steady operation and therefore will not operate at maximum efficiency. A generator matched to its load, without excess capacity, and with appropriate controls and voltage regulation, makes a compact, efficient package.

Along with voltage dip, another factor that must be considered is the voltage recovery characteristic after the dip. Voltage recovery is affected by the extent of the dip and by the amount of load already on the line. If a motor is started under load, and there already is a large amount of electrical load on the line, the voltage may not recover fast enough after the initial dip to accelerate the motor in sufficient time to prevent drop-out of the starting contacts as a result of the overcurrent. Detroit Diesel Allison Distributors will furnish data that relate voltage recovery characteristics to voltage dip and the amount of other load already on the line.

Methods of overcoming a voltage-recovery problem include starting the motor unloaded or using reduced-voltage starting. Another method is to keep other loads off the line until the largest motor is started. Also, avoid a situation in which a large number of motors automatically start simultaneously when the generator picks up the load. For example, when a standby electric set starts after a power failure, motors equipped with hands-off-automatic magnetic starters, if in the automatic position, would all demand power as soon as the standby generator is connected to the load bus. One way of avoiding simultaneous motor starting is to equip motors with start-stop pushbutton magnetic starters so they will have to be restarted manually. Another way is to employ automatic sequencing to restart motors in a selected order. This may be achieved by time-delay relays or by a scanning device, or interlocks may be incorporated in the motor starting circuits so that the motors can be started only in a certain sequence, with the largest motor being started first.

Generator Efficiency

An electric generator is an exceedingly efficient energy converter, especially in larger sizes. Efficiency of 3-phase alternators may range from 90% for a 100 KW size to 94 or 95% for alternators with capacities of several hundred kilowatts. These are average efficiencies and manufacturing tolerances will cause a slight variation from one generator to another. When sizes go below 100 KW, efficiencies rapidly drop below 90%. Single-phase generators are 3 to 5% less efficient than 3-phase machines.

Load and operating conditions affect generator efficiency. Nominal efficiency as stated for a particular generator normally applies to operation at rated capacity. At lower output, the generator's efficiency is less. This difference might be important in the case of a generator with extra KVA capacity to accommodate motor starting without excessive voltage dip. Even when the electric set is serving the peak load, the generator is not using its full capacity. So it is not operating at maximum efficiency.

At lower power factor, the generator is less efficient. For example, assume a generator has a full-load efficiency of 92% when the power factor is 1.0. If this

Table 3-8. Motor Starting Inrush KVA

Three-Phase Motors

HP	RUNNING LOAD					STARTING INRUSH KVA
	KW	KVA	AMPERES			N.E.M.A DESIGN B-C or D
			208V	220V	440V	
1	.9	1.22	3.4	3.2	1.6	9.1
1.5	1.4	1.75	4.9	4.6	2.3	13.3
2	1.8	2.3	6.4	6.0	3.0	17.2
3	2.6	3.3	9.2	8.7	4.4	23
5	4.4	5.4	14.9	14.1	7.1	34
7.5	6.6	7.8	21.7	20.5	10.3	46
10	8.8	10.2	28.4	26.8	13.4	57
15	13.0	14.9	41.2	39	19.5	84
20	17.2	19.5	54	51	25.5	110
25	21.2	24	67	63	31.5	139
30	25.1	27.5	79	75	37.5	166
40	33.5	38	106	100	50	221
50	42	46.5	129	122	61	276
60	50	55	154	145	73	331
75	62	69	190	180	90	414
100	83	90	250	236	118	552
125	104	111	308	292	146	691
150	123	133	368	348	174	826
200	164	175	486	460	230	1105

Single-Phase Motors

RUNNING LOAD					STARTING INRUSH KVA
HP	KW	KVA	AMPERES		
			115 V	230 V	
1/4	.29	.53	4.6	2.3	3.45
1/3	.45	.75	6.5	3.25	4.15
1/2	.60	.92	8.0	4.0	5.75
3/4	.86	1.32	11.5	5.75	7.0
1	1.05	2.1	18.0	9.0	11.5

RUNNING LOAD					STARTING INRUSH KVA
HP	KW	KVA	AMPERES		
			115 V	230 V	
1.5	1.57	2.1	18.0	9.0	11.5
2	2.05	2.55	22.2	11.1	15
3	3.1	3.7	32.0	16.0	20.7
5	4.6	5.1	43.0	21.5	31.0
7.5	7.0	7.8	68.0	34.0	46.0

NOTE

DATA IN THESE TABLES ARE THE MOTOR LOADS AS "SEEN" BY THE GENERATOR AND INCLUDE COMPUTATIONS OF MOTOR EFFICIENCY AND POWER FACTOR.

Table 3-9. Motor Starting Code Inrush KVA/HP

Code Letter	Starting kVA/hp
A	.10– 3.14
B	3.15– 3.54
C	3.55– 3.99
D	4.00– 4.49
E	4.50– 4.99
F	5.00– 5.59
G	5.60– 6.29
H	6.30– 7.09
J	7.1 – 7.99
K	8.0 – 8.99
L	9.0 – 9.99
M	10.0 –11.19
N	11.2 –12.49
P	12.5 –13.99
R	14.0 and up

generator is serving a 0.8 P.F. load, the generator efficiency is only 90% for a typical generator.

Losses in a generator include I^2R losses of stator and rotor coils, core losses, and stray-load losses such as eddy currents or nonuniform distribution of current in the armature. Other losses are in the exciter, field rheostat, bearing friction and windage. Brush friction and contact losses are extra losses in D.C. generators. Friction, windage and core losses are constant and thus their proportion is greater at low load. The others increase with load, and field losses are also affected by power factor. In large high-speed alternators, of the size used in utility power plants, windage losses are so large a proportion of the total that it is beneficial to reduce them by using hydrogen for cooling in an enclosed housing. Efficiencies of hydrogen-cooled generators exceed 98%.

Phase Sequence

A.C. cycling in a 3-phase system occurs in a phase rotation or sequence with peaks and valleys of one phase following another phase at 120° intervals, as shown in Fig. 3-10(c). A motor rotates in the correct direction if its three phase leads are connected to the bus in the correct sequence.

The standby generator must be connected to the load bus with its phases in the same sequence as the utility power. After leads are connected to the generator, the phase sequence must be checked before connecting the generator to the load. Usually correct sequence will be achieved by identifying the leads and connecting terminal No. 1 at the transfer switch to No. 1 at the generator, etc. The phase rotation then should be checked at the transfer switch by means of a phase-sequence indicator. If the phase rotation is shown to be in the wrong direction, it can be corrected by interchanging two leads, either at the generator or at the transfer switch (not at both).

Electric sets cannot operate in parallel if their phase rotations are not the same. If the circuit breakers are equipped with short-circuit protection, they will kick out if an attempt is made to parallel one electric set with another having opposite phase rotation.

Telephone Influence Factor

When a power and a communication circuit are in proximity, the power circuit may produce extraneous voltages and currents in the communication circuit. These effects could be hazardous to persons and may damage apparatus or interfere with service. Communication circuits are usually equipped with protective devices to avoid the hazards or damage that might result from conductive or inductive effects.

A telephone circuit traversing the electric and magnetic fields associated with a power circuit will produce extraneous currents in all connected telephone receivers. These extraneous currents interfere with telephone transmission if they are in the noise-frequency range and if large enough in comparison with normal voice currents. The frequencies encountered are the incidental or harmonic frequencies produced by reluctance changes due to poles and slots in rotating machines, by saturation in magnetic circuits, and by cyclic circuit changes in rectifiers and commutating machines.

There are many factors that influence the interference effect in telephone reception. These include the many harmonic frequencies that may be present, coupling between power and telephone circuits, frequency-response characteristic of the telephone circuit and receiver, and perceptivity of the human ear. To find a single factor by which the severity of interference may be defined, frequency-weighting curves have been established. These are called T.I.F. curves, where T.I.F. means Telephone Influence Factor.

T.I.F. factors for generators or motors are of two kinds, balanced and residual component. Only the balanced T.I.F. is of concern if the generator supplies a 3-wire system and its neutral is not grounded. Both the balanced T.I.F. and the residual-component T.I.F. may be of concern if the generator supplies a four-wire system or its neutral is grounded.

Meters are available for measuring the telephone influence factor of both voltage and current waves. A voltage T.I.F. reading is the ratio of the current in the

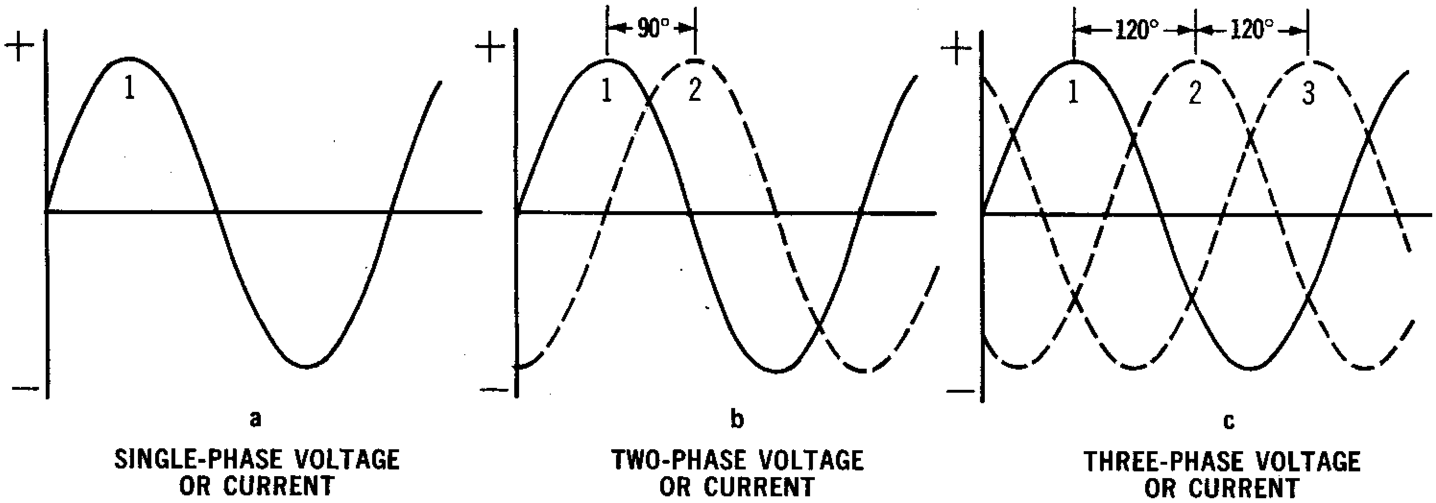


Figure 3-10. Comparison of Single-Phase and Multi-Phase Alternating Current

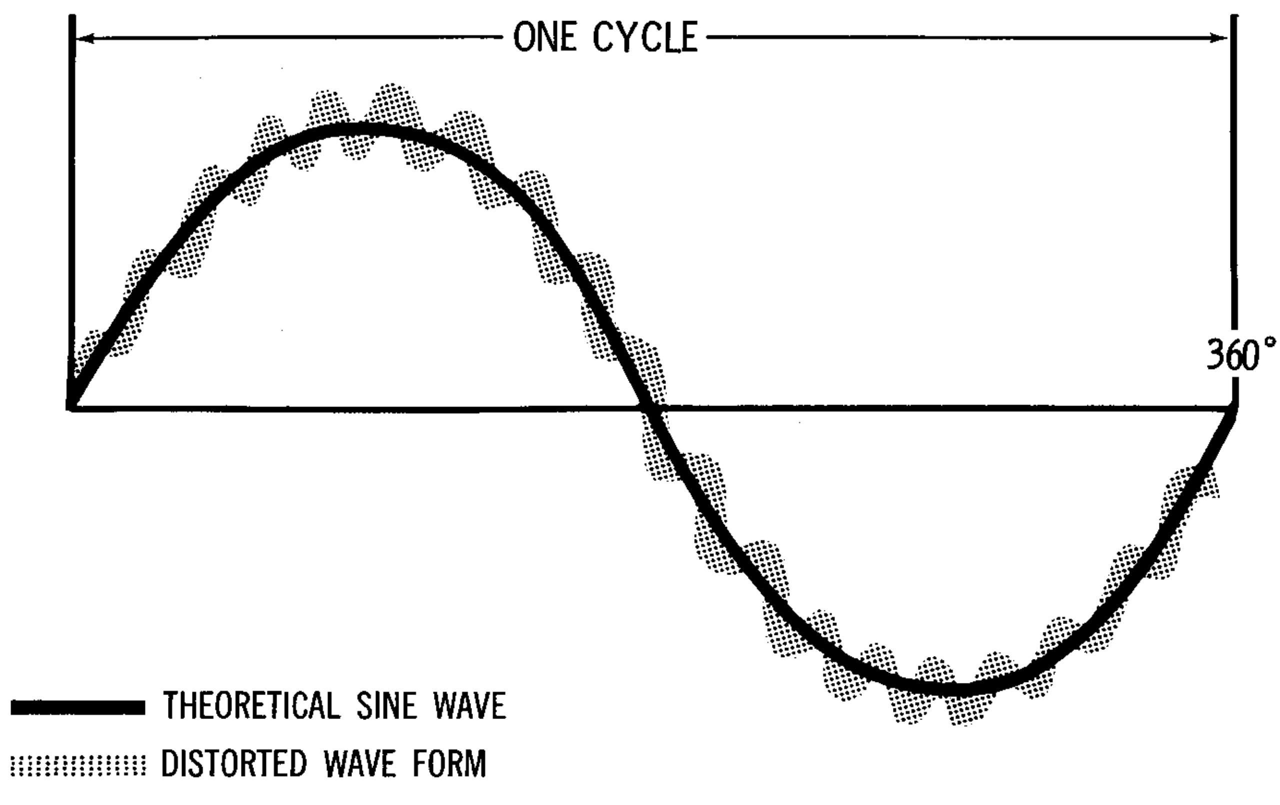


Figure 3-11. Wave Form Distortion (Exaggerated)

metering element in microamperes to the rms value of the voltage being measured. For a current T.I.F. measurement, the drop across a 1-millihenry inductance in series with the current being measured is impressed on the meter; and the reading is the ratio of the current in the metering element in microamperes to the rms value of the current wave.

Transformers usually are used to reduce the voltages and currents to magnitudes suitable for T.I.F. meters. Different connections to a generator are made for reading balanced T.I.F. and residual-component T.I.F.

On commercial power systems of either the 3-phase or the single-phase midpoint-grounded types, the terms balanced voltages or currents refer to those confined to the line conductors and the terms residual voltages or currents refer to those associated with ground. The coupling factors between the power circuits and the communication circuit may be as high as 50 times as great for residual votages and currents as for balanced voltages and currents. If a circuit is unbalanced, flow of current through unbalanced series impedances produces unbalanced voltages which include a zero-sequence component that may have a much greater induction effect because of the greater coupling inherent in the residual or zero-sequence paths. Therefore it is desirable to rearrange the system to balance it, such as transposing circuit conductors at intervals. This is common practice in telephone lines to avoid crosstalk.

N.E.M.A. standard values of voltage T.I.F. for synchronous machines range from 350 for 60 hz machines smaller than 300 KVA to 70 for machines of 20,000 KVA or larger. These are balanced T.I.F. for line-to-line terminals. Where difficult exposure conditions exist, and where a grounded-neutral machine is to be used, it is recommended that the cost of two different generator or motor specifications be compared: one guaranteed to meet N.E.M.A. standards for balanced T.I.F., and one guaranteed to have a residual-component T.I.F. not to exceed 2.5. Special filters or resonant shunts for the few cases of trouble may provide a more economical solution than having all machines with low T.I.F. values.

Wave-Shape Deviation Factor

The wave-shape characteristics of power systems are influenced principally by the harmonics generated in synchronous machines and converting apparatus and by exciting currents in transformers. The principal sources of harmonics in a synchronous machine are the field form, the variation in reluctance caused by slots, saturation in main circuits and leakage paths, and damper windings which may be unsymmetrically spaced.

There are different techniques used in generators and other synchronous machines to control harmonics. These include shaping of pole pieces, enlarged air gap, partly closed slots, skewing of poles or slots, number of slots per phase per pole, chording of the windings and fractional-slot windings. Of these, the most practical usually have been selecting a suitable ratio of slot opening to air-gap length and avoiding certain numbers of slots per pole per phase.

The wave-shape requirement of synchronous machines is defined in the A.I.E.E. standards in two ways, namely, deviation factor and telephone influence factor. The deviation factor is obtained from the magnitude-time curve of the machine no-load normal voltage wave and a sinusoidal wave of the same rms value, the two curves being adjusted so as to give the minimum maximum deviation. the A.S.A. Standards C-50 call for a maximum permissible deviation of 10 percent.

In addition to the normal distortion of wave form produced by a combination of the generator and the load, the use of a static regulator or static exciter-regulator will usually add to the wave-shape distortion. The rapid turn-on time of a series SCR-type regulator introduces a noticeable distortion. Whenever any SCR in series with the generator windings turns on, current flows through the SCR and the inductance of the generator winding coupled with the high rate of rise of current through the SCR causes a resultant L(di/dt) voltage notch to appear on the generator wave shape. The notch is not a single excursion but is composed of very high frequencies in the megacycle range which damp out in a few cycles. It is this notch that gives rise to some of the RFI problems associated with SCR regulators and exciters.

For most applications, this small added distortion is of no importance. However, for some applications, such as computer or transmitter power supplies, the high frequency present in the notch may pass through the load filters and cause erratic operation of the equipment. For such applications, special suppression in the voltage regulator should be specified.

Voltage Regulator

Generator voltage could be regulated manually by controlling a rheostat in the exciter field circuit but this is rarely practical because of widely fluctuating loads. Therefore, an electric set normally incorporates a voltage regulator that controls voltage automatically. The voltage regulator holds the generator output voltage at its rated value within a specified narrow range; and, when load transients cause a change of voltage, it acts to return the voltage to this range as quickly as possible.

While mechanical regulators are sometimes used, the quality of voltage necessary for the loads served by an electric set usually requires a static voltage regulator of the transistorized or controlled-rectifier type. The following text applies to static types of regulators.

A voltage regulator employs an error-sensing circuit that compares the generator terminal voltage, either directly or indirectly, with a reference voltage and uses the error signal to control the excitation level of the generator. The regulator holds generator voltage at any desired level within the limits of the generator-exciter design capability.

When field excitation of the generator is provided by a rotating exciter, the voltage regulator operates indirectly by controlling current in the field of the exciter instead of the field of the generator itself. The voltage regulator senses generator voltage and regulates the flow of rectified current to the field of the exciter. When there is a sudden increase in load, for example, causing a drop in generator output voltage, the regulator senses this change and boosts the exciter field current to a high level for quick recovery. The resulting increased exciter output strengthens the generator field and thus raises generator output voltage. As the generator voltage rises toward normal, the regulator cuts back the exciter to minimize voltage "overshoot."

A voltage regulator may be sensitive not only to voltage but also to current output of the generator. Under large load transients, when there is a rush of current through the generator leads, a large current is automatically induced in the exciter field, greatly increasing its output to combat the voltage dip of the generator. This effect, called field forcing, speeds voltage recovery.

When field excitation of the generator is provided by a static exciter, the generator output is sensed, rectified and amplified to supply D.C. directly to the generator field through slip rings.

All voltage regulators include a voltage adjusting rheostat for manual setting of the desired voltage range.

Voltage Stability and Regulation

A generator equippped with an automatic voltage regulator maintains approximately constant voltage at any steady load, but the voltage may vary slightly above and below the average. This slight variation is referred to as voltage stability or modulation and is usually stated as a plus-or-minus percentage of rated voltage.

For most generator-regulator systems, the average voltage is not the same at one steady load as at another. Usually voltage droops with load, being higher at light loads and lower at heavy loads. However, some regulators increase voltage with load. The difference in voltage from one steady load to another is referred to as regulation. Specifically, regulation is defined as the difference between the average steady voltage at no load and at full load. It is usually expressed as a percentage of rated voltage.

Typical regulation and stability limits are shown in Table 4-1. Regulation of 4% is adequate for many installations and can be achieved with some mechanical regulators and "economy model" static regulators. Extremely tight regulation, on the order of 1% or 1.5%, is provided by the most expensive static voltage regulators and is required where the load includes electronic equipment, lighting, or instrumentation which becomes inefficient or shortlived if voltage is below or above normal. Generator-regulator systems commonly have a stability of ±2%, and ±0.5% may be provided by the most sensitive regulators.

Voltage Dip and Recovery

Sudden load change causes a momentary voltage deviation. The voltage then recovers and settles out near its former level. The momentary dip or rise as load is applied or removed often must be limited to avoid light flicker or malfunction of sensitive equipment. Both the magnitude of the deviation and the recovery time may be of concern. As shown in Table 4-1, voltage dip limit is usually expressed as a percentage of rated voltage, and recovery time is stated as the time in seconds to recover to and remain within a specified steady-state band.

The most severe voltage dip condition usually occurs when a large amount of low-power-factor load is suddenly applied. An example would be the starting of a large induction motor. A generator with adequate capacity will respond to the large current requirement during motor starting without permitting excessive voltage dip. A high-performance voltage regulator, by responding quickly, limits the magnitude of the dip as well as shortening recovery time.

A typical voltage response to a step load application is illustrated in Figure 4-2. The voltage dips abruptly, rises again under the influence of the voltage regulator, overshoots the regulation band slightly, decreases and settles out within the band. Its new average steady value may be slightly different from its original value, depending on the regulation characteristic of the regulator.

Where loads are sensitive to voltage variations, a generator-regulator system with fast response may be required to shorten voltage dips or rises and speed recovery after load transients. An example would be a hospital where light flicker must not occur and where X-ray equipment would be affected by voltage variations. If light flicker is merely an annoyance rather than a critical condition, it may be ignored, especially for a standby electric set, which is connected to the load only a small percentage of the time.

While this discussion has centered mainly on voltage dip, voltage rise or overshoot could be equally objectionable if there is sensitive equipment in the load circuit. Although a large rise would occur when all load is suddenly removed, this would not be of concern because the sensitive equipment is removed from the line. A large, abrupt part-load removal, with sensitive equipment remaining on the line, is a situation in which severe voltage rise might be of concern.

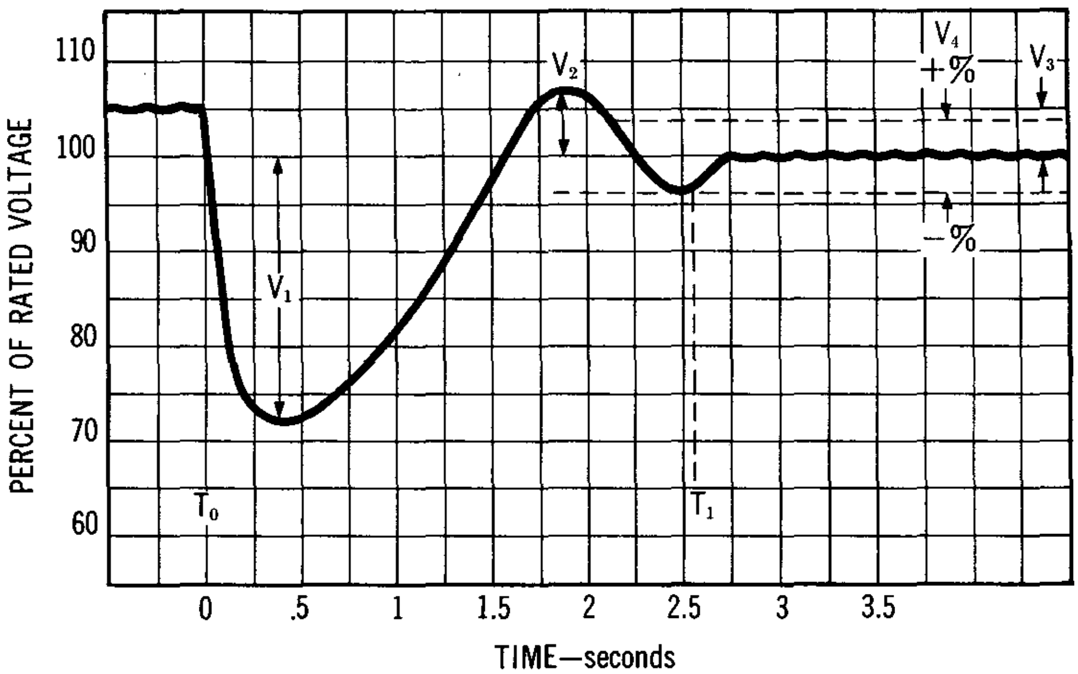
If some equipment is sensitive to momentary overvoltage, a voltage rise limit should be specified along with a statement of the maximum load removal that will be encountered with the sensitive load remaining on the line. Voltage regulators generally are designed to respond more positively to load application than to load removal. A special voltage regulator may be required if voltage rise limit is critical.

Although limiting voltage dip may be important, there is a practical limit to the performance that should be sought in the voltage regulator. The response of the voltage regulator should be reasonably matched to the response of the speed-regulating governor that controls engine speed. When a large load is applied, there is a momentary reduction of speed and the governor responds to restore frequency to or near its original value just as the regulator responds to restore voltage.

To restore speed fast, the engine must have enough power for the KW load plus a margin of power for acceleration. Since, for a given impedance, KW is proportional to E^2, quick restoration of voltage increases load and leaves less power margin for acceleration. Therefore, if the voltage regulator is too "stiff"--responds too abruptly while speed is falling off--a greater load is imposed on the engine during the time that its speed is being reduced; and thus, acceleration is delayed. On the other hand, if the regulator responds at a rate to raise voltage as the governor is restoring speed, both respond smoothly.

Table 4-1. Typical Voltage Regulation Characteristics of Diesel-Electric Generating Sets

	General Appli-cations	Precise Appli-cations
Voltage Regulation	4%	1.5%
Maximum Voltage Variation at Constant Load (Stability)	± 2%	± 0.5%
Maximum Voltage Dip —Step Application of Full Load, 0.8 P.F.	30%	10%
Maximum Voltage Recovery Time—Step Application of Full Load, 0.8 P.F.	4 sec.	1 sec.
Minimum Range of Voltage Adjustment at No Load, 60 hz	± 10%	± 10%



V_1 = Maximum transient voltage dip
V_2 = Maximum transient voltage overshoot
V_3 = Steady state regulation
V_4 = Stability band width
T_0 = Time at which load is applied
T_1 = Time to recover to and remain within allowed band width

Figure 4-2. Generator Voltage Transient Response vs. Time for Load Application

Selection of Voltage Regulator

If desired electric-set performance and the type of service are defined, the electric-set supplier will incorporate or recommend the most suitable and economical voltage regulator. The specification of desired plant performance should be practical to avoid unnecessarily high cost. Basically there are three situations that will be encountered.

1. The load includes sensitive elements that demand close voltage regulation. A high-performance voltage regulator is required.

2. Close regulation is not needed. Generator size is based on peak load. A standard voltage regulator probably will be satisfactory and most economical.

3. Close regulation is not needed. Motor starting and voltage dip are the controlling factors in establishing the required generator capacity. The combined cost of a smaller generator with a high-performance regulator should be compared with the cost of a larger generator and standard regulator.

In situation (2) above, it may seem obvious that a standard regulator is adequate and the cost of a high-performance regulator would not be justified. Even here, however, it would be worthwhile to compare the economics of a high-performance regulator versus a low-performance regulator, weighing greater first cost against possible lower maintenance costs, greater protection from shutdowns, and improved performance and life of loads and of the generator.

Types of Static Voltage Regulators

There are basically two types of static regulators for controlling excitation current to the fields of rotating exciters. These are silicon controlled rectifier (SCR) regulators and transistorized regulators. Each is a completely static electronic device which uses no moving parts to perform the regulating function. Through the use of electronic components, switching functions are performed almost instantaneously, enabling the regulator to respond rapidly to any voltage fluctuation.

Silicon Controlled Rectifier Voltage Regulator

In a silicon controlled rectifier (SCR) voltage regulator, voltage from the output terminals of the generator (usually sensed through a potential transformer) is converted from A.C. to D.C. by silicon rectifiers. The D.C. output from the rectifiers is filtered and applied to a voltage comparison network, which compares the output voltage of the generator with a reference voltage network output.

Typically, the voltage reference is a zener diode bridge, which has the characteristic of maintaining an essentially constant voltage. The difference between the reference and the sensed voltage constitutes an error signal that controls the firing time of the SCR, enabling it to conduct long enough during each cycle to supply the required exciter field excitation. When the generator load changes, causing a voltage rise or dip, the regulator changes the conducting time of the SCR to supply a new level of exciting current to the exciter field.

Transistorized Voltage Regulator

A transistorized regulator employs a potential transformer and rectifier for voltage sensing and a zener diode bridge for a reference voltage, as is done in controlled-rectifier regulators. However, in the transistorized regulator, the error voltage is applied to switch one or more control transistors which in turn control a power transistor that controls the current in the exciter field.

Current Transformer Boost

To minimize voltage dip when motors are started or heavy load is abruptly thrown on the line, the voltage regulator must respond quickly and drive the exciter to high output until the generator voltage nears normal. High-performance voltage regulators employ current transformers to obtain this field-forcing effect.

The current transformer is used in addition to the normal potential transformer. Sometimes a current-potential transformer is used. Connected to an output lead of the generator, the current transformer senses the sudden rush of current when a motor is started or load added. It thus makes the regulator load-sensitive as well as voltage-sensitive so it responds instantly and more vigorously to load changes.

Another function of the current transformer is to supply fault current in case of a short circuit in the load. When a short circuit or overload occurs, generator voltage drops. If the voltage regulator employs only a potential transformer, it cannot supply adequate excitation to the exciter field to maintain generator output. The generator thus will not supply fault current to the load circuits.

This situation may be desirable in some cases because it protects the generator and load from excessive current. However, loads usually are protected by circuit breakers, and normally it would be desired that the generator supply fault current until one or more circuit breakers open, taking the fault circuit off the line. Then the generator can continue to serve the balance of the load.

If the regulator is equipped with a current transformer in addition to the potential transformer, it will continue to supply adequate excitation current to the exciter field during a load short circuit. Under this condition, a generator may be able to supply three times normal current or more until the breakers open, isolating the fault load, and operation returns to normal.

The regulator specification should state if it is desired that the generator be able to support fault currents or overloads.

Static Exciter-Regulator

A typical static exciter-regulator incorporates a magnetic amplifier exciter and a semiconductor regulator. Three magnetic amplifiers supply the required level of field excitation current that otherwise would be supplied by a rotating exciter.

The regulator functions by sensing generator voltage through a potential transformer. The A.C. voltage of the transformer is rectified and compared with the voltage of a zener diode reference bridge. The derived error signal, which is the difference between the reference and the sensed voltage, is used to control the relative resistance of a transistor. The transistor is part of an R-C network, and its variable resistance provides a variable time constant that controls the triggering point in each cycle of a silicon controlled rectifier. The SCR controls the amount of energy supplied to the control winding of the magnetic amplifiers. The amount of control energy supplied depends on the firing time of the SCR in each cycle. The earlier it fires, the more energy is supplied.

In addition to the potential transformer, the exciter-regulator includes a current transformer that applies additional flux in the magnetic amplifier (saturable reactor). This flux adds vectorially in determining the voltage applied to the generator field. With unity power factor loads, the vector additions are approximately at right angles, resulting in only a slight increase in field excitation voltage. With zero power factor load, the vector addition is approximately arithmetic, resulting in a large excitation voltage. Thus, generator field current is boosted under the conditions when it is most needed, such as the low power factor and high current draw that occur when large motors are being started.

Field Build-Up

When a generator begins to rotate, its ability to generate voltage is minimal. The exciter must build up magnetism in the generator field in order to generate voltage that permits the voltage regulator to supply current to the field of the exciter. Without excitation from the exciter, the generator can't generate; and without generator output, the exciter can't excite. It looks like a vicious circle with no starting point. Actually, for generators equipped with rotating exciters, residual magnetism in the generator field produces a small voltage that stimulates further excitation, and it spirals upward from there until rated voltage is produced at the generator terminals.

Although the residual magnetism usually is capable of providing field build-up without any auxiliary devices, regulators may incorporate a field build-up relay or semi-conductor build-up device to hurry the build-up. The build-up device bypasses regulator action until generator voltage has reached a predetermined percentage of rated voltage. Then the build-up device connects the regulator in its normal operating mode.

The static device offers greater reliability than an electro-mechanical field build-up relay.

A static exciter normally requires flashing of the generator field from an auxiliary power supply to provide positive build-up of generator voltage. Auxiliary power for field flashing may be obtained from the electric set's cranking batteries or from a control battery. Flashing power must not be applied except when the generator is rotating.

Reactive Power Division In Parallel Generators

When generators are connected in parallel to a load, the engine speed governor controls engine power so that each electric set carries a share of the load in proportion to its capacity. Even though each generator is supporting its share of the real load, one may have greater field excitation than another. Each voltage regulator senses the voltage from a common bus and, unless equipped with a compensating circuit, would not be aware that its generator has more or less excitation than another generator connected to the same bus.

If the load is purely resistive, the generator with greater field excitation would supply reactive KVA to the under-excited generator. Thus the over-excited generator would be serving an apparent lagging power factor load while the other serves an apparent leading power factor load. If the load includes inductive elements so it has a lagging power factor, the generator with greater excitation would be supplying more than its share of KVAR to the load and thus would be serving an apparent low lagging-power-factor load while the other generator, supplying less KVAR, would be serving an apparent higher lagging-power-factor load or even a leading-power factor load, depending on the difference in excitation.

When the power factor of one generator is lagging while that of another generator connected to the same load is leading, reactive current flows between the generators. This reactive current flowing between generators is called cross-current or circulating current.

It is desirable to balance the field excitations to prevent these cross-currents and to cause each generator to supply its share of reactive current in proportion to its capacity when serving loads whose power factor is less than unity. The methods for doing this are called cross-current compensation. They fool the voltage regulator into thinking its voltage is high when it needs to reduce field excitation, and vice versa.

The most common method is an open-loop or individual compensation method. The voltage- sensitive element of each regulator is biased in direct proportion to the reactive current component of the generator. The regulator reacts to the sum of the actual voltage plus the bias and will sense an apparent high voltage if there is a large lagging reactive current component. This causes the regulator to decrease field excitation to reduce generator voltage. Thus the output voltage droops with reactive current. This droop adds to the inherent droop of the generator.

