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NAVAL SHIPS' TECHNICAL MANUAL

CHAPTER 310

ELECTRIC POWER GENERATORS AND CONVERSION EQUIPMENT

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NOTE

THIS CHAPTER HAS BEEN REFORMATTED FROM DOUBLE COLUMN TO SINGLE COLUMN TO SUPPORT THE NSTM DATABASE. THE CONTENT OF THIS CHAPTER HAS NOT BEEN CHANGED.

CHAPTER 310

ELECTRIC POWER GENERATORS AND CONVERSION

SECTION 1.

ELECTRIC GENERATORS

310-1.1 GENERAL AND SAFETY PRECAUTIONS

310-1.1.1 SCOPE. This section covers a description of and operational instructions for generators other than those used in electric propulsion systems. Instruction for the operation of electric propulsion systems are in**NSTM Chapter 235** of the Naval Ships' Technical Manual (NSTM). Instructions on maintenance are in **NSTM Chapter 300** .

310-1.1.2 TECHNICAL MANUALS. The personnel responsible for the operation, care, and maintenance of equipment should be thoroughly acquainted with the contents of the appropriate technical manuals. Prints of sufficiently detailed plans are also available to enable the ship's force to handle most of the repairs ordinarily required. These plans should be indexed, kept up to date, and should be referred to when machines require overhaul or repair, or when ordering new parts by requisition.

310-1.1.3 SAFETY PRECAUTIONS. Safety precautions must be observed when working around electrical equipment to avoid injury to personnel and equipment. NSTM Chapter 300 provides detailed procedures and precautions. In addition, generators are frequently equipped with various accessories having separate sources of power. Internal illuminating fixtures, internal heaters, and externally powered temperature detectors and alarm contact makers are examples of accessories whose terminals must be de-energized when working on these generators. Check to ensure that all such separate circuits are de-energized prior to attempting any maintenance or repair work on the equipment.

310-1.2 DESCRIPTION OF ALTERNATING CURRENT GENERATORS

310-1.2.1 GENERATOR CHARACTERISTICS. Alternating current (ac) generators on United States naval ships include:

a. Generators may be used for ship service or emergency service. In some cases, they can be designated interchangeable for either ship service or emergency service. These generators are normally 450-volt, 60-hertz, three-phase machines except:
   1. A few 230-volt, 60-hertz, three-phase generators used on some auxiliary ships.
   2. Some 1,000-volt, 400-hertz, three-phase generators.
   3. Some 4,160-volt, 60-hertz, three-phase generators used on aircraft carriers.

b. . Generators for special services, such as aircraft servicing and electronic and other applications, include 1,000-volt and 450-volt, 400-hertz, three-phase generators, and single-phase and three-phase generators of the voltage and frequency required for particular applications.

310-1.2.2 GENERATOR CONNECTIONS. The ac windings of most generators are contained in the stator (frame) and are either Y- or delta-connected. There is no preference for either insofar as the service requirements are concerned, and the choice depends solely on the most economical design selected by the manufacturer to obtain the required operating characteristics and to ensure ease and simplicity of manufacture and repair.

a. In a Y-connected generator, the voltage per leg or phase of the winding (that is, between the line terminal and the neutral) is equal to the line voltage divided by 1.73; the current per leg is the same as the line current.

b. In a delta-connected generator, the voltage per leg or phase of the winding is the same as the line voltage; the current per leg is equal to the line current divided by 1.73.

310-1.2.3 KILOVOLT-AMPERES AND KILOWATTS. The following relations involving kilovolt-amperes (kVA), kilowatts (kW), voltage (V), current (A), power factor (PF), and frequency (F) hold for both Y- and delta-connected three-phase generators:

a. kVA =kW/PF =line (V x line A x 1.73)/1,000

b. kW =kVAXPF/ =(line V x line A x 1.73 X PF)/1,000

c. line A =(1000 x kVA)/1.73 x line V =1000 x kW/(1.73 x V x PF)

d. F (hertz) =(No.of poles x rpm)/120

310-1.2.4 SYNCHRONOUS SPEED. The synchronous speed of an ac generator is the speed at which it must be driven to generate rated frequency. The synchronous speed depends upon frequency and number of poles, and can be calculated from equation d. of paragraph 310-1.2.3. Synchronous speeds of 60-hertz and 400-hertz generators with two, four, or six poles are as follows:

60-Hertz Generator

Number of poles	**Synchronous Speed, rpm**
2	3,600
4	1,800
6	1,200

400-hertz generators

Number of poles	**Synchronous Speed, rpm**
2	24,000
4	12,000
6	8,000

310-1.2.5 TYPES OF ROTORS. Most alternating current generators are usually of the dc excited revolving field type, although some of small capacity may be of the revolving armature type. Two types of rotors are used for generators of the revolving field type; namely:

a. Salient pole. Salient pole type rotors are used on generators of 1,800 rpm and below. The poles with their windings, are separate parts from the rotor spider and are secured to it by dovetails which are keyed to the spider with steel keys. The rotor spider may be either a separate laminated steel core pressed on and keyed to the shaft or a part of the shaft forging itself. The length of this type of rotor core is usually less than its diameter. An amortisseur or damping (squirrel cage) winding is provided on all engine-driven and some turbine-driven salient pole generators to damp out hunting effects when the generators are in parallel and to equalize flux distribution when an unbalanced load condition exists.

b. Cylindrical. Cylindrical type rotors are normally used for generators of 3,600 rpm and above. The rotor consists of a solid steel forging in which slots are milled for the field coils. In these machines the length of the rotor exceeds the diameter. These rotors are usually not provided with an amortisseur winding, but the slot wedges which secure the field winding and the rotor body itself produce the effect of such a winding.

310-1.2.6 TYPES OF DRIVE. The generators on naval ships are driven either by steam turbines, gas turbines, diesel engines, or electric motors.

a. Turbine-driven generators. Turbines for driving generators operate at relatively high speeds, between about 5,000 and 12,000 rpm. Turbine-driven Navy generators of 3,600 rpm and less are driven through reduction gears, except on submarine applications where direct drive is used to reduce noise output. Higher speed (400 hertz) generators are usually direct-connected to the turbine.

b. Engine-driven generators. The 60 hertz generators driven by diesel engines are 600, 720, 900, 1,200 or 1,800 rpm machines. They are all of the salient pole type and are direct-connected to the engine. Single engine drive is preferred; however, in some applications, 1,800 rpm, twin engine driven units (one engine at each end of generator in tandem) are necessary because of weight and size constrictions. Engine-driven 400 hertz generators are driven through step-up gears.

c. Motor-driven generators. Motor-driven ac generators are used to convert direct current to alternating current, or alternating current of one frequency to alternating current of a different frequency.

310-1.2.7 AUXILIARY EQUIPMENT. For efficient operation of ac generators, various auxiliary equipment is required.

310-1.2.7.1 Excitation. The fields of ac generators are excited by direct current. This is obtained from:

a. A rotating exciter which is mounted on the same shaft as the ac generator and which is either:
   1. A conventional dc generator as described in paragraphs 310-1.3.1 to 310-1.3.5.
   2. A rotating amplifier which is built similar to a conventional dc generator but using a complex system of field windings to obtain high response dc output.
   3. A brushless ac generator in which the ac generated in its rotating armature is rectified by solid state rectifiers mounted on the same shaft, and this dc is connected directly to the main generator field.

b. A dc bus, where available, usually in the case of dc to ac motor generators; or

c. A static excitation system which is energized from the ac generator terminals and which consists of various combinations of potential and current transformers, magnetic amplifiers, reactors, rectifiers, controlled rectifiers, transistors, and other solid state devices.

310-1.2.7.2 Metering. AC generator performance requires monitoring at key locations.

a. Generator switchboards are equipped with meters to indicate the generator voltage, current, watts, frequency, and on older ships, power factor. Synchroscopes and synchronizing lamps are provided for paralleling generators. Indicator lamps are provided to give visual indication of the operating status of various circuits.

b. Alternating current generators of 500 kW capacity and over are usually equipped with temperature detectors located between the coils at various points around the periphery of the stator and connected through a transfer switch to temperature measuring instruments on the switchboard. By means of this transfer switch, it is possible to observe the temperature at several different points in the windings during operation.

c. Many bearings are equipped with thermometers by which the bearing temperature may be observed during operation. Generators of 200 kW capacity and over are equipped with a bearing temperature alarm thermostatic switch (contact maker) which operates a warning bell or horn when temperatures become excessive. (See **NSTM Chapter 430** .)

310-1.2.7.3 Control. Frequency, voltage, and kilowatt load division must be controlled.

a. Frequency. Frequency is controlled by controlling speed, which is proportional to frequency. Speed is automatically controlled by a speed governor, except in some motor-generators in which speed is controlled by the inherent characteristics of the driving motor. The speed governors for large machines with mechanical hydraulic governors are set to the required speed by a governor motor. Those using electro-hydraulic governors are set by a speed adjusting potentiometer. Both are controlled from the switchboard. The speed governors for small machines not equipped with governor motors cannot be set to the required speed from the switchboard. These must be set by manual adjustment at the governor.

b. Voltage. Voltage is controlled automatically by a voltage regulator. See Section 3 of this chapter for voltage regulators. Automatic voltage regulators are provided with a transfer switch which permits a shift to manual voltage control in case of trouble in the voltage regulator.

c. Load division. The division of kilowatt load between two ac generators operating in parallel is controlled by the settings and characteristics of the prime mover governors and is not affected by the voltage control, either manual or automatic.

310-1.2.7.3.1 After the desired division of kilowatt load between the two generators has been obtained by adjustment of their governor settings, the desired division of reactive kilovolt-amperes can be obtained by adjusting the voltage rheostat settings, or adjustment of the manual control if failure of the voltage regulators makes it necessary to go to manual voltage control. In some dual automatic voltage regulators, no manual control exists, so reactive power control will be determined by the adjustment of the voltage adjusting rheostat. When the kilowatt load is equally divided between two machines, unequal division of reactive kilovolt-amperes is indicated by unequal current readings for the two machines. If power factor meters are installed, the unequal division of reactive kilovolt-amperes is also indicated by unequal power factor readings. The machine with the lower power factor reading will have the larger current and the larger reactive kilovolt-ampere load.

310-1.2.7.4 Protection. AC generators need to be protected against excessive current, speed, and temperature.

a. A generator circuit breaker is connected between the generator and the switchboard to protect the generator from damage by the excessive current which flows in case of a fault or short circuit in the distribution system or connected equipment. This circuit breaker is set to open when the current exceeds a predetermined value, and, when open, disconnects the generator from the switchboard bus work, except the vital power bus (if a vital power bus is provided) which is connected to the generator ahead of the generator circuit breaker. It is extremely important for operating personnel to realize that no provision is made in the generator circuit breaker or elsewhere for automatic protection of the generator from damage by long continued operation at a current only moderately in excess of rated capacity. Sole reliance for this type of protection is placed upon the vigilance of the operator. This is possible because a moderate overcurrent can be carried without damage for sufficient time to permit the operator to recognize the conditions from this instrument readings and take steps to remedy it.

b. In order to prevent the generator from operating as a motor when running in parallel with other generators, the circuit breaker in the generator line is equipped with reverse power protection which trips the breaker and takes the generator off the line when power flows from the line to the generator instead of from the generator to the line.

c. Protection against overspeed is provided with the prime mover which operates to shut the unit down when a preset value of overspeed is reached due to failure of the normal speed governing system. The overspeed protective system is completely independent of the governing system. In the case of some motor-generator sets, this protection is given by a speed limit switch mounted on the shaft of the set. This switch disconnects the motor of the set from the supply circuit when speed reaches a predetermined limit.

d. Water-air-cooled generators are equipped with air temperature alarms which give a signal when the temperature exceeds predetermined limits. The temperature indicating instruments mentioned in paragraph 310-1.2.7.2 also will indicate any excessive temperatures.

310-1.2.7.5 Enclosures. Alternating current generators may be of the open, protected, dripproof, totally enclosed, or water-air-cooled type. Generators 500 kW or over are of the water-air-cooled type. One or more make-up air inlets with filters are provided to clean the air used to pressurize the bearing housing and the generator enclosure thus minimizing the entrance of oil vapor and other contaminants into the machine. One or more filtered make-up air inlets are provided at the point of lowest internal pressure. These are normally located just behind the fan blades. This source of clean air ″makes-up″ for the air pumped from the generator enclosure to pressurize the bearing housings to minimize the amount of vapor entering the generator.

310-1.2.7.6 Heat Exchangers. Water-air-cooled generators are equipped with heat exchangers. To remove the heat generated during operation, the air within the generator enclosure is circulated through the generator and the heat exchanger. Heat is thus transferred to the cooling water which is pumped through the heat exchanger.

310-1.2.7.7 Heaters. Totally enclosed and water-air-cooled generators and some generators open to outside air have electric heaters installed within the generator enclosure. These heaters are used to keep the generator warmer than its surroundings and prevent the condensation and accumulation of moisture within the generator when it is not in operation.

310-1.3 DESCRIPTION OF DIRECT CURRENT GENERATORS

310-1.3.1 TWO-WIRE AND THREE-WIRE. The dc distribution systems used on United States naval vessel are 120-volt, two-wire; 240-volt, two-wire; and 120/240-volt, three-wire. Ship’s service and emergency service dc generators have these voltage ratings. A three-wire generator is a modified two-wire generator which has the ends of a balance coil connected to taps on the armature 180 electrical degrees apart. The electrical midpoint of the balance coil is connected to a third wire which is known as the neutral of the distribution system.

