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EDQP STUDY PAPER

ELECTRICAL POWER DISTRIBUTION

CATEGORY:

SPECIFIC DESIGN-SD

SYSTEMS ENGINEERING-3B

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ENGINEERING DUTY OFFICER BASIC QUALIFICATION PROGRAM (EDQP)

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Lesson Topic. Electrical Power Distribution SD-31, Revision B.

Time. 2 Hours.

Instructional Materials.

1. References:
   - (a.) NAVSEA Standard Drawings Nos. 803-5001027 and 803-5184170.
   - (b.) Design Data Sheet DDS310-1, Design Details of Generating Plants.
   - (c.) MIL-STD-251, Power Output Ratings for Electric Generators.
   - (d.) Design Data Sheet DDS304-1, Electric Cable Voltage Drop Calculations.
   - (e.) DOD-STD-1399, Section 300, Interface Standard for Shipboard Systems, Electric Power, Alternating Current.
   - (f.) Design Data Sheet DDS304-2, Electric Cable Ratings and Characteristics.
   - (g.) Naval Ships Technical Manual, 59086-KC-STM-0001, Chap 300R1, Electrical Plant, General.
   - (h.) MIL-S-16036, Naval Shipboard Power Switchgear.
   - (i.) Naval Ships Technical Manual, 59080-K9-STM-000, Chap 330, Lighting.
   - (j.) Design Data Sheet DDS300-2, AC Fault Current Calculations.
   - (k.) Design Data Sheet DDS300-1, Fault Current Calculations for Direct Current Systems.
   - (l.) Design Data Sheet DDS311-3, Ship Service Electric Power System, Application and Coordination of Protective Devices.

Terminal Objective. Complete the Engineering Duty Officer Basic Qualification Program.

Enabling Objective. Obtain an understanding of the fundamental technology involved in the design of the electrical power distribution system aboard ship.

Practical Factors. See attached sheet.

Questions. See attached sheet.

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INTRODUCTION

1. INTRODUCTION

The electrical power produced by the ship's power generating plant and distributed by the ship's power distribution systems provides vital support to interfacing ship systems such as habitability, mobility, and mission support. Electrical power is normally provided by the ship service power generating plant, supplemented by an emergency power generating plant which can be either separate from or integrated with ship's service plant. Equipment requiring electrical energy at voltage and/or frequency ratings different from those at which ship service power (450 volts, 60 hertz) is generated (e.g. 400 hertz and DC equipment) require special conversion equipment fed from the ship service and/or emergency power distribution systems. Storage batteries provide a source of electrical energy independent of the ship service power system for equipment requiring mobility (e.g., forklift trucks) and for selected vital equipments requiring uninterrupted power supplies. However, storage batteries require charging equipment fed from the ship service power system. Shore power connection facilities provide for the acceptance of electrical power from a shore source or from the power generating plant of another ship.

Electrical power is distributed from the ship service power generating plant to consuming equipment throughout the ship. Propulsion auxiliaries, steering, auxiliary machinery, deck machinery, shops, IC, electronics, weapons, hotel, air conditioning, ventilation and power conversion equipment loads are supplied from the electric plant.

The ship's electric plant, including power generators, power distribution, consuming equipment and connecting cables must, of functional necessity, be located throughout the ship. Survivability and vulnerability factors require physical isolation of electric plant equipment and cable in order to maintain maximum reliability in the delivery of ship service power. Consequently, electric plant equipment and cable are subjected to a wide variety of ship environmental conditions. Generally, all components of the electric plant, with the exception of welding motor-generators, battery charging panels, test panels, test switchboards, shore power terminal boxes and electric furnaces must meet Grade A shock requirements. Applicable Military Specifications (Mil Specs) set forth general environmental standards (e.g., vibration, inclination, humidity, moisture and salt atmosphere) for electric plant components in the absence of specific requirements for a particular piece of electrical equipment.

Basic design requirements for a ship's electric plant are contained in Sections 300 through 332 and Section 422 of the General Specifications for Ships of the United States Navy and the applicable Mil-Specs, Mil-Standards and Design Data Sheets referenced in the General Specifications. NAVSEA Drawing 803-5001027 sets forth standard installation methods for electrical fittings, fixtures and equipment as related to combatant ships. Auxiliary ships, such as oilers, combat stores ships, ammunition ships, tugs, tenders, and ships operated by the Military Sealift Command, may have electric power plant components and systems designed in accordance with commercial marine standards. These standards include Coast Guard Regulations (Code of Federal Regulations, Title 46), American Bureau of Shipping (A.B.S.) Rules, and Institute of Electrical and Electronics Engineers, Inc. (I.E.E.E) Standard No. 45. Utilization of commercial marine design standards for non-combatant ships is beneficial and can result in substantial cost savings as they do not require electric plant components to be built in accordance with the stringent Mil-Spec requirements necessary for combatant ship equipment.

2. POWER GENERATING PLANTS

2.1 Ship Service Power Generation. The ship service power generating plant is the normal source of primary power to the ship's power distribution systems. This is usually supplemented by an emergency power generating plant, which can be either separate or integrated with the ship service plant. The ship service plant consists of the ship service generators and associated auxiliary equipment. For a particular ship service power generating plant design, the following requirements must be determined: the number of generators, the size of the generators (i.e., rating in kilowatts--KW) and the type of generator prime mover (present state-of-the-art includes steam turbines, diesel engines and gas turbines).

a. Load Analysis - Throughout the ship design process a power load analysis is maintained to determine and monitor the total electrical power requirements of the ship under various operating conditions, such as anchor, cruising and battle. It should be understood that the load analysis does not sum connected load for each operating condition, but weighs each load by a load factor which can be in the range of .9 to 0 and takes into consideration the actual load at which the equipment operaters, as opposed to its connected (rated) load, and the intermittent duty cycle of the equipment. Multiplying connected load by the load factor gives the demand load which is summed for all loads in each operating condition. For example, a steering gear control electric motor would have a 0 load factor for anchor condition and possibly a .5 load factor in cruising condition, indicating the .5 of the total connected steering gear control motor load is added to the cruising load summary as a demand load. Obviously, the total connected load for a given ship is usually much larger than actual demand loads. This factoring of connected loads is done so that realistic maximum operating electric power load requirements for the ship can be determined. These loads, in turn, determine the quantity and size of ship service generators required to handle the maximum electrical load under any ship operating condition, with an allowance for future load growth during the life of the ship. In sizing the electrical plant, the calculated maximum electric load plus these design margins are to be met with one generator assumed out-of-service. The remaining generators are not to be loaded in excess of 90% to allow for distribution system load imbalance during parallel operation.

Design Data Sheet DDS310-1 sets forth the method of performing a power load analysis and the General Specifications for Ships of the United States Navy, Section 300, contains the format for a power load analysis report.

b. Generator Prime Movers - The choice of prime movers for ship service generators is based upon a number of considerations, including the type of propulsion plant, arrangement, reliability/availability, vulnerability and life cycle costs. Particular prime mover characteristics must be considered; for example, with diesel driven ship service generators, determination of the number and size of generators must be tempered with the fact that running diesel generators for long periods of time at light loads can lead to excessive diesel engine maintenance.

c. Standard Generator Sizes - For normal maintenance and ease of parallel operations, all ship service generators should be of the same type, design and manufacture for the electric plant on a ship. Standard size generators are preferred over custom design generators because of lower acquisition cost, shorter delivery time and availability of replacement parts.

d. Primary Power Generation - Ship service power generation is 450 volts, 3 phase ungrounded, 60 hertz, AC, at .8 power factor. For a generator of this type, the maximum output rating is 2500 KW due to a maximum design limitation of 4000 amps for present surface craft shipboard generator circuit breakers. The maximum number and size of generators connected in parallel is limited by the limitations of circuit breaker fault current interrupting capabilities.