While one regulator responds by reducing field excitation and thereby reduces its reactive current component, the regulator of another generator connected to the same load, buth with less field excitation, would be sensing an apparent low voltage and would increase excitatiion. If the excitation of one generator increases about the same as the excitation of the other decreases, the line voltage is constant. If the droop characteristics are not the same, so that one regulator changes excitation more than the other, the line voltage would shift slightly and the excitations and KVAR would be slightly unbalanced under most load conditions.

The means of inserting voltage bias into the regulator is a current transformer sensing current in one phase of the generator, with its secondary connected to a resistor in series with the voltage sensor (usually the secondary of a potential transformer). The emf sensed by the regulator is thus actual voltage plus the drop through the resistor. As shown in Figure 4-3, the current transformer is connected to a phase opposite the phase connections of the voltage sensing input to the regulator so it is 90 degrees out of phase (e.g., current transformer connected to sense current in line 2 when the voltage sensor is connected between lines 1 and 3).

Thus, at unity power factor, the current through the resistor is out of phase with the voltage sensor so that its voltage drop adds very little to the sensed voltage. But a lagging power factor brings the resistor voltage drop somewhat in phase so that a component of the drop adds to the sensed voltage. The lower the lagging

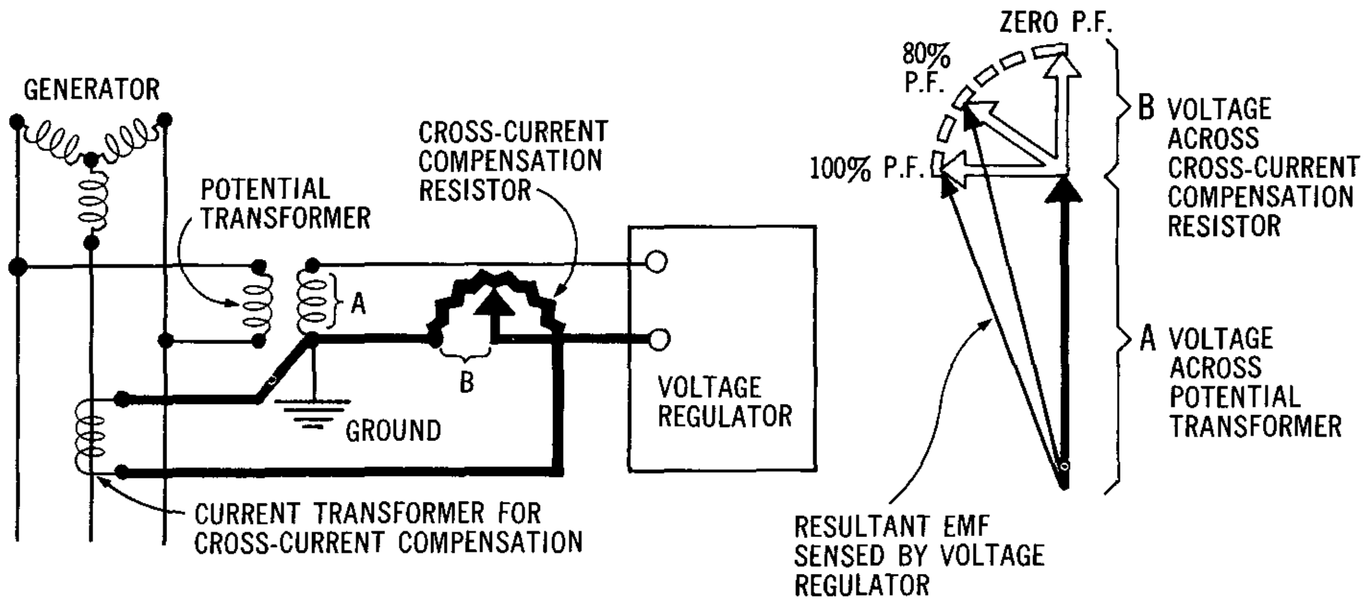


Figure 4-3. Cross-Current Compensation

power factor, the more the resistor voltage drop comes into phase with the sensed voltage and the greater the added component. A leading power factor would bring the resistor partly in phase also but in a direction to subtract from the voltage.

Thus the total of actual voltage plus resistor drop is greater in a generator operating at lower lagging power factor with higher field excitation and supplying more than its share of reactive current. Responding to this greater apparent voltage output, the regulator decreases excitation while the regulator of a generator with less excitation and higher lagging P.F. (or a leading P.F.), sensing less total emf, increases excitation.

For special applications where individual droop compensation is not acceptable, a closed-loop method of differential compensation is used. The voltage-sensitive element of each regulator is biased by the difference in reactive current outputs of the paralleled generators. The voltage characteristic with respect to reactive load is flat since there is no biasing effect on the regulators as long as all machines share the reactive load equally. This method adds complexity with cross-connected current transformers.

After parallel generators are installed, any of several methods may be used to check the presence or absence of cross-currents. Reactive KVA meters can check reactive KVA load of each generator. If these reactive loads are balanced in proportion to the generator ratings, there are no cross-currents. Power factor meters can check the P.F. of each unit. If equal, there are no cross-currents. As a third method, use wattmeters to check that KW loads are balanced in proportion to generator ratings while ammeters check that the sum of individual generator amperes equals the total load amperes. If the sum of individual generator amperes exceeds the total load amperes, cross-currents are flowing between the generators.

Underspeed Protection

Voltage output of a generator is proportional to speed as well as to field flux. If the generator rotates at less than rated speed, voltage decreases and the voltage regulator will increase field excitation in an attempt to maintain voltage at the normal level. Therefore, prolonged operation at reduced speed may cause excessive output of the regulator and exciter, resulting in increased heating and possible failure of the regulator and the exciter field or alternator field.

An electric set normally will always operate at rated speed except during starting and stopping when the load is disconnected. Of course, an overload or a mechanical failure in engine or generator might slow down the generator. To determine whether underspeed protection is required for the voltage regulator, consult a Detroit Diesel Allison Distributor.

Voltage Control Back-up

Failure of a voltage regulator could stop generator output or permit voltage to vary widely over the load range. If the regulator does not have a current boost transformer, failure of the regulator would permit excitation to decay so that generator output would go to zero.

Manual control systems are available as back-up for the voltage regulator. Maximum back-up reliability is afforded if the back-up control is separate from the regulator. Thus, the manual control incorporates its own rectifiers and power transformer, which is a variable-ratio transformer. In case of regulator failure, the transformer ratio is adjusted manually to control excitation and compensate for load changes.

A manual back-up is practical only if the loads will operate with low-quality voltage regulation. Obviously, a manual control cannot be fast enough to prevent large voltage dips or rises during abrupt load changes. If the load varies continually, it would be a full-time job for an operator to repeatedly adjust the rheostat, and it would be virtually impossible to maintain steady voltage within a band of a few percent.

If tight voltage control is essential, the only practical back-up system is another regulator that has the same performance as the prime regulator. Often, this is less expensive than a manual back-up system. In case of regulator failure, control is switched to the back-up regulator either manually or automatically.

Power Transfer Devices

The two main functions of the switchgear associated with emergency electric power systems are: (1) Reconnect the load to the appointed power source (standby or normal) on command; (2) provide fault protection for the generator and load devices. The switchgear must be rated according to the voltage and current it is intended to carry and must be equipped with the necessary fault protection devices to protect the generator from damage when there are faults or overloads on the system.

Engine starting and power transfer may be performed manually or automatically. Before designing the system and selecting switchgear components, it must be decided whether operation will be automatic or manual.

Manual Operation

Engine starting, adjusting voltage and frequency, and transferring the load to the emergency source may be performed manually. This is the most economical method, and is practical when an operator is available around the clock and when a longer interval is acceptable between power failure and the time when the emergency source is on.

The engine is started by a pushbutton or other manual control, depending on whether the starting system is battery, hydraulic or air powered. The activating device could be lockable or key-operated so the engine can only be started by authorized persons. A manual double-throw switch can be used to transfer the load to the standby generator after it reaches correct voltage and frequency.

If a qualified operator is on duty 24 hours per day, it may be determined that manual starting is adequate. Employing manual starting in installations where the emergency source is to power only the critical equipment will allow the operator to manually disconnect the noncritical equipment or to alternate the equipment as required.

Semi-Automatic Operation

If it is necessary to initiate the manual start signal from a remote location, devices must be provided which will automatically control the engine and generator. Once the starting sequence is complete, the load may be transferred manually or automatically. In the latter case, power-status instruments should be included at the remote control station so that the operator will be assured that the starting sequence has been completed.

This method is often employed where the electric set is located outside or on the roof.

Automatic Operation

An automatic system is always on duty, and it saves time in responding to a power failure. It incorporates intelligence devices and circuitry that monitor the normal power supply and initiate a start signal when there is a failure or voltage reduction in the normal supply, and automatically transfer the load to the standby generator.

When the standby system includes two or more electric sets, which are to be connected in parallel to the load, both automatic starting and automatic synchronizing can be provided.

The desirability of automatic operation depends on

1 The purpose of the emergency power system,

2 the changeover time interval that can be tolerated,

3 the availability of operating personnel.

Because automatic starting and load transfer add substantially to the cost of the system, the practical approach is to use an automatic system only where it is essential.

Power Interruption Interval

Unless an uninterruptible power supply is installed, there will always be an interval of no power (or inadequate power) between the time of normal-source failure and the time when the transfer switch has been thrown and the load is being powered by the emergency source. The length of this power interruption interval (changeover interval) depends on the starting method. An automatic starting system will be faster than a manually started unit.

The acceptable length of the changeover interval is dictated by the type of installation and the purpose for which the electric set is installed. Some installations can tolerate a longer power interruption interval than others. The allowable changeover interval must be determined by the owner or operator. The shorter the interval, the greater the sophistication that must be built into the starting system to ensure that the unit will start within the prescribed interval.

The electric set may be capable of starting in just a few seconds, but how many more seconds are required for the voltage and frequency to stabilize? Both voltage and frequency overshoot beyond their normal levels as the engine reaches its designated speed range. The amount of overshoot and the time for the electric set to stabilize depend upon the quality of the voltage regulator and the speed governor.

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going frequent ormal source is y voltage dips occur, several different time-delay relays may be added to the automatic control circuitry. These accessories and their purposes are:

1. **Power-failure evaluation relay** to avoid starting the electric set when harmless momentary voltage dips or outages occur.
2. **Normal-source sampling relay** to avoid retransferring the load to the normal power source while that source is in an erratic condition.
3. **Minimum operating time relay** to keep the engine running long enough under load to reach normal operating temperatures.
4. **Coolant-stabilizing relay** to provide engine cool-off running time to stabilize engine temperatures after the load has been retransferred to the normal power source.

With all of these timing accessories installed, the electric set starts and operates as follows: When the power-failure relay signals a start command, the engine starts only after a short delay indicates that the normal source fault is not momentary; the electric set assumes the load; after the power-failure relay signals that the normal power has recovered, or after a specified minimum running time has elapsed, whichever occurs later, the electric set continues to operate under load for a preset period of time; then, if the normal power is still in satisfactory condition, the load is transferred to the normal power source and the electric set continues to run for a few minutes unloaded.

The functions of these timing devices are described in the following subsections.

Power-Failure Evaluation Relay

If the area in which the electric set is to be installed experiences frequent electric storms, there may be many harmless momentary dips or outages in the normal power source. To avoid frequent and useless starting or attempted starting of the electric set, a time-delay relay may be inserted in the intelligence circuit between the power-failure relay and the automatic starting control. As a result, the power failure must last until the timer has cycled before a start signal can be initiated, thus establishing a failure-evaluation circuit to prevent false starts.

The timer should be adjustable from 0-60 seconds to suit the requirements of different installations. In some cases, it is useful to change the delay time for different seasons.

It should be noted that when a failure-evaluation relay, also referred to as a start-delay timer, is used, the time required for the engine to start is delayed by the timing cycle of the timer. However, the benefits of the failure evaluation offset the longer starting interval.

Normal-Source Sampling Relay

Sometimes when the normal power source fails, it may be restored momentarily and then fail again. The electric set may shut down and immediately restart, or

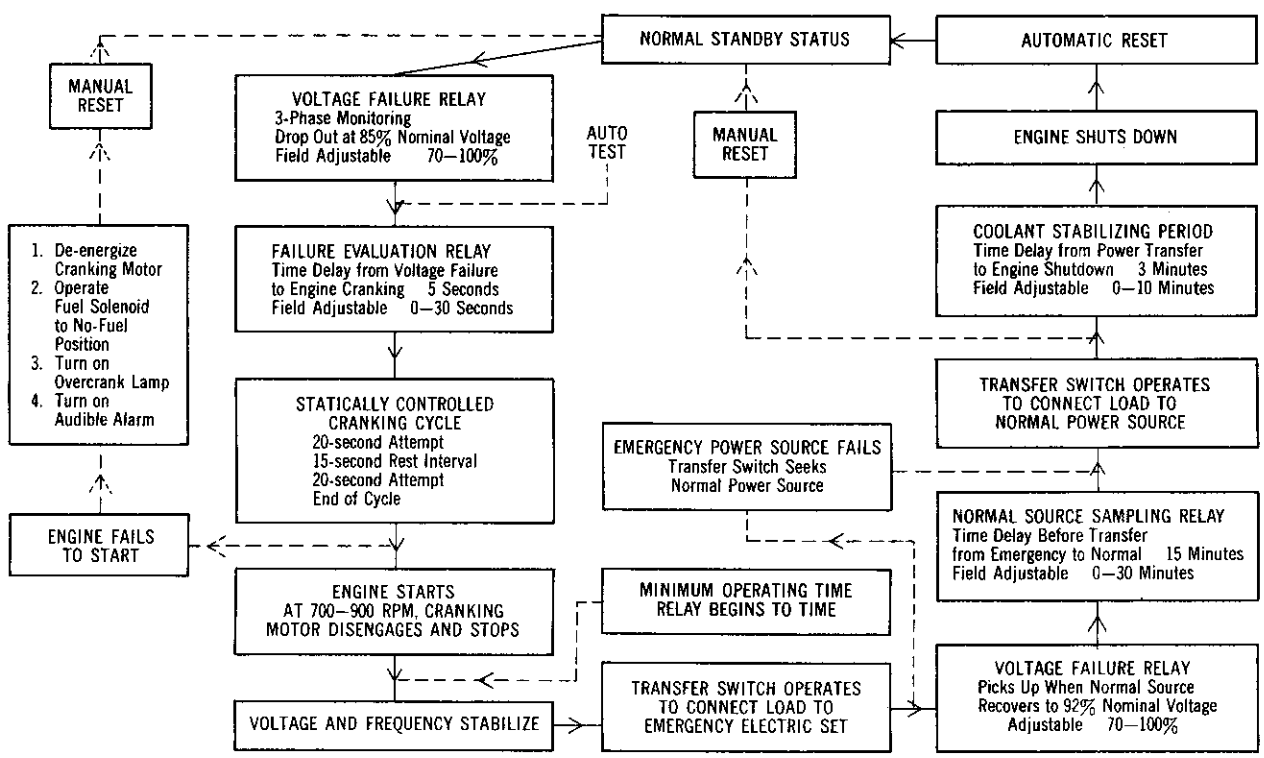


Figure 5-2. Automatic Starting and Load-Switching Sequence

it may attempt to restart during a shutdown cycle, in which case there will be a loss of the emergency power system if the proper circuitry is not provided. Repeated subsequent starts also will not allow the batteries to be recharged as fast as they are being drained.

To avoid these occurrences, a timing device can be inserted in the intelligence circuit between the power-failure relay and the transfer switching control. This timer would only operate as long as the power-failure relay remains in the pickup position (signalling retransfer to normal). The transfer to normal will be delayed until the timer has cycled.

If the power-failure relay should drop out during the timing cycle, the timer also drops out and resets itself, and the delay period is repeated after the power-failure relay again picks up. Obviously, retransfer to normal will not take place if normal-source recovery does not last through the timing cycle. Thus the timer serves as a normal-source sampling relay.

This relay, sometimes referred to as a holdover timer or "TIME DELAY, EMERGENCY-TO-NORMAL," should be adjustable to match the individual requirements of the installation. Generally the timer is set between 15 and 30 minutes.

Minimum Operating Time Relay

It is beneficial to the engine if it always is allowed to operate long enough to reach normal operating temperatures. To make sure of this, a timer having a sufficient range of adjustment can be inserted between the sampling relay and the power-failure relay to establish a minimum operating time. This timer begins to cycle when the engine attains operating speed, and at the end of its cycle closes the circuit to the normal-source sampling relay. If the power-failure relay in the meantime has switched to its pickup position, the sampling relay timer begins to cycle as soon as the minimum-time relay completes its cycle.

Thus the minimum operating time is the total of the delay period of the minimum-time relay plus the delay period of the sampling relay. For example, if the minimum-time relay is set for 45 minutes and the sampling relay is set for 15 minutes, then the total timing cycle for operation under load would be 60 minutes. This would establish a minimum of 60 minutes of operating time whenever the engine is required to operate.

The desired minimum operating duration is determined by the operating conditions of the site--that is, the ambient temperature and the amount of existing load in kilowatts. A fully loaded electric set will achieve normal operating temperatures sooner than a lightly loaded unit. Generally, the minimum operating time is set between 30 and 60 minutes.

Some types of electrical, electronic or mechanical problems in the electric set or its controls do not show up until operating temperatures have stabilized. Therefore, establishing a minimum operating time also increases reliability by uncovering deficiencies--for example, during test and exercise runs.

An optional manual override can be inserted in the circuit, permitting manual retransfer to normal without waiting for the timer to complete its cycle.

Coolant-Stabilizing Relay

When an electric set has been operating for some time and is shut down immediately following transfer of the load to the normal power source, the engine coolant temperature will increase and remain at the higher temperature until the heat is radiated from the engine. The higher coolant temperature occurs because the coolant circulating pump stops when the engine stops.

To stabilize block and head temperatures, a timer can be inserted in the control circuit between the transfer-to-normal control and the engine-shutdown control. The timer will allow the engine to operate for several minutes unloaded at its rated speed after the transfer to normal. The engine cools down while operating in this condition, and the circulating coolant keeps temperatures even.

If the electric set is equipped with a set-mounted radiator and fan, this practice will also assist in cooling the generator room.

During the cool-down period, the electric set must operate at rated speed to protect the voltage regulator and generator. Normally there is no reason to idle an electric set or to operate it at low speed. Upon starting, it should accelerate immediately to rated speed, and upon shutdown it should be decelerated quickly to a stop. For protection of the voltage regulator, steady running at less than rated speed must be avoided unless the voltage regulator is equipped with an underspeed cutout.

Power Source Indicating Lamps

It may be useful to equip the system with an indicating lamp or lamps (one per phase) to provide a quick means of observing:

1 which source is powering the load,

2 if the normal power has recovered.

Generally, white or green lamps are used to represent the normal source, and almost always red is used for the emergency source. In either condition, the lamps should be powered by the source they are indicating.

After lights indicate normal power recovery, it may be desired in some instances to override the normal-source sampling relay and return the load to the normal source immediately. In such a case, it is recommended that voltmeters be observed to make sure voltage is normal in all phases before transferring the load.

The lamps can be located in the transfer switch enclosure, the control cabinet, a power distribution center, or some central remote location. The preferred choice should be the location where the lamps are most readily observed.

Generator Fault Protection

Automatic short-circuit and sustained-overload protection should be provided for protection of the generator. The most efficient method of doing this is to connect a circuit breaker equipped with automatic trip mechanisms which will interrupt the circuit when short circuits and/or sustained overload occur.

A circuit breaker equipped with magnetic trips will trip the breaker under high-current short circuits only, while a breaker equipped with thermal/magnetic trips will operate on short circuits and sustained overloads. Thermal trips protect against overloads only.

The circuit breaker also serves as a disconnecting mean for the generator to permit servicing, troubleshooting or repair. For maximum safety, the breaker should be located near the electric set and provisions made for locking it in the open position.

When employed as disconnect switches to disconnect the electric set from the bus, the circuit breakers may be operated manually or devices may be added to provide manual remote or automatic operation.

The circuit breaker should be connected in the line, not in the exciter field. It is false economy to employ a circuit breaker in the exciter field because it does not sense the current that does the damage and therefore does not provide full protection. In a 3-phase system, overloading one phase would not cause appreciable increase in exciter field current and therefore would not be sensed by an exciter-type circuit breaker. With leading power factor load, exciter current decreases when generator output increases, and therefore high generator current would not be reflected in the exciter field circuit. This situation could also occur in paralleled electric sets if the droop compensation (reactive power division) system fails. Even when a fault is reflected in the exciter field circuit and causes the breaker to open, it would not protect the generator stator against current feedback. The only sure protection is a circuit breaker in the line between generator and bus.

Breakers should be specified according to required capacity (voltage and amperes per phase), construction (molded case, air or oil-immersed), fault protectin (thermal/magnetic trip), manual or automatic disconnect switch operation.

Reverse-Power Relays for Parallel Operation

Should an electric set operating in a paralleled system lose its power producing capability, the companion electric set or sets will assume the affected unit's portion of the load as its power output decreases, and the affected electric set will be motorized by the companion sets, thus imposing additional load on the system.

As the power output of the affected set decreases, the load which must be assumed by the companion set or sets increases. To prevent overloading the system, or damage to the affected set, a device must be incorporated having the necessary intelligence to recognize this adverse condition and the capability of disconnecting the affected set and, if necessary, the companion sets. This device used for this purpose is a Reverse-Power Relay (or Reverse-Current Relay), which is connected to the circuit breaker shunt trips, so that when it operates, it will shunt-trip the breaker.

If the companion sets in the system have the capacity to assume the additional load resulting from the partial loss or complete loss of the affected set, then only the affected set needs to be disconnected. If the companion set or sets do not have the capacity to assume the load rejected by the affected set, it will be necessary to (1) disconnect all the generators from the system, then adjust the load accordingly and reparallel the system, or (2) provide an automatic means of shedding load until it is within the capacity of those sets still on the line.

Reverse-power relays are preset to operate when they sense a given amount of reverse power. The amount is usually stated as a percentage of the rating in kilowatts of the generator being motorized. A common operating setting is 25% of the generator's rating.

Motor Protection

During the interval between failure of the normal source and transfer to emergency power, synchronous and induction motors get out of phase while developing high regenerative voltage. If these motors, while in this condition, are connected to the emergency power source or are reconnected to the normal source, large magnetic stresses may damage the motors. To safeguard motors, it may be advisable to interlock the transfer system so that synchronous motor circuits are opened before the transfer is completed, and the transfer should be delayed until the residual voltage of other motors has dropped to 25% of rated voltage.

Engine

Since this manual presents information related to diesel-electric generating sets, the use of the word "engine" always denotes a diesel engine unless otherwise stated. Other than specifying a diesel engine, it is recommended that you don't attempt to specify a particular type of engine, but rather specify the performance required in terms of KW, speed or frequency, response to transients, and operating conditions (ambient temperature and altitude or ambient pressure). This will place the burden on the supplier to propose an engine that will meet the requirements.

Required Engine Characteristics

An electric-set engine must have enough power to serve the peak load and must have an adequate power margin (HP-KW) to recover frequency after an abrupt load application. The power rating used should be the rating established by the engine manufacturer to afford adequate engine life in the type of service to which it is being applied. A so-called "flash" rating is not acceptable. An engine design with inherent quick response helps maintain frequency within specified limits. Other factors of concern are durability, reliability, cost of operation and upkeep, availability of service, cleanliness of exhaust, space occupied, and type of fuel required.

Cost of Operation and Upkeep

Engine operating cost factors are fuel consumption, routine servicing, maintenance and overhaul, replacement of parts or accessories, and fuel replacement cost. Fuel consumption is a significant cost factor in prime power applications. In a standby electric plant, engine fuel consumption rate is a minor factor because normally little fuel is consumed over a period of months. The cost of replacing a tank load of fuel every year or two, to keep it fresh, may be significant. This is explained in a companion volume, ELECTRIC SET INSTALLATION, under the heading, MAINTAINING FRESH FUEL. An engine capable of operating satisfactorily on kerosene will minimize this cost. An engine that is easier to service, with lower-cost replacement parts, will save both cost and downtime when servicing is required.

Engine Types

To assure adequate power and engine life, it isn't desirable to specify piston displacement or type of engine. There are 2-cycle and 4-cycle diesels, turbocharged or naturally aspirated, direct injection or precombustion types, manufactured in various models with power ratings suited to different applications. A turbocharged engine doesn't require as much piston displacement to achieve the same maximum power as a naturally aspirated engine. A 2-cycle engine doesn't require as large a displacement as a 4-cycle engine. It produces the same maximum power with fewer cylinders or smaller cylinders. Thus, different types of engines will have different displacements for the same power rating. So it's pointless and falsely restrictive to include displacement in the engine specifications.

The same applies to engine speed. Some engines are rated for industrial continuous service at 1800 RPM or higher. Such engines are designed for that speed and thus give satisfactory service when driving generators at 1800 RPM. Other engines, designed for lower speed, may give satisfactory service only when driving generators at 1200 RPM. It is up to the supplier to determine which of his engines is most suitable for a particular application.

Don't restrict yourself or add unnecessary cost by including displacement or speed in the specifications. Just specify the load in kilowatts, limits of frequency dip and recovery time, the ambient conditions, and the type of service (standby, peaking power, prime power or continuous). Let the supplier propose an engine to suit.

Engine Power Ratings

An engine is given a certain power rating by the manufacturer according to the type of service in which the engine will be used. The objective is to limit the maximum power output so that a desired engine life will be achieved. For example, a *prime power* rating is higher than a *continuous* rating but lower than a *standby* rating.

Engine life expectancy is usually expressed in terms of engine operating hours before its first major overhaul. In some cases, engine life in terms of years of service may be more significant. Life expectancy for a heavy-duty diesel engine in either continuous or prime power service will average 15,000-20,000 hours, provided the engine is properly applied and maintained. The same engine with a higher rating would have a shorter life expectancy.

An engine for standby service might operate an average of only 100 hours per year. So it would be ridiculous to rate its power capacity low enough to achieve a 20,000-hour life because it would be in service 200 years before it needed an overhaul. Therefore, an engine for standby service can be rated at a much higher power level. Even if its operating life is only 2,000 hours, it could be 20 years before its first major overhaul.

Rating Examples

As an example of different ratings for the same engine, assume that a certain engine is capable of producing 750 HP at 1800 RPM with factory-specified fuel input. If this engine is to be used in continuous service, driving a pump or generator at a constant power level day in and day out, it might be rated at only 465 HP to achieve the desired life expectancy. This would be an example of a continuous rating.

If the engine drives a generator continuously 24 hours a day, 365 days a year, but its load varies with fluctuations in demand and averages not more than 465 HP, it might be rated at 560 HP to achieve the desired life expectancy. This would be an example of a "prime power" rating.

If the engine drives a generator in standby service, where it operates an average of about 100 hours per year, it might be rated at 750 HP allowable maximum output. This would be an example of a standby rating. At this rating, it would have an adequate life expectancy in terms of years of service.

It should be understood that 750 is not the maximum power of which the engine is capable. It is the power capability with a factory-specified fuel input related to the type of service. The maximum horsepower that can be demonstrated at the factory is substantially in excess of 750 HP.

In Detroit Diesel engines, the proper size of injector is installed to match the power rating to the particular type of service and desired engine life. Other types of engines might depend on the governor's load-limiting adjustment to achieve the same purpose. A drawback of depending on the load-limiting adjustment is that it could be tampered with to raise the power limit and thereby degrade engine life and increase smoke and emissions.

In selecting an engine for a standby application, it is obvious from the foregoing that it would be uneconomical to base your selection on a continuous or prime power rating. You would be paying for an engine that is much larger and has much greater life expectancy than you need. Moreover, such an oversize engine would suffer greater efficiency loss at part-load, which is the load condition in which a standby electric set is likely to operate most of the time.

While there is general agreement among engine manufacturers on the definition of continuous-duty rating, unfortunately there are no industry standards for prime power or standby ratings, and each manufacturer establishes his own rating definition. This creates some confusion in making a true comparison of one manufacturer's definition with another's. However, the following should clear up this confusion.

Continuous-Duty Rating

The engine manufacturer establishes a continuous-duty rating for each basic engine model, which indicates the amount of horsepower the engine is allowed to deliver when operated 24 hours a day, 365 days a year, while powering a constant fixed load, at a constant fixed operating RPM. Generally, for most engine manufacturers, the same basic engine models are used to power mechanical equipment as are used to drive electric generators. Thus, the continuous-duty horsepower rating is the same no matter what type of equipment the engine drives. The 1800 RPM speed of Detroit Diesel electric-set engines affords long life and reliable operation because it is the same or less than the industrial continuous rated speed of each engine.

When applied to heavy-duty diesel engines, the continuous-duty rating defines a power output and speed at which the engine can be operated steadily with a life expectancy of 15,000-20,000 hours. The desired life can be expected if the rated power and speed are never exceeded.

In electric-set applications, a constant fixed load is the exception rather than the rule. Therefore, in the interest of proper and efficient application of engines to power electric sets, it is necessary to recognize two other types of rating that fit the majority of electric-set applications. These ratings are called *prime power* and *standby power*.

Prime Power Rating

"Prime power" is the rating for applications in which the electric set is the sole or normal power source, and in which optimum engine life is to be expected. Examples are small municipalities; remote industrial construction, mining or power installations; and commercial or industrial plants. In a prime power application, the electric set might be operated steadily, day in and day out, but its load varies throughout the day. The prime power rating is somewhat higher than a continuous-duty rating to take advantage of the fact that the load is variable. The prime power rating assumes that the measured average output over a 24-hour period of operation does not exceed the industrial continuous rating of the engine.

The average output is measured in kilowatt-hours, based on a 24-hour operating period. A kilowatt demand meter can be used to measure the average demand, or the 24-hour average fuel consumption can be measured and converted to kilowatt-hours. If the average horsepower output over a 24-hour operating period exceeds the industrial continuous horsepower rating, the engine life will be decreased proportionately.

Standby Rating

In recognition of the limited running time experienced in standby service, the standby power rating is higher than a prime power rating. The engine should be capable of producing its standby rated horsepower continuously for the duration of each electric power failure. Thus a "flash" rating would be unacceptable for standby service. A flash rating is a rating for a limited period of time such as 5 seconds, 5 minutes, 2 hours, etc. The word "continuously" as used here in the standby context should not be associated with the continuous-duty rating because continuous-duty ratings and standby ratings are meant for two entirely different applications.

Detroit Diesel standby ratings are based upon a maximum horsepower that can be obtained at a factory-specified fuel input and should not be misinterpreted as the maximum horsepower that could be produced by the engine at a higher fuel input.

Occasionally a term such as "standby continuous rating" is seen. Such terminology is confusing and can be misleading because it combines elements of two different ratings. If the term "standby continuous rating" merely means a standby power output that can be produced continuously for the duration of the electric power failure, then it is the same as "standby rating".

In summary, there are three distinct ratings for engines used to power electric sets:

1. Electric-set continuous rating (same as industrial continuous rating)
2. Prime power rating
3. Standby rating

Rating Baseline Conditions

The power output capability of an engine depends on the ambient temperature and atmospheric pressure in the generator room. High air temperature or low air density reduces the maximum power capability of an engine. Therefore, when specifying the required KW capacity of the electric set, also specify the maximum ambient air temperature and the altitude or atmospheric pressure of the site.

Engine power ratings published by engine manufacturers are based on operation at some standard, or baseline, temperature and altitude. If the engine will be operated in a different ambient condition, its power capability must be corrected to the actual conditions. That is, a new power rating is calculated based on the numerical relationship of the actual temperature and pressure to the baseline temperature and pressure.

When actual ambient conditions are stated in the specifications, the electric-set supplier will take this into account and make the correction in the engine's power rating before proposing an engine for the electric set.

Two generally accepted ambient condition baselines are used by manufacturers in rating diesel engines:

S.A.E. Conditions	Standard Conditions
85°	60°
500 ft. above sea level	sea level

Because the S.A.E. conditions more realistically represent average site conditions, Detroit Diesel electric-set engines are rated at this baseline. The Standard Conditions rating applies to marine and other sea level applications but usually must be corrected for the higher temperature found in engine rooms.

Detroit Diesel basic engine horsepower performance curves indicate the available horsepower at the flywheel. The power required to drive the blower, water pump, fuel pump and lube oil pump has been deducted. The power absorbed by optional engine-driven accessories (such as direct-driven cooling fans, or direct-driven raw water pumps or air compressors) must be deducted from the available horsepower.

Frequency Control

To produce alternating current at a specified frequency, the engine must drive the alternator at a corresponding "synchronous speed." Common synchronous speeds are 1800 RPM for 60 hz A.C. and 1500 RPM for 50 hz A.C. The speed of the engine and alternator is controlled by a speed-regulating governor that automatically adjusts the engine fuel control linkage as the load varies, increasing or decreasing engine power as necessary to maintain steady speed.

Depending on the requirements of the load, the governor may hold the same average frequency at all steady loads or may permit the frequency to be higher at light loads than at heavy loads. At any steady load, there is a slight, random frequency variation. When load is applied or removed, there is a momentary drop or rise in frequency, and the governor responds to change the engine fuel rate and restore frequency.

The amount of frequency variation that is acceptable depends on the requirements of the critical electrical equipment in the load. The electric-set supplier will select a suitable governor if you tell him your load requirements. Therefore, do not attempt to specify a particular type of governor. Instead, specify the frequency performance required by the load. This makes the supplier responsible for achieving the specified performance. The performance factors that you will specify are:

1. Regulation
2. Limits of frequency dip or rise on application or removal of load
3. Maximum recovery time after application or removal of load
4. Steady-load stability and bandwidth

Regulation

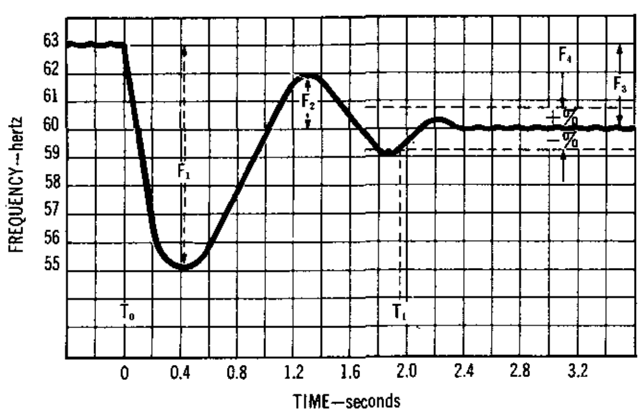
The difference between the average steady speed or frequency at no load and at full load is termed "regulation." It is expressed as a percentage of the full-load speed.