310-1.3.2 FIELD WINDINGS. Field windings are used to produce the magnetic flux that is necessary for generator operation.

a. Types. A shunt field winding is connected in parallel with the armature, a series field winding in series with the armature. A shunt generator has a shunt field only. Stabilized shunt and compound generators have both a shunt field and a series field winding.

b. Shunt generators. Shunt generators are designed to give the proper droop in the voltage regulation curve so that, when necessary, two or more machines of this type may be operated in parallel with each generator carrying its proper share of the load.

c. Stabilized shunt generators. Stabilized shunt generators have a light series field winding on the same poles with the shunt field winding. At full load, the ratio of series field ampere turns to shunt field ampere turns does not exceed 15 percent. The purpose of the series winding is to give closer voltage regulation than that normally obtained from plain shunt generators. At the same time, however, stabilized shunt generators have sufficient voltage droop from no load to full load to ensure good parallel operation without the use of equalizer connections or voltage regulators.

d. Compound generators. Compound generators usually have enough series field to give a flat voltage regulation curve (without droop), i.e., the voltage is the same at full load as at no load. Such machines will not operate in parallel and divide the load successfully without the use of equalizers or of voltage regulators, which are not commonly used on dc generators for naval installations. For this reason, compound generators are infrequently used on our naval vessels.

310-1.3.3 SHUNTS OR DIVERTERS. Shunts or diverters are always connected in parallel with the series field windings of compound generators intended for parallel operation, and are sometimes used on stabilized shunt generators intended for parallel operation. The shunt or diverter is used to adjust the compounding effect of the series field winding and the voltage regulation of the generator. These shunts may be in the form of grids or ribbon resistors.

310-1.3.4 EQUALIZERS. An equalizer, or equalizer connection, is used to connect two or more compound wound generators which are to operate in parallel. The connection is made at a point where the armature and series field leads join, thus placing the armatures in parallel and the series field windings in parallel, so that the load may be divided between the generators in proportion to their capacities. Its use is necessary in paralleling compound wound generators when voltage regulators are not used. In order to be effective, its resistance must be considerably lower than that of the series field winding. Consequently, a very heavy conductor is required. especially if there is considerable distance between the machines to be paralleled. Because of its bulk and the required additional switching, its use is not considered desirable; hence, the preferable use of shunt or stabilized shunt generators which do not require an equalizer connection (or voltage regulators) for satisfactory division of load while operating in parallel.

310-1.3.5 COMMUTATING WINDINGS. Most dc generators, whether shunt, stabilized shunt, or compound wound, are furnished with commutating poles, also known as interpoles. These poles are located midway between the mainpoles, and their windings are in series with the armature. The function of these poles is to correct flux distortion caused by armature reaction and make it unnecessary to shift the brushes in order to obtain good commutation at varying loads.

310-1.3.6 TYPES OF DRIVE. Direct current generators are driven by steam turbines, gas turbine, diesel engines, or electric motors, (either ac or dc).

a. Turbine-driven. Because of the high operating speed of steam turbines (usually well above 5,000 rpm), dc generators are not directly connected to the turbine shaft but are driven at reduced speed through reduction gears. Direct current generator speeds range from 900 to 1,800 rpm, depending upon generator size and design. In rare instances, generators having a speed of 3,600 rpm may be used.

b. Engine-driven. Generators driven by diesel engines operate at speeds from 400 to 1,800 rpm. The shafts of these generators are directly coupled to the engine shafts.

c. Motor-driven. Motor-driven dc generators make up the generator end of ac to dc and dc to dc motor generators.

310-1.3.7 AUXILIARY EQUIPMENT. Various auxiliary equipment for dc generators must be provided.

310-1.3.7.1 Meters. Meters are required for observation of performance.

a. The switchboard meters installed for observing the performance of dc generators usually includes only voltmeters and ammeters.

b. Many bearings are equipped with thermometers by which the bearing temperature may be observed during operation.

310-1.3.7.2 Control. Operational control of dc generators is accomplished by various methods.

a. Generator speed is controlled by the speed governor of the prime mover. Remote speed control is not required and no governor motor control switch is used on the switchboard, as is done for ac generators.

b. Manual voltage control is obtained by a rheostat in the shunt field. This rheostat is operated at the switchboard.

c. Direct current generators are usually not provided with voltage regulators. The inherent characteristics of the generators provide all the voltage regulation that is needed for most applications. However, where the type of service demands constant voltage at all loads on shunt or stabilized-shunt generators, where it may be necessary to parallel either two or more compound generators or compound and shunt or stabilized-shunt generators, or where battery charging may occur, automatic voltage regulators may be used. This, however, is not common.

310-1.3.7.3 Protection. Direct current generators are protected against damage by short circuit current, overspeed, and reverse current in a similar manner to ac generators (paragraph 310-1.2.7.4) except that in addition to other protective features, a shunt trip switch is provided on turbine-driven dc generators to trip the generator circuit breaker when the throttle valve is tripped closed.

310-1.3.7.4 Enclosures. Direct current generators may be of the open, protected, dripproof, totally enclosed, or water-air-cooled type.

310-1.4 GENERAL OPERATION

310-1.4.1 OVERSPEED. Great care must be exercised in the operation of both ac and dc generators to prevent overspeeding. No other casualty arising from improper operation is likely to be so destructive to equipment, or so dangerous to personnel. It is, therefore, of the utmost importance to know and observe the precautions to prevent overspeeding, and to know what to do in an emergency if a generator set overspeeds because of an equipment failure, or a failure to observe the necessary precautions. Precautions to be observed to prevent overspeeding, are:

1. Ascertain that all parts of the governor, overspeed trip, and manual trip are clean, free moving, and functioning properly.
2. See that these safety devices are periodically tested, and that the prime mover is started and operated in strict accordance with the instructions for the type of prime mover used. See **NSTM Chapters 234** and **502** of this manual for auxiliary turbines, and **NSTM Chapter 233** for diesel engines. Proper attention to these points will prevent overspeeding.
3. Overspeed trip set points should be verified periodically in accordance with Planned Maintenance System (PMS) Maintenance Requirement Cards (MRC's). When overspeeding generator sets, at least two independent means of measuring speed with different principles of measurement should be used. At least one of these measurements should be on a non-stroboscopic tachometer. Where the design of the equipment permits, this should be a hand held tachometer. When a stroboscopic tachometer must be used, its reading must be compared to an independent speed measuring device at speeds equal to or less than rated speed before entering the overspeed range. Additional precautions concerning the use of stroboscopic tachometers can be found in**NSTM Chapter 491** .

310-1.4.2 OVERSPEED PROCEDURE. Immediate action is of the utmost importance. A generator set can overspeed to destruction with startling rapidity.

1. In case a generator overspeeds, whether ac or dc, turbine or diesel-driven:
   a. Immediately trip the manual shutdown device.
   b. Immediately thereafter trip the generator circuit breaker.
2. Always locate the manual trip before taking over a generator watch and find out exactly what must be done to stop the generator set of your particular installation in an emergency. There is no time to find out after the set overspeeds.

310-1.4.3 OVERLOAD. Automatically-operating devices are not provided to protect generators from damage by long continued operation at a current only moderately in excess of rated current. Sole reliance is placed upon the vigilance of the operator. See instructions on prevention of overload in NSTM Chapter 320.

310-1.5 OPERATION OF AC GENERATORS

310-1.5.1 BEFORE STARTING. Before starting an ac generator at any time (except automatically started emergency power generators):

1. Make sure that the generator circuit breaker is open.
2. Make sure that the voltage regulator control switch is turned to the MANUAL position. If the MANUAL selection is not available, as will be the case on certain types of dual voltage regulators, make sure the switch is turned to the NORMAL position.

3. Make sure that the manual voltage control is set at the position which gives the lowest ac generator voltage. For the cases where no MANUAL is available, turn the voltage adjust rheostat/potentiometer to its lowest position.
4. Examine both the prime mover and electrical ends for evidence of obstruction to moving parts.
5. See that the oil reservoir for oil ring lubricated bearings contains the proper amount of oil as indicated by the oil sight gage.

310-1.5.2 BEFORE STARTING AFTER INSTALLATION OR OVERHAUL. Before starting an ac generator for the first time after the initial installation and after each overhaul, proceed in accordance with paragraph 310-1.5.1. Remove the covers if necessary and make the following observations:

1. Measure the insulation resistance of all windings. If the insulation resistance is too low, due to long exposure to high humidity, the machine should be dried out before being placed in operation. Judgment should be used in interpreting the measured values because temperature and dirt on windings, as well as moisture, affect the insulation resistance. See **NSTM Chapter 300** of this manual for detailed instructions on the measurement of insulation resistance and drying out generator windings.
2. Check all connections with the connection diagram.
3. See that connections of field leads into pole windings and collectors, connections between the poles, and connections between stator leads and line cables are tight.
4. See that coupling bolts and foundation bolts are tight.
5. See that the collector rings are clean and have a polished surface.
6. Check collector brushes to make sure they have no tendency to stick in the brush holders, that they are properly located and seat squarely with no part overhanging the edge of the rings, and that the pigtails will not interfere with the brush rigging nor with each other.
7. Check the brush pressure. This should agree with the figure recommended in the technical manual. In the absence of specific instructions, use a brush pressure of approximately two psi of brush area.
8. Check the air gap to determine that the rotor is concentric with the stator with uniform clearance.
9. Carefully examine the air gap and interior of machine for any dirt or loose bolts, nuts, or tools. These and any other loose pieces of metal should be removed. Unless removed, they will be attracted into the air gap when excitation is applied, and result in serious damage to both the rotor and stator.
10. See that there is sufficient clearance between all moving parts.
11. Check the oil lines to and from forced-feed lubricated bearings to make sure there is no obstruction to the free flow of oil.
12. If the generator has an exciter, check the exciter in accordance with paragraphs 310-1.6.1 and 310-1.6.2. Exciters will normally be a dc generator for older units, but newer units are most likely to be brushless ac types using diode rectifiers positioned on or within the exciter rotor or shaft. The ac frequency of these units is normally higher than 60 Hz--typical values range from 180 to 400 Hz.
13. Check points under Maintenance in**NSTM Chapter 300** .
14. Replace covers and all cover-holding bolts if any have been removed.

310-1.5.3 BEFORE APPLYING LOAD. Before applying load to an ac generator at any time:

1. See that the unit is started and brought up to speed in accordance with the instructions for the type of prime mover used. See NSTM Chapters 234 and 502 of this manual for turbines; and NSTM Chapter 233 for diesel engines. Be sure that the overspeed device and manual trip and all other safety devices are tested and are functioning as required by these instructions.
2. Locate and correct any appreciable vibration. All rotating parts are balanced by the manufacturer. If vibration is apparent, search for possible misalignment, sprung shafting, loose foundation bolts, or something chafing the rotating elements.
3. Check lubrication of bearings.
   a. In oil ring lubricated bearings, see that the rings turn freely, have no tendency to stick or bind, and are carrying oil.
   b. In forced-feed lubricated bearings, observe, through the sight flow gage, that oil is freely flowing to and from the bearings.
   c. Check oil and bearing temperatures.
4. See that commutator and collector rings run true, that all brushes ride freely in the brush holders, and there is no chattering of brushes.
5. See that there is ample clearance between all rotating and stationary parts.
6. For totally enclosed machines with coolers, see that water is flowing through the cooler as prescribed in the technical manual and that there is no leakage of water.
7. If the machine is equipped with heaters, see that the heaters are turned off.
8. Replace covers and all cover-holding bolts if any have been removed.

310-1.5.4 BEFORE APPLYING LOAD AFTER INSTALLATION OR OVERHAUL. Before applying load to an ac generator after installation or overhaul, proceed in accordance with paragraph 310-1.5.3 and in addition:

1. Check the phase sequence of the generator. One convenient method of doing this is to use a phase sequence indicator. When the generator is connected to the switchboard buses, the phase sequence of the buses should be A B C. Another convenient method is to select a three-phase motor whose direction of rotation is known and connect it to the buses. Make sure that motor lead T1 is connected to bus A, lead T2 to bus B, and lead T3 to bus C. If the motor turns in the proper direction, the phase rotation of the generator is correct. In making this check, either with the phase sequence indicator or the motor, be sure that no equipment is connected to the buses which might be damaged if the phase sequence of the generator should happen to be incorrect.
2. See that the natural air flow through the machine does not have a tendency to suck oil out of the bearing housings, along the shaft, and into the machine.
3. Check the ends of bearing housings to see that no oil leaks along the shaft which may eventually get into the windings.
4. Examine the oil for metal particles or dust from defective bearings, dirt in the system, or water resulting from leakage in the oil cooler.
5. Check oil and bearing temperatures and operate for a long enough time to determine that there is no overheating.

310-1.5.5 NONPARALLEL OPERATIONS. To connect a single ac generator to its bus for nonparallel operation, proceed as follows:

1. Check before starting; start, and check before applying load in accordance with paragraphs 310-1.5.1 to 310-1.5.4 inclusive.

2. For generators having voltage regulators switchable to manual voltage control, adjust the generator terminal voltage to rated value. Carefully watch the generator voltmeter as the voltage is being adjusted manually and do not build the generator voltage up to more than its rated value. If the voltmeter reading does not change when the manual control setting is changed, check to make sure that the right voltmeter is being watched and that it is connected to the generator whose voltage is being controlled. Unless care is used, the generator voltage may be built up high enough to damage equipment. If manual control is absent, as it is on certain dual voltage regulators, keeping the control in the NORMAL (AUTOMATIC) position will ensure that if one regulator were to fail to prevent overvoltage, the other will take over control--were both to fail, the field voltage to the exciter would be reduced to zero.

3. Check the frequency by means of the frequency meter and raise or lower the prime mover speed, as necessary, until normal frequency (60 hertz) is indicated. Watch the frequency meter as the adjustment is being made and be sure that the meter measures the frequency of the generator which is being adjusted and not of some other generator. An operator who neglects this precaution may overspeed the generator and cause it to be tripped off by operation of the overspeed trip.

4. Place the voltage regulator in control by turning the control switch from MANUAL to the AUTOMATIC position. Check the generator voltage and, if necessary, adjust to the desired value by means of the voltage adjusting device. If the voltage regulator is of the dual voltage regulator type without manual, adjust the DROOP setting to the desired indicated value. Caution should be exercised if a load is connected when switching between MANUAL and AUTOMATIC--large differences which may exist in the exciter field voltage because of mismatched settings can result in undesirable transients. Normally the voltage regulator should be placed in and taken out of service only under steady load or no-load conditions.