In recent years, 400 hertz, AC generation and distribution systems have been studied for possible overall systems weight savings when compared with a 60 hertz, AC generation and distribution system. The PHM class patrol hydrofoils utilize a 400 hertz, AC generation plant. The small size of this ship is conducive to utilization of 400 hertz, AC power generation for weight savings. However, the weight savings benefit of a 400 hertz, AC system is off-set by the special design requirements for 400 hertz motors and power consuming components. Direct current power generation at 240 and/or 120 volts DC is no longer used aboard new Navy ships due to its disadvantages when compared to AC generation in terms of weight, utilization of available equipment and inflexibility of conversion to other voltages and frequencies. However, a few DC power systems in older service craft still exist in the fleet.

All ships operate with ungrounded electrical ship service power system to provide maximum continuity of service. Ground potential, the potential of the hull and all attached electrically conductive structures, is intentionally isolated from all current carrying conductors in the ship's generation and power distribution systems. A very high resistance level, although not infinite due to physical realities, is maintained between current carrying conductors and ship's ground. All electrical equipment enclosures, including generator and motor enclosures, are grounded and bonded to ship's structural ground for safety of personnel. If a current carrying conductor should accidentally be connected between a portion of the circuit and the equipment enclosure, the current will follow the low resistance ground path of the enclosure ground connection as opposed to the relatively high resistance path of a person making contact with the enclosure. If the enclosure was ungrounded, the person would provide the only path to ground which could result in serious injury or death.

2.2 Emergency Power Generation. A ship's emergency power generating plant can consist of either generators dedicated to emergency service or dual purpose units capable of operating as ship service or emergency generators. In either case, the emergency generator must be rated at the same voltage and frequency as the ship service generators. Small, limited function ships, such patrol and service craft do not normally require emergency generators. As with ship service generators, the design requirements to be determined for emergency generators are: the number of generators, their rating and type of prime mover. Usually, two dedicated emergency generators are required. However, large ships, such as aircraft carriers, can have up to four emergency generators.

The following loads must be carried by the emergency generators:

a. For cruisers, destroyer types and auxiliaries: emergency ship control load plus either one-half of the ship's ordnance or cold propulsion plant starting loads.

b. For aircraft carriers: emergency ship control load plus limited ship ordnance or limited air operations or cold plant starting loads.

c. For attack types: emergency ship control load plus either limited ship's ordnance and limited logistic unloading or cold propulsion plant starting loads.

The electrical power load analysis includes a summary of loads under emergency conditions.

Generally, the emergency generating plant size is smaller than the total demand load of the connected power distribution system under most operating conditions. Under emergency conditions, vital loads are transferred by means of Automatic Bus Transfer switches from the normal source to the emergency generator once the generator set has started and full voltage is available. Additional loads may then be selectively applied by means of Manual Bus Transfer switches up to the maximum capacity of the emergency generator set.

For ships with dedicated emergency generator sets, the prime mover is usually a diesel engine. A diesel engine provides quick automatic starting (either by means of a storage battery for an electrically started set when the generator is 200 KW or less, or compressed air for a pneumatic starter motor on larger generators) and operates with local fuel supply and self contained auxiliaries.

Recent ship designs, such as the LHA-1, DD-963, and FFG-7 classes, utilize dual purpose generators. The DD-963 class has three Ship Service/Emergency gas turbine generators, any two of which can supply total ship's load with the third generator acting as an automatic emergency stand-by generator. Similarly, the FFG-7 class has four Ship Service, Emergency diesel generators, any three of which can supply total ship's load with the fourth generator acting as an automatic emergency stand-by generator. Ships which have dual purpose Ship Service/Emergency generator sets installed utilize a method of automatic load shedding to reduce the functional load to a level that can be accommodated by one generator set under emergency conditions.

2.3 Battery Power Supplies. Storage batteries supply electric power independent of the ship service and emergency power generation plant to mobile equipment and selected vital systems. Most storage batteries in the Navy system are of the lead-acid or alkaline type. Batteries can supply direct DC power, or can be used to supply power to "no break" solid state power supplies which when ship service power is operating, act as an AC motor-DC generator combination for battery charging purposes. When ship service power is lost or voltage and frequency regulation deviates from acceptable limits, the motor-generator or solid state unit acts as a DC motor-AC generator combination, with the DC motor or DC section being powered by the storage batteries. With increased reliance on solid state electronic ship propulsion and electric plant control circuitry requiring DC logic power, storage battery backup power will be of major importance in maintaining maximum continuity of vital services. Although the storage battery produces electrical power independent of the ship service and emergency power generating plants, the battery is maintained in a proper state of charge by automatic battery chargers.

2.4 Shore Power Facilities. The ship's shore power connection facilities provide the means whereby the ship can take power via shore power cables from a shore installation or another ship. The ship's load power analysis includes a shore operating condition which is used to determine the required capacity of the ship's shore power facilities. The standard method of shore power connection utilizes 400 amp plugs, receptacles and cables in sufficient quantity to meet load demands, with each shore power receptacle and associated cable protected by an individual 400 amp circuit breaker.

2.5 Special Generation Systems. Shipboard electrical power conversion equipment, although not independent sources of electric power, can be considered as special generation systems capable of supplying power in forms different than those generated by the ship service or emergency plant. For example, automatic battery chargers must produce a regulated DC output. Electronics systems, including fire control and NTDS, utilize 400 Hertz power. Motor-generators or solid state frequency changers convert 60 hertz ship service power to 400 hertz power. (Specific types of power conversion equipment are described under the power distribution system section).

2.6 Frequency and Voltage Regulation. Whether power is generated by ship service generators, emergency generators, or supplied from shore power or power conversion equipment, regulation of the voltage and frequency at the power source is very important. Almost every electrical power consuming device is affected by deviations in voltage and frequency. The sudden demand or reduction of large electrical loads will cause transient frequency and voltage disturbances in the power distribution system.

a. Frequency Regulation - Frequency variations do not effect purely resistive electrical loads (e.g., incandescent lamps and electric heaters) but will effect synchronous and induction motors, transformers, control equipment, IC and FC systems and communications equipment. The results can be either equipment overheating with consequent damage or improper equipment operations.

Frequency is a function of generator speed, which is entirely dependent upon the speed of the prime mover. The generator itself has no effect on frequency control. Prime mover speed is a function of (1) the speed-load characteristics, which determine how the prime mover speed will vary as the generator load changes; and (2) the governor type.

Two types of governing systems are used on Navy generators; the speed governing system and the speed-load governing system.

Basically, the speed governing system senses a power differential between the prime mover input and generator output when there is a speed change and restores the prime mover/generator to its initial speed. This is termed isochronous governor operation, since the speed is kept constant while the electrical load on the generator varies. With the speed governing system, the particular prime mover speed-load characteristics are very important, especially for parallel operation. The speed load governing system senses both speed changes, as with the speed governing system, and electrical load changes. The advantage in sensing load changes is that the governor can compensate for the load change, which causes a speed change, before the speed change occurs. This results in reduced speed deviations greater than those which would be obtained with speed sensing along. The speed-load governing system can operate as a speed droop governor or, in the isochronous mode, as a "slave" unit to a similar unit which is acting as a "master". Operating as a speed droop governor, dissimilar type governor systems may be connected in parallel; however, the droop setting must be similar. As a speed droop governor, engine speed will be a function of governor speed setting and speed droop setting. Operating as an isochronous "slave" unit, all governors operate as a single system and the real load will be shared proportionately by all generators.

b. Motor Generator Frequency Control - Two types of 60/400 Hertz motor-generator sets are available for shipboard use: voltage regulated only and voltage and frequency regulated. If only the motor-generator output voltage is regulated, the unregulated output frequency will depend upon the speed of the electric induction motor drive. At full load output, the speed droop is limited to a maximum of two percent of synchronous speed or a minimum output frequency of 392 Hertz on the usual 1200 rpm motor. Therefore it follows that the output frequency will be higher for loads less than full load. The no load output frequency will be close to 400 Hertz. (Due to the inherent slip in an induction motor operating at no load, the synchronous speed will not be attained).