The speed-vs.-load characteristic of a governor is sometimes expressed as percentage "droop" instead of "regulation." The terms are often used interchangeably, but the distinction between them is that regulation refers to engine speed variation over the load range from no load to full load, whereas droop refers to speed variation over the motion range of the governor actuator.

The speed-vs.-load characteristics of some governors always permit the engine's steady speed to be slightly higher at no load than at full load. These are termed "droop type" or "drooping" governors, and their engine speed regulation range normally is 3-5%. That is, they may be adjusted for 3% regulation or 5% regulation or any point in between. As an example, if regulation is set at 5%, speed and frequency at full load are 1800 RPM and 60 hz, and at no load they are 1890 RPM and 63 hz.

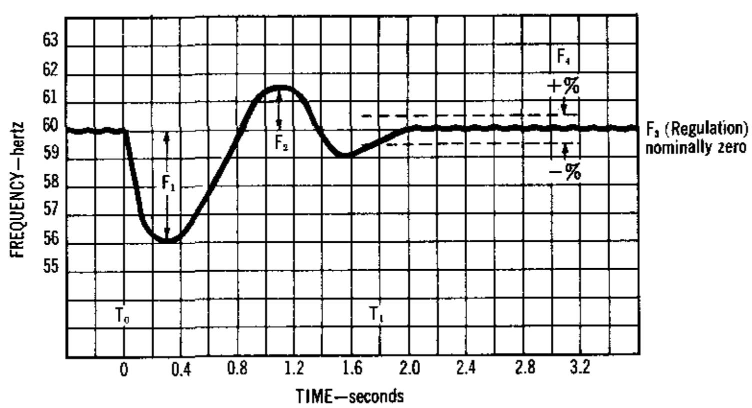
Some governors may be adjusted to maintain the same steady speed at any load up to full load. These are termed "isochronous" or "zero droop" governors, and their regulation adjustment is from 0% to 5%. As an example, when regulation is adjusted to zero, speed and frequency are 1800 RPM and 60 hz at full load, at no load, and at all steady loads in between.

The step load application illustrated in Figure 7-1 shows that the steady-state frequency is lower after the load application than it was before. This is an example of droop regulation. The step load application illustrated in Figure 7-2 shows that the steady-state frequency is the



F_1 = Maximum transient frequency dip
F_2 = Maximum transient frequency overshoot
F_3 = Steady state regulation
F_4 = Bandwidth
T_0 = Time at which load is applied
T_1 = Time to recover to and remain within allowed bandwidth

Figure 7-1. Electric-Set Frequency Transient Response vs. Time for Load Application (Droop Governor)



F_1 = Maximum transient frequency dip
F_2 = Maximum transient frequency overshoot
F_3 = Steady state regulation (nominally zero)
F_4 = Bandwidth
T_0 = Time at which load is applied
T_1 = Time to recover to and remain within allowed bandwidth

Figure 7-2. Electric-Set Frequency Transient Response vs. Time for Load Application (Isochronous Governor)

same both before and after the load change. This is an example of isochronous regulation.

Transient Response

When load is added or removed, speed and frequency dip or rise momentarily before the governor can correct for the speed error and stabilize the engine speed at the new load. Quick response of governor and engine not only shortens recovery time but also lessens the extent of the frequency deviation.

Transient response after an abrupt load application is illustrated in Figure 7-1 for an electric set controlled by a droop governor, and in Figure 7-2 for an electric set controlled by an isochronous governor. When load is applied, frequency dips, then rises as the governor reacts to increase fuel flow to the engine. Frequency overshoots, then decreases and settles out within the steady-state band. Recovery time is the time in seconds from the point at which frequency deviates from the steady-state band until it recovers to and remains within the specified steady-state bandwidth.

An actual recording of the transient performance of a diesel-electric set powered by a Detroit Diesel 16V-71T engine is reproduced in Figure 7-3. The recording illustrates performance with a one-step application and removal of full rated prime power load at 0.8 P.F. The governor is a Woodward PSG hydraulic type, which senses speed but not load. The governor is adjusted for isochronous operation (zero regulation).

The factors that influence transient response are the inertia of the rotating mass, type of governor, responsiveness of the engine, and the engine's power margin (i.e., ratio of rated HP to peak load KW). The inherent rapid response of a 2-stroke-cycle engine makes its transient performance with a hydraulic speed-sensing governor comparable to that of a 4-stroke-cycle engine of the same power rating equipped with a more expensive electric governor. The performance of the 2-stroke-cycle engine is even better when it is equipped with an electric governor.

To be sure it will have enough power for the specified performance, an engine should have some extra power capability beyond that required by the peak KW load. This extra power margin helps the engine to respond to load transients. An engine without sufficient power margin could maintain synchronous speed at full load if the load is applied in small increments. However, without sufficient power margin, that same engine may not recover to synchronous speed if the full load is applied in one step.

Power margin or HP-to-KW ratio should not be specified since the amount required is different for different engine designs. Precise specification of peak KW load, load starting requirements, and permissible frequency deviation during load transients will enable the electric-set supplier to determine the correct engine rating to meet the performance specifications.

The specified performance requirements will depend on the severity of expected load transients, how sensitive some loads are to frequency excursions, and how these loads are protected. Specify response in terms of frequency deviation limits and recovery time for application and removal of specified load. Analyze loads to determine the maximum amount of load that will be added or removed in one step with critical equipment already on the line or coming on the line. Where the step load application or removal is less than full load, it is recommended that performance be demonstrated both with and without the balance of the load on the line. This will help assure that the most severe condition is being demonstrated.

Steady-load Stability and Bandwidth

Bandwidth defines the limits of frequency variation at any steady load, as shown in Figures 7-1 and 7-2. The slight speed variation which occurs at steady load should be random and not cyclic. A cyclic variation shows instability in the governor and could cause undesirable effects on critical loads or between generators connected in parallel. A typical electric-set governor maintains frequency within a bandwidth of $\pm$ ¼%.

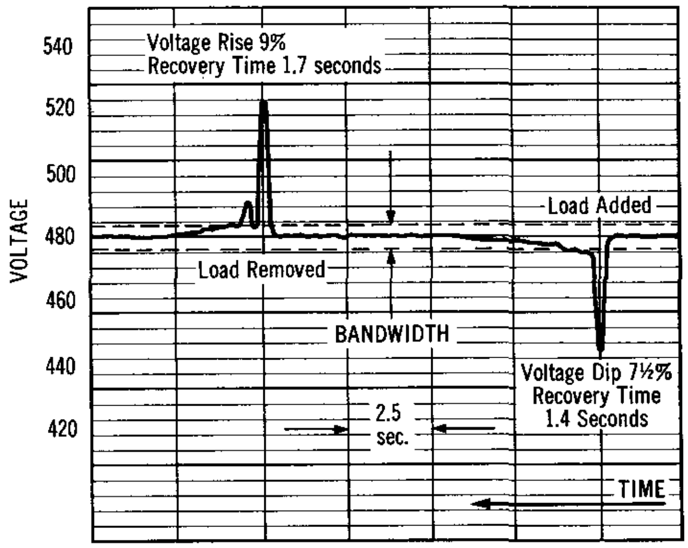
In applications of droop governors, the difference between no-load and full-load frequency exceeds the steady-state bandwidth, and therefore bandwidth is not as as critical as it is in applications of isochronous governors. Cyclic variations at any steady load are normally objectionable, regardless of governor type.

Linearity, Hysteresis and Drift

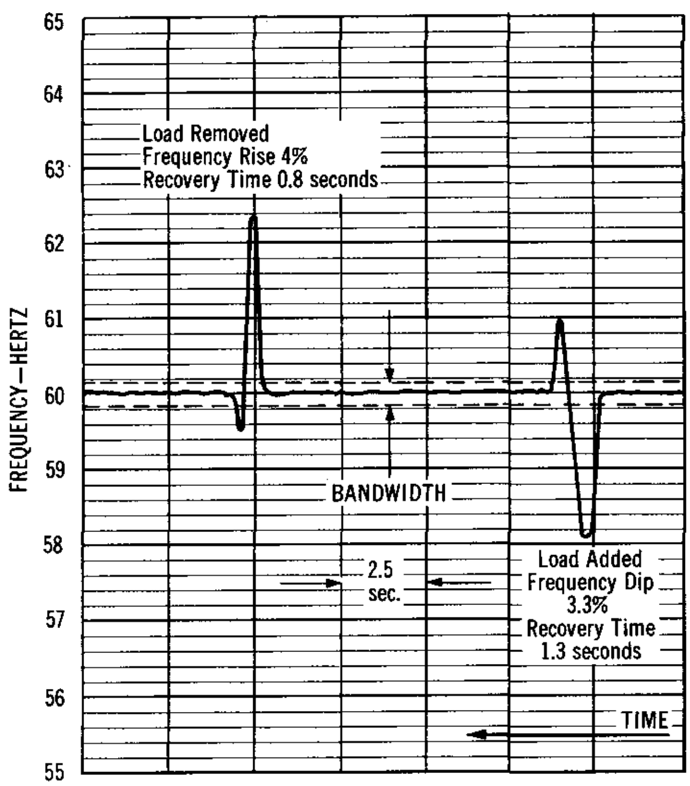
Where the speed-vs.-load characteristic of the governor is linear, the variation of speed from one steady load to another follows a straight line from no load to full load. Where the characteristic is nonlinear, the slope of the speed-vs.-load curve varies throughout the load range. Thus the response of the governor to speed or load change is different in one part of the load range than in another. This is less important in a single electric set than in parallel electric sets where the droop characteristics of governors should be closely matched in order to share the load proportionally.

If load is raised from no load to some steady load, the electric set will operate at a certain steady speed at that load. If load is reduced from full load to that same steady load, the electric set may operate at a slightly different steady speed. This difference in speed at a given load, depending on whether the load has been reached by increasing from a lower load or decreasing from a higher

Engine: Detroit Diesel Allison 16V-71T.
Governor: Woodward PSG—Isochronous Regulation
One Step Application and Removal of Full Rated Prime Power 0.8P. F. Load.



Voltage Performance shown for Specific Voltage Regulator
Specified Voltage Bandwidth ±½%
Voltage Rise 9% — Voltage Dip 7½%
Recovery Time 1.7 seconds — Recovery Time 1.4 seconds
Load Removed — Load Added



Specified Frequency Bandwidth ±¼% (±0.15 cycle)
Frequency Rise 4% — Frequency Dip 3.3%
Recovery Time 0.8 seconds — Recovery Time 1.3 seconds
Load Removed — Load Added

Fig. 7-3—Actual Strip Chart Recording of Transient Response of Turbocharged Diesel Electric Generating Set with Hydraulic Speed-Sensing Governor

load, is caused by hysteresis in the governing system. As long as the hysteresis of a particular governor is within the steady-load bandwidth, it is not objectionable.

Temperature changes at any steady load cause dimensional changes in governor internal components that may alter the governed speed at that steady load. This "temperature drift" effect occurs as the electric set warms up after starting and as ambient conditions change in the generator room. In some cases an operator will readjust the governor speed setting to compensate for temperature drift after the electric set has warmed up. If this is not practical, the governor can be equipped with an automatic temperature drift compensator.

If a governor without temperature compensation is adjusted for correct frequency when fully warmed up, frequency will be off temporarily at each subsequent restart until the electric set again warms up. Some frequency variation, resulting from temperature variation, is permissible provided that the total frequency variation caused by temperature and load changes does not exceed the frequency variation tolerance of the load. Otherwise, temperature compensation must be incorporated in the governor. The supplier can judge the need for temperature compensation based on the specified frequency performance.

Types of Governors

The two types of governors commonly used for diesel-electric set engines are hydraulic and electric. A hydraulic governor senses speed with revolving flyweights and employs a hydraulic actuator to operate the engine fuel control linkage. An electric governor senses speed electrically and also employs a hydraulic actuator to operate the fuel control linkage. By using electrical rather than mechanical speed sensing, the electric governor can be made sensitive to smaller variations in engine speed and normally achieves very fast engine response. Either type may employ electric load sensing to quicken response and to provide a means of load sharing during isochronous operation of paralled electric sets. Some hydraulic governors and most electric governors can be adjusted for zero speed regulation.

Hydraulic Governor

In a hydraulic governor, rotating centrifugal flyweights control a pilot valve which in turn controls the position of a power piston that actuates the fuel control linkage. At steady speed, the flyweights and pilot valve are in a neutral position, with the flyweight force balanced by a speeder spring. The pilot valve is positioned to shut off oil flow to or from the power piston so that trapped oil holds the power piston in a fixed position.

When load is removed and speed increases, the flyweights lean outward and displace the pilot valve to permit some trapped oil to escape so that the power piston moves in a direction that reduces fuel flow to the engine. Displacement of the power piston moves a lever that compresses the speeder spring to return the flyweights and pilot valve to their neutral position, again trapping oil and holding the power piston in its new position.

When load is added and speed decreases, the flyweights lean inward and displace the pilot valve to admit oil pressure to the end of the power piston. The power piston moves the fuel control linkage to increase fuel flow. Displacement of the power piston lever decompresses the speeder spring to permit the flyweights and pilot valve to return to their neutral position, trapping oil to hold the power piston in its new position. An adjustable stop limits maximum displacement of the power piston and thereby limits maximum fuel flow to the engine.

Hydraulic Governor with Load Sensing

Hydraulic governors are available with an electric load sensing feature. Response is quicker since the governor may react in response to a change in generator load current before it senses a speed deviation. Generator output current and voltage are monitored to produce a load signal. The load signal operates a solenoid to control a pilot valve and power piston that is mechanically connected to the fuel linkage in parallel with the speed-sensitive flyweight-controlled actuator. Solenoid force, proportional to load, is balanced against a spring. Change of load moves the pilot valve to cause displacement of the power piston, which changes fuel rate. At the same time, spring compression is altered to return the pilot valve to neutral and hold the power piston in its new position.

The electrohydraulic load-sensing portion of the governor reacts immediately to load changes and adjusts fuel rate to match load. The mechanical-hydraulic speed-sensing portion responds as necessary to maintain speed.

If parallel electric sets are being regulated isochronously, their load-sensing circuits must be interconnected as a means of sharing the load between electric sets in proportion to their capacities.

Electric Governor

Electric governors sense speed by sensing alternator frequency or the frequency of a magnetic pickup. Voltage spikes derived from the generated frequency are rectified and filtered to provide a D.C. voltage level proportional to the frequency. An adjustable constant voltage source serves as a speed reference. The frequency signal and reference signal are summed algebraically to produce an error signal that is applied to a solenoid to control the pilot valve of a hydraulic actuator.

The power supply for the reference signal transforms power from the alternator output and rectifies it. Zener diode circuitry in the power supply maintains constant voltage to the reference signal circuit, which also contains a zener diode for further refinement of the signal. A voltage divider permits manual adjustment of the reference signal level to establish the speed setting of the governor.

Sensing frequency from a magnetic pickup has the advantage that the pickup generates a measurable voltage through the full speed range from start-up to synchronous speed, whereas alternator excitation normally does not take effect on start-up until the electric set reaches 85% of rated speed. Therefore an electric governor that senses alternator frequency normally must have a mechanical-hydraulic governor backup that senses speed mechanically until the electric set speed is high enough to provide voltage for alternator frequency sensing. Otherwise the engine might overspeed on accelerating from start-up, and actuate the overspeed trip, causing the engine to shut down.

The mechanical-hydraulic section of the governor also serves as a safety backup to provide automatic speed control if the electrical signal is interrupted. The flyweight speed setting is above the normal operating range and the backup does not function to govern speed unless there is an electrical failure. Even without failure of the electric speed sensing, the governor can be operated as a hydraulic governor, if desired, simply by lowering the mechanical-hydraulic speed setting and raising the electrical speed setting so the hydraulic section has complete control.

Electric Governor with Load Sensing

When load sensing is incorporated in an electric governor, the governor senses and responds to the electrical load and the rate of change of electrical load as well as to generated frequency. The load signal and rate signal are summed algebraically with the speed signal and speed reference voltage. The resulting error signal is applied to a solenoid controlling the pilot valve of a hydraulic actuator.

The load signal is transformed from the alternator current and voltage output. The instrument transformers may be used for this purpose. The derived load rate signal is maximum during initial stages of load change, then decays to zero. The load rate signal, responding to load changes as they occur and before they affect engine speed, enables the governor to hold speed transients to a minimum.

Isochronous Regulation

To achieve zero regulation, a governor must include an integrating effect that causes the speed-controlled actuator to assume a new position for each steady load even though the speed and therefore the input to the speed-sensing device is unchanged. In hydraulic governors and some electric governors, this effect is achieved by the hydraulic actuator and linkage. As long as there is a speed error signal, the actuator moves in a direction to

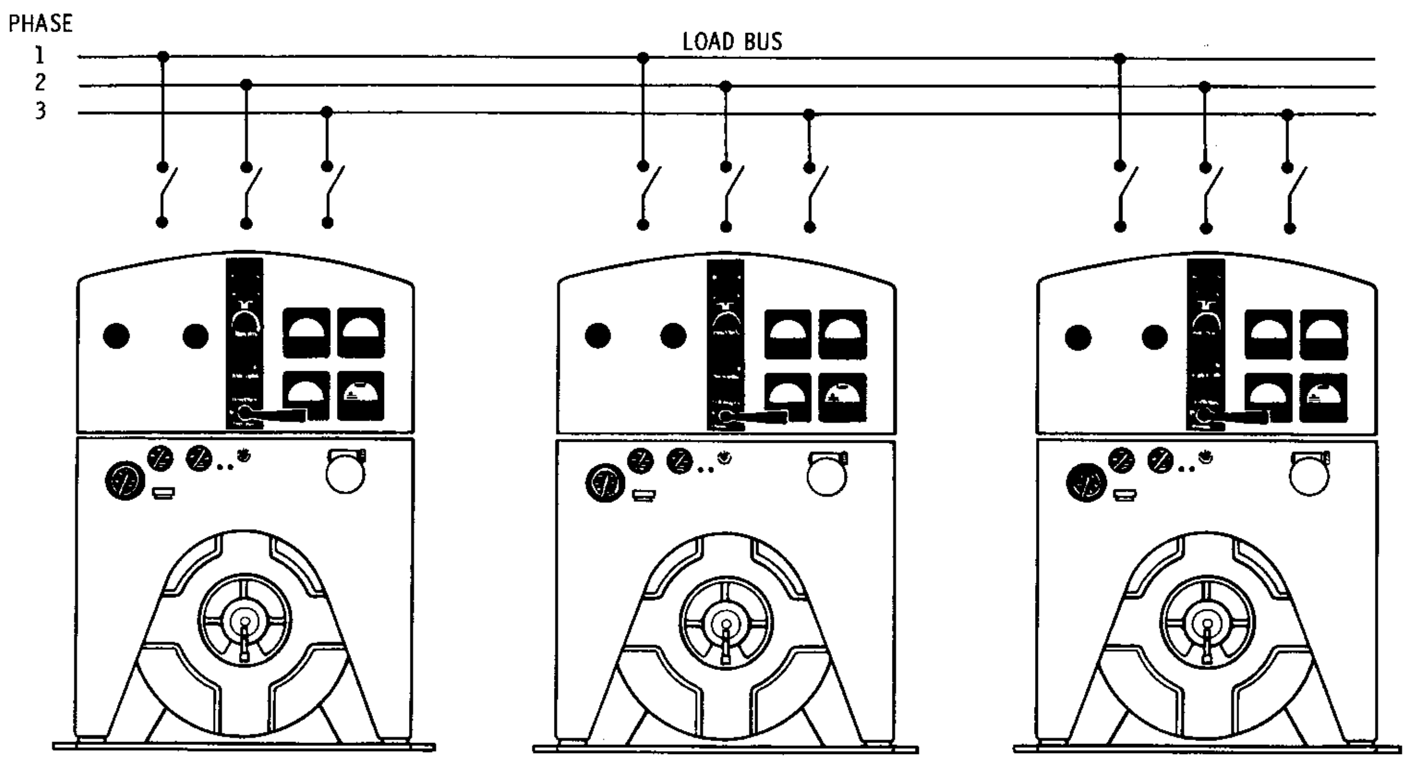


Figure 7-4. Three-Phase Engine-Driven Generators Connected in Parallel

adjust the fuel rate and correct the error. When the error reduces to zero, the actuator stops.

One form of electric governor performs the integrating function in the electrical circuits that produce a control signal to the actuator. The hydraulic actuator then is merely a proportional actuator whose output position is proportional to its input signal.

Parallel Load Sharing

When two or more electric sets are connected to the load in parallel, it is essential to make each unit carry its share of the load so no set will be overloaded when the plant approaches full load. Proper load division occurs automatically when the electric sets are controlled by drooping governors, provided that the regulation and other characteristics of the governors are closely matched. When regulation is isochronous, however, load-sensing governors are required, interconnected by a load-sharing circuit.

Alternators operating in parallel are locked together in synchronism, which means that their frequencies are always equal whether they are sharing the load proportionally or not. When all fuel controls are in approximately the same position, the paralleled electric sets are sharing the load in proportion to their KW ratings.

Droop-Droop Paralleling

In the simplest method of parallel operation, all of the electric sets operate with speed droop. It is essential that all governors be adjusted for the same droop with exactly the same speed setting at full load. The linearity, hysteresis and temperature drift of the governors should be closely matched.

A drooping speed governor relates fuel control position with speed since each steady load has a corresponding speed—for example, 1800 RPM at full load, 1827 RPM at half load, 1854 RPM at no load. Since paralleled electric sets are at the same speed, their fuel controls automatically assume the same position, corresponding to that speed, provided they have the same droop and speed settings. Thus they share the load proportionally.

Isochronous Paralleling

A governor adjusted for zero regulation, not having a speed droop that equates speed and load, must have some means of sensing load differences between the paralleled electric sets. Therefore governors equipped with load sensing are employed in parallel electric sets that must operate isochronously. The governors' load-sensing circuits are interconnected by a load-sharing circuit so that they sense and respond to differences in load between the paralleled electric sets. If one electric set is carrying more load than another, its load signal voltage is higher, causing current circulation between the governors and biasing the control circuits to make the overloaded set reduce its fuel rate while the underloaded set increases its fuel rate.

Droop-Isochronous Paralleling

Since isochronous paralleling requires a load-sharing circuit, governors not equipped with load sensing cannot be used for isochronous paralleling. Normally such governors are adjusted for equal droop, and the paralleled electric sets operate as a drooping system. However, there is a method of paralleling an isochronous governor with drooping governors to provide isochronous frequency regulation over part of the load range. None of the governors must be load sensing. The isochronous range can be extended over the complete load range by manually readjusting the speed settings of the droop governors when the operating range changes.

This paralleling method is not as desirable as using load-sensing governors, with a load-sharing circuit, which provides isochronous frequency control over the complete load range without any readjustment. If interested in droop-isochronous paralleling, contact a Detroit Diesel Allison Distributor for information.

Adding Parallel Electric Set

When a new electric set is installed in parallel with an existing set, the same considerations apply. Proper matching of governor characteristics will assure satisfactory operation of the system. Isochronous regulation requires load-sensing governors connected by a load-sharing circuit.

It is not necessary that the engine and alternators of the new and existing electric sets be the same. It is essential that governors be properly applied to make the frequency regulation characteristics of the electric sets the same. Linearity, hysteresis and temperature drift, as well as regulation, should be closely matched. A new electric set powered by a Detroit Diesel engine is compatible with an existing set powered by a different make engine, provided that the governors give the electric sets the same frequency characteristics.

Air Cleaners

Clean air is essential to the life and efficiency of an engine and should, therefore, receive serious consideration when planning an installation. Any dust, lint, or other foreign matter entering the cylinder causes excess wear on the piston rings, cylinder walls, valve mechanism, and bearing surfaces. It may accumulate in the lubricating oil, thus requiring more frequent oil changes. To insure a clean supply of air, the air should be drawn from an area that is clean and relatively cool, and the air must be filtered before entering the engine intake.

Filtering is provided by one or more air cleaners furnished with the engine. The proper air cleaner will remove the dirt in the atmosphere, pass the required volume of air, and maintain its efficiency for a reasonable period of time without being cleaned or serviced.

Air cleaners are either the oil bath type or the dry type, which uses a paper or felt filtering element. Either type is adequate for diesel-electric sets. Air cleaners are rated as light-duty, heavy-duty or extra heavy-duty. For most indoor standby applications, a light-duty air cleaner is satisfactory. If the engine operates in a dusty atmosphere, it may require a heavy-duty or extra heavy-duty cleaner.

Air cleaners can operate effectively only if they are given proper maintenance. A damaged filter element passes dirty air. A clogged air cleaner restricts air flow and reduces engine power. Manufacturer specifications for maintenance should always be followed. For these reasons, the air cleaner should always be accessible to the operator.

When a dry-type air cleaner is employed, it is recommended that the engine be equipped with an intake restriction alarm. The alarm should give both audible and visual notice when the intake air flow restriction exceeds the limit specified by the engine manufacturer.

For information on air cleaners and their applications. refer to Engineering Bulletin No. 39 and to Service Topics Jan.—Feb. 1973, both of which may be obtained from a Detroit Diesel Allison Distributor.

Remote Air Intake

Normally an air cleaner is mounted directly on the engine and draws its engine intake air from within the room. However, when the engine is confined in a small room where circulation and ventilation are restricted, fresh outdoor air can be provided by a duct from a wall ventilator to the engine air cleaner. Total restriction of duct and air cleaner must not exceed the limits specified by the engine manufacturer. There should be as few bends as possible, and duct length should be minimized by locating the electric set close to the outside wall.

The air cleaner normally would be located at the engine intake, although it could be outside the room or at some intermediate point within the duct. Outdoor location of the air cleaner is not recommended since it may invite vandalism that could disable the engine.

Engine Crank-Start Systems

To start a diesel engine, it must be cranked until compression ignition has been achieved and the engine is running on its own. Compression ignition occurs once the compressed air within a cylinder gets hot enough to burn the fuel being injected into the cylinder.

The Detroit Diesel 2-cycle engine achieves compression ignition sooner than a 4-cycle engine. The reason is that the cylinders warm up faster because each piston compresses air every time it goes up, rather than every other time as it does in a 4-cycle engine.

Fast cranking helps build up compression and minimizes cooling time between compression strokes, thus aiding heat build-up in the cylinder. So it stands to reason that the faster the engine is cranked, the sooner it will start.

Cranking is performed by a battery-powered electric motor or by an air motor or hydraulic motor. The cranking speed depends on the capacity of the cranking system, ambient temperature and oil viscosity. To assure quicker starting, it is therefore important to follow the engine manufacturer's recommendations for the starting system's capacity at a given ambient temperature.

For reliable starting at low ambient temperature, it may be necessary to employ starting aids, such as jacket water heaters, lube oil heaters or fuel heaters, as recommended by the engine manufacturer.

Some engine manufacturers recommend pre-lubrication of their engines prior to starting. To do this automatically, a pre-lubrication pump must be added to the engine. However, with proper routine maintenance and specified lube oil, Detroit Diesel Engines do not require pre-lubrication; consequently the pre-lube pump is not necessary.

Types of Cranking Systems

Electric cranking is the most common method of starting diesel-electric sets because of economics and ease of control. The engine is cranked by a battery-powered electric starting motor furnished as part of the engine assembly. The motor is connected by cables to batteries located on or near the electric set. When the engine starting contacts are closed either manually or by the automatic starting system, the batteries cause the starting motor to crank the engine until it starts or until a time limit in the automatic starting system stops the cycle.

Other types of cranking systems are air or hydraulic. In these systems, either an air motor or a hydraulic motor is used in place of the electric cranking motor.

Air Starting

Air starting may be used when compressed air of sufficient pressure is readily available. An air starting system usually is employed only for manual starting since automatic air starting systems tend to be complex, particularly if numerous start attempts are required. Quite often it is necessary to include a battery for a D.C. control system in the interest of economics.

Air compressors generally operate from line voltage. Thus, should the engine fail to start during a power failure, outside assistance will be required unless an adequate reserve of pressurized air is available from the air tank. One alternative is to drive the air compressor with a small engine.

Hydraulic Starting

Detroit Diesel Allison's hydrostarters can be applied to electric sets, either for manual starting or automatic starting. The hydrostarter uses pressurized hydraulic fluid to operate a hydraulic motor. Several pressure vessels may be employed in an automatic starting system to obtain multiple starting attempts.

Normally, an engine-driven pump recharges the sytem for subsequent starting. However, a hand charging pump may be provided as additional security in case all pressure vessels are depleted before the engine starts. An alternative is a small charging pump driven by a battery-powered D.C. motor.

Electric Starting Batteries

To insure optimum cranking current, batteries must be provided with total ampere-hour capacity not less than that recommended by the engine manufacturer. In addition, the battery cables must be of adequate size to minimize voltage drop.

Recommendations for SAE rated lead-acid batteries are shown in Detroit Diesel Engine specification sheets. Batteries are connected in series when 24 or 32 volts are desired. For larger engines, multiple batteries are connected in series/parallel to provide both the desired voltage and increased ampere-hour capacity.

There are two types of SAE battery electrical ratings. One is the 20-ampere-hour rate. It indicates the lighting ability of the battery. The fully charged battery is brought to a temperature of 80 degrees F and is discharged at a rate equal to 1/20 of the published 20-hour capacity in ampere-hours until the voltage falls to 1.75 volts per cell. This rating is not the primary consideration for diesel-powered electric sets.

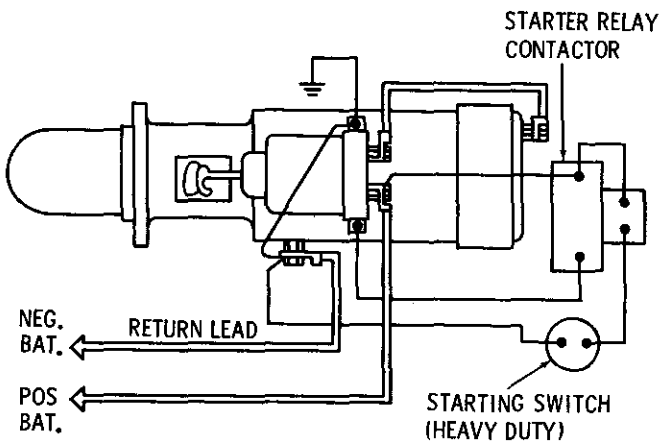


Figure 9-1. Typical Manual Electric-Starting System

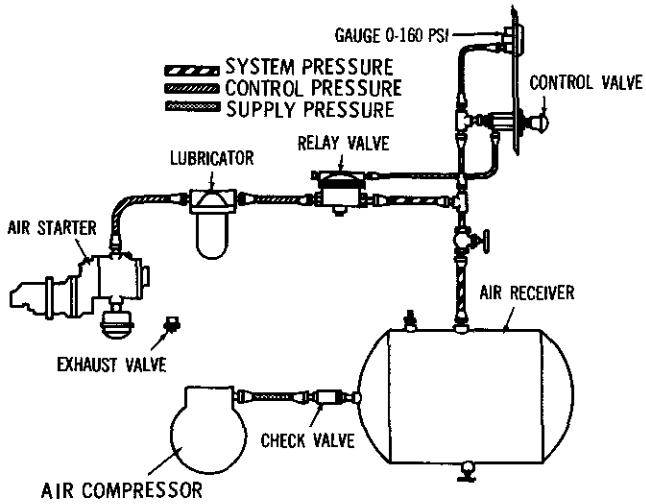


Figure 9-2. Typical Remote Control Air-Starting System

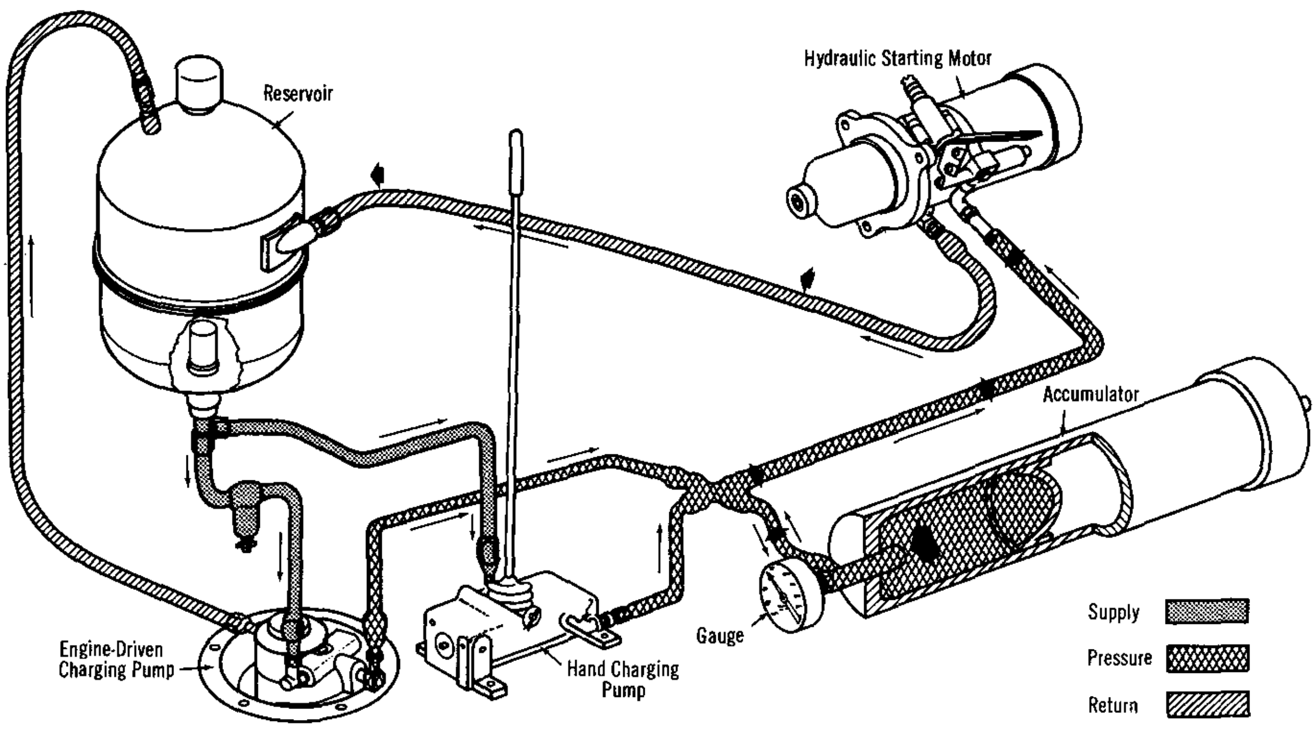


Figure 9-3. Typical Hydraulic Starting System

The other type of SAE rating is a cold rating at 0°F. This type of rating indicates the cranking ability of a fully-charged battery at low temperature. There are three versions of this rating:

A. The number of minutes required for the battery to reach a terminal voltage equivalent to 1.0 volt per cell when discharged at 300 amperes with an initial electrolyte temperature of 0°F.