5. Turn the voltmeter switch to read the voltage on the bus. Check the bus voltage for all three phases if the connections to the voltmeter switch are such as to permit this to be done. If all three phases cannot be checked, check those that can.

6. If the bus is de-energized, turn the handle of the synchronizing switch to the ON position. The synchroscope is not needed for synchronizing since the bus is dead, but in many installations an interlock makes it necessary to have the synchronizing switch ON before the generator circuit breaker can be closed.

7. Close the generator circuit breaker. This energizes the bus and load may be applied.

8. Turn the synchronizing switch to OFF.

310-1.5.6 SYNCHRONIZING FOR PARALLEL OPERATION. If the bus is already energized, never close the generator circuit breaker unless the generator and bus have approximately equal voltages and are in phase (synchroscope at appropriately the 11 to 12 o'clock position) and approximately in synchronism (synchroscope needle moving slowly). If the generator is not in phase at the time the circuit breaker is closed excess forces are developed in the generators and accordingly care should be taken to properly parallel the generators. A synchronizing protective device is installed on many ships to prevent closing of the circuit breaker unless proper conditions exist. The use of the synchronizing protective device should be a mandatory requirement on ships that have it installed and bypass of this protective device should be allowed only in the event of an emergency. Synchronizing procedure is the same where the synchronizing protective device is installed or not: that is, the synchroscope and synchronizing lights are used in each case. To parallel the generator to an energized bus proceed as follows:

1. Bring the generator up to approximately normal speed and voltage and place the voltage regulator in control as described in paragraph 310-1.5.5, steps 1 through step 4, inclusive.

2. Turn the voltmeter switch on the incoming generator to read generator voltage on the voltmeter.
3. Turn the voltmeter switch on the adjacent generator panel to read the bus voltage.
4. Turn the voltage adjusting device of the voltage regulator until the incoming generator voltage is equal to the bus voltage.
5. Compare the frequency of the generator with that of the bus and adjust to correspond.
6. Turn the synchronizing switch to ON and for ships equipped with the synchronizing protective device position the function switch to TEST, to establish that it is functioning, and then to OPERATE. The synchroscope will rotate in one direction or the other. Adjust the speed of the generator until the synchroscope rotates very slowly (one turn every six seconds or more) in the clockwise direction.
7. Make sure that the voltages of the bus and the incoming generator are still equal, and just before the synchroscope pointer passes very slowly through the zero position (pointing vertically upward or approximately the 11 o'clock position for remotely operated standard Navy breakers) close the generator circuit breaker.
8. When synchronizing lamps, instead of the synchroscope, are used, the circuit breaker should be closed just before the midpoint of the dark period of the lamps is reached. The midpoint of the dark period corresponds to the vertical position of the synchroscope pointer.
9. Turn the synchronizing switch to OFF.

310-1.5.7 ADJUSTMENT FOR PARALLEL OPERATION. Whenever ac generators are operating in parallel, the kilowatt loads and the current readings should be proportional to the generator ratings, and, if power factor meters are installed, the power factors should be equal. The desired division of the kilowatt load is obtained by adjusting the settings which control the speeds of the generators with mechanical hydraulic governors. For electro-hydraulic governors equal kilowatt load division is obtained automatically in the isochronous mode and by adjustment of the speed settings in the droop mode. Proportional division of generator currents and equality of power factors are obtained by adjusting the voltage rheostats of the voltage regulators after the kilowatt load division has been adjusted. These adjustments are made as follows:

a. Make necessary adjustments for wattmeters to have equal readings (if the generators have the same rating) or so that the kilowatt load is divided in proportion to the generator ratings (if the generator ratings differ from each other). For systems operating in speed droop:
   1. If the frequency is above normal, turn the governor control switches for the heavily loaded generators in decrease speed direction.
   2. If the frequency is below normal, turn the governor control switches for the lightly loaded generators in the increase speed direction.
   3. If the frequency is normal, make the adjustment in small steps. Turn the governor control switches for the lightly loaded generators in the increase speed direction and for the heavily loaded generators in the decrease speed direction.

b. Turn the voltage adjusting rheostats of the voltage regulators until generator line currents are divided in proportion to generator ratings or power factor readings are equal.
   1. If the voltage is above normal, turn the voltage adjusting rheostats for the generator with more than its fair share of line current (lowest power factor) in the decrease voltage direction.
   2. If the voltage is below normal, turn the voltage adjusting rheostats for the generator with less than its fair share of line current (highest power factor) in the increase voltage direction.
   3. If the voltage is normal, make the adjustments in small steps. Turn the voltage adjusting rheostat on the machine with the larger current in the decrease voltage direction. On the machine with the lower current

turn the voltage adjusting rheostat in the increase voltage direction. For systems with electric governors and operating isochronously, adjust each speed potentiometer to raise or lower the speed of the paralleled system.

310-1.5.8 SECURING. To secure an ac generator which is connected alone to the bus, hence, not operating in parallel with any other machine:

1. Reduce the load on the generator as much as practicable by opening feeder circuit breakers on the power and lighting circuits.
2. Trip the generator circuit breaker by pushing its trip button.
3. Check whether voltage regulator selector switch has a MANUAL position; if so, turn it to the MANUAL position. If not (as may be the case for some dual voltage regulator types) proceed to the next step.
4. If voltage regulator selector switch is in MANUAL position, turn the manual voltage control as far as it will go in the decrease voltage direction. If the MANUAL position is not available on the selector switch, turn the voltage adjust control to its minimum position.
5. Secure the prime mover in accordance with the prime mover instructions.
6. Shut off the flow of water through air coolers (if any).
7. Turn on the heaters (if any) within the generator enclosure or frame.

310-1.5.9 SECURING AFTER PARALLEL OPERATION. To secure an ac generator which has been operating in parallel with another generator, or with other generators:

1. Turn the governor motor control switch of the generator being secured in the decrease speed direction and the governor motor control switch (or switches) of the other generator (or generators) in the increase speed direction until all the load has been shifted from the machine being secured. This may be checked by reading the wattmeters. If the total connected load is greater than can be carried by the machine which is to continue operating, it will be necessary to decrease the load by opening feeder circuit breakers.
2. Trip the circuit breaker of the generator being secured.
3. Proceed in accordance with paragraph 310-1.5.8, steps 3 through 7.

310-1.6 OPERATION OF DC GENERATORS

310-1.6.1 BEFORE STARTING. Before starting a dc generator at any time:

1. See that the generator circuit breaker and field switch (if furnished) are open.
2. See that the field rheostat handle is set to cut in all the field resistance.
3. Examine both the prime mover and electrical ends for evidence of obstruction to moving parts.
4. See that the oil reservoir for oil ring lubricated bearings contains the proper amount of oil as indicated by the oil sight gage.

310-1.6.2 BEFORE STARTING AFTER INSTALLATION OR OVERHAUL. Proceed as in paragraph 310-1.6.1 before starting a dc generator for the first time after initial installation and after each overhaul; remove the covers if necessary to make observations; and:

1. Measure the insulation resistance and dry out windings if necessary. See **NSTM Chapter 300** of this manual.
2. Check all connections with the connection diagram.
3. See that all bolts, nuts, and electrical connections are tight.
4. Check armature banding wire for any evidence of looseness.
5. Clean out slots between commutator segments. Clean off any accumulated dirt or grease.
6. Examine the commutator. If the commutator shows polish from factory testing, it is ready for the immediate application of load. However, if the commutator is freshly turned, the generator should be operated at very light load for 24 hours, and then for an additional 24 hours at about half load. If the commutator then presents high and uniform polish, it is ready for operation at full load. Use no lubricant on the commutator either during the polishing period or at any other time.
7. See that the brush pressure and staggering of the brushes are in accordance with the technical manual. If specific information on the brush pressure for a particular machine is not available, use a brush pressure of approximately two psi.
8. See that there is no tendency for brushes to stick or bind in the holders.
9. See that the whole surface of each brush seats uniformly on the commutator.
10. Check spacing of brushes and adjust if necessary so that they are equally spaced around the commutator.
11. See that brush pigtails are tightly secured and that there is ample clearance between pigtails or opposite polarity.
12. Inspect all electrical clearances, particularly where bare conductors of opposite polarity approach each other.
13. See that the air gap is uniform as measured under poles of the same type and that poles are uniformly spaced between tips.
14. Examine the interior of the frame, the armature, the commutator, the air gap, and spaces between poles and remove any dirt, loose bolts, nuts, tools, or other pieces of metal.
15. Make sure of sufficient mechanical clearance between all moving and stationary parts.
16. In oil ring lubricated bearings, see that the oil reservoir contains the proper amount of oil as indicated by the oil sight gage. For forced-feed lubricated bearings, check the oil lines to and from the bearings to make sure there is no obstruction to the free flow of oil.
17. Check points under Maintenance in **NSTM Chapter 300** .

310-1.6.3 BEFORE APPLYING LOAD. Before applying load to a dc generator at any time:

1. See that the unit is started and brought up to speed in accordance with the instructions for the type of prime mover used. See**NSTM Chapters 502** for steam turbines, **233** for diesel engines and **234** for gas turbines. Be sure that the overspeed governor and trip and all other safety devices are tested and are functioning as required by these instructions.
2. Locate and correct any unusual vibration.

3. Check lubrication of bearings, and oil and bearing temperatures.
4. See that the commutator and the collector rings on three-wire generators run true, that all brushes ride freely in the brush holders, and that there is no chattering of brushes.
5. See that there is ample clearance between all rotating and stationary pans.
6. Turn off the heaters, if any are installed in the generator enclosure.

310-1.6.4 BEFORE APPLYING LOAD AFTER INSTALLATION OR OVERHAUL. Before applying load to a dc generator for the first time after initial installation and after each overhaul:

1. Check the ends of bearing housings to see that no oil leaks along the shaft which may eventually get into the windings.
2. Examine the oil for metal particles and dust from defective bearings, dirt in the system, or water resulting from leakage in the oil cooler.
3. Check oil and bearing temperatures and operate for a long enough time to determine that there is no overheating.

310-1.6.5 NONPARALLEL OPERATION. To connect a single dc generator to its bus for nonparallel operation:

1. Check before starting, start and bring up to speed in accordance with paragraphs 310-1.6.1 through 310-1.6.4.
2. Close the shunt field switch and gradually cut out the field resistance until normal voltage is obtained.
3. Close the circuit breaker.
4. Close the line switch (if used).

310-1.6.6 PARALLEL OPERATION. If the bus is already energized and it is desired to connect another generator to the line:

1. Check before starting, start, and bring the generator up to speed in accordance with paragraphs 310-1.6.1 through 310-1.6.4
2. Close the shunt field switch (if installed).
3. Gradually cut out field resistance until the generator voltage is from one to four volts higher than the bus voltage.
4. Close the circuit breaker.
5. Close the line switch (if open).
6. Adjust the field rheostat to cause the generator to take its proper share of the load. Turning the field rheostat in the increase voltage direction will cause a generator to take more load.

310-1.6.7 SECURING A SINGLE DC GENERATOR. To secure a single dc generator which is connected alone to the bus, hence, not operating in parallel with any other machine:

1. Reduce the load by opening feeder circuit breakers.

2. Trip the generator circuit breaker.
3. Secure the prime mover in accordance with the prime mover instructions.
4. Cut in all the shunt field resistance.
5. Turn on heaters (if any) within the generator enclosure.

310-1.6.8 SECURING AFTER PARALLEL OPERATION. To secure a dc generator which has been operating in parallel with another generator or with other generators:

1. Gradually cut in shunt field resistance to reduce the load to a minimum.
2. Trip the generator circuit breaker.
3. Proceed in accordance with paragraph 310-1.6.7, steps 3 through 5.

310-1.7 TROUBLES-THEIR CAUSE AND CORRECTION

310-1.7.1 GENERAL. The remedy for most troubles with either ac or dc generators is immediately apparent from their cause; the remedy for others will be found in **NSTM Chapter 300** in the instructions which deal with maintenance. The following summarizes the most probable causes to be looked for when different types of trouble develop.

310-1.7.2 VIBRATION. When a generator vibrates:

a. With no excitation on the generator or the direct or belt connected exciter of an ac generator, look for:
   1. Misalignment.
   2. Sprung shafting.
   3. Something chafing the rotor or armature.
   4. Loose coupling bolts, bearings, balance weights, or foundation bolts.
   5. Transmission of vibration from the prime mover.
b. Under load, or with excitation on the generator or its exciter, look for:
   1. Shorted field or armature coils.
   2. Unequal air gaps in either generator or exciter.

310-1.7.3 HOT BEARINGS. Proceed as follows:

a. When the bearings on a generator run hot, look for:
   1. Misalignment.
   2. Unequal air gaps in either generator or exciter.
   3. Unbalanced rotors or sprung shaft.
   4. Insufficient oil supply. Dirt in gage glass or a clogged vent may indicate oil when none is present.
   5. Sticking of oil rings.
   6. Clogging of oil lines.
   7. Dirt in lubricant or in bearings.

8. Overgreasing (in ball bearings).
9. Overload, particularly on belted machines.
10. Tight or poorly fitted bearings.
11. Scratched or corroded journals.

b. A generator with a hot bearing should be taken off the line as soon as the load can be shifted to other machines. Do not shut it down immediately. Keep it turning over slowly and supply plenty of clean oil until the bearing is cool. An immediate stop may cause the bearing to freeze.

c. When a generator with a hot bearing must be kept running, use plenty of fresh cool oil, or even water in an emergency to check overheating. Do not let oil or water get on electrical parts. Shut down for overhaul of the bearing as soon as practicable.

310-1.7.4 OIL LEAKS. When oil or grease leaks are detected, look for:

1. Damaged or inadequate seals.
2. Excess of oil or grease in bearing reservoir.
3. Excess of oil flow in oil lines to bearing.
4. Clogged return oil line form bearing.
5. Clogged or closed vent.
6. Use of vent as an oil hole.
7. Suction of oil from bearing housing or vent by intake air to generator.