Where the motor generator set is used to supply user equipments requiring very precise frequency regulation, a solid state frequency regulator is provided in addition to the voltage regulator. The output frequency is continuously monitored and the motor speed is automatically increased or decreased by the regulator control circuitry to maintain an output frequency of 400 Hertz ± 0.5%.

c. Voltage Regulation - Variations in voltage levels from those at which electrical equipment items are designed to operate will affect all equipment to some degree. Additionally, unbalance in phase voltages to three phase motors will produce an unbalance in phase currents with resultant overheating. The major shipboard voltage regulation problem is transient voltage fluctuations in the electrical system caused by the starting of large induction motors. This condition can be controlled by means of reduced voltage motor starting.

System voltage regulation is affected by the generator and excitation electrical characteristics and the voltage drop in feeder circuits. Generator characteristics (which include sub-transient reactance, transient reactance, negative sequence impedance and short circuit ratio) and generator excitation are considered during the design process to some extent to provide for more stable voltage regulation. Except for lighting circuits, current carrying capacity generally determines the cable size to be used. Since most cable runs aboard ship are relatively short, voltage drop factors are normally below critical levels. Voltage drop calculations are made in accordance with Design Data Sheet DDS304-1.

Generator output voltage is a function of the magnitude of the field current supplied to the generator field winding. The field current is also known as the excitation current and the circuit used to produce this current is called the excitation circuit. In an AC generator DC field current can be supplied by one of the three methods:

- o By means of an excitation generator driven by the AC generator shaft, with its output current supplied to the field winding located on the rotor of the generator by sliprings and brushes.
- o By means of controlled rectifiers connected to the AC generator output terminals, with rectified current supplied to the field winding located on the rotor of the generator by sliprings and brushes.
- o By means of an AC rotating armature type exciter located at one end of the generator rotor, with its output current rectified to DC by semiconductor devices and supplied to the field winding. This method does not require sliprings and brushes, since the exciter and field winding are located on the rotor of the generator.

The magnetic field, set up by the DC field current and caused to rotate by the prime mover, induces the generator output current in the armature winding (which is located in the stator, or stationary winding) of the generator. The magnitude of the field current determines the magnitude of the generator output voltage. Consequently, generator output voltage regulation depends upon control of the generator field current.

There are two types of automatic voltage regulators used with Navy generators: the rotary amplifier type and combined static exciter and voltage regulator system. The rotary amplifier type consists of a specially designed exciter having a number of control fields with a high ratio of amplification excited from a static control element. This control element is energized from the AC generator output voltage. The most common type of shipboard voltage regulator system is the combined static exciter and voltage regulator. In this type of voltage regulation system, the excitation current is controlled by an amplifier which corrects, for generator output, voltage deviations when detected by auxiliary circuits.

d. Electrical Power System Characteristics - As explained above, voltage and frequency can be regulated. One must then determine the degree of regulation required. Certain electronic equipment items, such as, radar power supplies, require a high degree of steady state and transient voltage and frequency regulation, while normal ship service power requirements are not so stringent. Consequently, a hierarchy of types of shipboard power quality requirements has been established and is set forth in DOD-STD-1399, Section 300. Briefly, there are three types of power designated I, II, and III. Steady state and transient voltage and frequency regulation requirements become more stringent from Type I to Type III. (Type I power is applicable to 60 hertz only; Types II and III apply to 400 hertz). Ship service and emergency power is normally Type I power: Type II and Type III power can be obtained by motor-generator sets and static converters.

2.7 Parallel Operation of Ship Service Generators. Ship service generators can be operated independently with each generator serving different groups of electrical loads, or with generators in machinery plants separated from each other. This mode of operation is called "split plant" and is normally used during battle conditions to avoid cascading failures of the entire electric plant. Ship service generators may also be operated in the parallel mode. In this mode, two or more ship service generators may be connected together, electrically. The number of generators which can be connected together in parallel is limited to a maximum total output of approximately 7500 KW at 450 volts, .8 power factor, due to present maximum fault current protection design limitations. The advantage of parallel operation is that the ship's electrical plant can be operated as a large KW combined plant which provides greater system stability and convenient electric plant operation with centralized control. The latest designs of electronic governors and current differential voltage regulators allow the governor and voltage regulator control circuits on each generator to be connected in parallel with those on other generators for maximum system stability. Split plant mode can be utilized in battle conditions to decrease the possibility of a single hit incapacitating, at least temporarily, the entire electric plant. Ships with central electric plant control can be configured to automatically change from parallel to split plant mode if an electrical casualty should occur.

a. <u>Synchronization of Generators</u> - Before generators can be paralleled, they must be synchronized. Synchronization means that all generators must have:

- o The same electrical phase rotation sequence (normally the sequence A, B, C), and phase angle
- o The same voltage
- o The same frequency

Without meeting these conditions before paralleling generators, maloperation and possible damage to the generators and/or prime movers may occur.

In order to assist in the paralleling of generators, synchronization lamps and/or a synchroscope are provided at switchboard control locations where parallel operation can be accomplished. The synchronization lamps indicate when the generators are in synchronization by their degree of brightness. Synchroscopes, although they do not show relative phase rotation, are more accurate and easier to use than lamps in paralleling generators, since they utilize a pointer whose speed and direction indicates whether the machine to be brought on the line is running faster, slower, or approximately the same as the machine already on the line. All new ships have a synchronizing monitor system which automatically senses whether the generators are close enough in synchronization for safe paralleling and will prevent the closing of the incoming source circuit breaker when safe limits are exceeded.

b. Load Division - Once generators have been paralleled, the division of load between the generators is important. Division of real power load (KW) and system stability is a function of only frequency regulation, and frequency regulation is determined by the prime mover's governor type. As discussed under governing systems, a speedload governor operating in the droop mode (i.e., decreasing speed with increasing load) will allow adjustable real load sharing. In the governor isochronous mode, all generators will automatically share the load proportionately. Reactive power load, which is the component of electrical power providing magnetizing current, but no useful energy is identified as Kilo Volt Amperes Reactive (KVAR) and is shared between generators according to the real power division relative excitation voltages, the electrical characteristics (reactance) of the generators, and the power factors of the loads. Large amounts of unbalanced reactive power can cause excessive heating and consequential damage to electrical equipment. The generator line currents can be adjusted by means of the generator voltage regulators adjusting rheostats to balance the reactive load. Differential cross current compensated voltage regulators whose sensing circuits are connected in parallel when the generator sets are operating in parallel provide automatic reactive load sharing in the latest design of ships.