B. The terminal voltage of a fully-charged battery taken 5 seconds after the start of a discharge at 300 amperes with an initial electrolyte temperature of 0°F. This rating is applied to automotive type batteries.

C. The terminal voltage of a fully-charged battery taken 30 seconds after the start of a discharge at 300 amperes with an initial electrolyte temperature of 0°F. This rating is applied to batteries intended for diesel service.

The cold ratings at 0°F are significant for electric-set starting, particularly if it is likely that low starting ambient temperature will be encountered. SAE cold rating C should be applied to batteries for diesel-electric sets.

The batteries should be located as close to the engine as possible to avoid the voltage drop caused by long leads. In addition, batteries should be readily accessible for servicing. Batteries are usually mounted on the base of the electric set or located in a separate rack next to the engine. If batteries are located relatively far from the starting motor, larger cables must be used to avoid excessive voltage drop. Table 9-4 shows cable size according to length of circuit.

While lead-acid batteries are the most common, nickel-cadmium batteries can be used at the customer's option. Although more expensive, nickel-cadmium batteries offer maintenance and safety advantages over the lead-acid type. Should you elect to use nickel-cadmium batteries, consult your local Detroit Diesel Allison Distributor for recommendations.

It may be useful to have some generator room lights powered by the engine batteries, especially if the set is to be started manually. The extra load of the lights must be taken into account in specifying battery capacity and also in specifying the capacity of a battery-charging generator if the engine is to be equipped with one.

Battery Charger

Batteries must be recharged after the engine starts, and battery charge must be maintained when the electric set is shut down for long periods. For the latter purpose, a static battery charger converts an A.C. input to a D.C. output at the rated voltage of the batteries. A static battery charger is required for standby electric sets and is recommended for all stationary electric sets.

If the engine is equipped with a battery-charging generator, the generator recharges the battery after a start; and the static charger (usually a "trickle charger") maintains battery charge during nonoperating periods. However, this method is not generally recommended unless an interlock is provided to automatically disconnect the charger that is not in use.

A preferred system is to use a "float battery charger" and eliminate the battery-charging generator. The input of the battery charger is connected to the A.C. load bus. Thus, in the case of a standby electric set, charging power is always available, being supplied by either the normal or the emergency A.C. source. A float battery charger is a static regulated charger having sufficient capacity to recharge the battery after a cranking cycle; it then tapers to a minimum or "float" charge rate sufficient to offset the battery self-discharge and to maintain full battery potential at all times. If properly adjusted, it is not likely to dry out the batteries as can happen with a trickle charger. The float charger offers the best insurance against low batteries since it is a constant-operating, single-source device. It is twice as efficient as an engine-driven battery-charging generator, requires less maintenance, and provides longer battery life.

Chargers are generally available with one of the following outputs: 6, 12, 24, 32 or 36 volts D.C. In most cases they have taps for several input voltages from 120 to 600 volts. A battery charger preferably should have an ammeter or voltmeter and a lamp to indicate operation. In addition, its components should be protected by a fuse or circuit breaker.

Cold Weather Starting Aids

Most standby electric sets, being located in heated buildings, are unlikely to encounter cold starting problems. However, it might be difficult to start a set in winter if it is located in an unheated building or in a room having open exterior doors or ventilators. If the engine is exposed to temperatures of 40°F or below, it will be necessary to utilize special starting aids to assure prompt starting in cold weather.

Cold weather starting can be aided by using an immersion heater in the engine oil pan or water jacket or both. The heater is thermostatically controlled and operates only as needed to keep the engine warm. The heater should be equipped with a switch that automatically shuts off the heater after the engine is running.

Heaters should be specified in terms of the oil or water temperature they must maintain in the engine (typically 90°F). The lowest likely ambient room temperature should be specified so the electric-set

12-VOLT CIRCUIT	
CABLE SIZE A.W.G.	TOTAL LENGTH
0	10 ft.
00	12 ft.
000	16 ft.
0000	20 ft.
Two Parallel Cables	
00 00	24 ft.
000 000	32 ft.
0000 0000	40 ft.
24- AND 32-VOLT CIRCUITS	
CABLE SIZE A.W.G.	TOTAL LENGTH
0	10 ft.
00	15 ft.
000	20 ft.
0000	30 ft.

Table 9-4. Starting Motor Cable Sizes

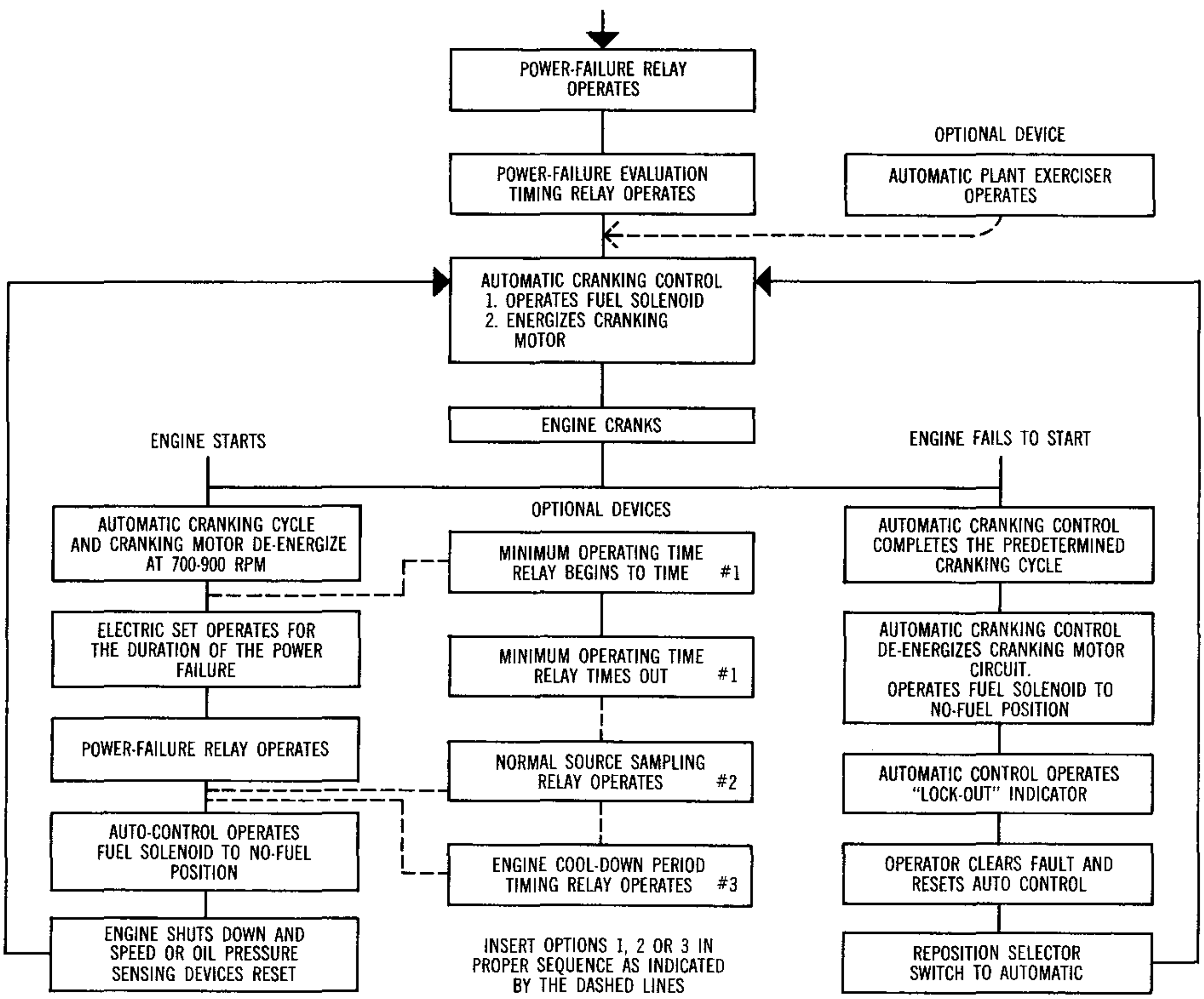


Figure 9-5. Automatic Starting Operating Sequence

supplier can select the proper heater to fit the conditions.

The most practical method of facilitating quick starting is to heat the power room rather than adding devices to the engine, because an even room temperature will reduce condensation and corrosion which can be harmful to the complete electric power system. If it is necessary to add a device, a water jacket heater is recommended, since it will maintain a uniform block and head temperature and reduce thermal shock stresses in the engine.

Automatic Starting (Electric)

To achieve automatic starting (as often applied to standby emergency electric sets), the necessary intelligence circuits and devices must be added to the system to start and stop the engine when signalled by the command relay. This intelligence is provided by adding automatic control devices in the fuel control and cranking systems.

The intelligence and functions which must be built into the cranking circuit are:

1. Recognize a start signal.
2. Energize the cranking motor on command.
3. Time the duration of the cranking interval and number of attempts to start.
4. Recognize that the engine started.
5. Recognize that the engine failed to start.
6. Deenergize the cranking motor.
7. Deenergize the starting circuit if the engine fails to start.
8. Provide an indication that the starting system has deenergized or locked out because the engine. failed to start.

An automatic starting control is designed so that when a start signal is received from the command relay the engine will be cranked according to a preset program. The program consists of one or more cranking intervals of a predetermined duration, and a rest interval between each cranking attempt.

Automatic starting controls are commercially available for almost any number of attempts and any cranking duration. However, programming many cranking attempts is undesirable. Keep in mind that failure to start even after only one sustained cranking effort probably indicates an engine malfunction. If a fault exists, repeated cranking attempts are futile until the malfunction is corrected. While it is true that a battery recuperates somewhat during each rest period between cranking attempts, each attempt depletes the cranking potential. Eventually repeated attempts will run down the batteries. It may be necessary to obtain outside assistance to start the engine after the fault has been cleared.

To avoid starting problems, the cranking cycle should limit the number of attempts to no more than two, and the duration of the attempts should not exceed 20 seconds each. The rest interval should be a minimum of 10 seconds.

If the engine fails to start in the prescribed cranking time, then the cranking circuit must be deenergized to prevent further drain on the battery, and a signal must indicate that the starting cycle has been completed. This indication is generally a lamp mounted in the autostart control panel which is labeled overcranking cutout or lockout. Once a lockout has been completed, it is necessary to manually reset the automatic control before another starting cycle can be initiated.

When the engine fires and becomes self-sustaining, it is necessary to deenergize the cranking motor to prevent it from overspeeding. The automatic starting control must include a device which will sense that the engine has attained a self-sustaining speed of 700 to 900 RPM before deenergizing the cranking motor. Either an engine-mounted speed sensing switch or a fuel oil pressure switch is generally used for this purpose.

Some automatic-starting installations incorporate motor-operated air intake louvers and/or radiator exhaust louvers. Contacts are provided to signal these devices to function when the engine is signalled to start. Speed sensing or fuel oil pressure sensing devices can be used for this purpose as long as the contacts have the required capacity.

Automatic Shutdown

Usually an electric set that is started automatically also is stopped automatically. Automatic engine shutdown may be accomplished by adding a solenoid which will shut off the fuel supply to the injectors. However, in a Detroit Diesel engine, a more positive shutdown is achieved by operating the injectors to the "no fuel" position instead of shutting off the fuel supply ahead of the injectors. A solenoid is employed either to operate the governor to a no-fuel position or to override the governor and place the injector racks in the no-fuel position. Either of these methods is preferred since operating the injectors to the no-fuel position effects a positive, immediate shutdown. Shutting off the engine fuel supply is not desirable because it takes longer to achieve a shutdown, and inserting a shut-off solenoid in the fuel supply line makes the system more vulnerable to trapping of air, which could delay or even prevent a subsequent restart.

No matter which method is used to shut down the engine, the device must automatically reset or be operated so as to make fuel available as soon as a start signal is initiated.

Engine Fault Monitoring

Most commerically available automatic starting controls have provisions for monitoring certain engine operating conditions since an automatic-starting electric set is normally left unattended. Generally, the monitoring devices are connected to the standard engine protection devices. If the preset limit in any of these conditions is exceeded, the engine is shut down automatically and an alarm or indicating light is activated. Some control manufacturers offer one indicator lamp to indicate that a fault has occurred. Others provide lamp indicators to identify each fault condition. This is discussed further under Automatic Electric Set Protection Systems.

Starting Control Location

The location of the automatic starting control is optional. It can be separately mounted, or located in the control cabinet or in the transfer switch enclosure. Ideally it is desirable to locate all controls and instruments in a centralized panel to facilitate operation.

Automatic Starting (Air or Hydraulic)

Electric cranking systems are the most popular for starting engines. However, it may be more practical to employ either an air or hydraulic starting system in certain installations.

If automatic starting of engines equipped with air or hydraulic cranking motors is required, the foregoing description of automatic electric cranking can be used as a guide for determining the functions which must be built into the system to provide automatic starting.

When air or hydraulic cranking systems are automated, it generally becomes an electro-air or electro-hydraulic system since the most practical and economical means of achieving automation is to add electrical control devices.

Should you want an automatic air or hydraulic starting system, consult your local Detroit Diesel Allison Distributor who will design a system to meet the requirements of your particular installation.

Selector Switch

All autostart controls are equipped with a selector switch to permit selection of different operating modes. The basic requirements are automatic and off. If only these two positions are provided, the off position permits manual operation. However, maximum benefits are realized when the automatic starting control includes a four-position selector switch. The purposes of the four positions are:

OFF-
Cut out the starting circuit so that the engine cannot be started. This is intended as a safety precaution to prevent engine starting during maintenance.

AUTOMATIC-
This places the engine in its intended standby mode.

AUTOMATIC TEST-
To facilitate testing the automatic operation, this position is provided to override the power-faulure relay, thus simulating a normal-source power failure. (This could also be done by placing a disconnect ahead of the power-failure relay).

MANUAL-
This position is intended to permit manual operation of the electric set, in the event the automatic system fails. It can also be designed to bypass the engine protection devices. Thus, in a case where a protection device malfunctions and would shut the engine down although the engine is in good running condition, the engine can be operated manually for the duration of the power failure.

The normal position for the selector switch is in automatic position. If the operator leaves the installation without the switch in that position, the electric set will not provide the service it was intended to. To prevent this, a light should be mounted in an obvious location in the control panel to indicate whether or not the switch is in the normal position. The lamp can be connected to light when the selector is in its normal automatic position, or it could light up as a warning when the selector is not in the automatic position. (In the latter case, it is referred to as a switch-off-normal lamp). An extra advantage is gained by connecting the lamp to light when the switch is at the automatic position, because it then also serves as an indication that battery power is on.

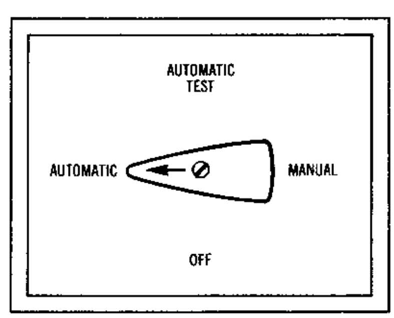


Figure 9-6. Operation Selector Switch

Exerciser for Standby Systems

To make sure that the standby electric power system is in good working order and ready to respond instantly in an emergency, the system should be operated periodically. Preferably the complete system should be tested, including simulated power failure with the active load being transferred to the electric set. Starting the engine without transferring the load only shows that the engine runs. It does not indicate that the whole system is functioning properly.

Periodic exercising of the electric set under load keeps the engine in good starting and running condition. This exercising can be performed manually or by means of an automatic programmed control that starts the engine at regular intervals and operates it for a set period of time. This automatic exerciser is required if there are no operating personnel available to operate the electric set on a regular schedule. The programmed control may be connected directly to the engine starting system, in which case it exercises the engine and generator with a load bank. Or it may be connected to the power-failure relays to simulate a power failure and effect a transfer from normal power to the electric set so that the standby plant operates under active load. In this way, the engine, generator, relays, transfer switch, and the whole system are being checked out.

Since exercising helps keep the engine and plant in good operating condition and also demonstrates its condition, reliability is in direct proportion to the frequency of exercising. It is recommended that the complete standby plant be exercised at least once a month. Each exercise run must be long enough to bring the engine and complete electric set up to normal operating temperature. Deficiencies of some components, such as electronic control elements, oil seals, etc., may only show up after temperatures have increased.

The exerciser may be equipped with a recorder to provide a continuous history of starting, stopping and running times for all exercise periods.

Automatic Electric Set Protection Systems

To protect against costly damage to the engine and/or generator when an abnormal operating condition occurs in the engine, it is necessary to equip the engine with devices which will sense the abnormal condition and respond through the necessary circuitry and related devices to automatically shut the engine down. This automatic protection is recommended even though the set is manually operated and attended. The automatic protection will recognize an abnormal condition and respond to shut down the engine much sooner than the operator can.

The number of protective functions employed is based on the requirements of individual installations or the desires of the plant engineer. Minimum protection should include protection against high coolant temperature, low lubricating oil pressure and engine overspeed.

The installation of additional protective devices should be selected on the merits of necessity and their contribution to the automation of the system. Some of these protective devices for high oil temperature, loss of oil, low coolant level, and loss of coolant.

It should be noted that the degree of protection is only as good as the quality of the devices used. Therefore, quality and reliability in protection devices are essential. Not only must they function when required, but they must not malfunction and initiate a false signal, thereby stopping the electric set unnecessarily.

Emergency Shutdown

The purpose of the protection system is to shut the engine down when a fault occurs and thus prevent costly damage to the equipment. The longer it takes to shut down an engine on a fault condition, the greater the degree of damage. Normally, to stop the engine, the injector rack is positioned to the no-fuel position. However, to effect a positive emergency engine shutdown, Detroit Diesel adds an air shut-off to the fault circuit. This air shut-off operates simultaneously with the fuel shut-off solenoid to shut the engine down under fault conditions. This added emergency safety device produces immediate results because the engine cannot run without air. The air shut-off can be operated either manually or automatically, or both ways.

Load Disconnect

It may be desirable to connect the protection system to the circuit breaker shunt trips, particularly in paralleled power systems, so that the affected unit will not be motorized by the remaining electric sets that continue to operate.

In standby power systems, the necessary intelligence should be provided to recognize a fault condition when it occurs in the standby power system and to command a transfer back to the normal power source when it becomes available.

Coolant Protection

An engine coolant temperature sensing device, which will operate the fault shutdown system when the coolant temperature exceeds a preset value, must be included in the protection system. The temperature at which the device will operate is established by the engine manufacturer. As a rule, it will be set to operate at a value between 205°F and 210°F.

Some temperature-sensing devices cannot sense the loss of coolant or the presence of steam. To obtain the maximum protection for the cooling system, the protection device must be able to sense both the coolant temperature and loss of coolant or a second device which will sense the loss of coolant should be added.

Sometimes a shutdown can be avoided if the operator recognizes the high-temperature condition and corrects the fault before the temperature gets high enough to trigger the shutdown. To warn the operator when temperature rises above normal, a second temperature-sensing device can be inserted in the circuit which is preset to a lower operating temperature than the high-water temperature device. When operated, this second sensing device will sound an alarm to warn the operator that the coolant temperature is increasing. This enables the operator to clear the fault before the high water temperature protection device operates and shuts down the engine. Logically this warning device could be called a preliminary high water temperature alarm.

Low Lube Oil Pressure Protection

The sensing device that provides low lube oil pressure protection should be set to trip when the oil pressure falls below the engine manufacturer's recommended minimum operating pressure. As there is no oil pressure when the engine is shut down, this device is in the tripped position when the engine is not operating. Therefore, provisions must be made to disconnect the sensing device so that it does not impose a drain on the battery or prevent restart. Conversely, the device must be reconnected to arm the protection circuit when the engine is operating. This arming could be accomplished by a manually operated ON-OFF switch on attended units, but the arming device must operate

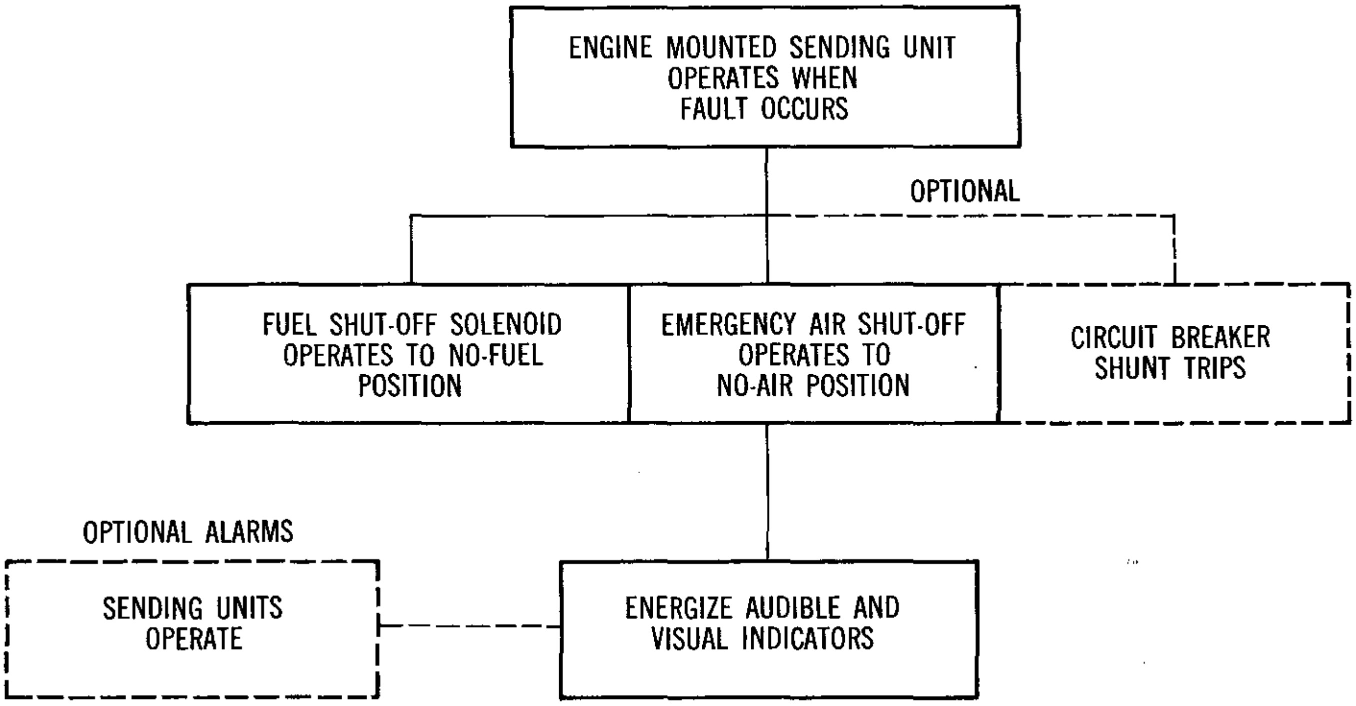


Figure 11-1. Block Diagram of Engine Protection Systems

automatically on automatic—starting models. The device used to arm the protection system automatically could be a fuel pressure-operated or speed-operated switch, of the normally open type, which closes when the preset fuel pressure or speed is attained.

If, when the engine starts, the arming device closes before the engine lube oil pressure opens the lube oil pressure sensing device, the engine will shut down. A time delay inserted between the arming device and the lube oil pressure sensing device will prevent unwanted engine shutdown during starting.

For instance, a fuel pressure switch used to arm the protection system may have a closing pressure of 20 PSI. Upon starting, this switch will close before the engine lube oil pressure has reached a sufficient value to open the lube oil pressure sensing switch. Therefore, to prevent a shutdown from occurring, a time delay between the fuel pressure switch and the lube oil switch will delay completing the arming circuit until the engine has built up enough oil pressure to open the lube oil pressure sensing device. In a manually starting electric set, an automatic time delay is not required because the operator does not close the arming switch until the lube oil pressure is built up.

Overspeed Protection

Engine overspeed is often misinterpreted to mean that the engine runs away. A diesel engine powering an electric set seldom runs away. However, it is possible through some abnormal condition for an engine to reach a speed above its normal operating range which would cause the generator to deliver higher frequency than desired. It might also operate the generator above its allowable speed, thereby causing the generator to throw its windings. Therefore a reliable overspeed protection device should be used. The recommended trip speed of the overspeed device is 15% above the rated full-load synchronous speed.

Fault Indicators

When a fault occurs in the engine, the fault can be signaled by visual and/or audible indicators in the control cabinet or switchgear enclosure. Audible fault indicators are not always a necessity, particularly in standby power systems where an electric set shutdown results in a loss of lighting. In installations where a shutdown would not be obvious, an audible indicator should be used.

Various types of visual indicators are available, ranging from pop-out type indicators to battery-powered colored lamps. Some installations use only a single indicator to monitor all faults. It is preferable to have an individual indicator for each fault, especially in installations where an inexperienced operator is on duty, so as to direct him to the affected protection device and thereby reduce troubleshooting time.

It is advisable to locate visual indicators in a central location, preferably near the automatic starting controls and/or other indicators.

Hydraulic or Air-Operated Engine Protection Systems

In some installations it is more practical to use a hydraulic or air-powered protection system. Although the devices and other related equipment are different for a hydraulic or air system, the functions must be the same as in an electrical protection system.

For further information on hydraulic or air operated protection systems, consult your local Detroit Diesel Allison Distributor.

Supplementary Alarm Systems

Some fault conditions do not require that the engine be shut down. However, any abnormal operating condition should be brought to the attention of the operator. Since these faults do not shut the engine down, they should incorporate an audible indicator. In addition, individual visual indicators aid troubleshooting. Some of these fault alarms are:

- Battery charging system failure,
- Low storage tank fuel level,
- Low day tank fuel level,
- Low coolant level when engine is not running,
- Low oil level when engine is not running,
- Air intake or exhaust louver failure,
- Room ventilation fan failure,
- Low voltage.

Engine Operating Status Instrumentation

Visual indicators are required to permit the operator to observe the operating status of critical engine support systems such as the lubrication and cooling systems. Therefore it is necessary to monitor lubricating oil pressure and coolant temperature.

Generally, mechanical type instruments are used which are engine mounted either in a separate panel or near the set-mounted control cabinet. However, electrically-operated instruments are available if remote mounting is required.

Aside from oil pressure and coolant temperature gauges, another essential instrument is the battery charging rate ammeter. If the battery charger is engine driven, the ammeter is mounted on the engine. If a static battery charger is used, the ammeter is included in the charger cabinet.

Other instruments are sometimes specified which are not essential but helpful. These include:

Engine oil temperature gauge - not essential but if used indicates the actual temperature of the lube oil. If the oil is not circulating properly through the oil cooler because the cooler is plugged or is bypassing the flow of oil, the temperature of the oil could exceed safe operating limits.

Tachometer - the use of a panel-mounted tachometer on an electric set that has a frequency meter is of little value since frequency is a product of speed. As a rule, the frequency meter is more accurate than the engine-driven tachometer. Therefore, it is better to have an accurate hand-tachometer for checking than to rely on the engine-driven tach.

Exhaust temperature gauge—the coolant temperature will increase as exhaust temperature increases, and conversely the exhaust temperature will increase as the coolant temperature increases. Therefore the exhaust temperature gauge does not normally add enough information to justify its cost.

Individual cylinder exhaust temperature indicator - individual thermocouples or pyrometers may be inserted in the exhaust manifold at each cylinder to monitor exhaust temperature and to provide an indication that the load is equally shared among all the cylinders. These are not required on Detroit Diesel engines. Before specifying these devices, their cost should be weighed against the minor economic benefit of being able to observe and adjust load differences among individual cylinders.

Exhaust back pressure indicator - except in unusual cases, exhaust back pressure generally will increase over a period of time as a result of accumulated carbon and corrosion or rust buildup. It is therefore more logical to provide a plugged hole in the exhaust system for insertion of a manometer to periodically check the back pressure.

Power Status Indicators

Assurance that the electric set is producing the desired level of electrical power is obtained by permanently connecting electrical measuring meters in the power circuit. These meters enable operating personnel to observe the status of the power output and, if necessary, to take the appropriate action to correct it to the desired level.

The number of electrical measurements to be monitored in a given installation is determined by evaluating their individual contribution to the successful operation of the total system. Factors which influence this decision are:

1. Application
   Peaking power
   Prime power
   Standby power

2. Type of power system
   Single electric set
   Paralleled system

3. Quality of power demanded by the equipment connected in the load
   Does the load require precise power
   or is a commercial grade acceptable?

4. Operating Personnel
   Is the system under the supervision of
   untrained operating personnel?

Required Power Status Indicators

The minimum power status indicators required for any electric-set installation are:

Voltmeter,

Ammeter,

Frequency meter (for A.C. systems only).

A voltmeter is connected in the circuit to measure the line voltage. In A.C. circuits, it may also be connected to measure the phase-to-neutral voltage. A single voltmeter can monitor several different voltages by means of a selector switch. To help maintain equal voltages between the phases of a multiphase A.C. power system, the voltmeter is connected through a selector switch which permits the operator to monitor each of the phase-to-phase voltages. The voltmeter can be made more versatile by providing a selector switch which will allow it to monitor both the electric-set voltage and the normal-source voltage.

An ammeter is connected in the circuit to monitor the current flowing in the power circuit. For reasons of economy and meter size, current transformers or shunts are used to reduce the current flow at a given ratio through the ammeter. A current transformer should be inserted in each phase of a multiphase system so that the load balance in each phase can be observed. A single meter connected through a drum-type phase selector switch is generally used for this purpose.

A frequency meter indicates the number of cycles per second (hertz) being produced by the generator. Since frequency is a product of speed, frequency is automatically controlled by the fuel-control governor of the engine. The desired frequency setting can be manually adjusted.

Three types of frequency meters common to power generation are:

Vibrating reed type,

Electromagnetic type,

Transducer type.

For most applications, the vibrating reed type is acceptable and is the least expensive. It includes a series of reeds, each tuned to a different frequency. The frequency of the generator output is indicated by the particular reed that vibrates with a visible amplitude while adjacent reeds vibrate at low amplitude or not at all.

However, a certain amount of error can be expected when adjusting the frequency to a given value with a particular meter. Because of tolerances in the reed material, the reeds do not vibrate at the same magnitude on all meters. The magnitude at which the reeds vibrate may also be influenced by resonant vibrations from an outside source. Consequently, the meter or the control cabinet should have vibration isolators.

The electromagnetic and transducer types provide a direct reading scale to indicate frequency output. The transducer type has become more popular in the past few years because of its accuracy and durability.

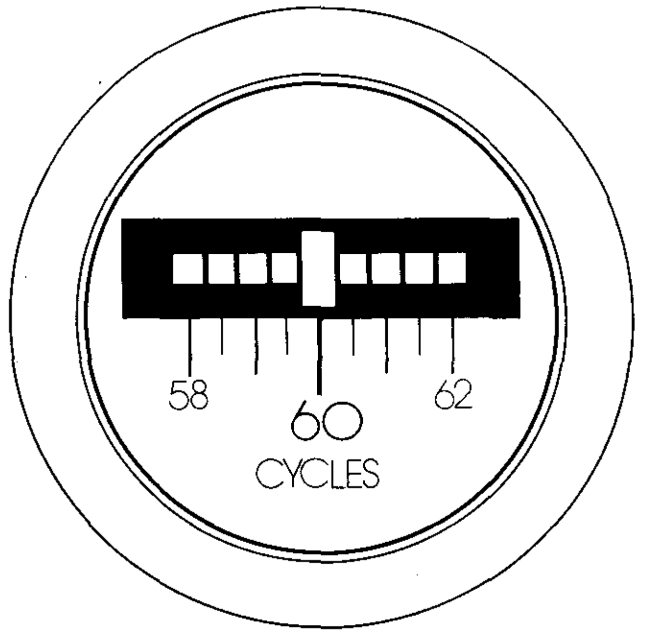


Figure 12-1. Vibrating Reed-type Frequency Meter

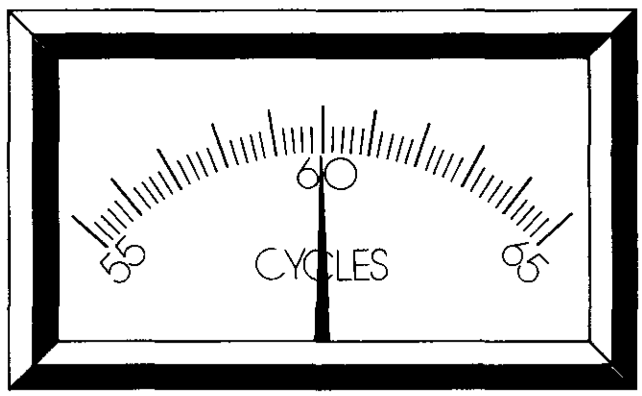


Figure 12-2. Direct-Reading Scale Frequency Meter

Optional Power Status Indicators

Optional power status indicators which can be useful in a diesel-electric power system are:

Wattmeter,

VAR (volt-amperes reactive) meter,

Power factor meter.

A wattmeter measures the true power output of the generator. Power output is proportional to the horsepower input and is controlled by the fuel input to the engine.

In A.C. power systems, the product of voltage times amperage is equal to volt-amperes, or apparent power, and is controlled by the voltage regulator. Watts can be determined by multiplying volt-amperes times power factor. If the power factor of the load is known and is constant, then a wattmeter is not necessary on a single operating set

Most paralleled A.C. power systems include both real and reactive current components which must be equally shared, or distributed according to the capacity of the individual sets in the system. Assurance that both current components are properly shared can only be established when indications of both components are known.