310-1.7.5 NOISY BRUSHES. When the brushes are noisy, look for:

1. Too much clearance between collector ring or commutator and brush holder. See instruction on maintenance in **NSTM Chapter 300** .
2. Incorrect brush pressure.
3. Rough collector ring or commutator due to:
   a. Flat spots.
   b. High mica.
   c. Loose bars.
   d. Pitting.
   e. Unbalance or eccentricity.

310-1.7.6 SCORING. When collector rings or commutators show signs of scoring, look for:

a. Hard particles embedded in the brushes.
b. Check brush pressure.
c. Check to make sure that all brushes are of the same grade and that the proper grade of brush is being used.

310-1.7.7 BLACKENING. Blackening on commutators and collector rings indicates:

a. Blackening of a commutator:
   1. On all bars indicates incorrect brush pressure or position or poor adjustment of commutating field.
   2. On groups of bars at regular intervals indicates the above conditions or poor brush contact.
   3. On a single bar, usually indicates open armature coil.
   4. At irregular intervals indicates roughness or eccentricity.

b. Blackening of collector rings:
   1. An unbalanced condition of the rotor.
   2. Electrolysis.
   3. Action of acid fumes or salt air on rings.

c. Wipe off blackening with a firm, lintless cloth such as canvas, wound around a block and held against the commutator or collector rings. Locate and correct the cause of the trouble. If the cause of the trouble is allowed to remain, it will lead to serious injury to the commutator or collector rings requiring extensive overhaul. See **NSTM Chapter 300** for the maintenance of commutators and collector rings.

310-1.7.8 UNDERVOLTAGE, SEPARATELY EXCITED GENERATOR. When a separately excited generator fails to generate full voltage:

a. If zero voltage or only a small voltage is shown with full voltage available for excitation at the excitation bus or exciter, look for an open circuit or ground in:
   1. The generator field rheostat.
   2. The leads in the circuit from the generator field terminals through the field rheostat to the excitation bus or exciter.
   3. The connection between the pole windings and from the pole windings to the field terminals in dc generators, or to the collector rings in rotating field ac generators.
   4. The connections between the generator field terminals and the brushes in rotating field ac generators.
   5. The diodes and connections in the rotating rectifier assembly on a brushless exciter.
   6. The PMA supplying the exciter.

b. When a separately excited generator produces a substantial voltage but will not come up to normal rated voltage, one of the following causes may be responsible for failure to develop normal rated voltage:
   1. Speed may be below normal.
   2. The switchboard instruments may read incorrectly.
   3. The regulator may be set to regulate for too low a voltage.
   4. Part of either the field or stator windings may be short-circuited or improperly connected.

310-1.7.9 UNDERVOLTAGE, SELF-EXCITED GENERATOR. A self-excited dc generator may fail to excite itself and build up voltage when started even though it operated perfectly during a preceding run.

a. Look for:
   1. Loose connection or break in the field circuits.
   2. Poor brush contact due to dirty commutator.
   3. Incorrect position of the brushes.
   4. Open circuit or high resistance in the rheostat.

5. Open or short circuit in the armature.
6. Series and shunt fields of compound wound generators connected to oppose each other.
7. No residual magnetism in field.
8. Low speed.

b. If a new machine fails to excite, interchange the leads from the positive and negative brushes.

c. When a self-excited generator builds up voltage but not up to normal rated voltage:

1. Speed may be below normal.
2. Switchboard instruments may read incorrectly.
3. Part of the shunt field may be short-circuited.
4. Polarity of one or more field poles may be incorrect.
5. Brushes may be incorrectly set.
6. Part of the filed rheostat or other unnecessary resistance may be in the field circuit.

d. To change the polarity of a self-excited dc generator, the rotation of the armature staying the same, it is necessary to reverse the residual magnetism. This is done by exciting the shunt field momentarily from some outside source (battery or other low voltage dc source), i.e., flashing the field.

e. Loss of residual magnetism in a self-excited generator used as an exciter for an alternator will result in a failure of the alternator to build up voltage. If the alternator fails to build up voltage under normal conditions the output voltage of the exciter should be checked. If this voltage is low (in the order of 0 to 3 volts) it is probably due to the loss of residual magnetism. To restore the residual magnetism the field will require flashing which is the application across the exciter field of a low dc voltage (not more than 15 volts) obtained from an outside source such as a battery. Refer to the technical manual of the generator set for more specific instructions on field flashing.

310-1.7.10 UNSATISFACTORY COMMUTATION. Unsatisfactory commutation with various degrees of sparking at the brushes may be due to one or a combination of causes. Investigate the following possibilities and try the commutation after any change is made:

a. The machine may be overloaded.

b. When containments and entrapped conducting material begin to bridge the gap between commutator bar segments sparking may occur. Reference NAVSEA handbook S9310-AC-HBK-010, **Commutator/Slip Ring Maintenance Handbook** , paragraph 3-2-4.2, 5-3-3, and 5-3-4 for causes and correction.

c. Contacts may be loose.

d. Check all connections and make certain that the commutating (interpole) field or any part of it or any one or more of the main field coils are not reversed.

e. Brush spacing and alignment.

f. Brushes not on neutral. Try shifting the brushes very slightly each way from the marked neutral.

g. Brushes may be wedged in holders or may be so worn as to have reached the end of their travel.

h. Pigtails may interfere with brush rigging.

i. Insufficient brush pressure.

j. Poor fit of brushes on commutator.

k. Brush contact surface or edges may be burned, chipped, or rough.

l. Brushes chatter.

m. Brushes may be of unsuitable grade.

n. Unequal brush pressures may cause some brushes to take more than their share of current.

o. Incorrect brush angle with respect to the commutator.

p. Commutator blackened, dirty, oily, or worn out.

q. Commutator rough or eccentric.

r. High mica on commutator. Will require grinding or turning.

s. Loose bar or high bar in commutator. Tap high bar back into place with a wooden or rawhide mallet, then tighten commutator clamping bolts.

t. . Burned out mica between segments. This is rarely, if ever, due to excessive voltage between bars. More likely it is caused by the mica becoming oil soaked, or by loose bars allowing foreign material to work its way in between them. This burning may be stopped by scraping out the burned mica and filling the space with a solution of sodium silicate (water glass) or other suitable insulating cement.

u. Open circuit or loose connection in the armature. This is indicated by a bright spark which appears to pass completely around the commutator. Eventually it will definitely locate itself by scarring of the commutator at a point of open circuit.

v. Loose soldered connection between the commutator risers and armature coils. This is one of the most difficult faults to locate by visual inspection as the joints may seemingly be tight when the machine is secured and then partially open up, due to centrifugal force, when the machine is running. This fault is indicated by a bright spark each time the loose contact passes under a brush. If there is a definite break in the contact at the joint, the spark will hold between the bars, causing a ring of fire around the commutator to burn the mica between segments. This burning will indicate the location of the broken contact.

w. Dirt, flat spots, or roughness on collector rings.

x. Improper strength of commutating field. Assuming that brush position is correct and no other faults are apparent, the commutating pole field may be adjusted. See**NSTM Chapter 300** for instructions on how to make this adjustment.

310-1.7.11 ARCING BETWEEN BRUSH STUDS. Arcing may be caused by:

a. Excessive voltage.

b. Sudden excessive overloads (short circuits on the line).

c. Rough or dirty commutator.

d. Water dripping on commutator.

310-1.7.12 OVERHEATING. Reasons for generator overheating include:

a. Overheating because of:
   1. Inadequate ventilation due to clogged air passages or ventilation ducts.
   2. Insufficient cooling water flow in water-cooled machines.
   3. Excessively high cooling water inlet temperatures in water-cooled machines.

b. The field coils on generators may overheat because of:

1. Too low speed resulting in insufficient ventilation and cooling while requiring excessive field current to generate rated voltage.
2. Too high voltage, and, hence, too much current through the field coils.
3. Too great forward or backward lead to the brushes, dc generators only.
4. Partial short circuit of one coil.

c. The stator of an ac generator or the armature of a dc generator may overheat because of:

1. Overloading.
2. Partial short circuit of one or more coils.
3. Short circuits or ground on armature or commutator.
4. Conduction of heat from hot commutator.
5. Excessive inequalities in air gaps or rotor rubbing the stator.

d. A commutator may overheat because of:

1. Overloading.
2. Sparkling brushes.
3. Excessive brush pressure.

310-1.7.13 OPEN CIRCUITS. Open circuits, which are not visually evident receive detailed coverage in NSTM Chapter 300.

a. Open circuits which develop in the field winding of a dc generator or a non-paralleled ac generator are indicated by the immediate loss of armature voltage and hence load. In the case of a paralleled ac generator, the effect of an open circuited field is influenced by the governor characteristics and the type of damper windings on the rotor. For some types of governors, the prime mover can increase speed to the point where the generator can act as an induction generator. Such operation would be evidenced by a low leading power factor and increased rotor temperatures to the point of damage. In cases where the governor reduces prime mover power to zero, the open field can result in induction motoring action. To prevent this:

1. Trip the generator circuit breaker to take the generator off the line if this has not already been done by the reverse power relay.
2. Open circuits in the field winding usually occur at the connection between poles and can be detected by visual inspection. Any open circuit within the coils themselves would be the result of an internal short circuit so serious that its location would be at once evident.

b. An open circuit seldom, if ever, occurs within the stator winding of an ac generator. A short circuit of such severity and duration as eventually to cause an open circuit would at once make its location evident by smoke, flame, or charred insulation. Should any other open circuit occur, it will probably be due to damaged connections on the ends of the windings where the various coils and circuits in each phase are connected.

c. Open circuits in dc armatures of the nature described above in paragraph 310-1.7.10.u. through 310-1.7.10.v. are indicated by sparking at the brushes which may leave visual evidence of their location on the commutator.

d. Open circuits can occur in brushless exciters as a result of centrifugal forces on the rotating diode assembly, although some designs using bore-pack rectifiers located within the exciter shaft can reduce this problem. Diode failure can result in either a reduction of exciter output (main generator field) voltage or a complete loss of output voltage. Diode failure by open circuiting can occur but tends to be uncommon.

310-1.7.14 SHORT CIRCUITS. Refer to **NSTM Chapter 300** for instructions on locating and repairing short circuits in field coils, stators of ac machines or armatures of dc machines. Short-circuits may be indicated by:

a. In field coils:
   1. The necessity for increasing field current to maintain normal voltage with the machine running at normal speed.
   2. Vibration of the rotor due to unbalanced magnetic pull.
   3. Smoke or the odor of burning insulation if the short circuit is severe.
b. In the stator of an ac generator or in the armature of a dc generator by smoke, flame, or odor of charred insulation.
c. In case of any short circuit, immediately secure the machine affected.
d. Short circuits occurring in brushless exciters are commonly the result of one or more defective diodes on the rotating rectifier assembly. Loss or reduction of field voltage combined with smoke or odor are symptomatic of this failure.

310-1.7.15 GROUNDS. Refer to **NSTM Chapter 300** for detailed procedures on testing for and correcting grounds.

a. A ground on a machine oil circuit that is not intentionally grounded is a zero or low resistance path which is caused by a breakdown in insulation and which extends from ground to a winding or some other conductor in the machine or circuit. If no other part of the system is grounded, a single ground in any of the windings of a generator will cause no particular harm to the machine. If, however, the generator and its connected circuit have two zero or low resistance grounds at points of widely different potential, the result will be similar to a short circuit and considerable damage may be caused. This danger can be avoided by keeping the generator and its connected circuits free from grounds.
b. The presence of grounds can be detected by the use of a permanently installed ground detector voltmeter, an insulation resistance measuring instrument, or a circuit continuity testing device such as a magneto, or lamp and lighting circuit.

310-1.7.16 GENERATOR ROTOR SHAFT INDUCED VOLTAGE. Generator magnetic circuit irregularities can give rise to a voltage difference between one end of the rotor shaft and the other. If the bearings are not insulated, a relatively low resistance path permits current flow thru the bearing, generator frame, and then thru the shaft back to the first bearing resulting in damage to the shaft journals and bearings. The damage occurs over periods of time ranging from several days to several weeks and is first evidenced by a satin appearance of the shaft journal later developing into small pits on the shaft surface. Babbitt bearing material seriously affected by continuous circulating shaft current is characterized by deep irregular holes and fissures that can penetrate to the bearing shell. In addition to requiring bearings to be insulated from the generator frame, those that are equipped with thermometers or thermocouples must also have these devices insulated to avoid the current path. In a related problem, some steam turbine units use brushes riding on the shaft to drain the static charge which can accumulate as the result of the action of steam on the turbine blades.

310-1.7.17 PARALLEL OPERATION OF AC GENERATORS. Trouble with parallel operation of ac generators of similar characteristics is not a common occurrence. When trouble is experienced, it is usually associated with unsatisfactory division of kilowatt (kW) load between the generators operating in parallel, or with unsatisfactory division of reactive kilovolt-ampere (kvar) load. Difficulties encountered when paralleling with shore power such as hunting and loss of synchronism can occur, requiring the operator to be prepared to trip the shore tie breaker. **NSTM Chapter 320** discusses shore power connection procedures.

310-1.7.17.1 KW Load Division. The following factors are involved in a kilowatt load division:

a. The division of kW load between two or more ac generators operating in parallel is determined by the settings and characteristics of the prime mover governors and is not affected by the generator field currents, hence, is not affected by the operation of the voltage regulators. When generators with mechanical hydraulic type governors are in parallel, the governor motor control switches are adjusted (see paragraph 310-1.5.7.a. until the total kW load is divided between the generators in proportion to their ratings (for electric governor operating in the differential load sensing mode the generators will share load upon closure of the circuit breaker and no adjustment of speed control should be required for dividing loads). If, however, the total kW load changes after this adjustment has been made, then the new load will be divided in the same proportion. The kW load division will be satisfactory if the following conditions are satisfied:
   1. The prime movers are free from speed pulsations of sufficient magnitude to cause objectionable hunting.
   2. For generators operating in the speed droop mode at all loads the speed of each generating unit decreases when the kW load on the generator increases, and increases when the kW load decreases.
   3. For generators operating in the speed droop mode, the curve which shows the speed of a generating unit plotted against kW load (both speed and load being expressed as percentages of their rated values) is the same for each of the generating units operating in parallel.

b. The fulfillment of the conditions given above is dependent upon the behavior of the prime movers and their governors. Fulfillment of the speed-load characteristics referred to in subparagraphs 1b and 1c above applies to governors operating in the droop mode. For electrohydraulic governors operating in the isochronous mode, adjustments should be made in the load sensing circuitry and not by adjusting the speed control of the governors. Consequently, when the division of kW load is unsatisfactory, check the governors and make sure that hunting and speed pulsations are reduced to a minimum, for droop operation ensure that the percentage speed droop from no load to full load is the same for all generating units, and that their speedload curves coincide as nearly as possible over the range from no load to full load. For electrohydraulic governors ensure that the load sensing circuits are matched between units.