3. POWER DISTRIBUTION SYSTEMS

3.1 Introduction. Ship's power distribution systems can be functionally classified by the following types: ship service, emergency, casualty and special. Unlike industrial and commercial design standards, which allow grounded neutral electrical distribution systems for general application, Navy design standards require all electrical distribution systems to be ungrounded. Some electrical equipment, particularly electronic digital equipments, require a common ground reference. In such instances, electrical power to the grounded equipment must be electrically isolated from the ship's power distribution systems. This is most commonly accomplished by means of a transformer or a motor generator set located in the electrical line between the equipment to be grounded and ship's power distribution system. Ungrounded power distribution systems are advantageous in that no service interruption is caused by a single ground condition, as might be incurred in a battle situation, since there is no ground return path for fault currents which would trip circuit breakers or blow fuses. Since single conductor grounds cannot be detected in an ungrounded distribution system be a tripped circuit breaker, ground detection lamps are provided on 450 volt, 60 hertz ship service and emergency switchboards and, generally, at the initial point of distribution on 120 volt lighting systems and 400 hertz power systems. A vital aspect of electric plant maintenance is to regularly check the ground detection lamps and insure that systems are kept free of grounds. Grounded and ungrounded electrical systems should not be confused with grounding of electrical and electronic equipment enclosures for the protection of personnel from electrical shock hazards. MIL-STD-1310 sets forth the method for grounding of shipboard electrical equipment and cable.

a. <u>Radial and Zonal Distribution</u> - Physically, a ship's electrical power distribution system can be identified as one of two types, radial or zonal. Radial distribution, the standard shipboard method of power distribution, starts at the generator switchboard with feeder cables supplying power and lighting distribution panels and individual loads. A zonal distribution plan, a modification of radial distribution, divides the ship into zones, using main subdivision bulkheads as boundaries. Each zone contains one or more load center switchboards which feed power panels and individual loads within the zone. Conceptually, with zonal distribution, the generator switchboard bus is extended via bus feeders to the load center switchboards. A combined radial/zonal system may be encountered on a single ship. For example, the DD-963 class utilizes a zonal 60 Hertz power distribution systems with a radial 400 Hertz power distribution system. In later ship designs of both the radial and zonal configurations, ship service switchboards may be electrically interconnected by bus-tie circuits in a "ring bus" (closed loop) configuration, where all generators are connected, electrically, in a ring arrangement by bus-tie circuit breakers and cables in order to provide maximum flexibility in operation of the ship's electric plant.

b. <u>LHA-1, DD-963, and FFG-7 Switchboard Arrangements</u> - Figure (1) illustrates the arrangement of ship service and emergency switchboards for the LHA-1 class. Each ship service switchboard consists of a generator section and a bus-tie and distribution section. Each emergency switchboard consists of a generator section and two distribution sections. In parallel configuration, three of the four 2500 KW ship service turbine generators will supply total load in all operating conditions except battle. In split plant configuration, the two forward ship service turbine generators are connected in parallel to supply forward electrical loads. The two aft ship service turbine generators are connected in parallel to supply aft electrical loads, with no bus-tie connection between the forward and aft plants. In both parallel and split plant configurations, the two 2000 KW, ship service/emergency diesel generators are in automatic standby mode. These two diesel generators can be paralleled automatically with the ship service turbine generators. By means of the bus-tie connection, shore power can be distributed through the forward and aft distribution sections.

Figure (2) illustrates the arrangement of ship service/emergency switchboards with a typical distribution scheme for the DD-963 class. Each ship service/emergency switchboard consists of a generator section and two distribution and bus-tie sections. The three, 2000 KW, ship service/emergency gas turbine generators are arranged in a ring bus configuration. Two of the three generators can supply total load in all operating conditions. By means of bus-tie connections, shore power can be distributed through the three switchboards.