A wattmeter separates the real from the reactive current, while ammeters cannot. Therefore, electric sets operating in paralleled power systems should be equipped with a wattmeter in addition to the ammeter. The wattmeter will provide an indication that the real load is properly shared, and the ammeter will indicate that the reactive load is properly shared.

Real load division indicated by the wattmeter is controlled automatically by the fuel control governor, or manually by adjusting the fuel input. The reactive load division is controlled automatically by the voltage regulator or manually by the voltage adjusting rheostat.

A volt-amperes reactive (VARS) meter indicates the amount of reactive volt-amperes flowing in the circuit. It can also indicate if the reactive current is inductive (lagging) or capacitive (leading). It is used when the reactive current fluctuates beyond the normal operating band of 0.8 inductive to unity P.F. The VAR meter is necessary to enable the operator to compensate for any increase in the amount of reactive current.

A VAR meter is also advantageous in a paralleled power system to serve as an indication that the reactive load is properly shared between sets in parallel.

To determine the power factor of the load, a power factor meter or wattmeter is connected in the circuit. A power factor meter indicates the ratio of watts to volt-amperes. It also indicates whether the reactive current component is inductive (lagging) or capacitive (leading).

Using a voltmeter, ammeter and wattmeter in place of a power factor meter, the power factor of the load can be calculated by dividing watts by volt-amperes.

In planning loads, it is general practice that the power factor of the load is improved to an acceptable degree. It will not vary to any great extent except during load transients or if some new equipment is added to the load. Therefore the contribution of a permanently installed power factor meter to the overall operation of a power system is limited unless certain equipment causes considerable fluctuation of the power factor. If this condition exists, some method of improving the power factor should be used.

Meter Accuracy

The quality of power required for a particular installation will dictate the accuracy of the instrumentation to be used. Meters are classified as follows:

Panel Instruments -- generally classified as having a ±2% accuracy rating and may be magnetically shielded or unshielded. Specify the degree of accuracy in percent and also specify that the instrument accuracy must not be affected by magnetic fields.

Switchboard Instruments -- self-shielded instruments having a ±1% accuracy rating.

Test Instruments -- as a rule of thumb, the accuracy of testing instruments should be twice the accuracy of the product being checked.

Portable laboratory type instruments -- available in the range of ±1/4% to ±1% accuracy.

Recording laboratory type instruments -- also can have an accuracy of %1/4% but have the advantage of recording all variations with respect to time and therefore can be used to record voltage and frequency variations during load transients, as well as steady-load stability.

The two basic types of direct-acting recording instruments are the light beam oscillograph or equivalent and pen-type recorders. Light beam types are the most precise. There may be appreciable variations in the accuracy of pen-type recorders, although these are frequently satisfactory for production testing.

Other design factors related to accuracy and readability are meter scale range and meter scale length:

Meter Scale Range -- The selection of an instrument's scale range is based on the amount of the electrical quantity to be measured. Ideally, the range should be selected so that the meter will read in the upper half of the range when the electric set is operating under normal running load steady state conditions. The reason for this is that readings in the lower half of the scale have a higher percentage of error than readings in the upper half. This is not to say that the instrument's accuracy is affected by where the meter is read; it is simply that the error represents a higher percentage of the value being read as you go lower on the scale. Thus it is desirable that the scale range be no greater than required.

Multi-range panel meters should not be used since there is danger that the operator may read from the wrong scale.

Meter Scale Length—Whereas scale range is the latitude of measurement in the units of the electrical quantity being measured, scale length is the actual length of the scale in inches. Adequate scale length is necessary for readability. The desired scale length is determined by the required reading precision and the distance from which the instrument will be read. In paralleled power systems, the operator may be some distance from the bus instruments, and therefore greater readability is required. Naturally, the longer the scale length the easier it is to read from a distance, but other factors affect readability.

Although there is a relationship between scale length, readability and accuracy, a long scale length does not necessarily mean that the meter is more accurate. It is possible for a 5-inch scale length panel instrument to be read to 1/4% at some given distance, and yet the instrument itself is only accurate to ± 1% (2% total). It is therefore possible to read greater accuracy into the instrument than its performance can guarantee. In selecting an instrument, consider scale length from the standpoint of viewing distance, reading ease, and the accuracy required.

Synchronizing Indicators

Before multiple electric power sources can be connected together in parallel, they must be brought into synchronization with one another. That is, their frequencies must be the same. The power sources are brought into synchronization by adjusting the fuel input of the incoming electric set.

To determine when the power sources are in synchronization with one another, a visual synchronizing indicator must be provided. Either incandescent lamps or a synchroscope may be used. A synchroscope should be used on large units because indication by lamps is not as accurate.

Synchronizing lamps generally consist of two incandescent lamps and an on-off switch. When the frequencies are different, the phase relationship of the voltages of the two sources cycles from in-phase to in-opposition. The lamps are bright when the voltages of the sources are in opposition and the lamps are dark when the voltages are in phase and thus neutralized. This varying phase displacement of the two sets of voltages causes the lamps to flicker at a rate equal to the difference in frequency of the two sources. As the frequencies of the two sources become nearer in step, the flicker becomes slower. When the flickering stops, the breaker of the incoming source can be closed.

A synchroscope indicates the phase relation of two sources on a dial type instrument. The hand of the synchroscope will rotate in one direction if the frequency of the incoming source is higher than the source on the line, and in the opposite direction if it is lower. When the two sources are synchronized, the hand will stand still at a mark on the dial, at which time the circuit breaker can be closed.

Control Cabinets and Switchgear Enclosures

Sheet metal enclosures are used to provide a panel on which the instrumentation and control devices are mounted, and to house the necessary related equipment. Each manufacturer offers a line of standard control cabinets, which are generally acceptable, but if additional functions and/or instrumentation are required the standard cabinet must be modified or the additional equipment must be housed in another enclosure. Therefore the cost of adding to the standard cabinet should be weighed against the cost of a customized cabinet which would centralize all the equipment.

The control cabinet should be designed so that it is functionally compatible with the requirements of the individual installation. The design is influenced by the purpose of the electric set, location, type of building, number of functions, required instrumentation and ease of operation. The control cabinet can be mounted on the electric set, or on a wall, or can be a floor-mounted type.

Set-Mounted Control Cabinet

A control cabinet mounted on or over the generator is the most popular type of mounting, particularly on smaller capacity models. The size is limited to the width of the generator or base, and the size and amount of equipment contained in the cabinet contributes to the weight of the electric set.

A set-mounted control cabinet must be isolated from the generator or base mounting to eliminate vibration transmission to the instruments.

Wall-Mounted Control Cabinets

The control cabinet can be mounted on a wall either remotely or adjacent to the electric set. There are no restrictions on the dimensions, and therefore it can be made large enough to house all the equipment and instrumentation.

Floor-Mounted Control Cabinets

A floor-mounted cabinet is the most popular type for large-capacity electric sets and paralleled power systems. There are no restrictions on size or location of the cabinet. Floor-mounted control cabinets can provide a centralized control center.

In the case of paralleled power systems, it is desirable to have a central control panel rather than individual panels. Some cost savings are available from the centralized panel since certain meters could serve all of the units in the system by using meter selector switches.

Instruments such as a bus voltmeter, synchroscope and lights can be mounted on a swing panel which can be positioned to improve the operator's observation of the instruments.

Mimic Panel

It may be desirable in some installations to employ a mimic panel, having a duplicate set of instruments and controls but located remotely from the electric set. An example would be a manufacturing plant having several electric sets strategically located throughout the plant but controlled from a central location.

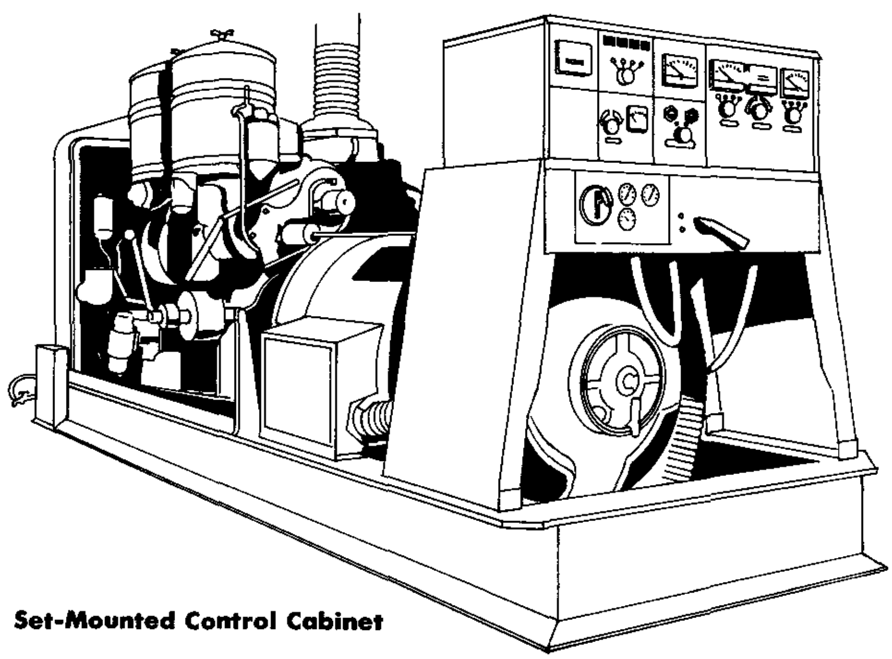


Figure 13-1. Set-Mounted Control Cabinet

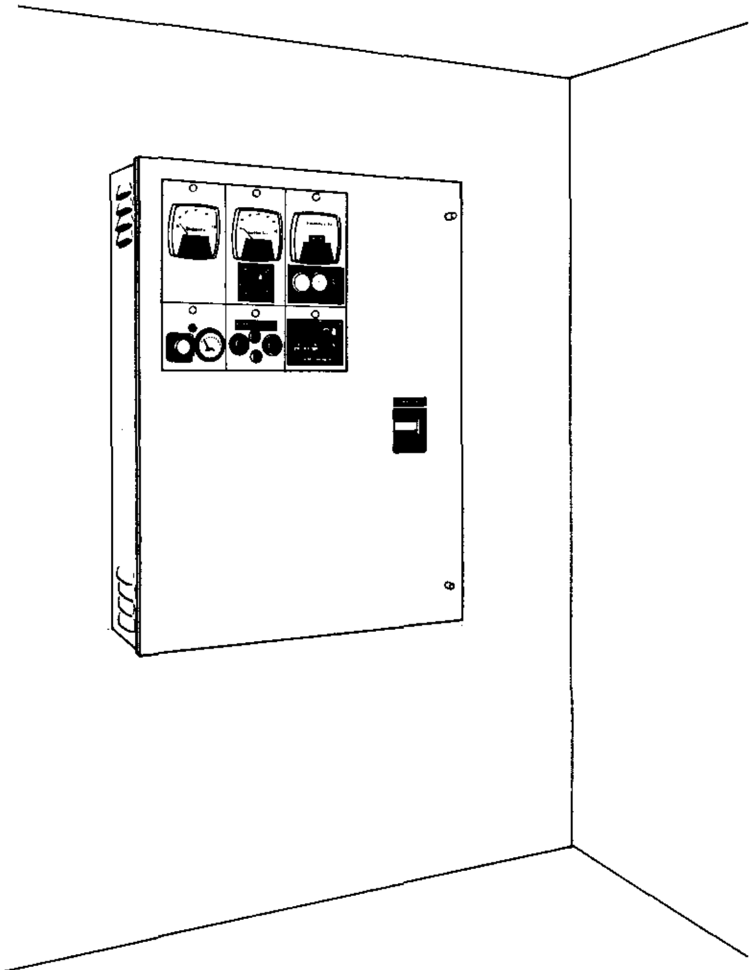


Figure 13-2. Wall-Mounted Control Cabinet

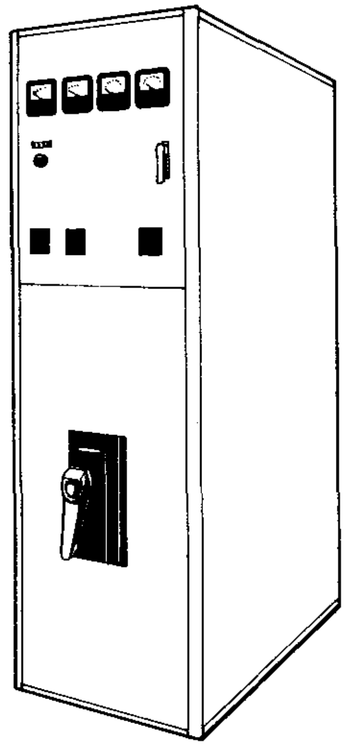


Figure 13-3. Floor-Mounted Control Cabinet—Single Electric Set

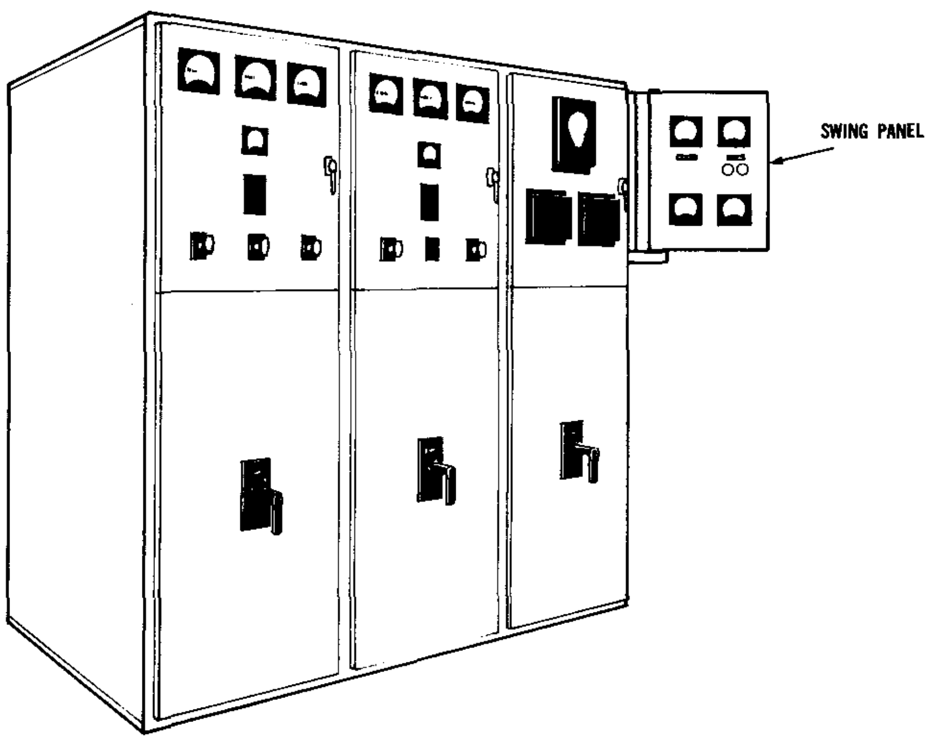


Figure 13-4. Floor-Mounted Control Cabinets—Parallel Electric Sets

Uninterruptible Power Systems

Even though the diesel engine is the fastest starting prime mover available, a changeover from the normal electric power source to the emergency source cannot be accomplished without an interruption in electric power. Therefore, if the critical load demands a continuing source of electric power, the emergency system must include equipment that will furnish power during the changeover period to form an uninterrupted, or "no-break", power system.

The three basic methods used in the industry to furnish power during the changeover period are:

1. Parallel electric sets
2. Electro-chemical energy (batteries)
3. Mechanical inertia-kinetic energy

Each no-break or uninterruptible power supply must be tailored to the individual requirements of a given installation. The decision as to which type should be used depends upon the importance of the critical load. If you are contemplating an uninterruptible power system, contact a Detroit Diesel Allison Distributor for information.

Paralleled Diesel-Electric Sets

Probably the most reliable method of providing an uninterruptible power supply employs a prime power generating system having two or more engine-driven electric sets. Optimum reliability is afforded when three electric sets are used, each having sufficient KW capacity to power the load alone.

The normal operating mode consists of two sets operating in parallel, each carrying half of the load, while the third set is shut down, serving as a back-up or swing set. Should either of the sets which are on the line fail, the companion unit would assume the full load, thus providing uninterrupted power. At the same time the back-up unit would start, and full reliability would be restored as soon as it is paralleled to the load.

After the failed unit is repaired, it would be returned to service as the back-up or swing set. The electric sets can be alternated between operating and back-up so that their operating hours are equally shared.

Electro-chemical Energy (Battery) Systems

This method, employing storage batteries as the interim power source during changeover, is referred to as an uninterruptible power supply. The elements of a basic uninterruptible power supply are shown in the accompanying block diagram.

The battery output is connected through an inverter in order to supply A.C. power to the load. The normal source A.C. power is rectified, then fed to the inverter. The reason for not connecting the load directly to the normal power source is that loads requiring uninterruptible power also usually require high quality power, which can be supplied by the inverter. If the normal source fails, the batteries supply power through the inverter while the engine of the emergency generator is being started.

When the load is transferred to the emergency generator, the connection may be made at the input to the rectifier or at the output of the inverter. In the latter case, an optional transfer switch is used to bypass the inverter and rectifier and connect the critical load directly to the emergency power source. If this latter scheme is to be used, the engine-driven electric set must have a performance capability equal to the performance characteristics of the equipment in the critical load.

The rectifier and inverter may be static (electronic) or synchronous (motor-generator).

It may be desirable to disconnect the noncritical load when power fails so that the UPS and emergency electric set serve only the critical load. If the critical load includes a computer, then the load must also include air conditioning equipment. The air conditioning load would not be connected to the inverter but would take power directly from the normal supply or from the emergency electric set.

The required battery capacity depends upon the power demand of the critical load and how long it will take the emergency electric set to come on the line. The battery capacity will affect first cost and maintenance cost, and therefore should be held to the allowable minimum.

Mechanical Inertia Systems

This type of system employs an electric motor-driven inertia flywheel having sufficient kinetic energy that, when power is shut off to the motor, the flywheel can drive a generator and produce the required level of electric power at the required frequency for the duration of the changeover period. A simple version of an inertial no-break system is shown in the accompanying illustration. During normal operation, a synchronous motor, powered from the normal electric power source, drives both the flywheel and the generator, which in turn serves the load. An engine serving as a standby prime mover is mounted on a common base with the generator, motor and flywheel. The engine can be coupled to the generator and flywheel through an automatically engaging clutch.

As long as the normal power source remains in a steady condition, the synchronous motor drives the flywheel and generator, producing power for the load. When the normal source fails, the flywheel drives the generator to continue producing power without a break, and the engine starts by one of the following two methods:

1. The clutch is immediately engaged, and the engine is rotated by the flywheel energy.

2. The engine is started by an electric, air or hydraulic cranking motor, and then the clutch is engaged once the engine has attained synchronous speed.

The latter method is preferred because it reduces the shock loading imposed on the clutch and engine when the engine is started from a static condition. Although the second method does not require flywheel energy for cranking the engine, it does not offer any reduction in flywheel weight because the flywheel must provide energy for a longer period of time while the engine is started and accelerates to synchronous speed before engagement.

The simple system described is the forerunner of more sophisticated systems that have been developed for maximum reliability with precise frequency control during the changeover period. In comparison with battery back-up systems, no-break systems of the inertia flywheel type offer both lower first cost and lower operating cost.

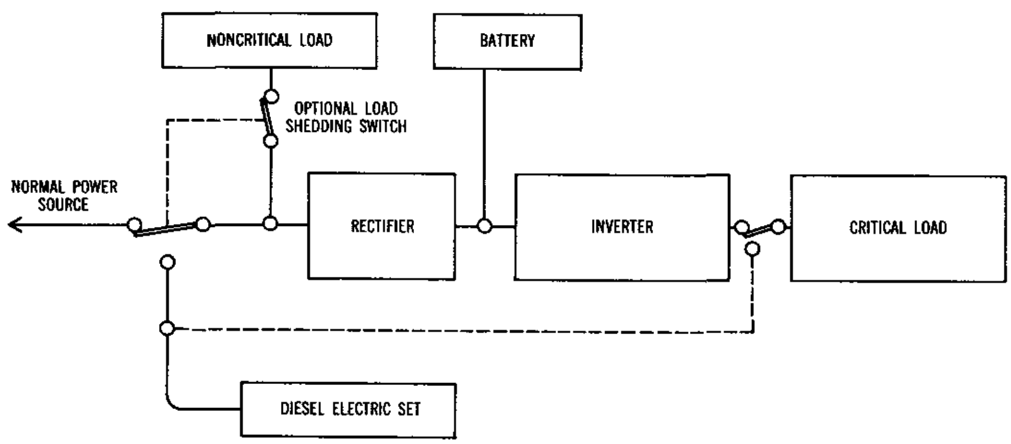


Figure 14-1. Uninterruptible Power Systems—Electrochemical System

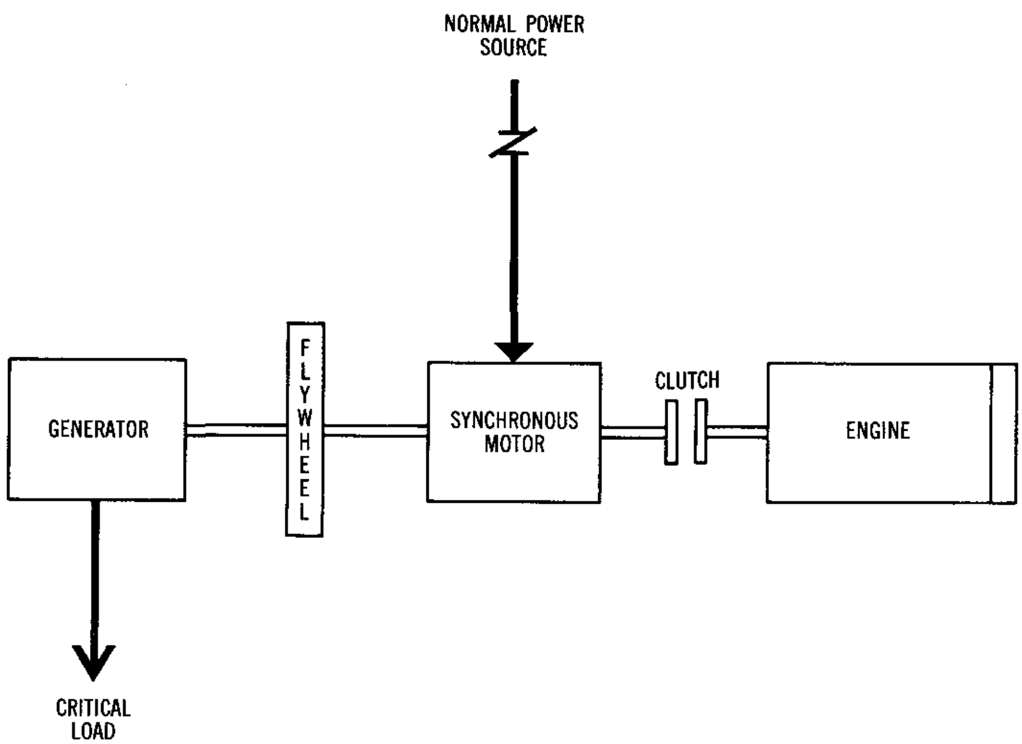


Figure 14-2. Uninterruptible Power Systems—Mechanical Inertia System

Noise Control

Noise level must be limited in many applications to meet EPA and OSHA regulations or to avoid annoying neighbors, residents, personnnel or hospital patients. (EPA has no noise standards at this time.) The architect should obtain from electric-set suppliers data on the basic free-air noise level of the electric set. With this information, he can design the installation to achieve the desired noise environment.

The Engine Manufacturers Association has established a procedure for engine sound measurement whereby the sound pressure level of the engine is measured at specified points one meter away from the engine. This procedure provides a direct comparison of the noise characteristics of different engines and may be used to establish the noise level of a complete electric set.

The procedure calls for testing a bare engine and/or a fully equipped engine at rated speed and load, at governed speed and no load, at maximum torque, and at idle. Noise related to intake, exhaust and other sources is largely eliminated from the measurement. The sound pressure level measurements are recorded as dbC, representing a linear relationship, and dbA, which is weighted in accordance with human ear sensitivity. The measurements may be made with the electric set located in a flat open (outdoor) space. Or equivalent measurements, with a correction factor, may be made in a calibrated test cell.

Keep in mind that these are free-field sound levels, with the only reflection being from the ground plane. When the electric set is installed in the generator room, the actual sound level will depend on the acoustic characteristics of the room. The sound level will be raised considerably in a reverberant room but only slightly in a good sound-absorbent room. Sound barriers or sound-insulated rooms will reduce noise transmission to surrounding areas.

The architect should specify that the electric set must achieve a certain dbA free-air sound pressure level when tested by the Engine Manufacturers Association procedure (may become SAE procedure). The architect can calculate sound power level, if required for his building design, from the sound pressure level measurements. Then the architect can design the generator room to reduce the actual sound pressure level to an acceptable value.

The desired noise level within the generator room may be achieved by designing sound absorption into the walls, floor or ceiling. A sensitive situation may require sound barriers around the electric set, or the controls and instruments may be located in a separate sound-insulated control room so that personnel normally do not enter the generator room when the electric set is operating. Methods of noise attenuation are discussed in Detroit Diesel Allison's companion volume: ELECTRIC SET INSTALLATION.

When specifying a free-air sound pressure level for the electric set, specify a level that is practical and achievable. An electric set supplier can furnish data on the practical sound levels that are achieved with the present state of the art. If lower levels are specified, the supplier probably would be required to design and contruct some kind of sound-insulating hood for the engine or complete electric set. It may not be possible to build a hood that achieves the required sound attenuation without considerable development testing. Obviously, unusually low noise level specifications add cost and development time.

It is more practical to specify an achievable sound pressure level for the electric set and then design the installation to insulate the electric set or the generator room so that no objectionable noise reaches sensitive areas.

Note that the specification should be in sound **pressure** level - dbA - not sound **power** level. The reason is that sound pressure level is readily measured while sound power cannot be measured directly and cannot be conveniently determined except under very closely controlled laboratory conditions. The sound pressure level measurement provides a direct comparison of electric sets and a direct means of determining that an electric set meets the specification.

DIESEL-ELECTRIC POWER SYSTEMS GLOSSARY OF TERMS

A.C. Ammeter - measures the current from the generator or feeder and is used to check load and load balance.

A.C. Voltmeter - measures the voltage of the generator and is used to see that rated voltage is maintained.

Accessories, Engine-Driven - accessories driven from the engine such as the fan or auxiliary fuel or water pumps, air compressors, hydraulic pumps, etc. Engine jacket water, lube oil and fuel pumps are not considered accessories, and the power required to drive them has been deducted from net horsepower at the flywheel.

Accessories, Externally Driven - accessories driven electrically from the generator. The power required to drive them must be deducted from the generator's capabilities.

Air Box - air passage which is cast as part of the cylinder block used on Detroit Diesel Engines to facilitate uniform distribution of intake air to the cylinders. Comparable to the intake manifold used on 4-cycle engines.

Air Box Drain - cast-in drain passages which allow liquid accumulations (condensation and combustion byproducts) to drain externally from the block.

Air Cleaner (Dry Type) - air intake filter designed so that the air will pass through a dry-type element.

Air Cleaner (Oil Bath Type) - air intake filter designed so that the air must pass through an oil bath, where the dirt is deposited.

Ambient Temperature - the air temperature surrounding the electric set. If the electric set is located in a room, the ambient temperature would be the room temperature.

American Bureau of Shipping (A.B.S.) - a classification and inspection society.

American Wire Gauge (A.W.G.) - the gauge used for designating the sizes of solid copper wires used in the United States. It is the same as the Brown & Sharp gauge.

Ammeter And Voltmeter Selector Switch - permits reading current or voltage in each of the three phases by using a single voltmeter and ammeter.

Artificial Load - nonproductive electric power-absorbing devices, which are connected to the generator to simulate or to supplement the real load.

Artificial Load (Reactive) - load banks to which devices that operate at a lower power factor have been added. Generally, variable reactors are used so that the amount of reactance can be adjusted to match the power factor of the actual load. Air core reactors provide the most stable operation for testing purposes.

Artificial Load (Resistive) - load banks usually consisting of heater coils or strip heaters which operate only at a unity power factor.

Artificial Load (Supplemental) - a permanently installed load which is used to supplement the existing load in installations where the electric set is operating at light load (less than 40% of the generator's nameplate rating). The purpose is to permit the engine to operate more efficiently. This practice is employed where a generous growth factor has been used.

Artificial Load (Water Rheostat) - a tank containing a salt or brine and water mixture in which electrodes are submerged to create a load. The further the electrodes are submerged into the mixture the greater the load becomes. To stabilize the load the mixture must not be allowed to boil. This type of artificial load operates at unity power factor.

Audible Alarm - horn, siren, bell or buzzer which is used to attract the attention of the operator when a fault occurs in the electric power generating system.

Batteries (Parallel Connected) - two or more batteries whose terminals are connected positive-to-positive and negative-to-negative, with the load connected across the positive and negative leads at any point. The current is equal to the sum of the individual battery current ratings, and the voltage is limited to the voltage rating of one battery.

Batteries (Series Connected) - two or more batteries with the positive terminal of one connected to the negative terminal of the next, with the load connected to the negative terminal of the first battery and the positive terminal of the last battery in the series. The voltage is equal to the sum of the individual batteries' voltage ratings, and the current is limited to the rated current capacity of the largest battery connected in the circuit.

Battery Ratings (S.A.E. LEAD ACID) - 20-hour rate - indicates the lighting ability of a battery. The fully charged battery is brought to a temperature of 80°F and is discharged at a rate equal to 1/20 of the published 20-hour capacity in ampere-hours, until the voltage falls to 1.75 volts per cell.

Cold ratings at 0°F - these ratings indicate the cranking ability of a fully charged battery at low temperatures and are expressed as follows:

A. By the number of minutes required for the battery to reach a terminal voltage equivalent to 1.0 volt per cell when discharged at a rate of 300 amperes with an initial electrolyte temperature of 0 °F.

B. By the terminal voltage of a fully charged battery taken 30 seconds after the start of a discharge at 300 amperes with an initial electrolyte temperature of 0 °F. This rating is applied to batteries intended for diesel service.

Brake Mean Effective Pressure (B.M.E.P.) - the average net effective pressure exerted on the piston during the power stroke. Equals I.M.E.P. minus F.M.E.P., where I.M.E.P. is the average actual gas pressure on the piston and F.M.E.P. is the equivalent resistance of the engine's internal losses expressed in pressure units.

Capacitance - that property of a system of conductors and dielectrics which permits the storage of electricity when potential differences exist between the conductors. Its value is expressed as the ratio of a quantity of electricity to a potential difference. A capacitance value is always positive.

Capacitor - a device whose primary purpose is to introduce capacitance into an electric circuit. Capacitors are usually classified, according to their dielectrics, as air capacitors, mica capacitors, paper capacitors, etc.

Circuit Breaker, Magnetic Trips - trips the circuit under high-current, short-circuit conditions only.

Circuit Breaker, Thermal Trips - trips the circuit under sustained overload but does not protect against short-circuit currents.

Circuit Breaker, Thermal/Magnetic Trips - thermal/magnetic trips employ a thermal bimetallic element having an inverse time/current characteristic for protection against sustained overloads. In addition, the breaker contains an instantaneous magnetic trip element for short-circuit protection.

Coolant, Jacket - liquid pumped through the engine water jacket and head to cool the cylinders and valves. Usually a mixture of ethylene glycol and water. The heated coolant is itself cooled by being pumped through a radiator or heat exchanger before returning to the engine.

Convection - motion in a fluid resulting from differences of density and the action of gravity. For example, hot air, being less dense, tends to rise while adjacent cold air flows downward, thus creating circulation in a room.

Cycle - a cycle in an internal combustion engine is the complete series of events wherein air is inducted and compressed, fuel is injected and burned, combustion gases expand to do work and then are expelled (exhausted).

Dielectric Strength - the maximum potential gradient that an electrical insulating material can withstand without rupture. It is usually specified in volts per unit thickness.

Dielectric Tests - tests in which a voltage higher than the rated voltage is applied for a specified time for the purpose of determining the adequacy against breakdown of insulating materials and spacings under normal conditions.

Direct Injection - refers to open combustion chamber engines, in which fuel is injected directly into the combustion chamber and not into a precombustion chamber or swirl chamber. (See "Open Combustion Chamber" and "Precombustion Chamber.")

Drip-Proof - construction of the frame air openings of a power generator to prevent moisture from entering these openings by gravity.

Electric Set (Peaking Power Plant) - an electric set that assumes part of the load during peak-load periods.

Electric Set (Prime Power) - an electric set which is operated as the primary source of power. It may be primary because it is the sole source or because it provides a special type of power.

Electric Set (Standby) - an emergency electric power system which is on "standby alert," ready to assume the load when the normal power source fails.

Emergency Circuits - building load circuits separated from the normal circuits and operated separately only during emergencies.

Engine, Diesel - an internal combustion engine in which the fuel is injected into compressed air and ignited entirely by the heat resulting from the compression of the air supplied for combustion. Thus, a diesel engine is also referred to as a "compression ignition" engine. In this book, the term "engine" refers to reciprocating diesel engines unless otherwise identified.

Engine, Four-Cycle (Four-Stroke Engine) - an engine completing one cycle in four strokes or two revolutions is called a four-cycle engine. The cyclic events are designated by the following strokes: (1) Induction (intake) or suction stroke; (2) Compression stroke; (3) Expansion (power) stroke, and (4) Exhaust stroke.

Engine Shutdown (Emergency Method) - a method of closing off the engine air intake passage to effect a positive emergency engine shutdown. This feature is standard on Detroit Diesel electric sets. It can be operated manually or automatically for automatic starting.

Engine Shutdown (Normal Method) - the normal method of shutting down Detroit Diesel engines is to operate the injectors to the no-fuel position through the governor and throttle control.

Engine, Turbocharged - an engine equipped with one or more intake air compressors driven by exhaust turbines. (See "Turbocharger.")

Engine, Two-Cycle (Two-Stroke Engine) - an engine completing one cycle in two strokes or one revolution is called a two-cycle engine. The two strokes are primarily compression and power (expansion), with induction and exhaust occurring near the end of the expansion stroke and the beginning of the compression stroke.