310-1.7.17.2 Reactive KVA Load Division. The following factors are involved in dividing the reactive kVA load.

a. If the total kW load is divided between the machines in proportion to their ratings, the total reactive kVA load will be properly divided if the total current is divided in the same proportion. If power factor meters are installed, the power factor readings will be equal. If the ammeter readings are not the same when the wattmeter readings indicate proper division of kW load, the machine with high proportional current readings and low power factor readings will be carrying an excess of reactive kVA load and the machine with low proportional current readings and high power factor readings will be carrying less than its proper share of reactive kVA load. After the division of kW load has been adjusted in accordance with paragraph 310-1.5.7.a. the division of reactive kVA load should be adjusted in accordance with paragraph 310-1.5.7.b. If the total reactive kVA load changes after this division has been made, the new reactive kVA load will be divided in the same proportion as before, provided the following conditions are satisfied:
   1. At all reactive kVA loads the voltage of each generating unit decreases when the reactive kVA load increases, and increases when the reactive kVA load decreases.
   2. The curve which shows the voltage of a generating unit plotted against reactive kVA expressed as a percentage of rated kVA is the same for each of the generating units operating in parallel.

b. The fulfillment of the conditions given above is primarily dependent upon proper operation of the voltage regulators. Consequently, when difficulty is experienced with division of reactive load between generators operating in parallel, check the voltage regulators in accordance with the instructions in paragraph 310-3.2.3.8.

c. Another possible source of trouble is failure of exciters to build up voltage of correct polarity. It has been found that sometimes the residual magnetism of an exciter reverses. This makes the exciter build up voltage of the wrong polarity and causes misoperation of the voltage regulator. Consequently, whenever trouble is experienced, check the polarity of the exciter. If the polarity is incorrect, reverse the residual magnetism of the exciter by flashing its field. (See paragraph 310-1.7.9.d.)

310-1.7.18 PARALLEL OPERATION OF DC GENERATORS. Shunt and stabilized shunt wound generators furnished for naval use where parallel operation is necessary are required to possess characteristics such that they will operate satisfactorily in parallel without an equalizer connection (paragraph 310-1.3.4). Two-wire compound wound generators require one equalizer connection, and three-wire compound wound generators require two equalizer connections for parallel operation when voltage regulators are not used. The difficulties which are sometimes experienced in parallel operation of dc generators are usually not due to deficiencies in the inherent characteristics of the generators and their prime movers but to failure to adjust the generating units so that they satisfy certain conditions which must be fulfilled before satisfactory parallel operation is possible.

310-1.7.18.1 Parallel Operation. The following factors are applicable when operating dc generators in parallel without equalizers.

a. Necessary conditions. For satisfactory parallel operation of dc generators without an equalizer connection:
   1. The prime movers must be free from speed pulsations of sufficient magnitude to cause objectionable fluctuations in generator voltage.
   2. At all loads the terminal voltage produced by each generating unit must decrease appreciably when its load current increases, and increase when its load current decreases.
   3. The curve which shows terminal voltage plotted against load current expressed as a percentage of full-load current must be substantially the same for each of the generating units to be paralleled.

b. Reasons for conditions. The first two of these conditions are to prevent surging of the load and ensure stable operation: the third is to provide for dividing the load between the generators in proportion to their ratings.

c. Speed pulsation. Excessive speed pulsation of a generating unit causes voltage fluctuations which make the load surge back and forth between the units in parallel and prevent satisfactory parallel operation. No difficulty from this source should be experienced in the parallel operation of shunt and stabilized shunt generators provided that:
   1. At no load, the voltage does not vary from the average voltage by more than 1-1/2 volts for a 120-volt generator or more than three volts for a 240-volt generator.
   2. At any constant load between 20 percent and 100 percent of full load, the voltage does not vary from the average voltage by more than one-half a volt for a 120-volt generator or by more than one volt for a 240-volt generator.

d. Stability of operation. Parallel operation without an equalizer will be stable when the generating units have the drooping voltage characteristic required by the condition stated in paragraph 310-1.7.18.1.a., and the stability will be greater the more the voltage drops with increased load current. Excessive voltage drop is undesirable from the standpoint of system operation, but enough must be tolerated to ensure stable operation. The way in which a drooping characteristic provides stability can be seen by considering a constant total load current which is supplied by two or more such generating units operating in parallel. If, for any reason, one unit should momentarily supply more that its normal share of the total current, its voltage will drop. The other unit or units, being relieved of load because the total load remains the same, will rise in voltage. These voltage changes restore the original division of load since the low voltage unit will drop its excess load, and the higher voltage units will pick it up. This is stable operation because when the system is momentarily disturbed it automatically comes back to the original condition. Shunt and stabilized shunt generators operate in this way without requiring an equalizer because they have a drooping voltage characteristic. The terminal voltage decreases when the load current increases because the inherent characteristics of the generator cause such a change even if the speed of the generator is kept constant for all loads, and, in addition, the speed of the prime mover decreases when the load is increased except when the prime mover of the generating unit is equipped with an isochronous governor which maintains constant speed irrespective of load. The decreased speed causes an additional decrease in voltage. The drop in voltage with increased load when the speed is kept constant is a characteristic of the generator alone. The drop in voltage due to the combined effect of the generator characteristic and the drop in speed of the prime mover is a characteristic of the complete unit including generator, prime mover, and governor. The overall or combined unit voltage regulation characteristic is the one which is important for parallel operation of generating units. It can be conveniently shown by a curve in which the quantity plotted horizontally is the load current expressed as a percentage of full-load current, while the quantity plotted vertically is the terminal voltage produced by the unit at each load current when the unit is running under the control of the governor so that speed decreases with increased load in accordance with the governor characteristics and setting. Examples of such curves are shown in Figure 310-1-1 for three different pairs of generators.

e. Division of load.

1. If, as in Figure 310-1-1 part A, the overall voltage regulation characteristics of two generating units are identical (or substantially identical), the two units will parallel satisfactorily and divide the total load between them in proportion to their ratings, whatever the total load may be.

2. If, however, the characteristic curves are as shown in Figure 310-1-1 part B, the two units will not divide the total so that each carries the same percentage of its full-load current even assuming that it has been possible to parallel the units without tripping the breakers or damaging the machines. When two units are operating in parallel, their terminal voltages must be the same except for the negligible drop in potential in the connecting leads. Reference to Figure 310-1-1 part B shows that when the common terminal voltage is V volts, for example, unit No. 1 will be loaded to P1 percent of full load, and unit No. 2 to P2 percent. Unit 2 is more lightly loaded. Further consideration of the figure will show that when the total load is increased until unit No. 1 is carrying full load, unit No. 2 will still be only partially loaded. The total output that can be obtained from the two units without overloading either one is, therefore, less than the sum of their ratings.

3. By adjusting the shunt field rheostat of one or both of the units, their terminal voltages can be made to coincide at no load as shown in Figure 310-1-1 part C. The total load still will not divide correctly since unit No. 2 will take less than its fair share. It is necessary to change the slope of the characteristic curve for one of the units; unit No. 2, for example. This can be done by adjusting the series field diverter, or the brush position, or the speed regulation of the prime mover, or all three. By means of these adjustments, which are made once and for all when adjusting the units for parallel operation combined with the use of the shunt field rheostats which require setting each time the units are paralleled, the terminal voltages can be made to coincide at no load and at full load. Since the characteristic curves showing terminal voltage plotted against current region are nearly straight lines in this region, the two units will properly divide the total load at all loads. Voltage is the same for each unit, the percentage of full-load current supplied by each is also the same.

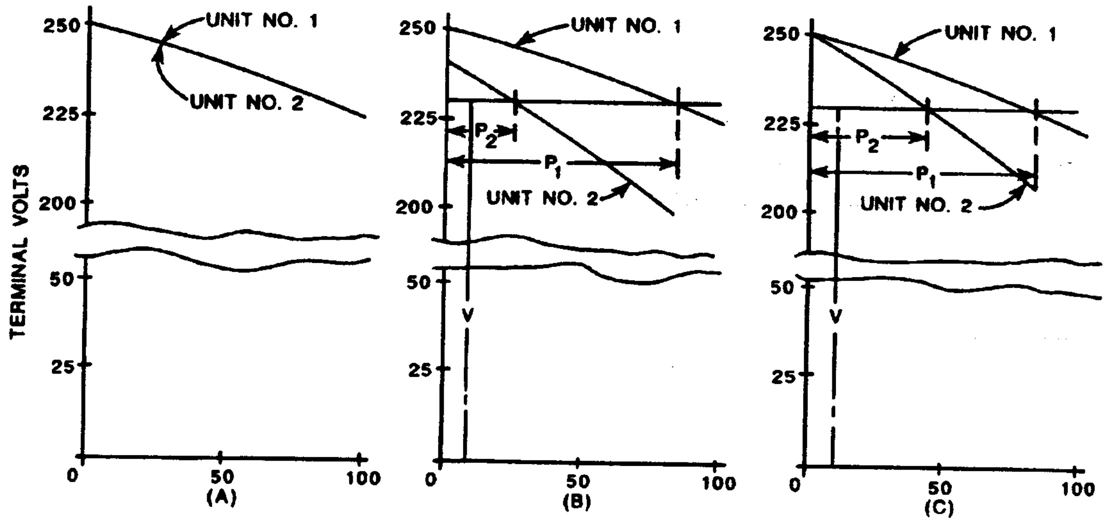

Figure 310-1-1 Load Current Expressed as a Percentage of Full Load Current.

310-1.7.18.2 Adjustment of Shunt and Stabilized Shunt DC Generators for Parallel Operation. In case the parallel operation of shunt or stabilized shunt dc machines is unsatisfactory, the correct solution of the difficulty is not the addition of an equalizer connection. Shunt and stabilized shunt wound generators are used on naval ships for several reasons. One is to save the weight and space required for the installation of equalizer connections and switches. Another is to ensure against the unsatisfactory operation that will be caused on an equalized system by a change in the resistance of switch contacts and connections. Since the equalizer connection must be of very low resistance, even a small change in resistance will disturb the operation. To install equalizer connections to obtain satisfactory parallel operation of shunt or stabilized shunt wound generators is to defeat the purpose of using this type of generator. The correct solution of unsatisfactory parallel operation is to adjust the units until they satisfy the conditions of paragraph 310-1.7.18.1. The recommended procedure for making this adjustment is as follows:

1. Start the prime mover of one of the generating units in accordance with the applicable instructions and safety precautions, and bring up to rated speed.
2. Measure the voltage fluctuation at no load. If the voltage fluctuation is greater that the value given in paragraph 310-1.7.18.1.c., do not disturb the governor adjustment before looking for and correcting other causes of excessive speed pulsation such as:
   a. Unbalanced rotor.
   b. Unequal air gaps.
   c. Poorly aligned shaft or baring.
   d. On diesel engine-driven units, sticking valves, incorrect valve timing, or one or more cylinders not operating satisfactorily.
3. If the voltage fluctuation at no load is still in excess of the limit specified, adjust the governor to reduce the speed pulsation. If the governor has a hunt or compensation feature, adjust this, if possible, until the speed pulsation is within suitable limits. If the governor has no such feature increasing the speed droop will decrease the speed pulsation.
4. Apply a light load to the generating unit operating alone, that is, not in parallel with any other. Increase the

load to about half rated load; warm up the unit at this load for about 30 minutes; and then gradually build up to full rated load adjusting the field rheostat to maintain full-load rated voltage. Run at full load for one hour and then check the generator voltage, current, and speed. If necessary, readjust the load, governor, and field rheostat until the generating set is operating at full load rated current, voltage, and speed.

5. Gradually reduce the load on the generator to zero without changing the governor or the field rheostat settings. Note the no-load speed and no-load voltage.

6. Adjust the shunt field rheostat until the voltage at no load is equal to the rated full-load voltage. Increase the load to full load without changing the governor or field rheostat settings. Note the full load speed and voltage.

7. Compare the observed speed regulation and voltage rise with Table 310-1-1. The speed regulation is the no-load speed minus the full-load speed expressed as a percentage of full-load rated speed. The voltage rise is the no-load voltage minus the full-load voltage expressed as a percentage of full-load rated voltage. The voltage drop is defined similarly. Note that when measuring voltage rise, the shunt field rheostat is set to give rated full-load voltage when the machine is carrying full load: but when measuring voltage drop, it is set to give rated full-load voltage when the load is zero. In both cases the field rheostat is then left unchanged while the load is changed. The generator operates at different points on the saturation curve in these two cases, which is the reason for the difference between voltage rise and voltage drop as given in Table 310-1-1.

8. Adjust the prime mover governor, if necessary, until the speed at full load is equal to the speed recommended by the manufacturer, the speed regulation is within the limits given in Table 310-1-1 and the voltage fluctuation at no load and any load between 20 percent and 100 percent of full load is not greater than the values given in paragraph 310-1.7.18.1. The adjustments should be made gradually. After each small change, apply full load and recheck. It may not be possible to obtain by the speed adjustment alone a voltage rise and drop which are in accordance with Table 310-1-1 but the adjustment should be made to approach this condition as closely as possible. For example, if the speed regulation is less than 3.5 percent for a turbine-driven unit and the voltage rise is less than 7 percent, adjust the governor to increase the speed regulation (though not to above 3.5 percent) as a change in this direction will increase the voltage rise.