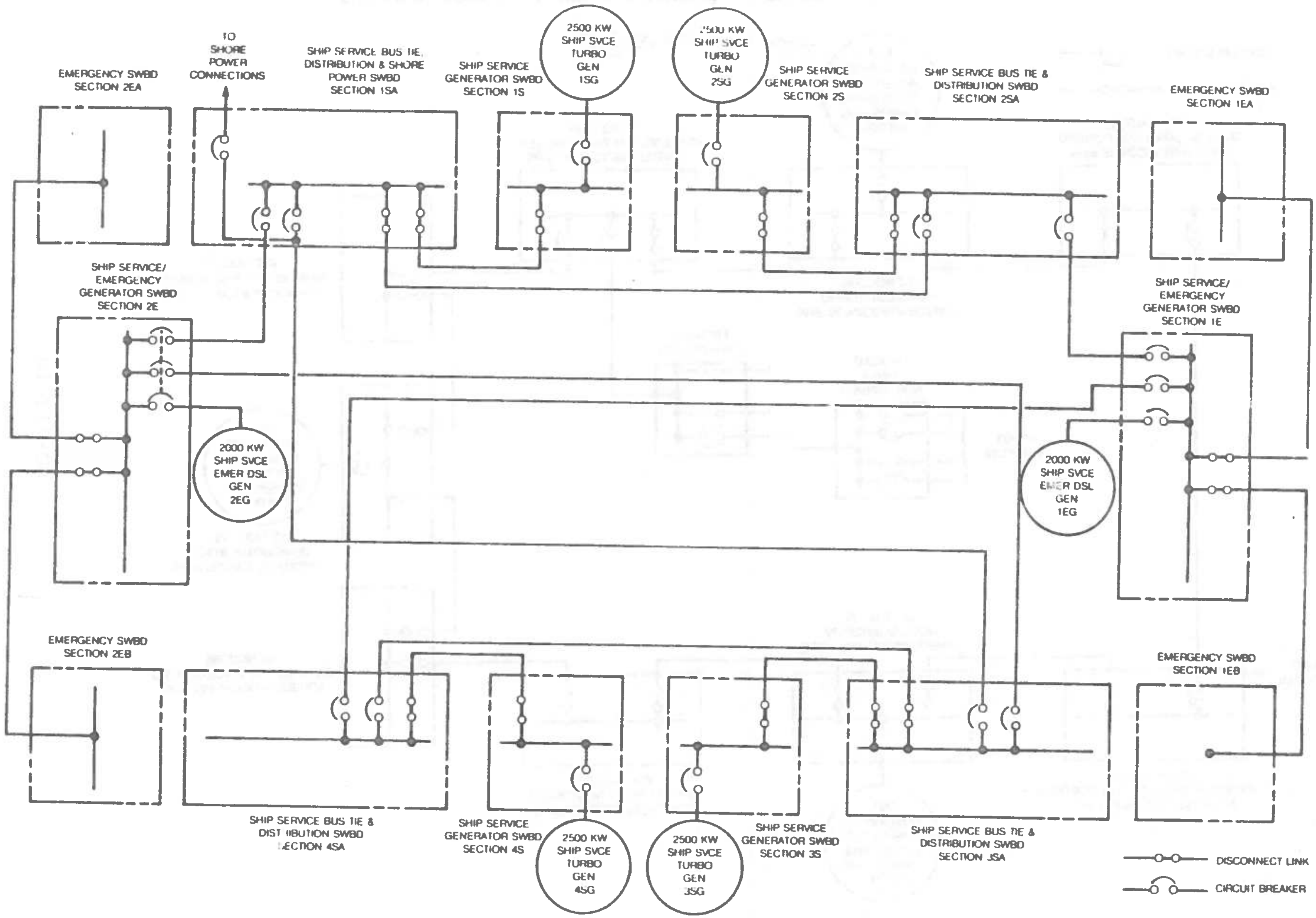

FIGURE 1. LHA-1 SHIP SERVICE AND EMERGENCY SWITCHBOARDS WITH BUS TIE CONNECTIONS

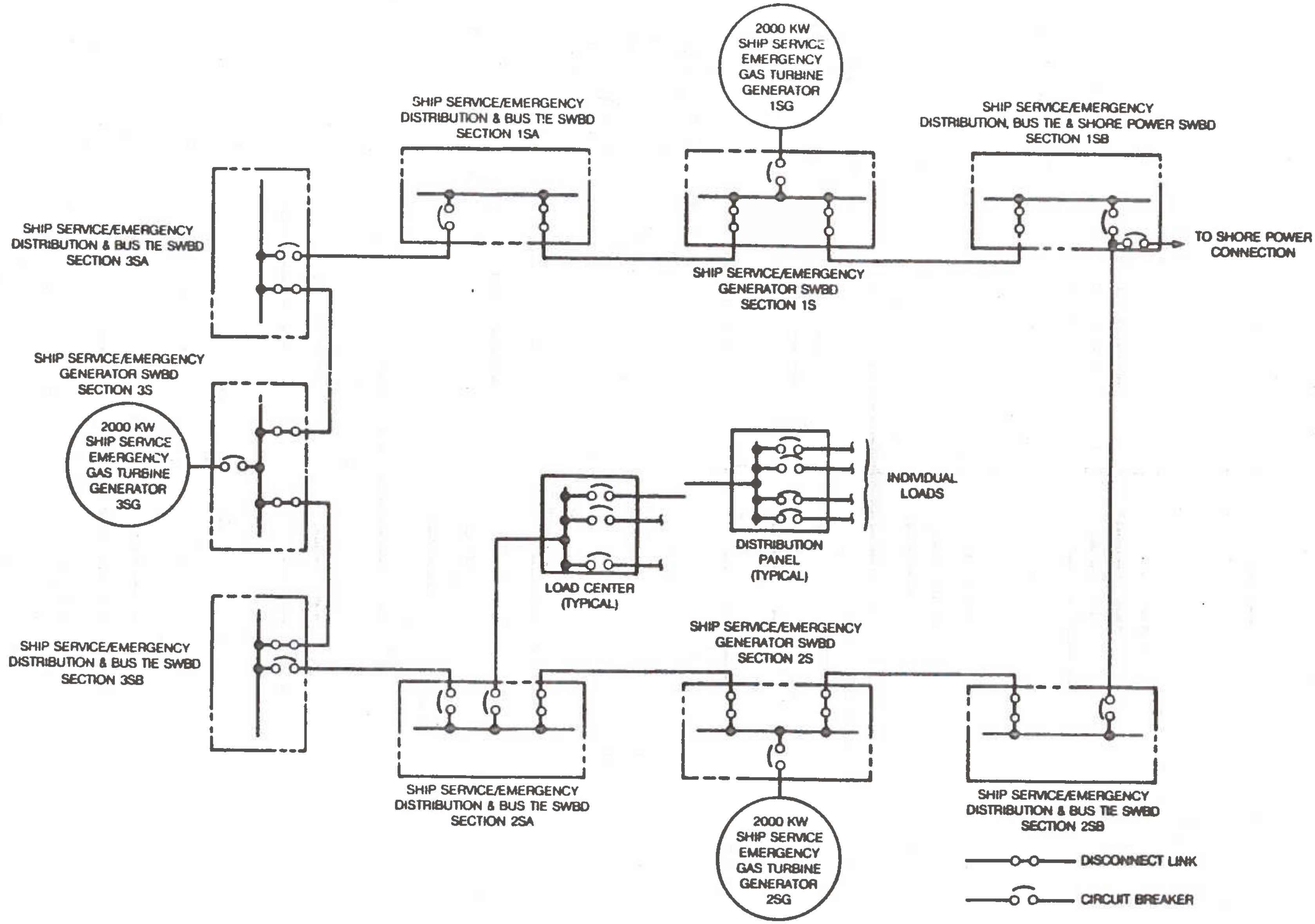

FIGURE 2. DD-963 SHIP SERVICE/EMERGENCY SWITCHBOARDS WITH BUS TIE CONNECTIONS AND TYPICAL DISTRIBUTION SCHEME

Figure (3) illustrates the arrangement of ship service/emergency switchboards for the FFG-7 class. Each ship service/emergency switchboard consists of a generator and bus-tie section and distribution section. The distribution sections contain two separate buses connected together by cable and a "bus unloader" circuit breaker which automatically opens to shed non-vital loads in emergency situations when the maximum capacity of the electric plant is not available. The four, 1000 KW, ship service/emergency diesel generators are arranged in a ring bus configuration. Three of the four generators can supply total load under all operating conditions. Shore power can be connected through one of the ship service/emergency switchboards.

c. Vital and Non-Vital Loads - Certain vital loads require two sources of power supplied by independent cable runs and transferable through bus transfer switches. One supply is designated "normal" and the other is designated "alternate". Bus transfer equipment can operate either automatically or manually. Section 320 of General Specifications for Ships of the United States Navy sets forth the requirements for automatic or manual bus transfer equipment for a particular application. Vital loads include those equipment items whose operation is essential to the military effectiveness of the ship (e.g., guns, steering gear, engine room auxiliaries, lighting, IC and radar). Non-vital loads require only one source of electrical power and include galleys, shops, laundries and certain deck machinery. All loads associated with a common function, or closely related to that function, should be supplied from the same distribution panel. The functional separation and redundancy provided by utilization of normal and alternate sources of power supplied from feeder cables segregated by routing along different decks, port, and starboard are the major design methods by which maximum continuity of service is achieved.

d. Designation and Marking - Designation and marking of electrical equipment and cable is important for proper identification for