Exciter - a current-producing device which furnishes magnetizing current to the fields of the generator.

Exciter Ammeter - an ammeter connected to the output terminals of the exciter to indicate amount of excitation current.

Exciter (Rotating) - an exciting generator, either externally mounted and driven or located within the alternator frame, with its rotating armature mounted on the same shaft as the alternator fields.

Exciter (Static) - use of non-moving electrical devices to produce excitation current, by diverting A.C. current from the alternator output and converting it to a D.C. input to the alternator fields.

Exhaust Manifold - a casting mounted externally to the cylinder head which connects the exhaust outlet of each cylinder to a common outlet.

Exhaust Manifold (Dry) an exposed manifold having no insulation to reduce heat radiation.

Exhaust Manifold Guard - a metal fixture spaced to provide an air gap and wrapped around the manifold to form a safety guard.

Exhaust Manifold (Water-Cooled) - a manifold having a water jacket through which the engine water pump circulates water and thereby reduces exhaust heat radiation to the room.

Flywheel Effect - internal combustion engine-driven electric sets must have sufficient rotating mass to provide a flywheel effect to minimize cyclic speed fluctuations at constant load. This rotating mass essentially comprises the engine flywheel and generator rotor.

Frequency Drift - the band that the output frequency stays within, at a fixed load, if the ambient temperature is allowed to vary over a specified range after adjustment is made for initial electric set warm-up.

Frequency Meter - indicates frequency in hertz of the alternator voltage, which is proportional to engine speed.

Frequency Regulation - the difference between average no-load frequency and full-load frequency. Expressed as a percentage of nominal full-load frequency. (See "Governor Droop.")

Frequency Transient - the maximum immediate change in output frequency when a specified load is suddently applied or removed.

Frequency Transient Recovery Time - the total time required for the output frequency to stabilize within the frequency band after a specified load change.

Governor - a device that regulates generator output frequency by adjusting the engine fuel lever to maintain synchronous speed. Governors sense speed changes either mechanically or electrically. Some governors also sense load changes. Fuel lever actuation is either by mechanical or hydraulic means. Some mechanical govenors are speed-limiting rather than speed-regulating, but these are not used in electric sets.

Governor Droop - the difference between engine speed at full load and at no load. Percentage droop is this difference divided by the full load RPM and multiplied by 100. (See "Frequency Regulation.")

Governor, Droop-Type - a governor that regulates speed so that steady-state speed increases slightly as load is removed. Speed is highest at no-load and lowest at full-load. All mechanical governors have speed droop, and the droop is not adjustable. In electric and hydraulic governors, speed droop is adjustable. In all electric governors and some hydraulic governors, droop can be adjusted to zero (isochronous operation).

Governor, Electric - a governor that senses speed electrically by means of a magnetic pick-up or tachometer generator or by sensing the frequency of the electric-set generator. Fuel lever actuation is usually by a hydraulic actuator. Electric governors are fast-acting and hold speed variations within close limits.

Governor, Electric Load-Sensing - an electric governor that senses load as well as speed. Load is sensed by monitoring the electric-set generator output current. Sensing load changes quickens response by causing the governor to respond immediately before a significant speed change occurs. In parallel electric sets operating isochronously (no variation of steady speed with load), each governor senses differences in load between its electric set and the others and adjusts its engine fuel lever to balance the load.

Governor, Hydraulic - a governor that senses speed mechanically and employs a hydraulic actuator to move the fuel control linkage. Hydraulic governors respond faster than mechanical governors.

Governor, Hydraulic Back-Up - an electric governor that includes a separate mechanical speed sensor and hydraulic valve connected to the governor's hydraulic actuation system. If the electric governor fails, the back-up governor controls engine speed. The hydraulic back-up is set for a faster speed than the electric governor to prevent interaction between the electric and hydraulic sections. The electric governor is adjustable for either droop or isochronous operation. During normal operation, the hydraulic back-up is set for about 3% speed droop. When the electric governor is inoperative, the hydraulic back-up governor can be set to operate isochronously or with droop.

Governor, Isochronous - a governor that can be adjusted to zero droop so that steady-state speed is the same at all loads.

Governor, Mechanical - a governor in which speed is sensed by revolving flyweights. Mechanical actuation of the engine fuel control linkage is provided by the flyweights acting against a compensator spring. Since fuel lever position (corresponding to load) relates directly to flyweight position, and flyweight position varies with speed, speed varies with load, and thus droop is inherent in this type of governor. Mechanical governors are slower to respond than hydraulic or electric governors. Droop is not adjustable; and therefore, mechanical governors cannot be used for electric sets operated in parallel.

Harmonic Content, Single - the RMS value of the specified harmonic expressed as a percentage of the RMS value of the fundamental.

Harmonic Content, Total - the RMS sum of the RMS values of all harmonics appearing in the output voltage expressed as a percentage of the RMS value of the fundamental.

Impedance - the apparent resistance of an A.C. circuit, being the combination of both the resistance and reactance and is equal to the ratio of the value of the EMF between the terminals to the current, there being no source of power in the portion under consideration. Impedance is represented by the symbol Z.

Inductance - Inductance is the (scalar) property of an electric circuit or of two neighboring circuits which determines the electromotive force inducecd in one of the circuits by a change of current in either of them.

Injector Rack (Detroit Diesel) - a movable shaft connected between the injector fuel output metering mechanism and the fuel controller (governor). The shaft includes a rack (straight gear) that engages a gear on the fuel injector. Movement of the fuel rack rotates the gear to change the fuel quantity per injection. The governor regulates the fuel input necessary to maintain the generator at the synchronous frequency by varying the rack position.

Interchangeable Parts - parts which are common between engine models. For instance, the Detroit Diesel Series 71 engines have the same bore and stroke. Therefore, most of the cylinder components, including pistons, connecting rods, liners, bearings, are generally the same among all engines in the series.

Internal Combustion Engine - an engine in which combustion occurs in a confined mixture in discrete repetitive cycles and produces power by positive displacement of a piston or rotor by expanding combustion gases.

Inverter - a static electrical device on a motor-generator set which converts direct current to alternating current. (See "Rectifier.")

Lloyd's Register of Shipping - a classifying society, not part of Lloyd's of London.

Megohm - a unit of resistance equal to one million ohms.

Naturally Aspirated - the cylinders of a naturally aspirated engine are charged with fresh air by the pumping action of the blower (2-cycle) or the piston (4-cycle). No turbochargers or superchargers are used.

N.E.C. - The National Electrical Code is the standard of the National Board of Fire Underwriters for electric wiring and apparatus, as recommended by the National Fire Prevention Association and approved by the American Standards Association.

N.E.M.A. - National Electrical Manufacturers Association, a non-profit trade association, supported by the manufacturers of electrical apparatus and supplies. N.E.M.A. is engaged in standardization to facilitate understanding between the manufacturers and users of electrical products.

N.F.P.A. - National Fire Prevention Association.

Oil Control Rings - wiper rings located on the bottom part of the piston which control the excess oil splash on the cylinder wall.

Oil Cooler - a heat exchanger used to transfer lubricating oil heat to the engine waterjacket coolant. This is standard equipment on Detroit Diesel engines.

Oil Cooler Bypass - a valve included in the oil cooler housing to permit cold or unfiltered oil to bypass the cooler.

Oil Filter, Bypass Type - only a percentage of the total oil capacity will flow through the filter over a given period of time. Eventually all the oil will be filtered. Bypass filters have the capability of filtering out minute foreign particles and are sometimes used in conjunction with a full-flow filter.

Oil Filter, Full Flow - all the lubricating oil must pass through the filter before entering the block. A bypass valve is included to allow the oil to bypass the filter if the filter is plugged or the oil is too thick to pass through the filter. Full-flow lube oil filters are standard equipment on Detroit Diesel engines.

Oil Heater - an electrical heating element submerged in the oil pan to keep the oil warm. Used to facilitate starting in extremely cold ambient conditions.

Open Combustion Chamber - engine combustion chamber having no connected chamber such as a precombustion chamber or swirl chamber. Same as "Direct Injection" combustion chamber. Engines having open combustion chambers generally are more efficient and easier starting than engines with precombustion chambers. (See "Direct Injection" and "Precombustion Chamber.")

Open Ventilated - a generator having large openings for cooling air flow. Safety guards are placed over the air inlet and outlet.

Operation Selector Switch - a multiposition switch which can be set to the selected mode of operation. The selected modes are usually Automatic, Automatic Test, Manual Operation, and Off.

Oscillograph, Electro-mechanical - a production-type instrument used to record voltage and/or frequency performance.

Oscillograph, Light Beam - a laboratory-type instrument used to record voltage and/or frequency performance. This instrument is more accurate and expensive than the electro-mechanical type.

Overcrank Cut-Out - a device which is part of the automatic starting control system. It de-energizes the starting circuit when the cranking cycle has been exhausted and the engine fails to start.

Overspeed Protection - a speed or frequency sensing switch which is connected to the emergency engine shutdown circuit and operates when the engine speed exceeds the speed at which the switch is set. The switch is set to operate at 15% above the engine full-load operating speed.

Paralleled Power Systems - an electric generating system consisting of two or more electric sets with the generators connected in parallel to the load. The total system capacity is equal to the sum of the individual electric set capacities.

Phase Balance - the amount of voltage difference between phase voltages under balanced load conditions.

Phase Balance With Unbalanced Loads - the amount of voltage unbalance between phase voltages when one phase is loaded to a specified level and the other two phases are unloaded.

Piston Cooling - pistons are cooled in Detroit Diesel engines by directing a spray of pressure oil to the underside of the piston crown and by the cool intake air pumped through the cylinder when the piston is near BDC.

Piston Speed - equals the amount of piston travel (in feet) per revolution times the engine speed (RPM). The result will be expressed in feet per minute.

Piston Travel - the total distance the piston moves up and down in two strokes (one revolution of crankshaft).

Power Factor - the ratio of real power to apparent power (KW/KVA) when voltage and current are out of phase in an A.C. circuit. Power Factor is equal to the cosine of the angle by which the current leads or lags the voltage.

Power Factor Meter - measures the power factor of the system or of the individual feeders, as applied.

Precombustion Chamber - a small separated part of the engine combustion chamber connected to the main part in the cylinder through one or more small passages or orifices. Fuel is injected into the small (precombustion or ignition) chamber. (See "Open Combustion Chamber" and "Direct Injection Combustion Chamber.")

Prelubrication - pumping pressure oil to engine main oil galleries prior to starting. Not required for Detroit Diesel engines.

Protected Power Circuits - critical load circuits which are separated from the remainder of the normal load and protected by the emergency power system (standby power system). (See "Emergency Circuits.")

Reactive Volt-Ampere Meter - measures the reactive or magnetizing current furnished by the generator when the load power factor is less than unity.

Rectifier - a device which changes alternating current into direct current. (See "Inverter.")

SCR - Silicon Controlled Rectifiers used to rectify and control D.C. output in some voltage regulators.

Supercharger - a compressor that blows air into a cylinder under pressure, thus increasing the quantity of air inducted and raising the initial pressure within the cylinder. In effect, it increases the "displacement" of the engine by enabling it to ingest more air per stroke, and thus it increases maximum power. A supercharger may be driven mechanically or by an exhaust turbine. If the latter, it is called a "turbocharger."

Synchroscope - provides a visual indication of proper time for closing the switch when synchronizing generators connected in parallel to the load.

Synchronizer, Automatic - a device which will synchronize an oncoming electric set with the bus or another electric set and will automatically close the circuit breaker which connects the multiple power sources in parallel.

Swirl Chamber - a precombustion chamber shaped so that a vortex motion is generated in the air in the chamber during the compression stroke. Intended to improve fuel/air mixing by motion of air past injector nozzle.

Temperature Rise, Generator - difference between ambient temperature and the average temperature in the windings after the generator has warmed up and is operating at full load.

Temperature Rise, Room - is the difference in room temperature between the initial start-up of the electric set and the final temperature after the electric set has been operating for several hours. Temperature rise equals the final room temperature minus the non-operating room temperature.

Temperature Rise, Ventilation Air - difference between room and outdoor temperature with electric set operating at full load.

Transfer Switch - a switch designed so that it will disconnect the load from one power source and reconnect it to another source. Both automatic and manual transfer switches are available.

Transfer Switch, Contactor Type - a throw-over switch having arc protected open contactors.

Transfer Switch, Circuit Breaker Type - motor-operated circuit breakers arranged to form a transfer circuit.

Turbocharged/Aftercooled - engine equipped with a turbocharger and a means of cooling the air discharged from the turbocharger before it enters the intake manifold. The cooler air holds down cylinder temperatures and permits a greater quantity of air to be inducted, with consequent higher maximum power. The term "aftercooled" applies to engines in which the air passes from the cooler directly into the manifold instead of to another compressor stage or blower.

Turbocharged/Intercooled - engine equipped with a turbocharger and a means of cooling the air discharged from the turbocharger before it enters a second compressor stage or the engine's blower. The term "intercooled" is applied to turbocharged Detroit Diesel engines when they are equipped with a cooler between the turbocharger and the blower. The cooler air aids blower efficiency as well as holding down cylinder temperatures.

Turbocharger - a centrifugal air compressor driven by an exhaust turbine. In four-cycle engines and some two-cycle engines, it pumps air directly into the intake manifold, while in other two-cycle engines, such as Detroit Diesels, it pumps air to the inlet of the engine's blower. Since it uses otherwise wasted energy, it improves engine efficiency and fuel consumption and increases power. It may accomplish these effects primarily by reducing pumping losses in the engine or it may also supercharge the cylinders. Unlike mechanically driven superchargers, it does not waste power at low loads. A turbocharger tends to change the torque curve of an engine, and this effect can be controlled by design to get suitable characteristics for different applications. (See "Supercharger.")

Uninterrupted Power Supply - a power supply which provides a continuous source of electric power without any voltage or frequency disturbances when switching from utility power to the standby power source.

If your application requires uninterrupted power, contact a Detroit Diesel Allison Distributor.

Valves, Exhaust - usually poppet valves located in the head. Made of special material to withstand high temperature. Actuated by a camshaft, they open and close in a timed sequence to release combustion gases from the cylinder after each power stroke. Four-cycle engines have both exhaust and intake valves in the head. Two-cycle engines, having only exhaust valves in the head, can have larger valves or more valves. Thus, Detroit Diesel engines are offered with either two or four exhaust valves, providing a choice of engine characteristics to fit the requirements of each application.

Valves, Intake - in four-cycle diesels, these are usually poppet valves located in the head. Actuated by a camshaft, they open and close in a timed sequence to admit air to the cylinder on each intake stroke. Not required in two-cycle engines, which rely on ports instead.

Vibration Damper - a mechanical device used to damp torsional oscillations at the front of the engine crankshaft.

Vibration Isolators - resilient mountings supporting the electric set. Usually comprising a steel spring and rubber pad, they prevent the transmission of electric set vibration to other equipment.

Voltage Drift - the band that the output voltage stays within at a fixed load if the ambient temperature is allowed to vary over a specified range after adjustment is made for initial machine warm-up.

Voltage Modulation - a random variation in output voltage at any steady-state load. Voltage modulation is defined as a plus-or-minus variation from the average voltage, expressed as a percentage of rated voltage.

Voltage Recovery Time - the total time required for the output voltage to stabilize within the voltage modulation band after a specified load change.

Voltage Regulation - the difference between average no-load voltage and full-load voltage. Expressed as a percentage of rated voltage.

Voltage Transient - the maximum instantaneous change in output voltage when a specified load is suddenly applied or removed.

Voltage Transient Recovery - the voltage level, during starting of an induction motor, to which the generator recovers before the motor accelerates to rated speed.

Water Filter - a bypass connected filter having a replaceable element which contains chemicals capable of improving the quality of the engine waterjacket coolant.

Watthour Meter - totals the kilowatt-hour output continuously for record purposes.

Wattmeter - measures the three-phase kilowatt output of the generator. When electric sets are operated in parallel, wattmeters are desirable.

Waveform Deviation Factor - the maximum deviation of the actual voltage trace from a true sine wave expressed in percent.

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Detroit Diesel Allison

electric
set
installation

Foreword

This Installation Manual will guide you to the factors to be considered in the installation of your diesel-electric power system. It discusses location and mounting of the electric set; size of room; ventilation and air flow; engine cooling water supply or radiator location; exhaust outlet; fuel tank and fuel transfer system.

By following the suggestions in this Installation Manual, you will be able to plan an economical, efficient electric set installation with operating characteristics suitable to each particular application.

You can make your work easier by enlisting the aid of a Detroit Diesel Allison Distributor when planning your electric set installation. Getting his advice early may save cost and avoid problems. He knows engines, electrical equipment, local laws and insurance regulations. With his help, you can be sure your electric set installation will fulfill your needs without unnecessary cost.

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Installation Factors

Once the size of the electric set and the associated control panel and switchgear have been established, plans for installation can be prepared. Proper attention to mechanical and electrical engineering details will assure a satisfactory power system installation.

Factors to be considered in the installation of an electric set are:

- Space required and location
- Floor loading
- Vibration transmitted to building and equipment
- Ventilation of room
- Engine exhaust piping and insulation
- Noise reduction
- Method of engine cooling
- Size and location of fuel tank
- Local, state or insurance regulations
- Smoke and emissions requirements

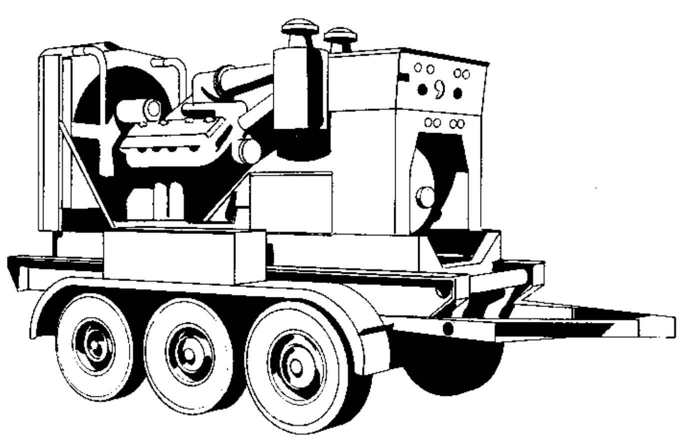

FIG. 1-1 – TYPICAL OPEN TRAILER-MOUNTED ELECTRIC SET

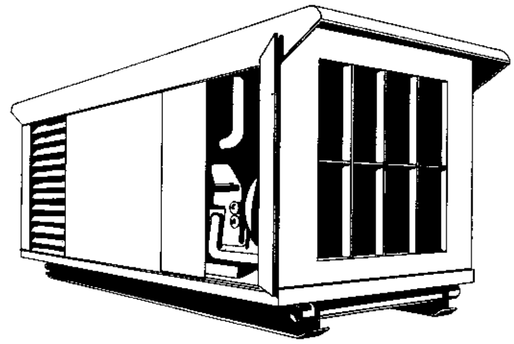

FIG. 1-3 – TYPICAL HOUSED ELECTRIC SET

Electric Set Location

The set may be located in the basement or on another floor of the building, on a balcony, in a penthouse on the roof, or even in a separate building. Usually it is located in the basement for economics and for convenience of operating personnel. The generator room should be large enough to provide adequate air circulation and plenty of working space around the engine and generator.

If it is necessary to locate the electric set outside the building, it can be furnished enclosed in a housing and mounted on a skid or trailer. This type of assembly is also useful, whether located inside or outside the building, if the installation is temporary. For outside installation, the housing can be "weather protected" or "weatherproof". The latter is necessary to prevent water from entering the engine compartment if the electric set will be exposed to rain accompanied by hurricane-type winds.

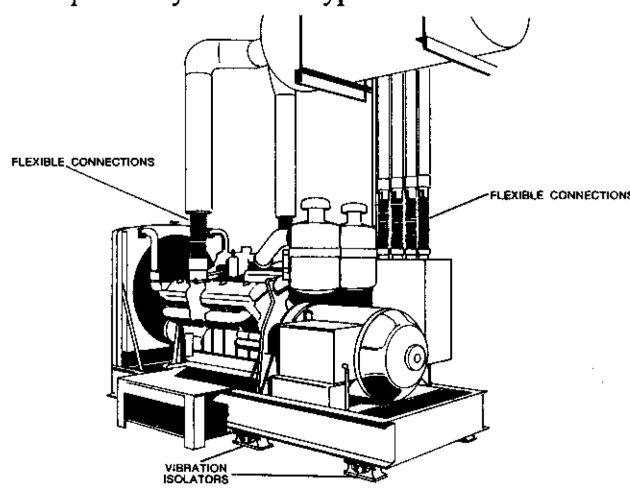

FIG. 1-5 – TYPICAL INSIDE INSTALLATION OF ELECTRIC SET

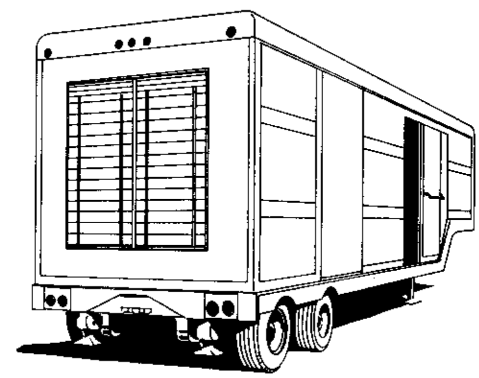

FIG. 1-2 – TYPICAL ENCLOSED TRAILER-MOUNTED ELECTRIC SET

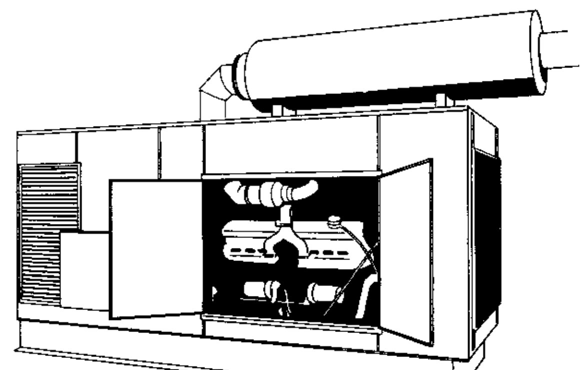

FIG. 1-4 – TYPICAL ENCLOSED ELECTRIC SET

Electric Set Mounting

A properly engineered electric set will be shipped assembled on a rigid base that precisely aligns the generator and engine and needs merely to be set in place on vibration isolation pads and leveled.

Vibration Isolation

It is recommended that the electric set base be mounted on vibration isolation pads to prevent the set from receiving or transmitting injurious or objectionable vibrations. Pads should be adjustable to equalize loading and level the set on uneven floors. Adjustable rubber or cork isolation pads are sometimes used when some vibration transmission to other equipment is acceptable. However, such pads have relatively low vibration isolation efficiency and consideration should be given to possibly shortened life when exposed to fuel, oil and floor cleaning compounds. Steel springs in combination with rubber pads are used to combat both light and heavy vibrations. Mountings of the steel spring type are strongly recommended for all installations because they are highly efficient in isolating vibration, retain their supporting and isolating properties, and can be adjusted to equalize loading and level the set. Other effects of engine vibration can be minimized by providing flexible connections between the engine and fuel lines, exhaust system, radiator air discharge duct, conduit for control and power cables, and other externally connected support systems.

Floor Loading

Floor loading pressures depend on total electric set weight and the number and size of isolator pads. If load is equally distributed over all isolators, the floor pressure is:

$$\text{Floor Unit Pressure} = \frac{\text{Total Electric Set Weight}}{\text{Pad Area} \times \text{No. of Pads}}$$

Thus, floor loading can be reduced by increasing the number of isolaton pads.

If load is not equally distributed, the maximum floor pressure occurs under the pad supporting the greatest proportion of load (assuming all pads are the same size):

$$\text{Floor Unit Pressure} = \frac{\text{Load on Heaviest Loaded Pad}}{\text{Pad Area}}$$

The electric set supplier should furnish calculated floor unit pressure in pounds per square foot of pad area.

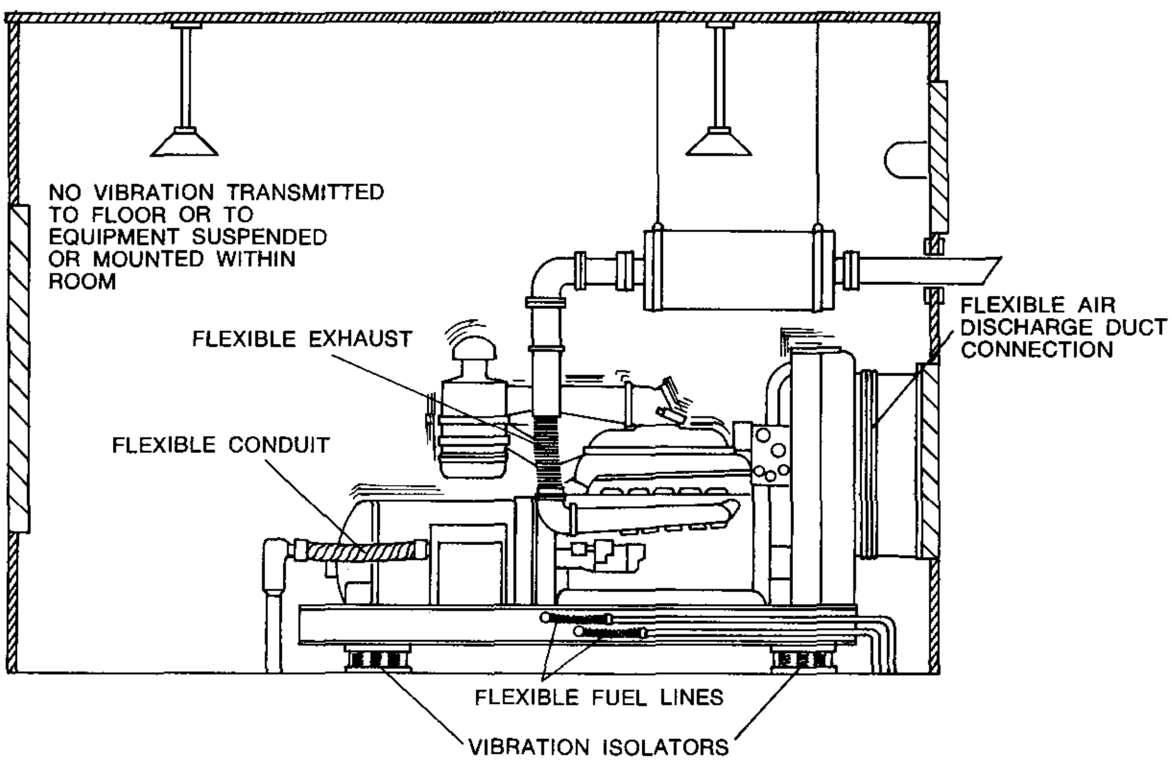

FIG. 1-6 — REDUCING VIBRATION TRANSMISSION

Ventilation

Any internal combustion engine requires a liberal supply of cool, clean air for combustion. If the air entering the engine intake is too warm or too thin, the engine may not produce its rated power. Operation of the engine and generator radiates heat into the room and raises the temperature of the room air. Therefore ventilation of the generator room is necessary to limit room temperature rise and to make clean, cool intake air available to the engine.

When the engine is cooled by a set-mounted radiator, the radiator fan must move great quantities of air through the radiator core. There must be enough temperature difference between the air and the water in the radiator to cool the water sufficiently before it recirculates through the engine. The electric set supplier can provide the maximum air temperature limit for which the cooling system is designed. The air temperature at the radiator inlet depends on the temperature rise of air flowing through the room from the inlet ventilator. By drawing air into the room and expelling it outdoors through a discharge duct, the radiator fan helps to maintain room temperature in the desirable range.

In providing ventilation, the objective is to maintain the room air at a comfortable temperature that is cool enough for efficient operation and full available power, but it should not be so cold in winter that the room is uncomfortable or engine starting is difficult. Though providing adequate ventilation seldom poses serious problems, each installation should be analyzed by both the electric set supplier and the customer to make sure the ventilation provisions are satisfactory.

Circulation

Good ventilation requires adequate flow into and out of the room and free circulation within the room. Thus, the room should be of sufficient size to allow free circulation of air, so that temperatures are equalized and there are no pockets of stagnant air. The electric set should be located so that the engine intake draws air from the cooler part of the room. If there are two or more electric sets, avoid locating them so that air heated by the radiator of one set flows toward the engine intake or radiator fan of an adjacent set.

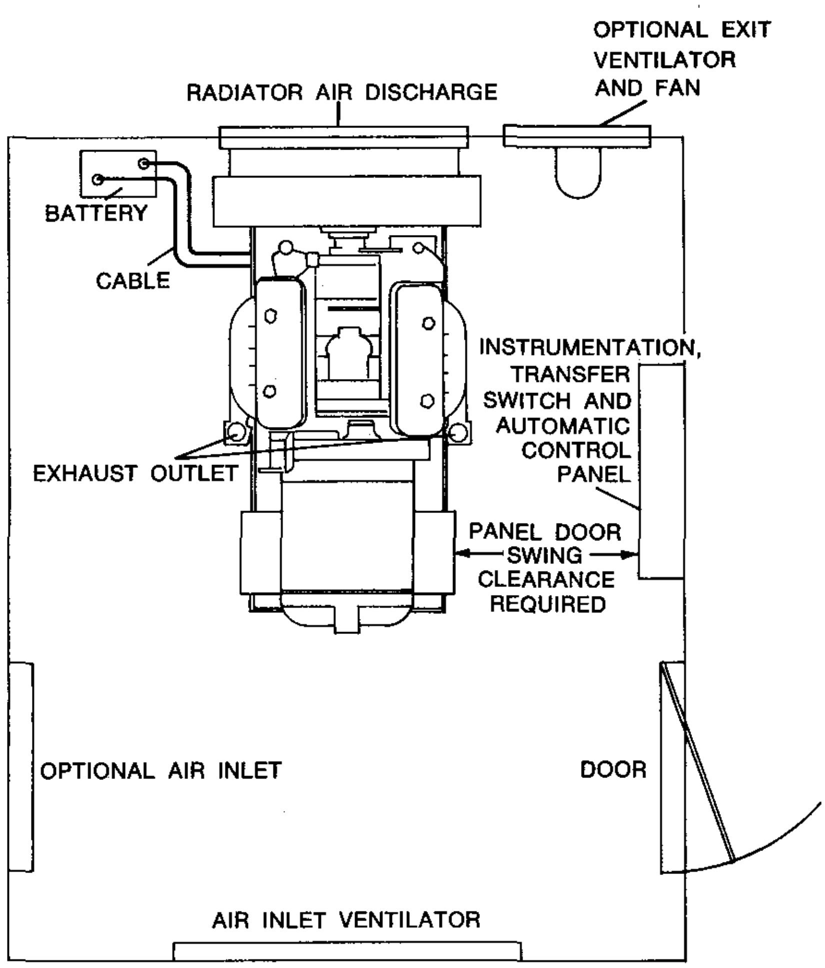

FIG. 2-1 — TYPICAL ARRANGEMENT FOR ADEQUATE AIR CIRCULATION AND VENTILATION

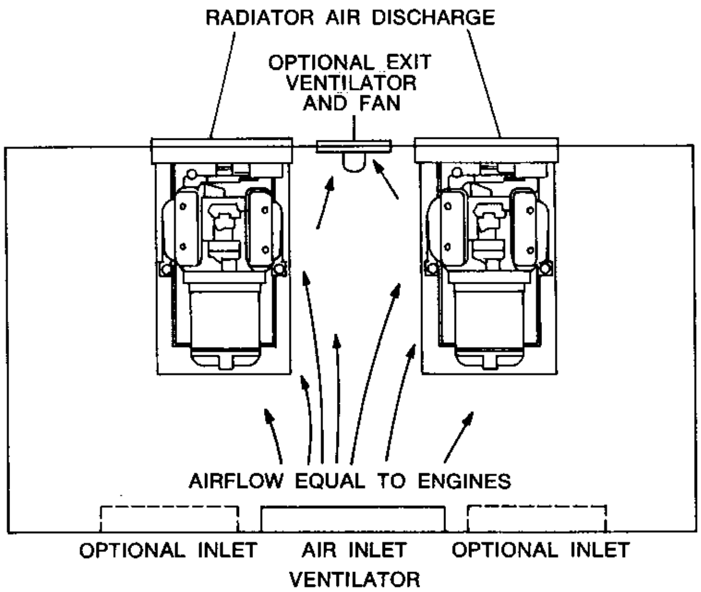

FIG. 2-2 — TYPICAL ARRANGEMENT FOR PROPER VENTILATION WITH MULTIPLE ELECTRIC SETS

Ventilators

To bring in fresh air, there should be an inlet ventilator opening to the outside or at least an opening to another part of the building through which the required amount of air can enter. In smaller rooms, ducting may be used to bring air to the room or directly to the engine's air intake. In addition, an exit ventilator opening should be located on the opposite outside wall, preferably high up, to exhaust warm air. If the exit air ventilator is located high on the outside wall, with the inlet ventilator in a lower position, sufficient air flow may be generated by convection. Otherwise, a fan must be installed in the exit ventilator.

Both the inlet and exit ventilators should have louvres for weather protection. These may be fixed but preferably should be movable in cold climates. For automatic-starting electric sets, if the louvres are movable, they should be automatically operated and those on the air **inlet** ventilator should be programmed to open immediately upon starting the engine. The louvres and fan in the **exit** ventilator may be thermostatically controlled so that the fan operates as needed and louvre position is varied in response to room temperature. If the electric set is equipped with a set-mounted radiator and there is a discharge duct for radiator air, most or all of the air required for room cooling is drawn into the room and discharged outdoors by the radiator fan. In this case the exit ventilator will be quite small (if required at all), and the exit ventilator fan probably will operate to exhaust a portion of the air flow outdoors only when the electric set is operating at high load or when outdoor temperature is high.

The signal for controlling the exit ventilator louvres and fan normally comes from a temperature sensor on a wall of the generator room. If temperatures at the engine are close to specified limits for engine intake or radiator inlet, the sensor may be located at one of these points. However, an economical alternative is to measure temperatures with the electric set operating at maximum load and set the wall thermostat low enough to assure cool air at the engine intake and radiator fan inlet.

Inlet Ventilator Size

Before calculating the inlet ventilator size, it is necessary to calculate the air flow required to limit the room temperature rise due to radiation, when the electric set is operating at its rated load. Total heat radiated by the complete electric set, including the exhaust system in the room, should be taken into account.