Table 310-1-1 PERCENTAGE OF SPEED REGULATION VERSUS VOLTAGE VARIATION

		Combined unit	
Prime Mover	**Minimum permissible speed regulation (percent)**	**Voltage rise full load to no load**	**Voltage drop no load to full load (percent)**
Turbine	3.5	7 to 8	9 to 12-1/2
Diesel engine[1]	4.0	7 to 8	9 to 12

[1]Certain diesel engines have isochronous or constant speed governs. The speed regulation on these should be practically zero.

9. If after the speed adjustment has been completed, the voltage rise and drop are not within the limits shown in Table 310-1-1, the voltage regulation must be adjusted. Always stop the generator before making an adjustment. Three methods of adjustment are possible:

   a. For machines having adjustable shunts or diverters connected in parallel with the series fields on the generators, satisfactory voltage regulation can usually be obtained by changing the resistance of the diverters. To increase the difference between no-load and full-load voltage, decrease the resistance of the diverter.

   b. For generators without series field diverters, the voltage regulation adjustment must be made by shifting the brushes. The brush position selected by the manufacturer will be indicated by marks or pointers on the brush rigging and corresponding marks on the generator frame. Adjustments will usually be simplified by initially setting the brushes in this position. To increase the difference between no-load and full-load voltage, shift the brushes in the direction of rotation of the generator. Only a small change (about 1/32 inch) should be made in brush position for each adjustment. After the final adjustment, check the commutation. If there is still objectionable sparking after operating under load for one hour, it will be necessary to reset the brushes.

c. For generators equipped with diverters, method a, can be supplemented by method b.

10. When the generating unit has been adjusted to have the desired speed regulation and voltage rise and drop, operate at no load; adjust the field rheostat to give rated voltage; and then increase the load to rated load in steps of approximately 20 percent of the rated load without changing the governor or field rheostat setting. Note and record the values required in Table 310-1-2 under Voltage Drop. When increasing the load during this test, and when decreasing it (see paragraph 310-1.7.18.2.11) to obtain the data for Voltage Rise, do not bring the load back to a point which has been skipped unless the load change has first been carried to completion, that is, from no load to full load or from full load to no load.

Table 310-1-2 RECORD OF SINGLE UNIT OPERATION TEST RESULTS

A. Voltage Drop				
Load approximate (percent)	**Load Amperes**	**Generator terminal volts**	**Shunt Field Amperes Volts**	**Speed r.p.m.**
0------	------	------	------	------
20------	------	------	------	------
40------	------	------	------	------
60------	------	------	------	------
80------	------	------	------	------
100------	------	------	------	------
B. Voltage Rise				
100------	------	------	------	------
80------	------	------	------	------
60------	------	------	------	------
40------	------	------	------	------
20------	------	------	------	------
0------	------	------	------	------

11. When rated load is reached, readjust the load and field rheostat until the unit is delivering rated full load at rated full-load speed and voltage. Decrease the load in steps of about 20 percent of rated load without changing the governor or field rheostat and record the data required in Table 310-1-2 under Voltage Rise. The test results should show no increase in voltage with increase in load, or drop in voltage with decrease in load at any point in the Table 310-1-2.

12. Next adjust each of the other generators to be paralleled until its voltage regulation is the same as that of the first one adjusted which is taken as the reference machine. Unless a number of generator sets are already properly adjusted and matched, it is advisable to select as the reference machine the generator which is most difficult to adjust. All of the foregoing adjustments are made on generators when operating alone, that is, not in parallel with any other.

310-1.7.18.3 Parallel Operation Test. When all the machines which are to operate in parallel have been adjusted individually in accordance with paragraph 310-1.7.18.2 they should be tested for parallel operation as follows:

1. Start the machines and connect them in parallel at no load and rated voltage, observing all necessary precautions for this operation.
2. Gradually increase the load on the common bus to a value as close as practicable to the sum of the full-load ratings of the connected machines.
3. Adjust the generator field rheostat until each generator is carrying a load proportional to its rating, and the voltage of the common bus is equal to the rated voltage of the generators. Let the generators warm up for about one hour and readjust the generator loads and bus voltage, if necessary.
4. Reduce the load to 20 percent of the combined rated load in steps of approximately 20 percent of the combined rating of the connected generators, without changing the prime mover governor or the generator field rheostat settings. Read and record the values required in Table 310-1-3 under Decreasing Load.
5. With the generators operating at approximately 20 percent load, adjust the generator field rheostats until the generators give rated full-load voltage. Increase the load to 100 percent in steps of approximately 20 percent of the combined ratings of the generators, without changing the prime mover governor or the generator field rheostat settings. Read and record the values required in Table 310-1-3 under Increasing Load.
6. For all bus loads between 20 percent and 100 percent of the combined ratings of the connected generators and for both the decreasing and increasing load conditions, the load current of each generator, expressed as a percentage of its rated full-load current, should not differ from the total system current, expressed as a percentage of the total rated full-load currents of all connected generators, by more than 7.5 percent for generators of the same kW rating, or by more than 15 percent for generators of different kW ratings. Parallel operation is satisfactory if this condition is satisfied. Suppose, for example, that three 120-volt generators, A, B, and C, rated at 60, 100, and 100 kilowatts, respectively, are operating in parallel. If the generator currents are 210, 450, and 500 amperes, respectively, generator A does not satisfy the requirement for satisfactory parallel operation.

310-1.7.18.4 Compound Wound Generators. Conditions necessary for parallel operation of compound wound generators are given.

a. Conditions to be satisfied for the parallel operation of compound wound generators (generators with full-load voltage nearly equal to or greater than no-load voltage as distinguished from stabilized shunt machines with a drooping voltage characteristics) are:
    1. The generating units must be free from excessive speed pulsations.
    2. Equalizer must be used (unless the division of load is controlled by voltage regulators) one equalizer for two-wire generators, and two equalizers for three-wire generators. The resistance of the equalizers should be as low as practicable. (See paragraph 310-1.7.18.4.c.)
    3. The compounding must be so adjusted that the combined unit voltage regulation, or the change in voltage from no load to full load with rheostat and prime mover governor settings left unchanged, is approximately the same for each of the generators to be operated in parallel. The more closely this condition is satisfied, and the more closely the generator voltage characteristics match over the entire range from no load to full load, the more nearly equal the division of load will be.
    4. When the series field circuit (including the series field itself and the series field diverter) of each generator is carrying the rated full-load current of the generator, or the same fraction of rated full-load current, the voltage drop across the series field circuit from bus to equalizer must lie the same for each of the generators to lie paralleled. This condition must lie satisfied for 10th series field circuits on three-wire generators. The more closely it is satisfied, the more nearly equal the division of load will be.

b. Two-wire compound wound generators have a single series field and require one equalizer connection: three-wire compound wound generators have two series fields and require two equalizer connections. The condition stated in paragraph 310-1.7.18.4.a.4 is equivalent to the requirement that the resistance of each series field circuit from bus to equalizer be inversely proportional to the rated full-load current of its generator.

c. It is desirable that the resistance of the equalizer connection be less than approximately 20 percent of the resistance of the series field circuit (series field with diverter plus all other connections between the equalizer terminal and the switchboard). This often results in excessively large equalizer cables and is not mandatory. However, the size of equalizer cable should satisfy the following conditions:

1. Where the main power circuit connections per terminal, between the generator and switchboard, have a total conductor cross-sectional area of one million circular mills or less, the conductor cross-sectional area of the equalizer should not be less than the area of the main power circuit connections per terminal.
2. Where the main power circuit connections per terminal have a total cross-sectional area more than one million circular mills, the total conductor cross-sectional area of the equalizer connection should not be less than one-half that of the main power circuit connections per terminal.

Table 310-1-3 RECORDS OF PARALLEL OPERATION RESULTS

A. Decreasing Load											
			Machine No. 1			**Machine No. 2**			**Machine No. 3**		
Load	**Total Amperes**	**Terminal volts**	**Armature current**	**Shunt field current**	**Shunt field terminal volts**	**Armature current**	**Shunt field current**	**Shunt field terminal volts**	**Armature current**	**Shunt field current**	**Shunt field terminal volts**
100---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
80---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
60---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
40---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
20---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
0---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
B. Increasing Load											
0---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
20---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
40---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
60---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
80---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
100---	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

310-1.7.18.5 Adjustment of Compound Wound Generators. The adjustment of compound wound generators to satisfy the conditions of paragraph 310-1.7.18.4 is made by working on each generator individually when not connected to any other. The recommended procedure is:

1. Start the generator which is selected as a reference machine to which the others are to lie matched, connect it to the line alone, and adjust the prime mover governor until the speed regulation is in accordance with Table 310-1-1, paragraph 310-1.7.18.2, and the voltage fluctuation is within the limits specified in paragraph 310-1.7.18.1.c. except that for compound wound generators of less than 60 kW capacity, the permissible voltage fluctuations is twice as great. See paragraph 310-1.7.18.2 step 1 through step 5 inclusive for the details of the adjustment.

2. Adjust the shunt field rheostat to give the desired no-load voltage, increase the load, and measure the change in voltage from no load to full load.

3. Adjust the series field diverter (see paragraph 310-1.3.3) to give the desired change in voltage from no load to full load. For a flat compounded machine, the no-load and full-load voltages should be the same.

4. Use an accurate low range voltmeter (0-0.5, 0-1, or 0-3 volts are required) to measure the voltage drop across the series field or fields when the generator is carrying full-load current. With the equalizer switch open and with no other generator connected to the bus, the current through the parallel circuit consisting of series field and series field shunt (diverter) will be the same as the load current, and can be read on the generator ammeter.

5. Repeat steps 1 through 4 for each of the generators to be operated in parallel. Be sure that the measurement of the voltage drop across the series field circuits are made with the windings at the normal full-load temperature for all machines.

6. If the voltage drops measured across the series field circuits satisfy the requirements of paragraph 310-1.7.18.4.a.4, no further adjustment should be necessary. If the voltage drops are higher for generator No. 1 for example, than for the others when all are measured at their respective normal full-load temperature, insert an adjustable resistor in series with each series field circuit of each of the other generators. Run each generator separately and adjust the resistor until the condition discussed in paragraph 310-1.7.18.4.a.4 is satisfied when all voltage drops are measured with field windings at the proper temperatures.

310-1.7.18.6 Test for Parallel Operation. After each of the generating units to be operated in parallel has been adjusted individually, in accordance with paragraph 310-1.7.18.5, parallel the units and test for parallel operation as in paragraph 310-1.7.18.3.

310-1.7.18.7 Manufacturer's Representatives. It is advisable, whenever possible, to secure the assistance of manufacturer's representatives when adjusting generators for parallel operation.

310-1.8 MAINTENANCE

310-1.8.1 GENERAL. The following supplements the Planned Maintenance System (PMS). When PMS is installed, conduct preventive maintenance in accordance with PMS.

a. The essential points in the maintenance of generators are:
   1. To keep the insulation clean and dry and of high resistance.
   2. To keep the electrical connections tight.
   3. To keep the machine in good mechanical condition. More generator trouble is caused by mechanical difficulties and derangements than by electrical malfunctions.

b. A regular schedule of cleaning and inspection will go far to ensure trouble-free operation and the detection of incipient faults before they develop sufficiently to be a major source of difficulty. The PMS tasks and schedule should be adhered to as established for the specific equipment on each ship. The following points should also be kept in mind.
   1. A new machine should be carefully watched until extended operation has demonstrated that it is performing satisfactorily.
   2. An old machine requires more frequent cleaning and inspection than a similar machine which has seen less service.

3. Time spent in cleaning, inspecting, and correcting defects before they grow serious means time saved in overhauls and repairs.

c. See **NSTM Chapter 300, Electric Plant - General,** for further instructions on maintenance.

310-1.8.2 PRECAUTIONS. There are numerous precautions which should be carefully observed in the operation and care of generators to ensure the continuous operation and long life of the equipment. In this connection, the technical manuals should be frequently consulted together with the preceding instructions on operation, the instructions on maintenance on the PMS cards and in **NSTM Chapter 300, Electric Plant - General** , and the following summary of precautions.

1. Check all connections to see that they are tight and correctly made.
2. Check periodically the insulation resistance of all windings for possible grounds. The temperature of the windings should be taken at the time of measurement and this temperature together with values of insulation resistance recorded in the log. If any grounds or short circuits are detected, don't operate the generator until they are corrected. Record in the log the location, nature, and correction of any grounds or short circuits.
3. For insulated bearings, make sure that there are no short circuits caused by temperature probes, drain lines, oil lines, or other drainers connected or in contact with the insulated portions of the bearings. Further, check for adequate bearing electrical insulation to minimize current flow at journal bearing locations.
4. A generator which has been subjected to moisture should not be operated until its insulation resistance has been brought to the proper value by drying out the windings. Record in log. Don't allow oil, oil mist, or water to come in contact with the windings. Two pole 3,600 revolutions per minute (rpm) ship service generator rotors must be kept free of moisture. These units have nonmagnetic retaining rings of MnCr alloys which are susceptible to stress corrosion cracking in the presence of moisture.
5. The generator circuit breakers of a generator which is secured should not be closed even though the line may be dead. Under such conditions, should any other generator be started up, the generator connected to the line may operate as a motor and possibly wreck itself and its prime mover.
6. Don't start a generator unless the generator circuit breaker is open and the voltage regulator is first adjusted to minimize generator field excitation by whatever means appropriate for the particular unit.
7. See that overspeed protective system is tested in accordance with the applicable prime mover instructions. Never continue to operate a generator unless these devices are functioning satisfactorily. Record in log. Generators and their prime movers have been wrecked, and personnel fatally or otherwise injured, due to failure of these devices to function before dangerous overspeeds were reached.
8. Don't turn the voltage regulator switch from MANUAL to NORMAL until the ac generator voltage has been adjusted to approximately the desired operating value. Voltage regulators having no MANUAL selection (dual types) should be switched to the NORMAL position and the voltage control set near the desired operating value with the DROOP control set near maximum.
9. Turn the synchronizing switch of an ac generator to the ON position before attempting to close the breaker for an ac generator.
10. The generator circuit breaker (non-parallel operation of an ac generator) should not be closed until the voltage and frequency of the generator are normal.
11. In paralleling ac generators, the circuit breaker of the incoming generator should not be closed until the voltage and frequency are normal, and the generator is in synchronism with other generators on the line.
12. Don't close the generator circuit breaker to parallel an ac generator with other machines unless the pointer

of the synchroscope is in the eleven o'clock to twelve o'clock position, corresponding to the synchronizing lamps being dark. Also, the period of rotation of the synchroscope, or dimming of the synchronizing lamps, should not be greater than once every six seconds.