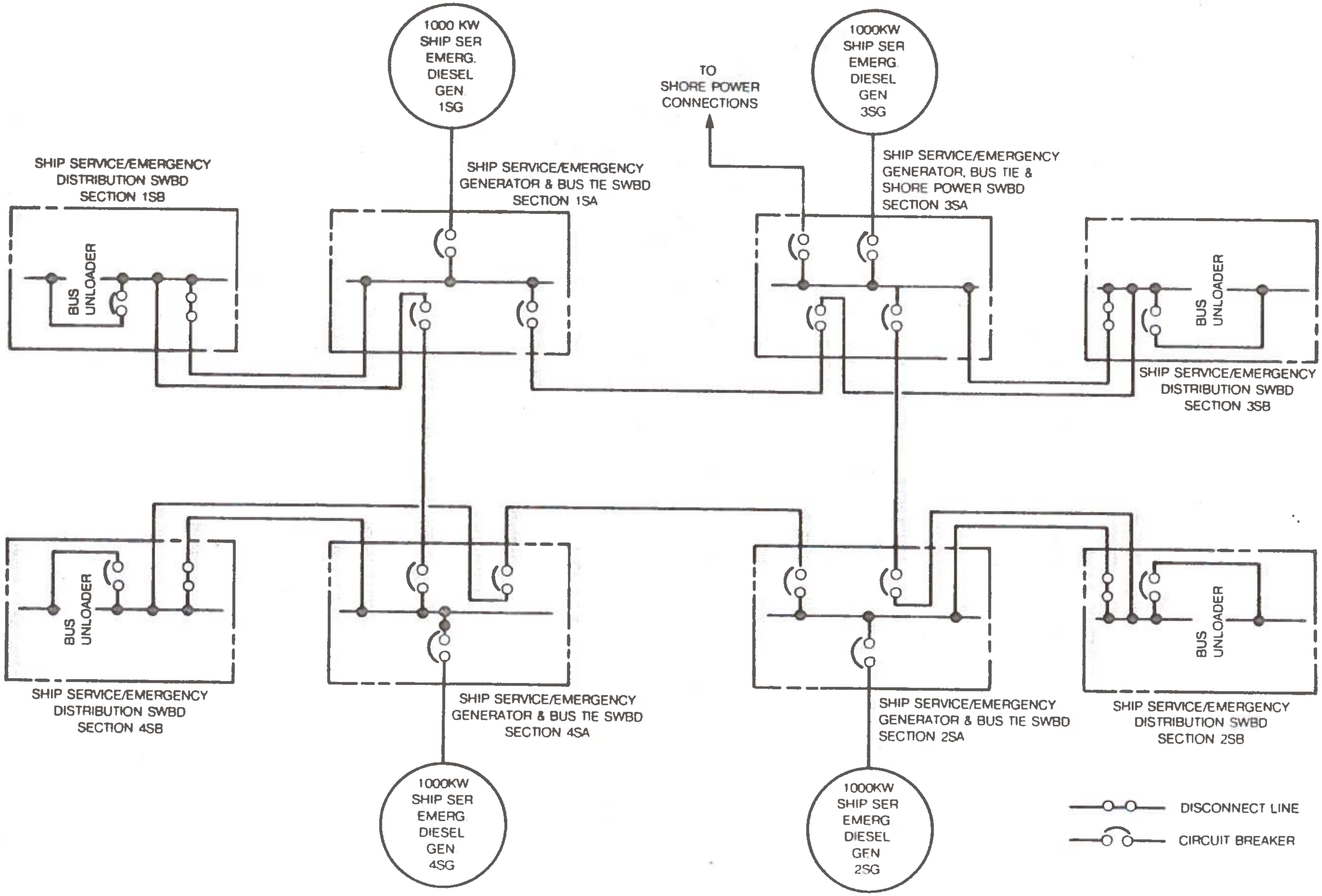

FIGURE 3. FFG-7 SHIP SERVICE/EMERGENCY SWITCHBOARDS WITH BUS TIE CONNECTIONS

maintenance and, particularly, to assist in damage control work. Section 305 of General Specifications for Ships of the United States Navy sets forth the basic rules to be followed in designating and marking electrical equipment and cable.

e. Drawings - The following types of drawings are usually produced for a ship's power system:

- Elementary (one line) wiring diagram of the power system indicating the type and size of generators; type and size of generator cables; bus-tie cables; bus feeder and feeder cables; and branch circuit cables; type and size of power panels showing number of circuits and rating of energy consuming devices, ci cuit breakers and switches. The rating or setting of overcurrent devices is also included.
- Isometric wiring diagram of ship service and emergency power systems which indicate location of equipment and routing of cable to power panels and loads fed directly from switchboards.
- Isometric wiring diagram of the casualty power system indicating permanently installed equipment.
- Wiring deck drawings indicating all wiring from the power panels to the loads.
- List of feeders and mains which includes cable data sufficient to demonstrate correct sizing of cable; data to indicate that specified limits of transient voltage dip during large motor starting has not been exceeded; and data to indicate type and rating of circuit protective devices.
- List of motors and controllers.
- The power load analysis, as described in Section 2.
- The fault current analysis, as described in Section 5, and voltage drop calculations, as described in Section 2.
- Application and coordination of protective devices as described in Section 5.
- Schematic diagrams and instrumentation wiring of switchboards.

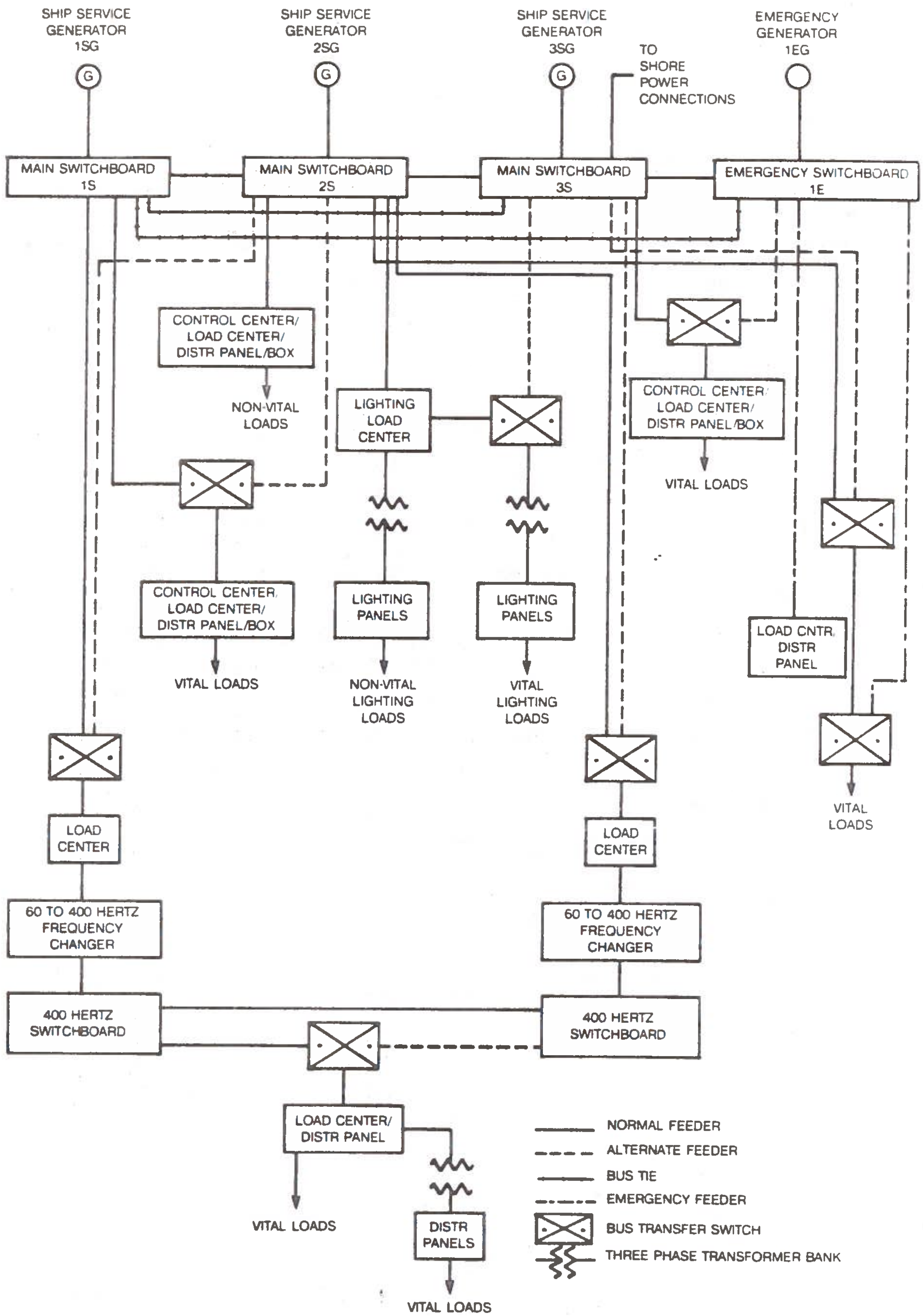

FIGURE 4. TYPICAL SHIP'S ELECTRICAL DISTRIBUTION SYSTEMS

3.2 Ship Service Power Distribution System. Figure (4) illustrates the typical electrical interconnections which can be made in a ship's power distribution system. The degree of complexity of a specific system is dependent upon the size of the ship. Generally, the overall "flow" of electrical power is from the ship service generators to ship service switchboards which may have bus feeder or feeder cables to:

a. Load centers (switchboard or panel types) which can feed large individual loads such as 400 hertz frequency converters, distribution panels, or lighting transformers.

b. Control center switchboards which usually feed large auxiliary motors and groups of functio·ally related motors.

c. Distribution panels which feed individual loads.

d. Lighting transformer banks which feed lighting load centers, distribution panels and boxes.

e. Large or vital individual loads such as steering gear motors.