Engine and generator heat radiation for Detroit Diesel Allison engines and representative generators, when operating at standby rated power, are shown on engine specification sheets. Exhaust system radiation depends on the length of pipe within the room, the type of insulation used, and whether the silencer is located within the room or outside. It may be possible to insulate the exhaust piping and silencer so that heat radiation from this source may be neglected in calculating air flow required for room cooling. Calculate the required air flow using the total heat radiation and an temperature rise that may be accommodated without exceeding temperature limits at the radiator inlet or engine intake. Compare the calculated room ventilation air flow with the total of engine combustion air flow and radiator air flow discharged from the room. The larger flow is the required inlet ventilator air flow.

After determining the required air flow into the room, calculate the size of inlet ventilator opening to be installed in the outside wall. The inlet ventilator must be large enough so that the flow restriction at a selected air velocity (ft/min) will not generally exceed 0.2 in H_2O, including the restriction of a screen and louvre that may be used in the ventilator. The inlet air flow restriction must be very low, since this restriction adds to the radiator fan loss and to the engine combustion air inlet depression.

Of course, screens, filters and louvres in the ventilators will tend to increase the air flow restriction. Therefore the inlet air velocity may have to be reduced accordingly by increasing the area of the ventilator. For example, 18 x 14 mesh window screen would itself have approximately 0.2 in. H_2O restriction at an air velocity of only 900 ft/min. Restriction values of air filters, screens and louvres should be obtained from manufacturers of these items.

Exit Ventilator Size

If the engine is cooled by a heat exchanger or remote radiator, the exit ventilator must be large enough to exhaust all of the air flowing through the room, except the relatively small amount that enters the engine intake. If the engine is cooled by a set-mounted radiator that discharges air outdoors through a duct, the exit ventilator size is based on that portion of the air flow required for room cooling which exceeds the total of radiator air flow plus combustion air flow. In some cases, the total of radiator and combustion air flow will exceed the air flow required for room cooling; then, of course, no exit ventilator is needed.

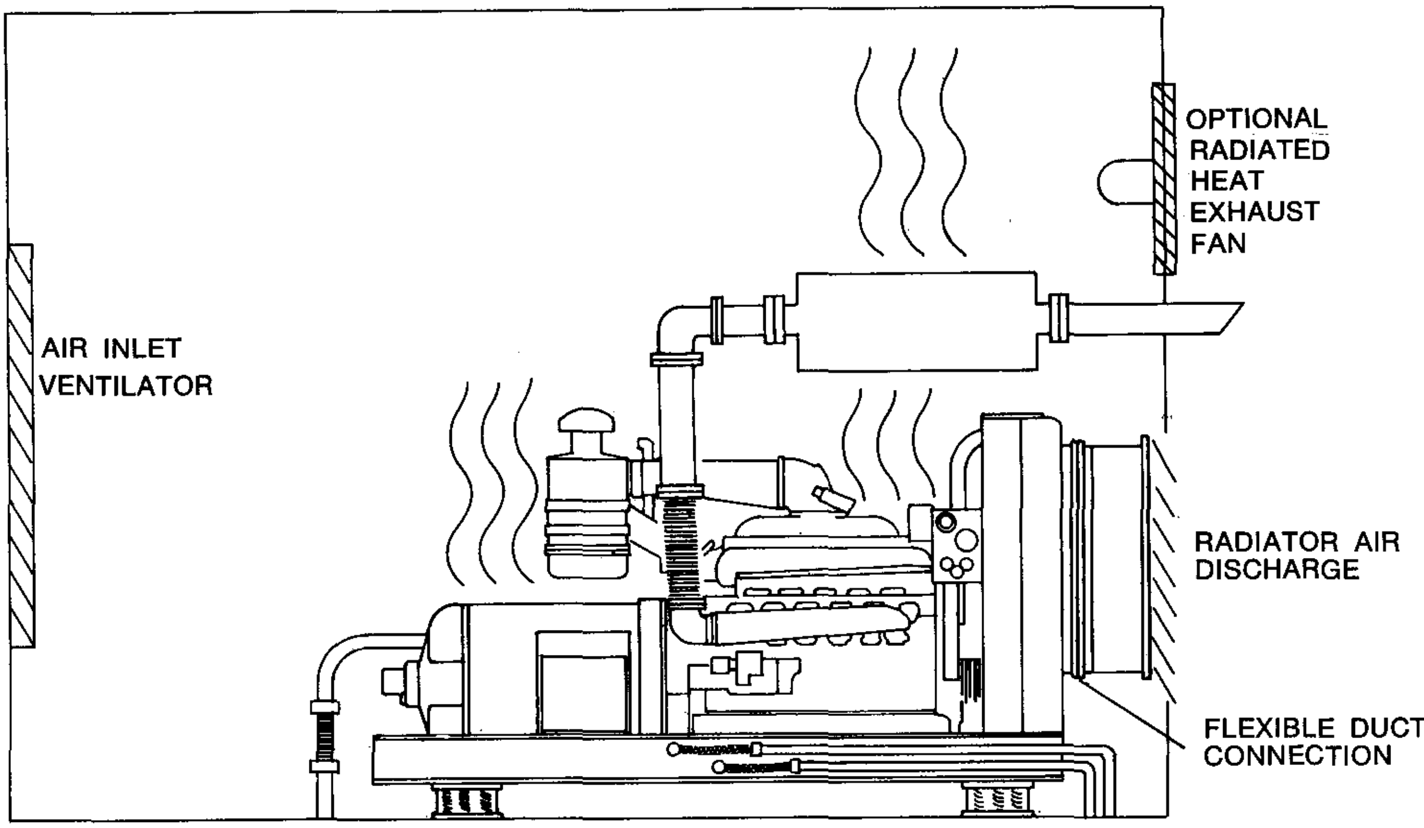

FIG. 2-3 — HEAT RADIATION TO ROOM

Engine Exhaust

Engine exhaust must be directed to the outside through a properly designed exhaust system that does not create excessive back pressure on the engine. A suitable exhaust silencer should be connected into the exhaust piping, either inside or outside the building. Exhaust system components located within the engine room should be insulated to reduce heat radiation. The outer end of the pipe should have an elbow or U shape and should be equipped with a rain cap to prevent rain or snow from entering the exhaust system. If the building is equipped with a smoke-detection system, the exhaust outlet should be positioned so it cannot set off the smoke-detection alarm.

Exhaust Piping

For both installation economy and operating efficiency, engine location should make the exhaust piping as short as possible with minimum bends and restrictions. Usually the exhaust pipe extends through an outside wall of the building and continues up the outside of the wall to the roof. There should be a collar in the wall opening to absorb vibration and an expansion joint in the pipe to compensate for lengthwise thermal expansion or contraction. Another method is to connect the exhaust pipe into a flue or stack (provided local laws permit), thus eliminating the tail pipe that would otherwise run up to the roof. There should be an expansion joint in the pipe and a collar in the stack wall, and inside the stack the end of the exhaust pipe should be directed upward. Directing the engine exhaust pipe upward avoids reflection of exhaust pulsations from the stack wall back into the exhaust pipe. Such pulsations may affect exhaust back pressure.

When the exhaust is connected into a flue or stack, the silencer may be mounted inside the building so the exhaust gas passes through the silencer and then into the stack, or the silencer may be mounted vertically inside the stack. When mounted vertically inside the stack, the silencer need not be insulated, but the stack may have to be larger to avoid air flow restriction. In rare cases, connecting into a stack may make it possible to eliminate the silencer since exhaust pulsations might be sufficiently dissipated in a large stack and would exit far enough above ground level to be less bothersome.

It is not normally recommended that the engine exhaust share a flue with a furnace or other equipment since there is danger that back pressure caused by one will adversely affect operation of the others. Such multiple use of a flue should be attempted only if is approved by Code and provided it is not detrimental to performance of the engine or any other equipment sharing the common flue.

The exhaust can be directed into a special stack that also serves as the outlet for radiator discharge air and may be sound-insulated. The radiator discharge air enters below the exhaust gas inlet so that the rising radiator air mixes with the exhaust gas. The silencer may be located within the stack, or in the room with its tail pipe extending into the stack, and then upward. Air guide vanes should be installed in the stack to turn radiator discharge air flow upward and to reduce radiator fan air flow restriction. Or the sound-insulation lining may have a curved contour to direct air flow upward. For an electric set enclosed in a penthouse on the roof or in a separate outdoor enclosure or trailer the exhaust and radiator discharges can flow together above the enclosure without a stack. Sometimes for this purpose, the radiator is mounted horizontally and the fan is driven by an electric motor to discharge air vertically.

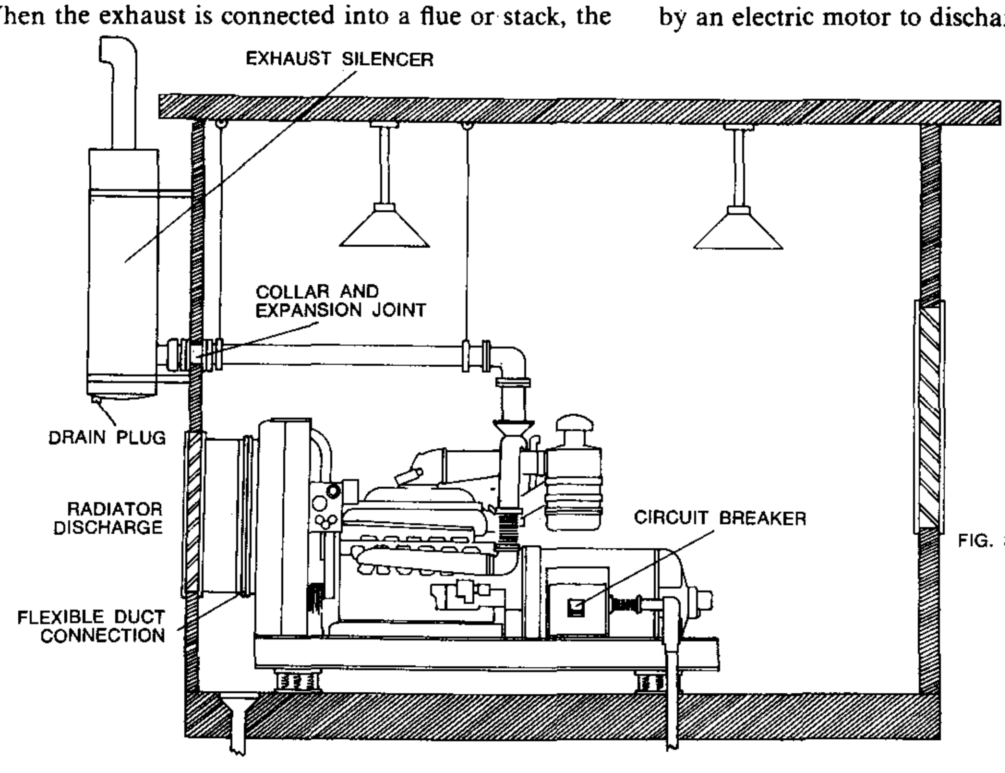

FIG. 3-1 – TYPICAL INSTALLATION WITH OUTSIDE VERTICALLY MOUNTED EXHAUST SILENCER

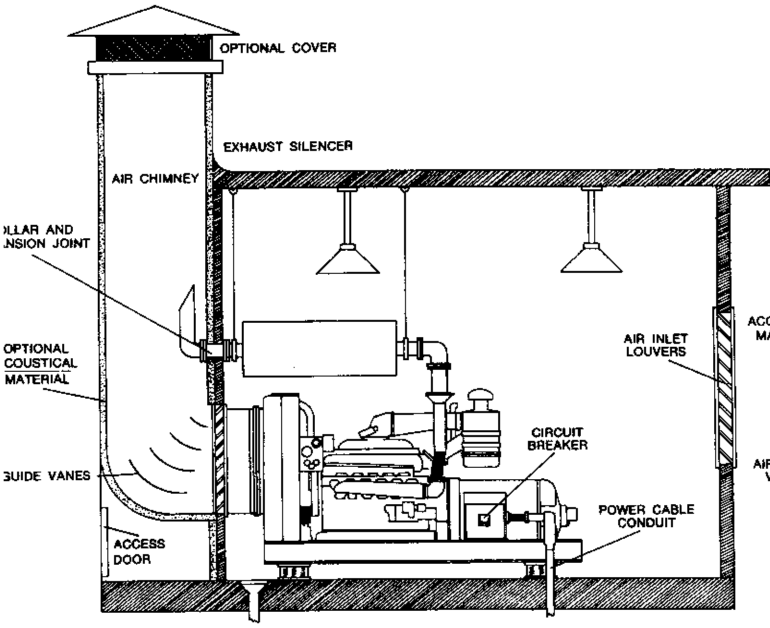

FIG. 3-2 – HORIZONTALLY MOUNTED EXHAUST SILENCER WITH EXHAUST AND RADIATOR AIR DISCHARGING INTO COMMON STACK

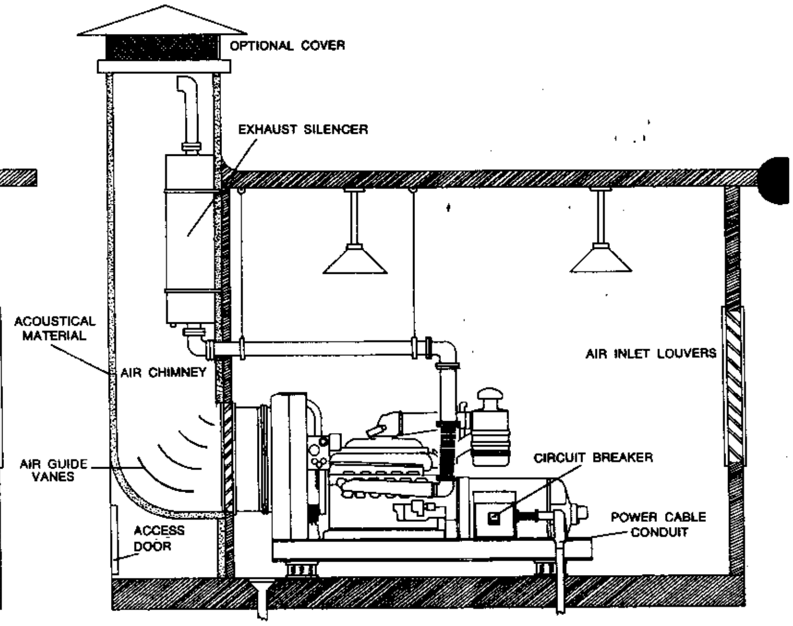

FIG. 3-3 – RADIATOR AIR DISCHARGING INTO SOUND-INSULATED STACK CONTAINING EXHAUST SILENCER

Exhaust Pipe Flexible Section

A flexible connection between the manifold and the exhaust piping system should be used to prevent transmitting engine vibration to the piping and building, and to isolate the engine and piping from forces due to thermal expansion, motion or weight of piping. A well-designed flex section will permit operation with ±1/2-inch permanent displacement in any direction of either end of the section without damage. Not only must the section have the flexibility to compensate for a nominal amount of permanent mismatch between piping and manifold, but it must also yield readily to intermittent motion of the electric set on its spring isolators in response to load changes. The flexible connection should be specified with the electric set.

Exhaust Pipe Insulation

No exposed parts of the exhaust system should be near wood or other inflammable material. Exhaust piping inside the building (and the silencer if mounted inside) should be covered with suitable insulation materials to protect personnel and to reduce room temperature. A sufficient layer of suitable insulating material, surrounding the piping and silencer and retained by a stainless steel sheath, may virtually eliminate heat radiation to the room from the exhaust system.

An additional benefit of the insulation is that it provides sound attenuation to reduce noise in the room.

Minimizing Exhaust Flow Restriction

Free flow of exhaust gases through the pipe is essential to minimize exhaust back pressure. Excessive exhaust back pressure seriously affects engine horsepower output, durability, and fuel consumption. By resisting the discharge of gases from the cylinder, it causes poor combustion and higher operating temperatures. The major design factors that may cause high back pressure are:

- Exhaust pipe diameter too small.
- Exhaust pipe too long.
- Too many sharp bends in exhaust system.
- Exhaust silencer restriction too high.
- At certain critical lengths, standing pressure waves may cause high back pressure.

Excessive restriction in the exhaust system can be avoided by proper design and construction. To make sure you will avoid problems related to excessive restriction, ask a Detroit Diesel Allison Distributor to review your design.

The effect of pipe diameter, length and the restriction of any bends in the system can be calculated to make sure your exhaust system is adequate without excessive back pressure. The longer the pipe, and the more bends it contains, the larger the diameter required to avoid excessive flow restriction and back pressure. The back pressure should be calculated during the installation's planning stage to make certain it will be within the recommended limits for the engine.

Measure the exhaust pipe length from your installation layout. Take exhaust flow data and back pressure limits from the electric set engine specification sheet (or from data furnished by a Detroit Diesel Allison Distributor). Allowing for restrictions of the exhaust silencer and any elbows in the pipe, calculate the minimum pipe diameter so that the total system restriction will not exceed the recommended exhaust

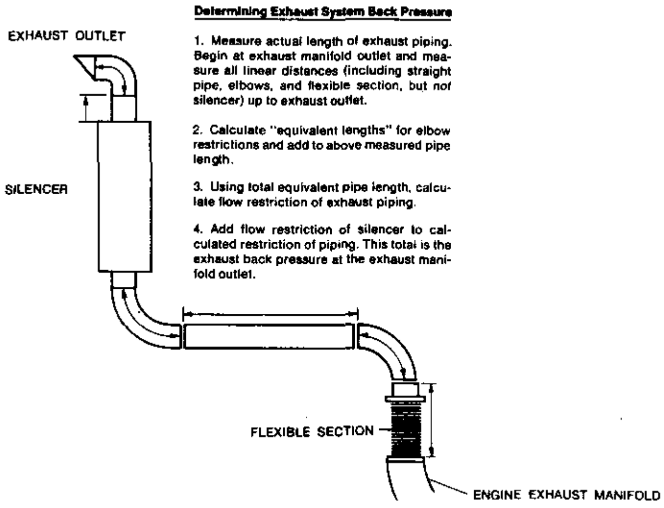

FIG. 3-4 – MEASURING EXHAUST PIPE LENGTH TO DETERMINE EXHAUST BACK PRESSURE

back pressure limit. Allowance should be made for deterioration and scale accumulation that may increase restriction over a period of time.

Elbow restriction is most conveniently handled by calculating an equivalent length of straight pipe for each elbow and adding it to the total length of pipe. For a 90 ° elbow, the equivalent length of straight pipe is calculated as follows:

$$L = 1.25 \times D$$

where L = equivalent length of straight pipe, ft
D = diameter of pipe, inches

Calculate back pressure of a proposed piping system as follows:

$$P = \frac{L \times S \times Q^2}{5184 \times D^5}$$

where P = back pressure, psi
To obtain P in inches of water, divide by 0.0361
To obtain P in inches of mercury, divide by 0.491
L = pipe length, ft (actual measured length of all piping plus "equivalent length" of elbow restrictions)
Q = exhaust gas flow, cfm
D = inside diameter of pipe, inches
S = specific weight of exhaust gas, lb/cu. ft.

S will vary with the absolute temperature of the exhaust gas as follows:

$$S = \frac{41}{460 \text{ X Exh. Temp. } ^\circ F}$$

The constant 41 is based on the weight of combustion air and fuel burned at rated load and SAE conditions. See engine specification sheet for exhaust gas temperature.

Exhaust Silencing

Excessive noise is objectionable in most locations. Since a large part of the electric set noise is produced in the engine's pulsating exhaust, this noise can be reduced to an acceptable level by using an exhaust silencer. The required degree of silencing depends on the location and may be regulated by law. For example, the noise of an engine is objectionable in a hospital area but generally is not as objectionable in an isolated pumping station.

Exhaust Silencer Selection

The silencer reduces noise in the exhaust system by dissipating energy in chambers and baffle tubes and by eliminating wave reflection that causes resonance. The silencer is selected according to the degree of silencing required by the site conditions and regulations. The size of silencer and exhaust piping should hold exhaust back pressure within limits recommended by the engine manufacturer.

Silencers are rated according to their degree of silencing by such terms as "low degree" or "commercial," "moderate" or "semi-critical," and "high degree" or "critical."

- Low-Degree or Commercial Silencing -- Suitable for industrial areas where background noise level is relatively high or for remote areas where partly muffled noise is permissible.
- Moderate-Degree or Semi-Critical Silencing -- Reduces exhaust noise to an acceptable level in localities where moderately effective silencing is required -- such as semi-residential areas where a moderate background noise is always present.
- High-Degree or Critical Silencing -- Provides maximum silencing for residential, hospital, school, hotel, store, apartment building and other areas where background noise level is low and electric set noise must be kept to a minimum.

Cost is lowest for commercial silencers and highest for high-degree silencers. The high-degree type is most often required for electric set applications.

Silencers normally are available in two configurations - (a) end inlet, end outlet, (b) side inlet, end outlet. Having the choice of these two configurations provides flexibility of installation, such as horizontal or vertical, above engine, on outside wall, etc. The side-inlet type permits 90 ° change of direction without using an elbow. Both silencer configurations should contain drain fittings in locations that assure draining the silencer in whatever attitude it is installed.

The silencer may be located close to the engine, with exhaust piping leading from the silencer to the outside; or it may be located outdoors on the wall or roof. Locating the silencer close to the engine affords best overall noise attenuation because of minimum piping to the silencer. Servicing and draining of the silencer is likely to be more convenient with the silencer indoors.

However, mounting the silencer outside has the advantage that the silencer need not be insulated (though it should be surrounded by a protective screen). The job of insulating piping within the room is simpler when the silencer is outside, and the insulation then can aid noise attenuation.

Since silencers are large and heavy, consider their dimensions and weight when you are planning the exhaust system. The silencer must be adequately supported so its weight is not applied to the engine's exhaust manifold or turbocharger. The silencer must fit into the space available without requiring extra bends in the exhaust piping, which would cause high exhaust back pressure. A side-inlet silencer may be installed horizontally above the engine without requiring a great amount of headroom.

Silencers or exhaust piping within reach of personnel should be protected by guards or insulation. Indoors, it is preferable to insulate the silencer and piping because the insulation not only protects personnel, but it reduces heat radiation to the room and further reduces exhaust system noise. Silencers mounted horizontally should be set at a slight angle with a drain fitting at the lowest point to allow the disposal of any accumulated moisture.

Sound-Attenuation

If noise level must be limited, it should be specified in terms of maximum allowable free-air dbA at certain points one meter away from the electric set, when tested in the open air (or equivalent) as defined in the Engine Manufacturers Association Procedure for Engine Sound Measurement. Then the power room installation must be designed to hold actual noise inside or outside the room to an acceptable level. Don't attempt to make this noise level unnecessarily low, because the means of achieving it may be costly.

Use of resilient mounts for the electric set plus normal techniques for controlling exhaust, intake and radiator fan noise should reduce electric-set noise to an acceptable level for many installations. If the remaining noise level is still too high, acoustic treatment of either the room or the electric set is necessary. Sound barriers can be erected around the electric set, or the walls of the generator room can be sound-insulated, or the electric set can be enclosed in a specially developed sound-insulated hood.

If it is desired to protect operating personnel from direct exposure to electric-set noise, the instruments and control station may be located in a separate sound-insulated control room. Thus personnel normally would not be in the power room when the electric set is operating.

Noise transmitted outside the building by the engine exhaust and radiator discharge can be reduced by having them discharge into a stack lined with noninflammable acoustic material. A lined canopy above the stack reflects noise back into the stack and keeps out rain and snow.

For information on the Engine Manufacturers Association Procedure for Engine Sound Measurement, refer to the Detroit Diesel Allison companion volume, "Electric Power System Planning." Also refer to Detroit Diesel Allison Engineering Bulletin No. 36 for information on noise reduction.

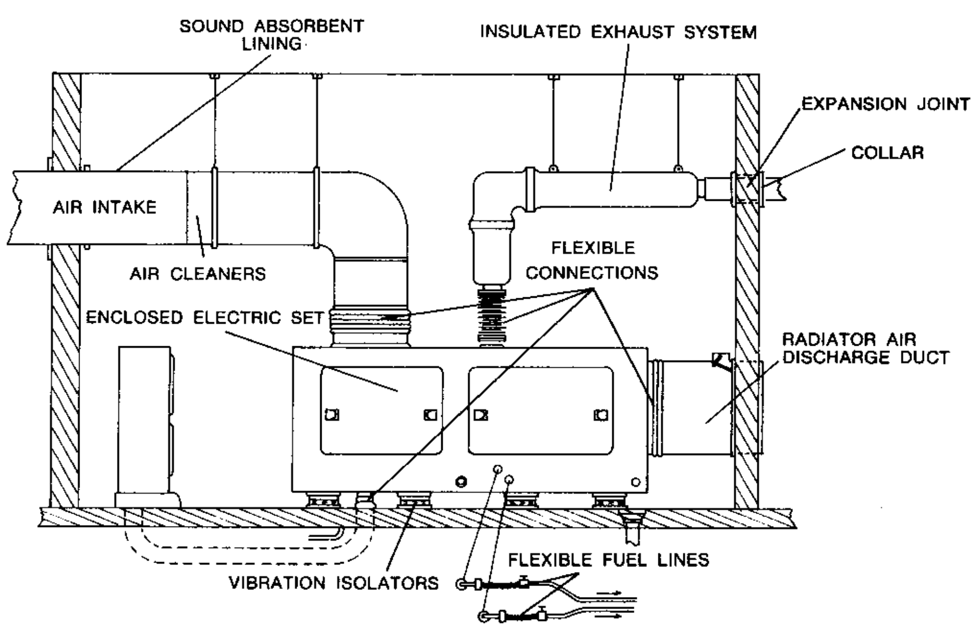

FIG. 4-1 — ELECTRIC SET IN SOUND-INSULATED ENCLOSURE

Engine Cooling

A diesel engine is cooled by circulating a liquid coolant through the oil cooler and through passages in the engine block and head. Hot coolant emerging from the engine is cooled and recirculated through the engine. Cooling devices are commonly coolant-to-air (radiator) or coolant-to-raw water (heat exchanger) types.

In the most common electric set installation, the engine coolant is cooled in a set-mounted radiator with air blown through the radiator core by an engine-driven fan. Some installations use a remotely mounted radiator, cooled by an electric motor-driven fan. Where there is a continuously available supply of clean, cool raw water, a heat exchanger may be used instead of a radiator; the engine coolant circulates through the heat exchanger and is cooled by the raw water supply.

An important advantage of a radiator cooling system is that it is self-contained. If a storm or accident disrupted the utility power source, it might also disrupt the water supply and disable any electric set whose supply of raw water depended upon a utility.

Whether the radiator is mounted on the electric set or mounted remotely, accessibility for servicing the cooling system is important. For proper maintenance, the radiator fill cap, the cooling system drain cocks, and the fan belt tension adjustment must all be accessible to the operator.

Set-Mounted Radiator

A set-mounted radiator is mounted on the electric set base in front of the engine. An engine-driven fan blows air through the radiator core, cooling the liquid engine coolant flowing through the radiator.

Set-mounted radiators are of two types. One type is used with the cooling fan mounted on the engine. The fan is belt-driven by the crankshaft pulley in a two-point drive. The fan support bracket, fan spindle and drive pulley are adjustable with respect to the crankshaft pulley in order to maintain proper belt tension. The fan blades project into the radiator shroud, which has sufficient tip clearance for belt tension adjustment.

The other type of set-mounted radiator consists of an assembly of radiator, fan, drive pulley and adjustable idler pulley to maintain belt tension. The fan is mounted with its center fixed in a venturi shroud with very close tip clearance for high-efficiency performance. The fan drive pulley, idler pulley and engine crankshaft pulley are precisely aligned and connected in a three-point drive by the belts. This second type of set-mounted radiator usually uses an airfoil-bladed fan with the close-fitting shroud and is therefore much more efficient and quieter, and considerably less horsepower is required to drive it. However, this type of radiator is generally more expensive than the first type described above.

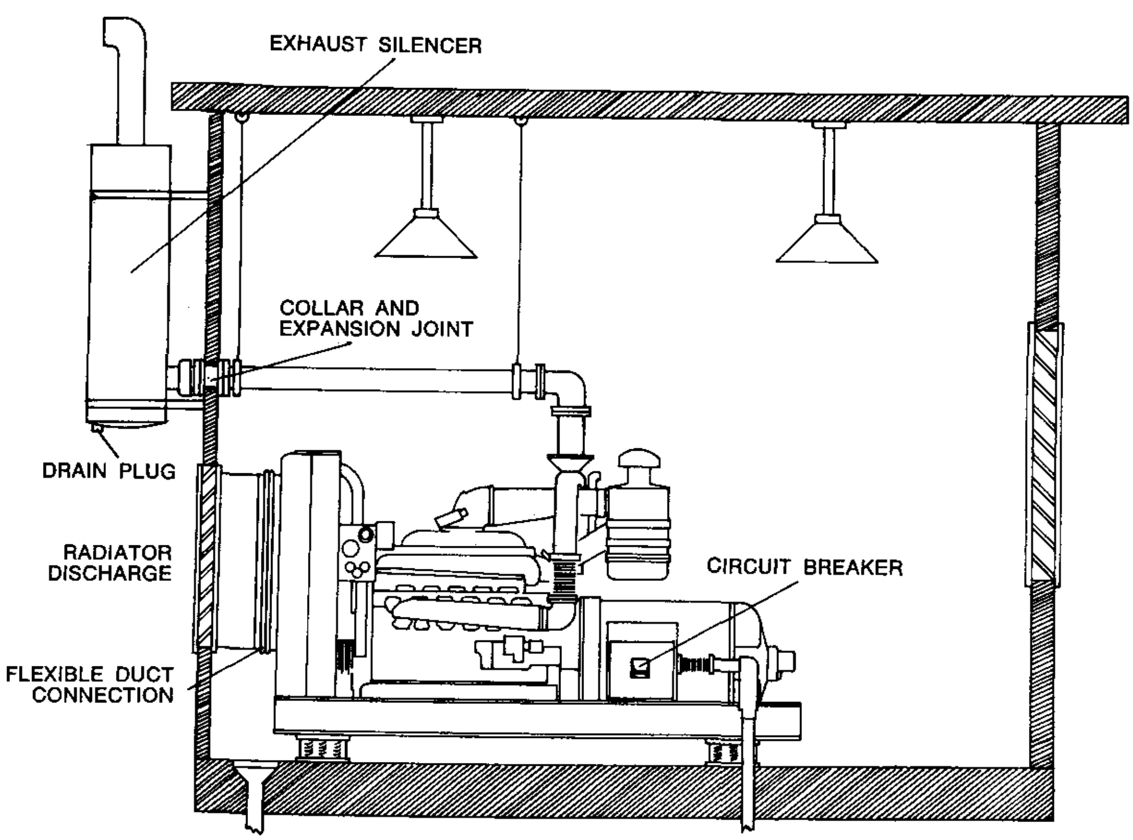

FIG. 5-1 — SET-MOUNTED RADIATOR DISCHARGING THROUGH OUTSIDE WALL

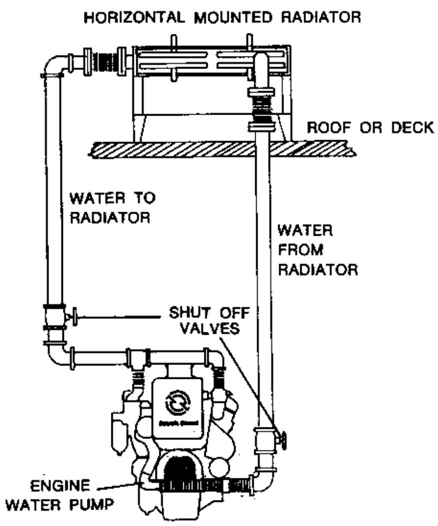

FIG. 5-2 — REMOTE RADIATOR CONNECTED DIRECTLY TO ENGINE COOLING SYSTEM

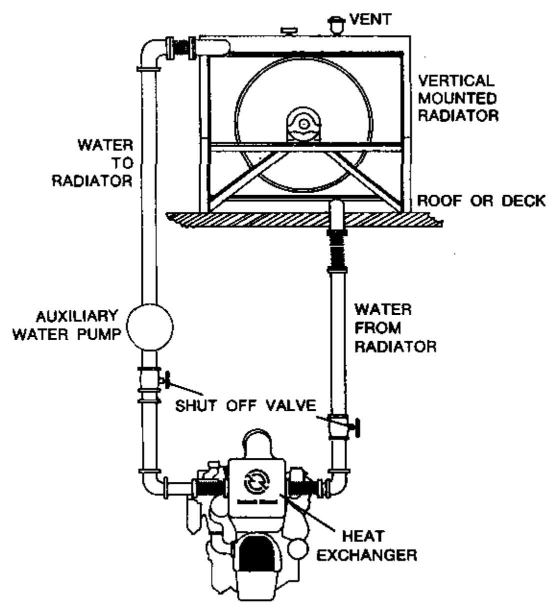

FIG. 5-4 — REMOTE RADIATOR ISOLATED FROM ENGINE COOLING SYSTEM BY HEAT EXCHANGER

The proper radiator and fan combination will be provided by your Detroit Diesel Allison Distributor and furnished with the electric set. Air requirements for cooling a particular Detroit Diesel Engine are given in the specification sheet. The radiator cooling air must be relatively clean to avoid clogging the radiator core. Adequate filtration of air flowing into the room should assure relatively clean air. However if the air at the site normally contains a high concentration of dirt, lint, sawdust, or other matter, the use of a remote radiator, located in a cleaner environment, may alleviate a core clogging problem.

It is recommended that a set-mounted radiator's discharge air should flow directly outdoors through a duct that connects the radiator to an opening in an outside wall. The engine should be located as close to the outside wall as possible to keep the ducting short. If the ducting is too long, it may be more economical to use a remote radiator. The air flow restriction of the discharge duct should not exceed 0.6 in. H_20.

When the set-mounted radiator is to be connected to a discharge duct, a duct adapter should be specified for the radiator. A duct adapter is simply a framework around the air discharge side of the radiator core area whose edges are perpendicular to the frontal plane of the radiator. The adapter may contain a series of holes to facilitate attaching one end of a flexible duct section to the front of the radiator. A length of flexible duct material (rubber or suitable fabric) between the radiator and the fixed discharge duct is required to isolate vibration and provide freedom of motion between the electric set and the fixed duct.