13. A generator should not be run continuously above its rated speed.
14. A generator should not be run at continuous overload. Record the magnitude and duration of the overload in the log together with any unusual conditions or temperatures observed.
15. A machine in which there is a vibration should not be continued in operation until the cause is found and corrected. Record in log.
16. A direct current (dc) generator in which the commutation is bad, should not be in operation until the cause has been found and corrected. Record in log.
17. Immediately disconnect the generator from the line in case of failure or derangement of either the prime mover, lubricating system, or the generator itself.
18. After tripping the generator circuit breaker, when securing a non-automatically started dc generator, minimize the field current by either: a) inserting maximum resistance in the field circuit by adjusting the field rheostat, or b) turning the voltage adjust on the voltage regulator to minimum--this may involve first selecting the MANUAL position on the regulator, but if the voltage regulator is of the dual automatic type, the MANUAL position may be absent, requiring that the voltage be minimized by adjustment in the NORMAL position.
19. After tripping the generator circuit breaker, when securing a nonautomatically started ac generator, remember to turn the voltage regulator control switch to the OFF or MANUAL position.
20. After turning the voltage regulator control switch to the OFF or MANUAL position, remember to turn the manual voltage control as far as it will go in the decrease voltage direction. For voltage regulators with no MANUAL position, turn the voltage adjust control to minimum and the DROOP adjust control to maximum.
21. Open all its switches and circuit breakers when securing a nonautomatically started generator. This rule does not apply to disconnect links installed solely to isolate the generator circuit breaker so that it can be worked on while the bus is hot.
22. Keep all its switches and circuit breakers opened as long as a non-automatically started generator is secured.
23. Blow out generators regularly with low pressure air and afterwards, wipe the windings with a lintless cloth to remove all accumulated dirt. This should be done at least once a week, preferably immediately after the generator is secured.
24. The current of air should not be directed on the windings until all moisture is blown out of the air hose.
25. Air at too high a pressure should not be used for blowing out machines. See **NSTM Chapter 300, Electric Plant General,** for instructions on air pressure to be used in cleaning machines.
26. Turn on heaters (if any) immediately after securing and blowing out a generator. Conversely, remember to turn them off when putting the generator in operation.
27. Turn off water in air coolers (if any) after securing a generator and turn it on again when putting the generator in service.

310-1.9 RECORDS AND REPORTS

310-1.9.1 RECORDS IN LOG. In addition to the entries in the log required in preceding sections of this chapter, observe and record in detail any unusual feature of generator operation, its cause, and effect.

310-1.9.2 REPORTS OF EQUIPMENT FAILURE AND IMPROPER OPERATION. All reports on any of these should include, in minute detail, observations made prior to, during, and after the improper operation in addition to comments as to the cause and results of the failure. Improper operation reports have been received which, beyond noting the fact that a operational error has occurred, give no information upon which to base action to prevent future similar disruptions in service. The complete allowance parts list (APL) number, identification plate rating, serial number, model number, and name of manufacturer of the equipment involved, should be given. Make a report using the Maintenance Data Form as prescribed in OPNAVINST 4790.4 Volume II.

SECTION 2.

GOVERNORS

310-2.1 DESCRIPTION OF GOVERNORS

310-2.1.1 GENERAL TYPES. Governors control the speed of the prime mover driving the generator by controlling the flow of steam or fuel to the prime mover under any load up to the capacity of the prime mover. When generators are run in parallel, the governors adjust so each generator carries its proportionate share of the kilowatt (kW) load. In alternating current generation, governors are most important since they keep speed constant to produce 60 hertz or 400 hertz. There are two types of governors.

a. The mechanical (or mechanical-hydraulic) types are described in the governor section of **NSTM Chapter 502, Auxiliary Steam Turbines, NSTM Chapter 233, Diesel Engines,** and **NSTM Chapter 234, Marine Gas Turbines** . These governors when operating singly, can operate isochronously, that is, having no change in speed as the load changes. However, in parallel operation they must depend upon their droop characteristic; that is, having a change in speed as the load changes in order to get proportional division of load between generators. Paralleled ac generators have the same speed. Droop should be set at a value of approximately 3.3 percent to provide for good load division (maximum of 5 percent difference between loads on each generator).

b. The electrohydraulic load sensing type is described herein. This governor has better transient response than the mechanical-hydraulic type. These governors allow their associated generators to operate isochronously, that is, having no change in speed as the load changes. This allows a system to operate at a chosen frequency regardless of load condition, and does not require the operator to periodically adjust the system frequency as the loads change.

310-2.1.2 ELECTROHYDRAULIC. The electrohydraulic governor is attractive in view of the simplicity with which electric signals can be manipulated to achieve fast, accurate, governor response. Basically, the EH governor receives electric signals representative of speed and load(s); compares them to a reference, and any difference becomes a signal for a hydraulic system to change the throttle setting. A typical EH governing system could be composed of these four basic elements:

a. Permanent magnet alternator (PMA) or equivalent, such as a toothed wheel and reluctance pickup, for measurement of prime mover speed. Its output frequency is converted to a voltage and compared to a frequency reference (see paragraph 310-2.1.2.b., below). The PMA may also supply the power for the brushless exciter.

b. The speed sensing circuitry receives the speed signal, converts it to a voltage, compares it to a reference, and produces an output to control the fuel or steam valves to provide the desired speed output. The reference voltage (representing the desired speed) is set by the speed setting potentiometer. Any resultant voltage difference between the speed and reference signals causes the hydraulic actuator to adjust the throttle. This basic regulation loop is altered by the signal from the load sensor such that a drooping speed-load characteristic is provided in the droop mode, and automatic kW load division is provided (at constant speed) in the isochronous mode.

c. A load sensor comprised of transformers, diodes, and a potentiometer, which converts its generator's three-phase voltage and current signal to a dc voltage signal proportional to load. In the isochronous mode, the output of the load sensor of one generator is compared to an equivalent output of another generator. Any difference results in a signal fed into the basic sensing circuit of each governor so as to equalize the loads automatically. In the droop mode the outputs of the load sensors are not compared. Each load sensor causes its individual generator to exhibit a drooping speed-load characteristic. A droop potentiometer provides for varying droop from 0 percent to 5 percent.

d. The fourth basic element of a governor speed control is an actuator which is controlled by the speed and load sensor circuitry. This actuator controls the fuel or steam, as required, to control the output speed of the prime mover.

310-2.2 OPERATION OF GOVERNORS

310-2.2.1 TECHNICAL MANUALS. The applicable technical manuals should be referred to for a detailed description of the construction, and detailed instructions for the operation, care, maintenance, overhaul, and repair of any particular governor. The personnel responsible for the operation, care, and maintenance of any piece of equipment should be thoroughly acquainted with the contents of its technical manual, as well as with the instructions contained herein.

310-2.2.2 START UP. In general, following the start-up procedure of a prime mover, the governor will automatically take over speed control when the speed gets to 80 percent synchronous speed.

a. The paralleling procedure for any particular installation is covered in the technical manual. Normal operation is with the governor set for the isochronous mode of operation. Use droop mode when paralleling with other sets not equipped with a similar EH governor or with a shorepower system. The oncoming generator is synchronized with the other generators; e.g., voltage and phase relationships are identical, and the oncoming generator's circuit breaker is closed, thus putting that generator on the line and in parallel with the other generator's.

b. In the isochronous mode, the generator immediately takes on its portion of the load and the generator is in parallel. In the droop mode, the generator takes on a part of the load but the speed potentiometer is manually adjusted to make the oncoming generator share the load equally.

310-2.3 MAINTENANCE

310-2.3.1 GENERAL. Maintenance information given herein supplements PMS. Where PMS is installed, conduct preventive maintenance in accordance with PMS. In addition, check the permanent magnet section for cracks or other damage.

310-2.3.2 PERMANENT MAGNET ALTERNATORS (PMA). For maintenance of the PMA see paragraph 310-1.8 which provides maintenance information on generators.

310-2.3.3 SPEED SENSING AND LOAD DIVISION CONTROLS. Satisfactory operation is dependent on adjustments made strictly in accordance with a prescribed procedure. Accordingly no adjustments shall be made unless specifically called out for the particular equipment.

310-2.3.4 HYDRAULIC ACTUATOR. This unit is sensitive to dirty oil and moisture. Dirty oil causes excessive wear of parts and can cause parts to stick, thus impairing operation. Moisture causes corrosion, further impairing operation. Every effort should be made to keep the oil clean and moisture-free. Oil filter elements should be replaced routinely. Disassembly and adjustments shall be made only by qualified personnel, and in accordance with instructions for the specific equipment.

310-2.3.5 TROUBLESHOOTING. Governor faults are usually revealed in speed variations of the prime mover but it does not necessarily follow that all such speed variations indicate governor faults. Therefore, when improper speed variations appear, the following procedure should be carried out:

1. Check the load to be sure that the speed changes observed are not transients resulting from continuing load changes. On a diesel engine, check the engine operation to be sure that all cylinders are firing properly, and that the injectors are in good operating condition.
2. See that the operating linkage between the hydraulic power piston and engine or turbine is free from binding or lost motion.
3. Check the voltage regulator to be sure it is functioning properly. If these checks do not reveal the cause of the speed variation, the cause may be in the governor.
4. Trouble in the governor can be located by measuring various dc signals to the actuator speed sensing and load division circuits. Test details are shown in the equipment technical manual for the particular installation

SECTION 3.

VOLTAGE REGULATORS FOR AC AND DC GENERATORS

310-3.1 DESCRIPTION OF VOLTAGE REGULATORS

310-3.1.1 SCOPE. The voltage regulators used on naval ships differ widely in type and design, and the auxiliary equipment used with each also differs in type, function, and design. Because of this fact, no attempt will be made here to describe in detail the construction, the operation, and the care and maintenance of each of these various types with its associated auxiliary equipment. The following discussion is, therefore, confined to an enumeration and brief description of the more important types of voltage regulators, and to general instructions which serve as a guide to the operation, care, and maintenance of all types of equipment.

310-3.1.2 TECHNICAL MANUALS. The applicable technical manuals should be referred to for a detailed description of the construction, and detailed instructions for the operation, care, and maintenance of any particular voltage regulator. The personnel responsible for the operation, care, and maintenance of any piece of equipment should be thoroughly acquainted with the contents of its technical manual as well as with the instructions contained herein.

310-3.1.3 USAGE. In general, naval use of voltage regulators is limited to the following:

a. Voltage regulators are not normally used on dc generators for naval use except where unusually close voltage regulation is needed, or where voltage regulators are provided to control parallel operation of flat-compound wound generators or generators having unlike compound characteristics, or for variable speed generators such as battery charging generators. The inherent characteristics of properly wound dc generators give sufficiently close regulation for most applications.

b. Voltage regulators are always used on ac generators.

c. One voltage regulator is used for each generator where voltage is to be regulated. In some cases, dual automatic voltage regulators are applied redundantly, so that the failure of one will not result in loss of regulation. The original voltage regulator applications for ac generators used electromagnet type voltage regulators which provide control by varying the resistance in the generator field. The practice for these installations was to incorporate a spare voltage element which could be put in service, if any other voltage regulator element on the switchboard failed, by simply turning a switch. Many of these installations still exist on naval ships. Spare elements are not incorporated in modern day silicon-controlled rectifier and transistor type regulators.

310-3.1.4 FUNCTIONS. When used on ac generators, the functions performed by voltage regulators are:

a. Maintain the generator terminal voltage within specific limits.

b. Provide for proper division of reactive current between generators operating in parallel.

310-3.1.5 OPERATING CHARACTERISTICS. Each complete regulator equipment will have the following operating characteristics:

a. The normal voltage can be set at any desired value, within specified limits, by means of the voltage adjusting rheostat of the voltage regulator.

b. At constant loads, from zero to full load, and from rated to unity power factor on ac generators, the equipment will maintain the generator terminal voltage within a plus or minus specified percentage of normal voltage without objectionable hunting.

c. With suddenly applied loads, the equipment will not cause the generator terminal voltage to rise or drop more than a specified percentage of normal voltage and will recover and hold the voltage to within a specified percentage of normal voltage within a specified time.

d. For unbalanced load on ac generators, where the variation in voltage between phases does not exceed a specified percentage of normal voltage, the equipment will automatically maintain normal voltage (average of three phases) within specified performance limits.

e. In the parallel operation of ac generators with each generator controlled by its own regulator, individual reactive current compensation by the regulators and their associated equipment will provide for the division of reactive current between the generators in proportion to their respective capacities. The division of the kilowatt load between the generators depends upon the power input from the prime movers and is controlled by the governor settings. Since voltage regulators control excitation but not power input from the prime movers, reactive current compensation for ac generators in parallel affects the division of kVA, but not the division of kW. Individual reactive droop compensation for ac generators requires no equalizer connections between either the generators or their voltage regulators but cause the voltage to droop as the lagging current carried by the generators increases. Since a slight voltage droop is not objectionable and the connections are simple, individual reactive droop compensation is used almost exclusively in paralleling ac generators on naval ships.

f. Voltage regulators are seldom used on dc generators. When they are, they eliminate any need for the heavy equalizer connections between the field windings of the generators which would otherwise be required for parallel operation of flat or overcompounded generators. When dc generators, each controlled by its own voltage regulator, are operated in parallel, either individual or differential cross-current compensation is used to divide properly the current and kilowatt load between generators.