The end item power consuming loads are of a wide variety, and include rotary (electric motor) loads; pulsed radar and sonar motor-generator sets; resistive loads including heaters and incandescent lights; electronics loads, and flourescent lighting. Proper interfacing of these various load types with the ship's power distribution system is governed by DOD STD-1399, Section 300. The loads must not cause system disturbances in excess of established allowances.

f. Cable - Providing the connection between all of the components of the electrical system is electrical shipboard cable. Cable application, selection installation and testing is covered in Section 304 of General Specifications for Ships of the United States Navy. Design Data Sheet DDS304-2 should be used in determining the proper size cable based upon capacity. Normally, for power cables, current capacity determines the size of the proper cable. For lighting events, maximum tolerable voltage drop usually determines the proper size of cable. A cable Comparison Guide, published by NAVSEA provides a condensed tabulation of all electric shipboard cable characteristics, with the exception of coaxial type cable which is used in high radio frequency energy transmission. Proper selection of the correct size and type of electric cable for a given application is prerequisite to attaining maximum efficiency in the distribution of electrical power. While an incorrectly selected cable may provide nominal service under most conditions, fire hazards and major circuit interruptions may be encountered over a period of time. Normally, a continuous section of cable should be routed directly from one electrical component to another. However, cable splicing may be considered advantageous where extensive lengths of cable must be installed. Also if installed cable is damaged or must be relocated, splicing may be the only alternative. Splicing creates a problem in terms of maintaining a high quality electrical connection at the splice. Consequently, no more than two splices are permitted in a cable run. Cable splicing may only be accomplished in accordance with NAVSEA Standard Methods Drawing No. 803-5001027. Certain types of cable such as coaxial, antenna system, repeated flexing service, cables run in voids, and normally inaccessible spaces, <u>should not be spliced</u>. Section 304 of General Specifications for Ships of the United States Navy and Navy Ships' Technical Manual, NAVSEA 59086-KC-STM-000, Chapter 300, set forth the full criteria for cable splicing. Measurement of cable insulation resistance (electrical resistance measured between cable conductors and ship's ground) provides the primary means of detecting a defective cable.

g. <u>Ship Service Switchboards</u> - Ship Service Switchboards accomplish the following functions: (1) control, operation and protection of local ship service generators; (2) control and operation of remote generators; (3) parallel operation of ship service generators; (4) control and protection through appropriate circuit breakers of the electric power distribution system. Ship service switchboard design requirements are set forth in MIL-S-16036. Physically, a ship service switchboard is composed of one or more switchgear units as described in MIL-S-16036. Ship service switchboards are of a "dead-front" design which means that all energized parts are within the switchboard enclosure. Standardized switchgear units are provided for AC generator control, bus-tie connection, shore power connection, and ship service electrical power distribution. The switchgear units required for a particular configuration can be assembled to form a switchgear group. Each switchgear unit has a main bus, which provides a convenient means of making electrical connections. Feeder cables are connected through circuit breakers to the bus in the distribution units of the switchboards. Where the ship's power generating plant is controlled from a central location, as on a cruiser or aircraft carrier, an Electric Plant Control Panel (EPCP), separate from the switchgear group, is installed. The EPCP provides the necessary instruments and controls for (1) centralized operation; (2) monitoring and control of the electric plant including the generator, bus-tie and feeder circuits (including battery operated circuits on submarines). Where no EPCP is provided, a master control switchboard is designated which contains the bus-tie and remote generator(s) control. In recent designs, for example the LHA-1, DD-963 and FFG-7, an Electric Plant Control Console is situated in a Central Control Station which provides centralized remote control of the electric and propulsion plants (see Section 4).

h. <u>Lighting Distribution</u> - The ship's lighting distribution system, basically a subsidiary of the ship service and emergency power systems, provides power for ship service illumination and furnishes power to small appliances and service outlets of the same voltage and frequency. Lighting feeders can be three phase, either 450 or 120 volts. Only on small vessels will primary power distribution be at 120 volts thus requiring lighting transformers to be utilized in transforming primary ship service power (usually at 450 volts) to 120 volts. Lighting distribution panels are energized from three phase feeders connected to 450/120 volt transformers installed in the vicinity of the distribution panel, or from three phase, 120 volt buses established in the lighting load centers. From the lighting distribution panels, single phase circuits supply lighting fixtures and 115 volt equipment. Ship's lighting can be functionally classified as follows: general, detail, special purpose and low level illumination. General illumination is white illumination provided by all lighting fixtures on the overhead and bulk-heads except detail lighting fixtures. Detail illumination is provided for specific seeing tasks, such as lights on desks, log desks and machine tools. Special purpose illumination includes navigation lights, task lights, helicopter visual landing aids, VERTREP platform visual landing aids and lights associated with night flight operations on aircraft carriers. Low level illumination includes broad band blue illumination provided in spaces normally operated in darkened condition such as CIC and similar Command and Control spaces containing cathode ray tube display consoles. Low level red illumination is provided for standing lights in berthing areas and passageways allowing minimum interface with dark-adapted vision and certain other applications involving darkened ship operation. Battery powered relay lanterns, operated by automatic relays, provide a dependable self-contained source of light to permit carrying out emergency measures when other means of lighting are not operable and instantaneous illumination is essential. Upon failure of the lighting in a compartment, where lanterns are installed, relays in the lanterns automatically energize these lights. Supplementing the relay operated lanterns are manually operated lanterns. Naval Ships' Technical Manual NAVSEA 0901-LP-330-000 contains general information regarding the proper operating and maintenance procedures for lighting installations.

3.3 Emergency Power Distribution System. Supplementing the ship service power distribution system is the emergency power distribution system which provides a source of electric power to a limited number of selected vital functions (including ship control, ordinance and cold propulsion plant start) in the event of failure of the normal system supply. Section 320 of General Specifications for Ships of the United States Navy establishes priority categories for loads receiving emergency power. The emergency power generation plant can also provide power through "feedback" bus-ties to the ship service power system to operate necessary auxiliaries during repair periods when shore power and ship service power are not available and to provide power to start up a cold propulsion plant. Certain loads, such as auxiliaries and ventilations associated with the emergency generator, fire pumps and fire extinguishing auxiliaries located in the same watertight subdivision, can be connected to the emergency switchboard and supplied under normal conditions from ship service power. Thus, the emergency switchboard can be utilized as a ship service load center.

The emergency power system can be either separate and distinct from the ship service power system or may be integrated. With a separate emergency power system, each emergency switchboard is supplied by its associated emergency generator. Feeders from the emergency switchboard and those from a ship service switchboard (or load center) supply bus transfer switches which, in turn, supply electrical power to vital loads. If all sources of ship service power fail, the emergency generator set starts automatically, usually within 10 seconds after the power failure. Automatic bus transfer switches will transfer vital loads to the emergency supply feeders. Manual bus transfer switches must be operated to transfer additional loads to the emergency supply. All automatic bus transfer switches do not instantaneously transfer from one source to another. A time delay is introduced in some units to allow running motors a chance to slow down, thus reducing EMF. Upon restoration of ship service power, automatic retransfer of vital loads to ship service power will occur. It will then be necessary to manually shutdown the emergency generator.