Remote Radiator

A remote radiator with electric motor-driven fan can be installed in any convenient location away from the electric set. A well-designed remote radiator has many useful features and advantages that provide greater flexibility of electric set installations in buildings. For example, remote radiators eliminate the need for radiator air ducts through the engine room wall. More efficient venturi shroud and fan provide a substantial reduction in horsepower required for engine cooling. The fan may be driven by a thermostatically controlled motor, which will only draw power from the electric set when required to cool the engine. A remote radiator can be located outdoors where there is less air flow restriction and air is usually cooler than engine room air, resulting in higher efficiency and smaller size radiator; and fan noise is removed from the building.

Remote radiators must be connected to the engine cooling system by coolant piping, including flexible sections between engine and piping. The higher cost of a remote radiator may be substantially offset by its higher efficiency and by the deduction of fan, mounting parts, belts and crankshaft pulley from the engine.

Remote Radiator/Hot Well System

In order to reduce the static head on the engine coolant system or to reduce the cost of antifreeze in a large system, a remote radiator mounted on the roof or other elevated location may be isolated from the engine by a hot well or mixing tank. The hot well is divided by a baffle into a hot side and a cold side. The engine water pump draws coolant from the cold side and returns it from the engine to the hot side. A separate pump circulates coolant from the hot side of the hot well through the remote radiator and returns it to the cold side. The baffle is perforated to permit enough flow between the two sides so that circulation through the radiator can be maintained and overflow avoided during engine warm-up when the engine thermostat shuts off flow to the hot side of the well.
When the engine is not operating, coolant drains from the remote radiator into the hot well, located inside the building, and thus avoids freezing in winter. The hot well or another isolation method must be used if the head exceeds 30 feet. The hot-well tank must have sufficient capacity to store all of the coolant which drains back when the engine is not operating. (The size of the hot well tank is the sum of the engine jacket water capacity plus radiator capacity plus pipe capacity plus allowance for heat expansion.)

Remote Radiator/Heat Exchanger System

Another type of remote radiator system employs a heat exchanger at the engine in place of the hot well. In this application, the heat exchanger functions as an intermediate heat exchanger to isolate the engine coolant system from the high static head of the remote radiator coolant. The engine pump circulates engine coolant through the engine and the element of the heat exchanger. A separate pump circulates radiator coolant between the remote radiator and the heat exchanger tank.

Heat exchangers also are used for cooling the engine without a radiator, as described in the following section.

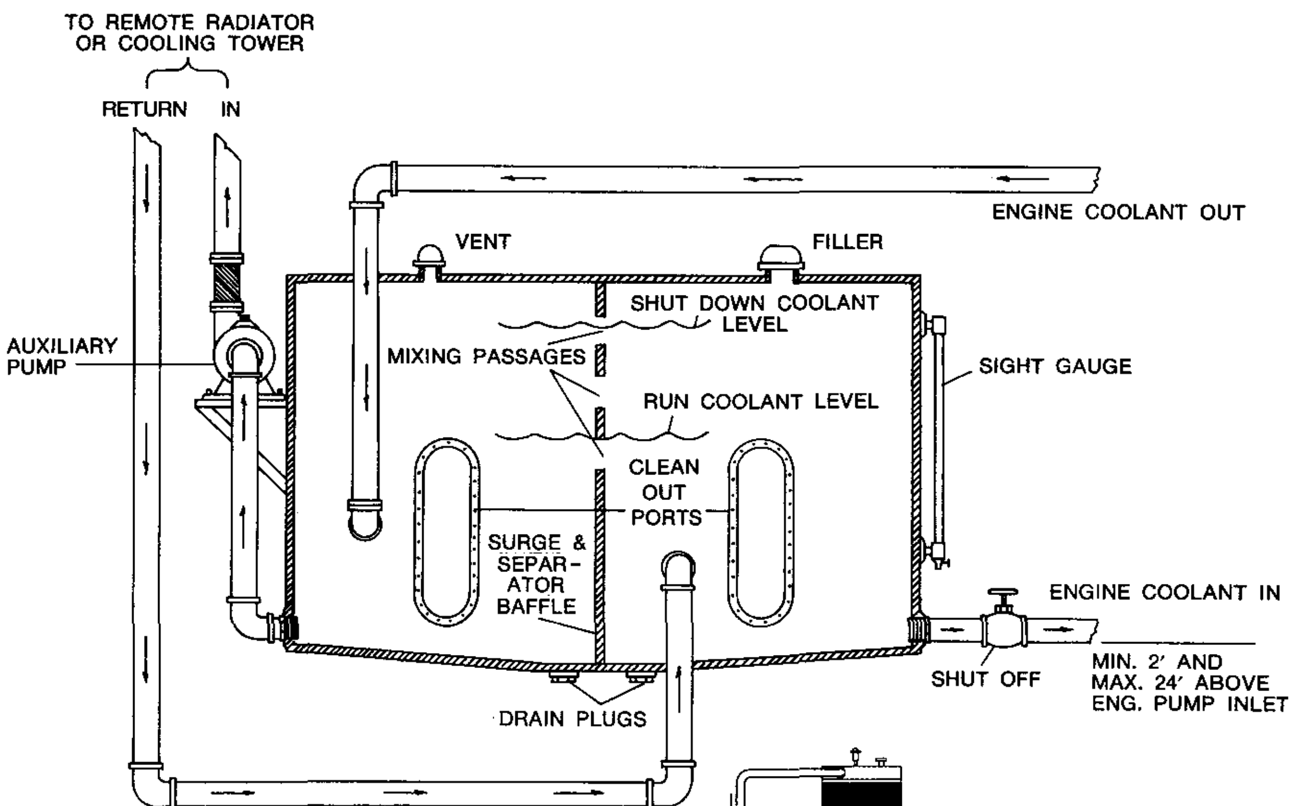

FIG. 5-3A — CROSS SECTION OF HOT WELL

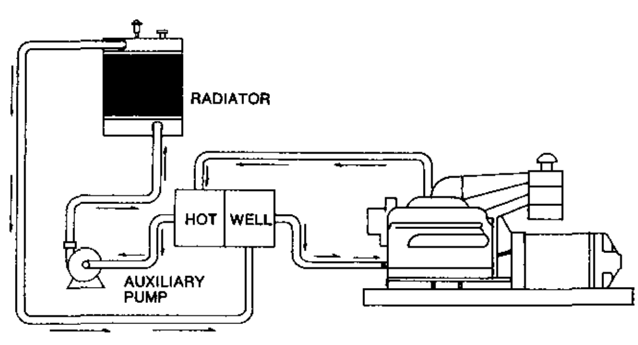

FIG. 5-3 — REMOTE RADIATOR ISOLATED FROM ENGINE COOLING SYSTEM BY HOT WELL

Heat Exchanger Cooling

A heat exchanger may be used where there is a continuously available supply of clean, cool raw water. Areas where excessive foreign material in the air might cause constant radiator clogging -- such as in cotton gin installations -- may be logical sites for heat exchanger cooling. A heat exchanger cools the engine by transferring engine coolant heat through passages in the elements to cool raw water. Engine coolant and raw cooling water flows are separated completely in closed systems, each with its own pump, and never intermix.

A heat exchanger totally replaces the radiator and fan. It usually is furnished as part of the electric set assembly, mounted on the engine, although it can be located remotely. Since the engine does not have to drive a radiator fan, there is more reserve power available.

The raw water side of the heat exchanger requires a dependable and economical supply of cool water. Soft water is desired to keep the heat exchanger in good operating condition. However, for standby service, a well, lake or cooling tower is preferred over city water since the latter may fail at the same time that normal electric power fails, making the electric set useless.

Antifreeze Protection

If the engine is apt to be exposed to low temperatures, the cooling water in the engine must be protected from freezing. In radiator-cooled installations, antifreeze may be added to the water to prevent freezing. Ethylene glycol permanent antifreeze is recommended for diesel engines. It includes its own corrosion inhibitor, which eventually may have to be replenished. Only a non-chromate inhibitor should be used with ethylene glycol. Refer to Detroit Diesel Allison Bulletin 7SE-298 and 7SE-304 for information on coolant additives and cooling system care:

The proportion of ethylene glycol required is dictated primarily by the need for protection against freezing in the lowest ambient air temperature that will be encountered. Another benefit is higher boiling point, which improves cooling in hot weather by permitting a higher temperature differential between the coolant and the ambient air. The concentration of ethylene glycol must be at least 30% to afford adequate corrosion protection. The concentration must not exceed 67% to maintain adequate heat transfer capability.

For heat exchanger cooling, antifreeze does only half the job since it can only be used in the engine water side of the head exchanger. There must be assurance that the raw water source will not freeze.

Water Conditioning

Soft water should always be used in the engine whether cooling is by radiator or by heat exchanger. Adding a commercial softener is the easiest and most economical method of water softening. Your Detroit Diesel Allison Distributor can recommend suitable softeners. Manufacturer instructions should be carefully followed.

Water filters can be used to keep the water clean and the system free of deposits and relatively free of electrolytic action. This will minimize cooling system trouble, especially in hard water areas. Water filters are available as options on Detroit Diesel engines. Refer to Detroit Diesel Allison Bulletin 7SE-304 for information on coolant filter elements.

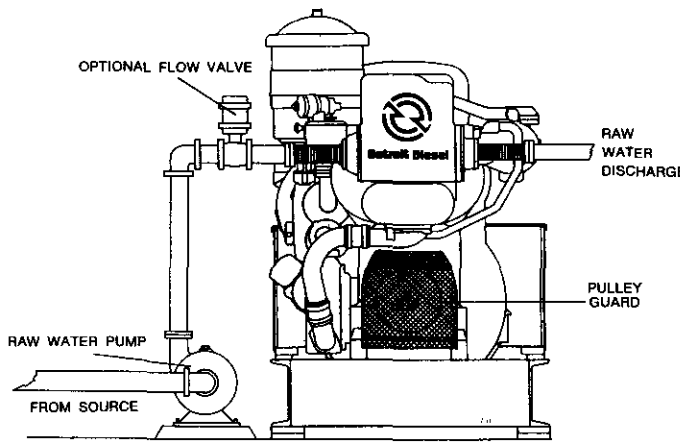

Fig. 5-5 HEAT EXCHANGER COOLING SYSTEM

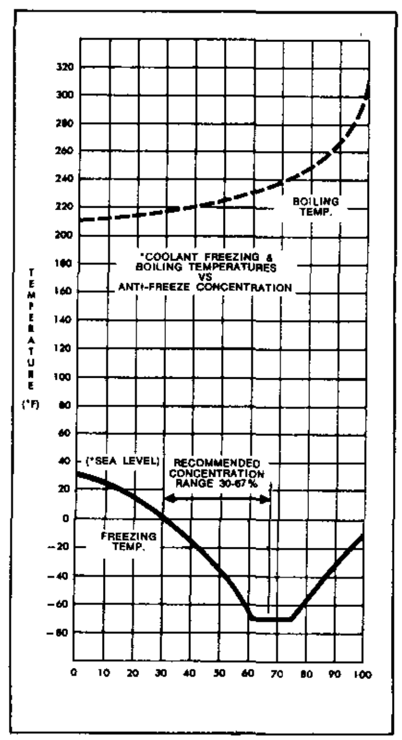

FIG. 5-4 — COOLANT FREEZING AND BOILING TEMPERATURES VS. ANTIFREEZE CONCENTRATION

Fuel System

Detroit Diesel Engine Fuel Injection System

Detroit Diesel engines are equipped with a unit injector fuel system. Each cylinder has its own injector, which provides the necessary pressure to atomize and inject the fuel into the cylinder without assistance from any supplemental pressure device.

The unit injector fuel system eliminates high-pressure fuel lines and provides uniform distribution of fuel to all cylinders. A simple low-pressure fuel transfer pump circulates fuel through the lines, filters and injectors and back to the supply tank. As the circulating fuel passes through the injector bodies, each injector measures out a precise quantity of fuel, pressurizes, atomizes and injects it in one smooth operation.

The fuel circulating through the injectors serves to lubricate and cool the moving parts of the injectors. (Even the lighter classes of fuel provide sufficient lubrication for the injectors.) Only a small portion of the circulating fuel is injected and consumed; the balance serves its cooling function by carrying away heat from the engine to be dissipated in the fuel tank.

This recirculating fuel system is self priming and self air-purging if the fuel tank is properly vented.

Two replaceable-element fuel oil filters are included as standard equipment on Detroit Diesel electric-set engines -- one at the inlet of the fuel transfer pump and one at its outlet.

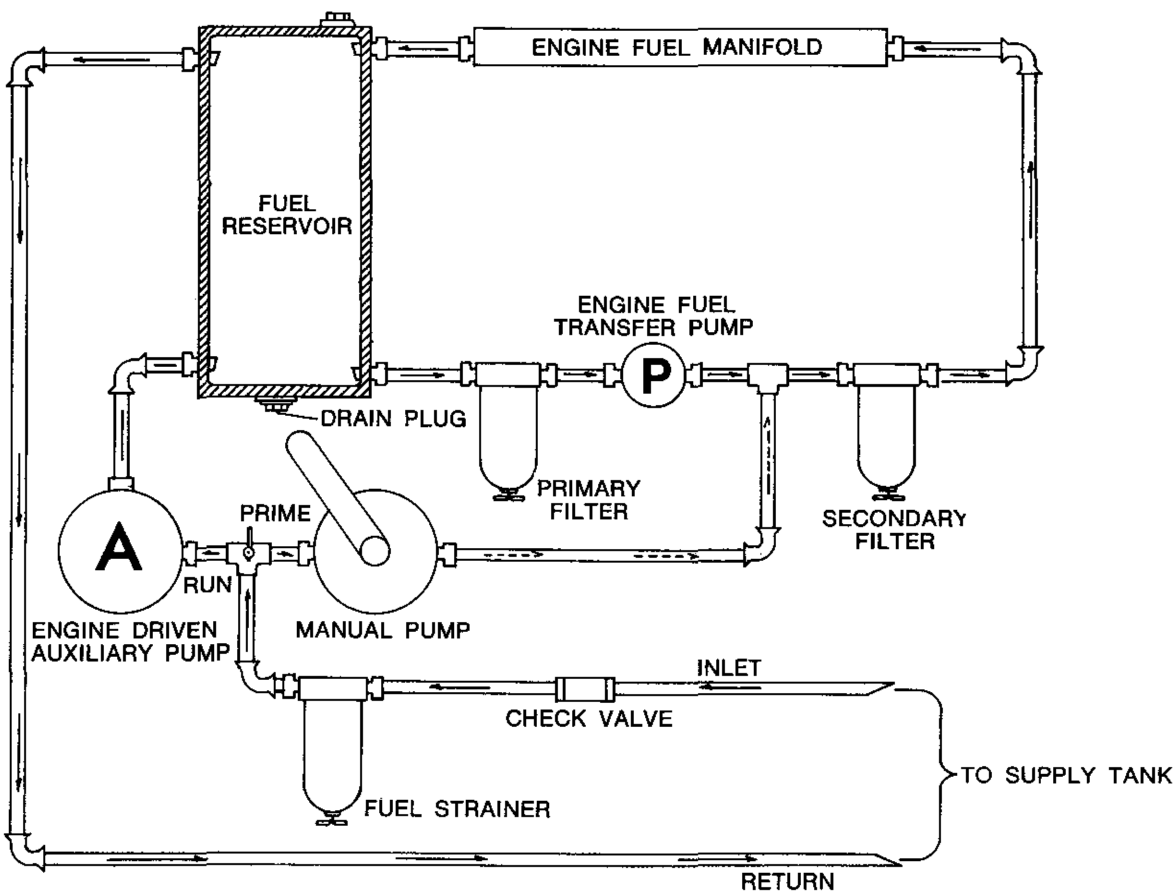

FIG. 6-1A—STANDARD DETROIT DIESEL AUXILIARY FUEL SYSTEM USING AN ENGINE DRIVEN AND MOUNTED AUXILIARY FUEL PUMP

Fuel Supply

A dependable fuel supply system must assure instant availability of fuel to facilitate starting and must keep the engine operating throughout the emergency. The essential elements of an electric set fuel system are:

Fuel storage tank

Fuel day tank and auxiliary fuel pump

Fuel piping with flexible sections at engine

Fuel transfer pump (part of engine)

Fuel strainers and filters (usually furnished with the electric set)

Storage Tank Location

To simplify the fuel supply system, the fuel tank should be as close to the engine as possible. Normally it is safe to store diesel fuel in the same room with the engine because there is less danger of fire or fumes than with gasoline. Thus, if building codes and fire insurance regulations permit, the fuel storage tank may be located alongside or in the base of the electric set or in an adjacent room. If this is not possible, the main fuel storage tank should be located outside the building or underground. The tank should not be located outdoors above ground if it will be exposed to freezing weather because fuel flow will be restricted as viscosity increases.

The location should be convenient for refilling and for cleaning and inspection.

For prompt starting, the ideal fuel level in the tank should be maintained equal to the level of the fuel transfer pump inlet. However, when the engine is not running, the fuel level should not be higher than the fuel injector nozzles in the engine. If the fuel level in the tank is below the pump inlet, a check valve installed in the pump suction line will prevent drain-back of fuel into the tank during standby periods. Positive head of fuel on the engine injectors must be avoided. If it is necessary to locate the storage tank so that its fuel level is higher than the injectors, positive-sealing valves must be located in both the suction and return lines to isolate the fuel head from the engine when it is not running.

As fuel is consumed, the level in the storage tank lowers. When fuel is fed directly to the engine from the storage tank, the receding fuel level increases the suction lift of the engine fuel pump. The lowest level of fuel below the pump should not cause the suction lift plus the combined flow restriction through the check valve and lines to exceed 6 in. Hg. The system should be designed well within this limit with allowance for increasing flow restriction as sediment

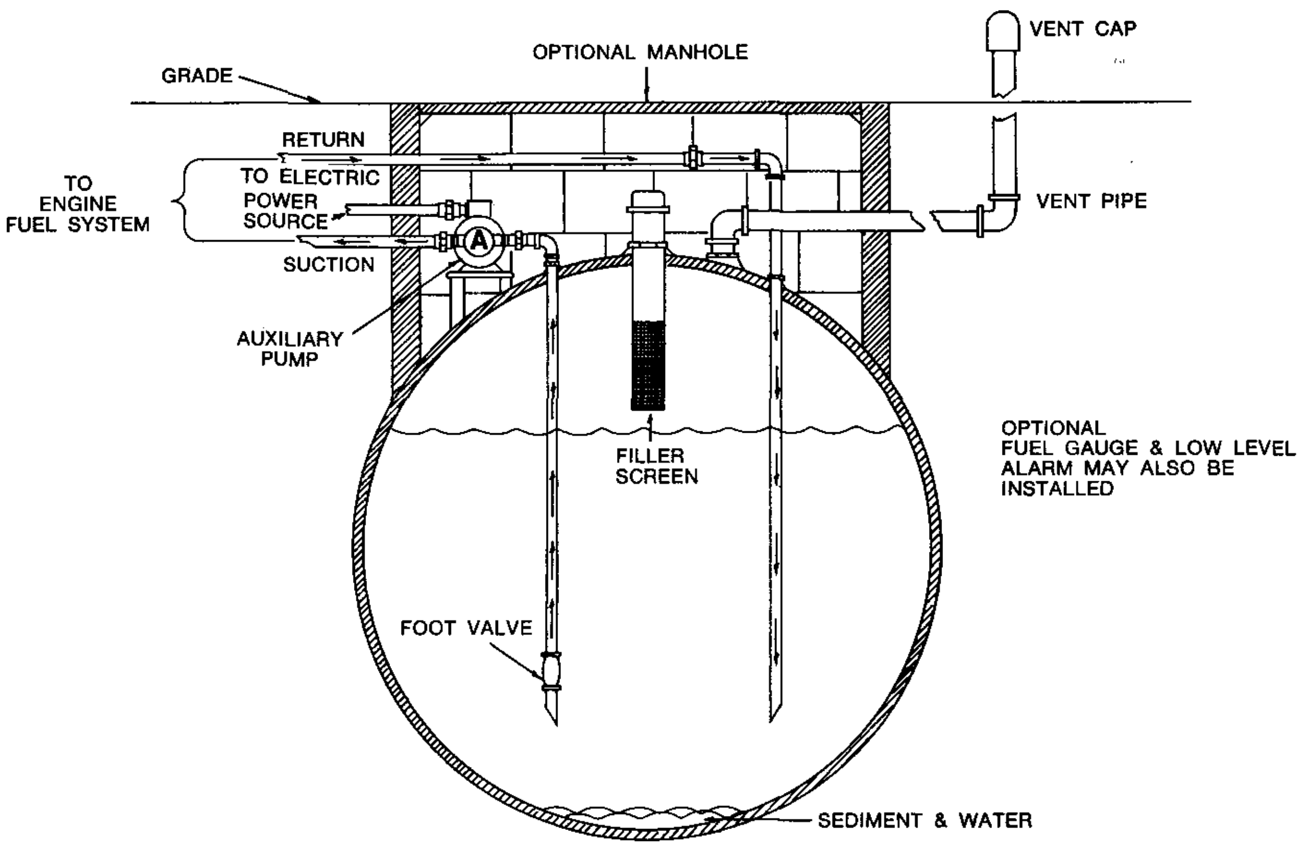

FIG. 6-1 — UNDERGROUND MAIN FUEL STORAGE TANK accumulates in fuel filters during the interval between filter changes. Engine fuel pump flow data can be obtained from Detroit Diesel Allison electric-set engine specification sheets.

If the storage tank must be located well below or away from the engine so that the combination of suction lift plus flow restriction exceeds the specified limit of 6 in. Hg. on the inlet side of the engine fuel transfer pump, an auxiliary fuel supply system should be interposed between the main storage tank and the engine.

Auxiliary Fuel Supply Systems

An auxiliary fuel supply system consists of a day tank, auxiliary fuel pump, fuel strainer and required piping. The fuel strainer is installed on the inlet side of the auxiliary fuel pump. Size of the day tank is optional, varying up to eight times the hourly fuel consumption of the engine at rated load and speed. The day tank should be located as near the engine as possible in order to accomplish its primary function of minimizing inlet restriction on the engine fuel transfer pump. The auxiliary fuel pump supplies fuel to the day tank from the storage tank. The engine fuel transfer pump draws fuel from the day tank for the engine fuel injection system and returns excess fuel to the day tank.

Two types of auxiliary fuel pumps are available, electric motor-driven and engine-driven. Each type has features and limitations that should be considered before a selection is made for a specific application.

In the system with an electric motor-driven auxiliary fuel pump, the pump operates intermittently, in most cases, supplying fuel to the day tank from a storage tank. A float switch starts and stops the pump motor as the fuel level in the day tank fluctuates within predetermined limits. The electric motor-driven pump may often be located near the day tank. In some cases it may be necessary to separate the motor-driven pump from the day tank and locate the pump nearer the storage tank according to suction lift capabilities of the pump and barometric pressure conditions at the site.

In the system with an engine-driven auxiliary fuel pump, the pump is flange-mounted on the engine and directly driven by the engine. Since the pump thus operates continuously, fuel is supplied to the day tank continuously; and overflow from the day tank is returned to the storage tank. The engine-driven auxiliary fuel pump is applicable to installations wherein the combined suction lift and suction line flow restriction does not exceed 15 in. Hg. Since fuel delivery to the day tank is continuous when the engine runs, the auxiliary fuel pump may be sized small enough to deliver only about 50% more fuel than the

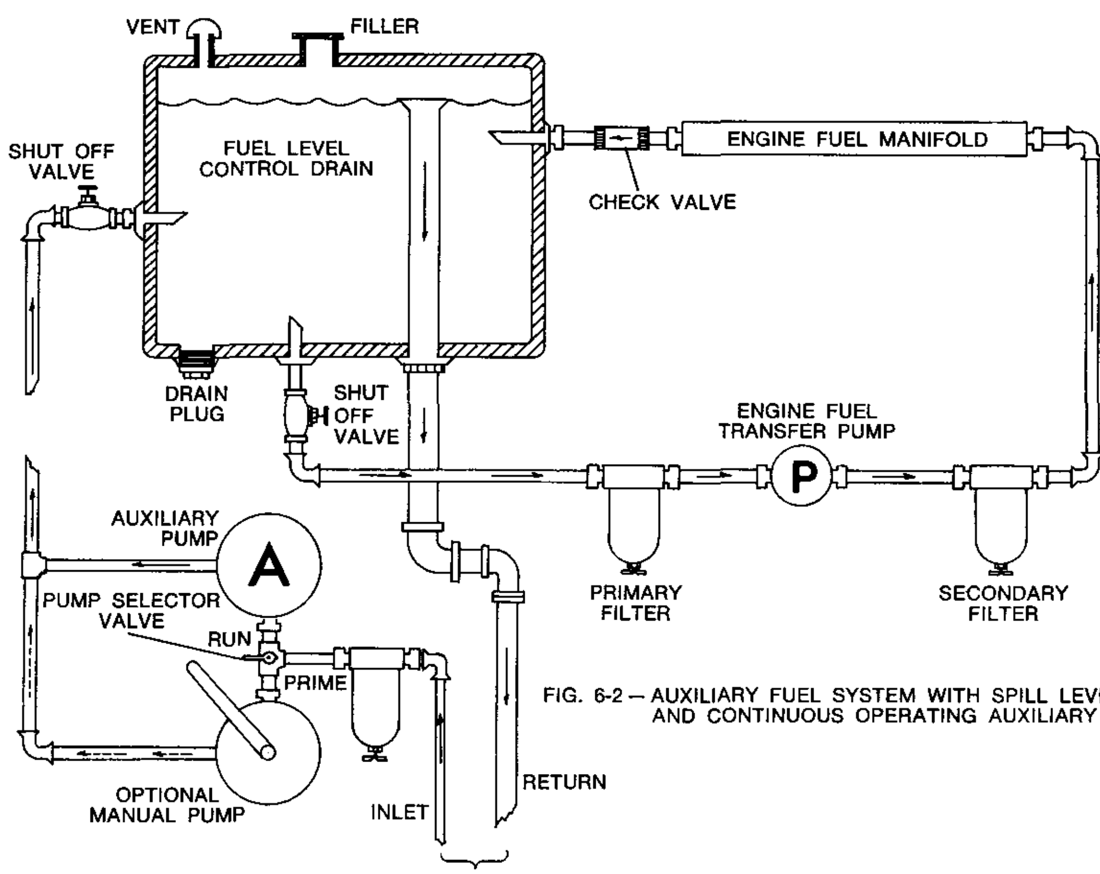

FIG. 6-2 — AUXILIARY FUEL SYSTEM WITH SPILL LEVEL CONTROL AND CONTINUOUS OPERATING AUXILIARY FUEL PUMP

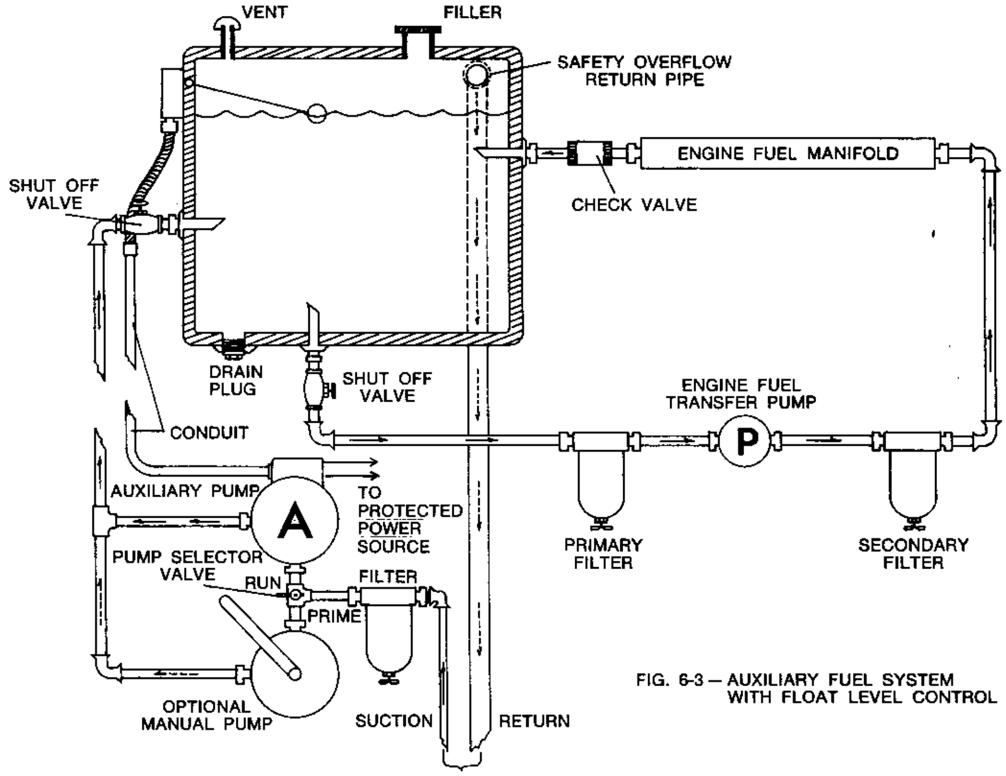

FIG. 6-3 — AUXILIARY FUEL SYSTEM WITH FLOAT LEVEL CONTROL

engine consumes at rated load and speed, thus minimizing power required to drive the auxiliary pump.

Although fuel is pumped into the day tank faster than it is consumed by the engine, fuel level in the day tank is maintained at a constant level by returning excess fuel continuously from the day tank to the storage tank when the engine runs. The fuel return line to the storage tank should exit near the top of the day tank, for best purging, and should be the same diameter as the supply line. The low pressure required to return fuel to the storage tank is generated by the auxiliary pump. This low return line pressure will be reflected in the day tank and also on the suction side of the engine fuel transfer pump. Consequently, the day tank used with the engine-driven auxiliary fuel pump cannot be vented to the room.

The day tank may be vented if it is close enough or high enough in relation to the storage tank to permit gravity overflow return to the storage tank without depending on pressure from the auxiliary pump. In this case, the level of fuel in the day tank is established by the position of the overflow return pipe outlet.

Compared with the electric motor-driven auxiliary fuel pump, the engine-driven auxiliary fuel pump is more reliable, less expensive, and requires no float-switch level control.

A manual priming pump is an optional component for use with either the electric motor-driven or engine-driven auxiliary fuel system. A priming pump facilitates getting a supply of fuel from the storage tank into the engine room to assist initial priming of the engine filters and the lines before initial start-up of the engine after completion of the electric set installation.

Tank Construction

Fuel tanks are usually made of aluminum, monel, stainless steel, black iron, welded sheet steel or reinforced plastic. They should never be made of galvanized steel because a chemical reaction between the fuel oil and the galvanized coating will cause flakes to clog the system. If an old fuel tank is used, be sure it is made of a proper material. It should be cleaned thoroughly to remove all rust, scale and foreign deposits.

Connections for fuel suction and return lines must be separated as much as possible to prevent recirculation of hot fuel and to allow separation of any gases entrained in the fuel. Fuel suction and return lines should both extend below the minimum fuel level in the tank. Extending the return line into the fuel avoids foaming. Where practical, a low point in the tank should be equipped with a drain valve or plug, in an accessible location, to allow periodic removal of water condensation and sediment. Or a hose may be inserted through the tank's filter neck when necessary on to suck out water and sediment.

The filler neck of the main storage tank should be located in a clean accessible location. A removable wire screen of approximately 1/16 inch mesh should be placed in the filler neck to prevent foreign material from entering the tank. The filler neck cap should be vented to maintain atmospheric pressure on the fuel and to provide pressure relief in case a temperature rise causes the fuel to expand. The highest point of the tank should be vented into the neck to reduce the possibility of air entrapment and fuel blow-back while filling the tank. The tank may be equipped with a fuel level gauge -- either a sight gauge or a remote electrical gauge.

Storage Tank Capacity

The capacity of the main storage tank is based on the expected rate of fuel consumption and the number of hours of operation that must be possible between refills. Particularly with standby generators, the availability of fuel delivery service will determine the number of operating hours that must be provided for. Don't depend on quick service the very day your set starts to operate. A power outage may hamper your supplier's operation also.

In specifying tank capacity, estimate the minimum fuel supply required to assure continued operation under the conditions you anticipate. You don't want to run short. But don't specify more than you'll need. This would add cost unnecessarily, not only in original cost of tank and fuel but also in fuel replacement costs over a period of time as explained later in this section under "Maintaining Fresh Fuel."

When practical, the preferred situation is to have a small supply that is used up by tests and exercise runs and kept fresh by frequent refillings. However, some conditions may require a supply of many hours, days or weeks. A building in a remote area might not have a handy fuel source. Hurricanes, tornadoes and earthquakes not only will put power lines out of commission but could make fuel delivery impossible for several days. If such conditions are anticipated, a large storage tank of many days' operating capacity should be specified.

Day Tank Capacity

Two factors influence the minimum fuel capacity required for the day tank. One is the need to minimize turbulence caused by supply and return flow of fuel in order that entrained air can freely separate from the warmer fuel returned from the engine. The other factor is the need for an adequate quantity of fuel in the day tank to provide some minimum duration of electric set operation in case the auxiliary fuel pump or lines or float-control switch should fail. Capacities may vary up to eight times the hourly fuel consumption of the engine at rated load and speed.

Example Calculation of Storage Tank Capacity

Consider a 60 KW electric set which will operate a maximum of eight hours a day. Fuel delivery is assured for at least every other day. A rule of thumb for estimated fuel consumption is: one gallon of fuel consumed per hour for every 10 KW of generator rating. Therefore, a 60 KW electric set at full load will use 6 gallons of fuel for every hour of operation. Since the electric set may be required to operate for 16 hours before replenishing the fuel, the minimum amount of fuel that must be available at all times is 96 gallons. Periodic exercising and tests will use about 3 gallons per week, and it is planned to refill the tank every six or seven weeks, whenever 20 gallons of fuel have been used. Therefore, the tank when filled will contain at least 116 gallons of fuel.

Increase the tank volume by 7 gallons (6%) to allow space for fuel heat expansion and for accumulation of condensation and sediment, making a total volume of 123 gallons. For this installation, a 125 gallon fuel tank would probably be selected.