1. Individual cross-current compensation for dc generators requires no connections between the voltage regulators on the generators operating in parallel, but causes the voltage to droop when the load is increased.
2. Differential cross-current compensation for dc generators requires connections between the voltage regulators of the generators operating in parallel, but does not cause a droop in voltage when the load is increased. Both types of compensation are used for dc generators on naval ships.

310-3.1.6 TYPES. A voltage regulator consists, essentially, of a voltage-sensitive element and associated mechanical or electrical means to produce the changes in generator field current that are necessary to maintain a predetermined, constant generator voltage. The possible combinations of different kinds of voltage-sensitive elements and associated control means give rise to a number of different types of voltage regulators.

a. The types used on United States naval vessels are:
   1. Indirect acting rheostatic type
   2. Direct acting rheostatic type
   3. Rotary dc exciter and electronic voltage regulator type
   4. Rotating brushless ac exciter with electronic voltage regulator.
   5. Static exciter and electronic voltage regulator
b. At present only the brushless exciter and static exciter systems are used on new installations because of their fast accurate response. However, many indirect acting and direct acting rheostatic type voltage regulators are still in service.
c. Voltage regulator reliability has been increased by means of the dual automatic voltage regulator. In these units, there are two regulators, a prime and a back-up, which are selected either manually or automatically using a combination of the internal logic circuitry and the controls on a remotely located control panel.

310-3.1.6.1 Rheostatic Types. There are two types:

a. Indirect Acting Rheostatic Type. The indirect acting rheostatic type of voltage regulator consists essentially of a voltage-sensitive element and a motor-operated rheostat which is connected in the field circuit of the ac generator being regulated. A small motor, which is controlled by the voltage-sensitive element, drives a contact arm over contact buttons on the field rheostat and changes the field resistance. The response of the motor-operated rheostat is too slow to handle large, sudden changes in voltage. When these occur, high speed relays are actuated by the voltage-sensitive element to insert or cut out large blocks of resistance in the field circuit. These may be cut in or out a number of times before the motor-operated rheostat makes the final adjustment for the new load conditions.
b. Direct Acting Rheostatic Type. The direct acting rheostatic type of voltage regulator has a voltage-sensitive element in the form of a solenoid, magnetic torque element, or torque motor which exerts a mechanical force directly on a rheostat. In the case of dc generators or small ac generators the rheostat is usually connected directly in the field circuit of the generator being controlled. In the case of large ac generators, the rheostat is usually connected in the field circuit of the exciter. This eliminates the need for a rheostat in the field circuit of the ac generator, and permits the use of much smaller voltage regulator equipment since the exciter field power is much less than the ac generator field power.

310-3.1.6.2 Rotary Exciter and Voltage Regulator System. There are two types:

a. The rotary dc exciter type of voltage regulator system furnishes a large change in output dc voltage for a small change in the control field current of the rotary exciter. The voltage-sensitive element is a network of capacitors, reactors, and resistors. It detects the variation of the ac generator voltage from a reference voltage which can be set to a predetermined desired value. The variation between actual ac voltage and the reference voltage sends a current through the control field of the exciter, changes its output voltage, and hence changes the ac generator field current to hold the ac generator voltage at the desired value.

b. The brushless ac exciter type of voltage regulator system controls the dc power delivered to the stationary field of a brushless exciter. Its rotating armature ac output is rectified by hermetically sealed silicon rectifiers mounted on or in its shaft and this resultant regulated dc is connected directly to the main generator field. This statically controlled rotating system is brushless, having no commutators or slip rings. Because of this design, measurement of main generator field voltage and current is not feasible.

310-3.1.6.3 Static Exciter and Voltage Regulator System. This system furnishes dc current to the ac generator field by rectifying a part of the ac generator output. The voltage detector consists of a network of capacitors, reactors and resistors and controls the power input to the generator field by means of magnetic amplifiers or silicon controlled rectifiers (SCR). Modern day systems use SCR exclusively, because of their improved performance characteristics.

310-3.1.7 AUXILIARY EQUIPMENT. The type of auxiliary equipment used in connection with the voltage-sensitive element depends upon the individual types and designs used by the various manufacturers. For a complete description of the auxiliary equipments and their operating principles, refer to the technical manual for the regulator.

310-3.2 VOLTAGE REGULATOR OPERATION, MAINTENANCE, AND CARE

310-3.2.1 TECHNICAL MANUALS. Reference should be made to the technical manual for the manufacturers detailed instructions regarding the operation, maintenance, and care of the voltage regulation equipment of the particular installation involved.

310-3.2.2 GENERAL INSTRUCTIONS. In addition to the detailed instructions given in the technical manuals, the following general instructions are to be observed prior to and during operation, as follows:

a. For all types of regulators.
   1. All connections to the voltage-sensitive element and between the element and all the auxiliary equipment shall be tight and strictly in accordance with the manufacturer’s connection and wiring diagrams.
   2. All necessary adjustments shall be made according to instructions.
   3. All contacts shall be clean and free from grease, dirt, or other foreign material.
   4. All moving parts must operate freely with no tendency to stick or move sluggishly.
   5. The movement of all brushes, relays, contactors, armatures of solenoids, damping devices, dashpots, etc., must be free, smooth, and unobstructed by any foreign material.
   6. All switches must operate properly and make tight contacts.
   7. All necessary lubrication shall be strictly according to the manufacturer’s instructions.
   8. Where an equalizing reactor is used, see that the current transformers and the reactors for the generators in parallel are connected in the same phase. The secondary leads of the transformer should be so connected

to the equalizing reactor that the voltage of each machine is decreased when its reactive load increases. This will equalize the power factors of generators operating in parallel.

b. For indirect acting rheostatic type voltage regulators.
   1. See that the connections to the contacts of the voltage-sensitive element and relays give the correct direction of rotation to the pilot motor of the field rheostat.
   2. See that the contact arm of the motor-operated field rheostat moves smoothly and freely over its entire range, and at the same speed up or down, when driven by the pilot motor or when operated by hand.
   3. See that the brushes on the contact arm of the motor-operated field rheostat move freely and do not stick in their holders.
   4. See that the resistance buttons of the rheostat are tight, with no tendency toward tilting or movement from side to side as the brushes of the contact arm pass over them. Any movement or tilting may cause the brushes to stick in their holders, create an arc, and result in a burnout or fusion between buttons.
   5. Make sure there are no worn resistance buttons or there is no accumulation of carbon or copper dust on or between the resistance buttons of the rheostat, and the brushes of the contact arm are not chipped, cracked, or unduly worn.
   6. Check the limit switches to see that they function properly to disconnect the pilot motor from the line when they are tripped by the contact arm.
   7. See that the correct tap of the variable permanent resistance of the rheostat is used so that the required excitation is obtained within the limits of travel of the contact arm over the resistance buttons.
   8. See that all contactors and relays have a positive make and break when energized or de-energized.
   9. See that the commutator of the pilot motor is clean and smooth, and is not excessively worn.
   10. See that the brushes of the pilot motor move freely in their holders and are not chipped, cracked, or unduly worn.
   11. See that there is no leakage of grease into the motor from its bearings.

c. Inspection should be made once a week for the above points.

310-3.2.3 TROUBLES. When troubles develop, the instructions given in the manufacturer’s technical manual shall take precedence over paragraphs 310-3.2.3.1 through 310-3.2.3.8. These paragraphs are supplementary to the technical manual and shall lie observed in all cases where they apply without conflicting with the technical manual.

310-3.2.3.1 Regulator Not Operating. If the voltage-sensitive element ceases to function look for:

a. Open circuit in leads to or from the rectifier or to the torque element.
b. Open circuit between the secondary of the damping transformer and regulator element.
c. Open circuit between exciter field and regulating resistance.
d. Short circuit of the regulator terminals.
e. Obstruction in any of the moving parts.

310-3.2.3.2 Erratic or Unstable Voltage. Should the regulated voltage become either erratic or subject to violent swings, investigate these possible sources of trouble:

a. Loose or faulty connections in the various circuits.

b. Open circuit from exciter circuit to damping transformer.

c. Wrong polarity of the primary of the damping transformer.

d. Wires crossed between terminals of damping transformer and the corresponding terminals of the regulator element.

e. Check clearance of regulator contacts.

f. Binding or friction in the torque device.

g. Faulty operation of dashpot in damping device: if a magnetic device, look for rubbing of damping armature on the pole faces.

h. Friction in the moving parts of relays or rheostat contactors.

i. Examine motor-operated rheostat for:
   1. Smoothness of operation.
   2. Freedom of movement of brushes on contact arm.
   3. Good contact between brushes and each resistance button.
   4. Change in ac voltage per button. This should not be in excess of the limit for which the regulator contacts are set.

j. Open circuits or shorts in the resistance stacks.

310-3.2.3.3 Abnormally High Voltage. If the voltage is abnormally high:

1. Look for an open circuit in the connections between the regulator contacts and contactors which they control to lower the voltage.
2. Look for open or short circuits in the contactor coils.
3. See that the contactors which raise the voltage are not stuck closed.
4. See that the motor-operated rheostat is not stuck in any one position and that its motor responds properly to the contactors which control it, also that there is no misalignment of the motor shaft or the screw or rods which support the contact arm.

310-3.2.3.4 Abnormally Low Voltage. If the voltage is abnormally low or droops badly when load is applied to the generator:

1. Check the generator speed to see that it is not below normal.
2. Look for an open circuit in the connections between the regulator contacts and the contactors they control to raise the voltage.
3. Look for open or short circuits in the contactor coils.
4. See that the contactor which lowers the voltage is not stuck.
5. See that the contactor which inserts the large block of resistance in the field circuit is not stuck to keep this resistance in the circuit.
6. See that the motor-operated rheostat is not stuck as indicated above.

310-3.2.3.5 Faulty Operation of Contactors. Should any of the contactors fail to function properly look for:

a. Open or short circuit in the contactor coils.

b. Dirt or other foreign material obstructing freedom of movement of the moving pans.

c. Dirt or grease on the contacts.

d. Insufficient contact pressure. Adjust according to manufacturer's instructions.

e. Beads of copper on and discoloration of contact tips due to overheating. Contact faces should be dressed with a fine file. Do not use emery or sandpaper.

310-3.2.3.6 Sparking of Rheostat. In case of sparking of the motor-operated rheostat, look for:

a. Excessive wear of one or more buttons.

b. Looseness of one or more buttons in the mounting.

c. Dirt or grease on the buttons.

d. Carbon or copper dust on or between the buttons.

e. Wrong pressure of contact brushes on buttons. Correct pressure according to manufacturer's instructions.

f. Metal beads or burn on buttons. Dress smooth with a fine file.

g. Contact brushes too loose or too tight in holders.

h. Brushes chipped, cracked, or worn.

i. Open or loose connections between resistance units.

j. Bent resistance units causing intermittent short circuits.

310-3.2.3.7 Sticking of Rheostat. If there is a tendency for the brush contact arm to stick or move with a jerky motion, look for:

a. Improper or insufficient lubrication of the operating screw and the rods supporting it.

b. Misalignment of the gears, screw, or rods.

c. Looseness of resistance buttons, allowing them to tilt and cause the brushes to jam.

d. Brushes too loose or too tight in holders.

310-3.2.3.8 Faulty Parallel Operation of AC Generators. In case of faulty parallel operation between two or more machines; i.e., the power factor is unstable and shifting from one machine to the other:

1. Look for loose connections or faulty contact in the voltage adjusting rheostat, the regulator circuit, and the rest of the ac potential circuit.
2. See that the current transformer and the equalizing reactor for each generator are in the same phase.
3. See that the connections of the current transformer to the equalizing reactor are such that with increase of reactive kVA, the regulated voltage of each machine is reduced when the reactor is in the circuit.
4. Adjust the voltage regulators so that all machines have the same voltage droop from no load to full load at rated power factor.

310-3.2.4 GENERAL PRECAUTIONS. Personnel are advised that in addition to those in the technical manuals which take precedence in every case, the following precautions should be observed.

1. Don't operate the regulator without first determining that the connections of the voltage-sensitive element and its auxiliary equipment are in accordance with the manufacturer's instructions.
2. Don't operate the regulator without first determining, by hand control, that the motor-operated rheostat functions properly.
3. Don't fail to follow, in detail, the procedure recommended by the manufacturer in putting the regulator in or taking it out of service.
4. In case of trouble, don't attempt any adjustments of the voltage-sensitive element until the auxiliary equipment and connections are first thoroughly examined for faults.
5. Don't make any adjustments, either of the voltage-sensitive element or the auxiliary equipment, except those recommended in the technical manuals.
6. See that all parts are kept clean of dirt, grease, or loose metal shavings. Check once a week.
7. See that all moving contacts are free of burrs or fused metal globules. Dress with a fine file. Check weekly.
8. See that all connections are tight and properly made. Check weekly.
9. See that all moving parts have free and unobstructed movements. Check weekly.
10. Examine the pilot motor for blackening or excessive wear of the commutator, condition and fit of brushes, or leakage of grease. Check weekly.
11. Inspect the motor-operated rheostat for loose or worn resistance buttons; dirt, grease, and carbon or metal dust on or around the buttons; misalignment of the pilot motor shaft, the gears in the gearbox, or of the screw which actuates and the rods which support the contact arm. Check weekly.
12. See that the brushes or contacts of the contact arm have the proper pressure on all the buttons in accordance with the manufacturer's instructions, also that the brushes or contacts move freely in their holders and are not broken, chipped, or worn. Check weekly.
13. Examine resistance buttons for burrs or evidence of burning or arcing. Dress with a fine file. Check weekly.
14. Where equalizing reactors and current transformers are used in paralleling two or more ac generators, see that the current transformer and reactor are in the same phase for each generator.
15. Obtain the proper division of kW load between ac generators by manipulating the equalizing reactors or regulators. It cannot be done. The only way to get proper division of kW load is by varying the input from the prime movers of the generators by means of the governor control switches.

REAR SECTION

NOTE

TECHNICAL MANUAL DEFICIENCY/EVALUATION EVALUATION REPORT (TMDER) Forms can be found at the bottom of the CD list of books. Click on the TMDER form to display the form.