On new ships with diesel driven ship service generators (e.g., FFG-7) and gas turbine driven ship service generators (e.g., DD-963), the need for a separate emergency generator does not exist since gas turbines and diesel engines are powered by local fuel sources, are quick starting and not dependent upon a remotely located boiler, as with a steam turbine plant. Consequently, each gas turbine or diesel driven generator can be considered an emergency generator when set up in the standby mode while the other ship service generators carry the load. This concept of "dual purpose" (ship service/emergency) generators requires a design where maximum functional ship service load plus growth load can be carried by all but one of the dual purpose generators. The generator not being utilized then becomes the emergency standby generator. This type of emergency system is integrated into the ship service system which maintains a high degree of power distribution reliability while weight and space savings are realized.

3.4 Casualty Power Distribution System. The casualty power distribution system is provided for the purpose of bridging damaged sections of the ship service and emergency systems in order to re-energize designated vital electrical functions so that the ship can survive severe damaged and leave the battle zone. The casualty power distribution system components are:

a. Casualty power terminals and circuit breakers located on ship service and emergency switchboards.

b. Through bulkhead and through-deck terminals, which maintain water tight integrity.

c. Permanently installed riser cables.

d. Portable cables located throughout the ship.

e. Terminals mounted on or near vital equipment (lighting transformers, vital power panels, electronic equipment, fire pumps, etc.) and connected in parallel with the normal feeder for the equipment.

Portable cables are connected, as required, between various bulkhead casualty power terminals and those on switchboards and vital loads.

3.5 Special Power Distribution Systems - Power Conversion Equipment. Special power distribution systems supply electrical power from the ship service and emergency power systems, through power conversion equipment, to equipment items having voltage, frequency and regulation characteristics not directly obtainable from the ship service system.

a. 400 Hertz Power Distribution - The most common of the special power systems is the 440 volt, 3 phase, 400 Hertz system. This system is used for:

- o Electronics
- o Combat systems equipment

208/120 volt, 400 Hertz AC grounded power is utilized for:

- o Fixed wing and rotary aircraft testing and servicing
- o Aviation equipment testing and maintenance

Some Navy ships utilize rotary (motor-generator) frequency changers. The trend has been from individual motor-generators dedicated to specific equipment to motor-generators supplying 400 Hertz power to a distribution system feeding most 400 Hertz equipment. Advances in solid state design have made 400 Hertz static frequency changers more feasible and desirable. Basically, a static frequency changer steps down, rectifies and inverts, by means of Silicon Controlled Rectifiers (SRC's), ship service power to special frequency power. Static frequency changers were first utilized on Navy ships as dedicated 400 Hertz power sources for specific equipments. All new ship designs will utilize static frequency changers as the supply source to a 400 Hertz power distribution system.

Depending upon the capacity required for a specific ship, the 400 Hertz distribution system can consist of switchboards, distribution panels (with or without bus transfer switches), and transformers used to supply 400 Hertz power at voltages different from the primary converted voltage. The number and type of frequency changers is based upon the system load power analysis, including standby and reserve capacity. For frequency changers serving a dedicated load, the individual connected load usually determines the size of the frequency changer.

a. Direct Current Power Supply - DC power is normally supplied from AC ship service or emergency power systems by AC to DC rectifier power supplies local to the DC equipment. DC power supplies are considered to be dedicated sources. AC Ship Service or emergency power also supply power to battery chargers which are used to recharge or maintain a charge on storage batteries. Providing local AC to DC rectifiers is more feasible, due to engineering and cost considerations, than a centralized DC power distribution system. AC to DC rectification, as with 60 to 400 Hertz frequency conversion, can be accomplished by means of a rotary (motor generator) or static (solid state rectifier). AC to DC motor generator sets are in common use as portable arc welding and degaussing system power supplies. However, the trend, as with 400 Hertz frequency changers, has been toward solid state AC to DC rectifiers. Rectification of AC ship service power to DC power requires less complex circuitry than that required for frequency changers. Other major DC equipments include searchlights, battery chargers, low voltage DC (28.5 volt) aircraft servicing and testing equipment, and IC and FC switchboard.

b. Transformers - Transformers are utilized to convert primary AC ships service power to AC voltages different from that at which ship service power is generated. Ship service lighting transformers supply 120 volt power loads except for electronic, interior communication and ordnance, which must be supplied by their own system transformers. Normally, three phase transformer banks, consisting of three single phase transformers connected in a configuration known as "closed delta" are utilized. Connected in delta configuration, if one transformer in the three phase bank is damaged, the remaining two transformers may be reconnected to supply power at reduced capacity.

c. Line Voltage Regulators - Line voltage regulators supply closely regulated steady state voltage from power systems whose steady state characteristics do not meet the requirements of the end use equipment. LVR's do not improve transient performance.

4. ELECTRIC PLANT CONTROL

Most Navy ships rely primarily upon local or remote manual electric plant control and monitoring which is most commonly accomplished at the ship service switchboards. Larger ships, such as aircraft carriers and cruisers, have remote manual electric plant control which is accomplished at an Electric Plant Control Panel (EPCP), usually located in an enclosed operator's control station. Electric plant control and monitoring functions which are of primary importance or would require excessive attention of the operator, such as frequency and voltage regulation, load sharing between generators and emergency power generation system operation, have been automated for some time. However, functions such as synchronization and paralleling of generators, operation of ship service generators to meet current system load conditions in an efficient manner, monitoring of system parameters and data logging requires manual operation. Automatic electric plant protection has been generally limited to circuit breaker short circuit and overload protection, reverse power protection for paralleled generators, and overspeed trip for generator prime movers. Many new ship designs incorporate centralized, automatic electric plant control along with propulsion plant control auxiliaries control and damage control which is usually accomplished from a Central Control Station. This configuration allows operation of the ship service electric plant without the need for a continuous watchstander under ship cruising conditions. The Electric Plant Control Console (EPCC), at which centralized electric plant control is accomplished, not only provides for manual control and monitoring functions available at an EPCP, but also enables the operator to remotely start and stop the generator prime movers (except for ships with steam turbine driven generators) and parallel generators automatically. Automatic supervisory control is provided to protect the electric plant against voltage and frequency deviations, real and reactive load unbalances and real load oscillations. The system automatically monitors the plant and provides corrective actions suited to the type of malfunction and the configuration of the plant. A large number of electric plant system parameters are monitored and data automatically logged. The EPCC provides a much more effective monitoring and decision making system than that provided by a single watchstander, which should reduce power interruptions caused by operator error or indecision. With automatic monitoring and control of the electric plant system, the maximum fault current interrupting capacity of circuit protective devices is the major limiting factor of the number of generators which can be operated in parallel simultaneously.

Automatic electric plant control for combatant ships has introduced major design emphasis on alarm and control circuitry. Alarm and control systems' components must be designed to meet the combat environment, particularly shock and vibration. Malfunctioning of the alarm or control circuitry generated by a spurious signal response or electro-magnetic interference in a combat environment could cause a false shutdown or maloperation of the electric plant which could severely cripple a ship's performance in a critical moment. Utilization of electronic signals for automatic electric plant control requires that there be maximum continuity of control system power. This has been achieved by means of a centralized Uninterruptible Power Supply (UPS) which supplies control power of the EPCC and local control stations at each ship service switchboard during remote control operations and localized emergency battery power supplied at each ship service switchboard for independent local operations.

5. ELECTRIC PLANT PROTECTION

Electric plant protection includes fault current protection, thermal overload protection, voltage and/or frequency deviation protection and generator reverse power protection. Providing electric plant fault current protection requires major consideration in the final stages of the ship design process. Once the ship's power generation and distribution systems have been finalized, a fault current analysis of the systems can be made. Basically, a "fault" is an unintentional electrical connection in a power system which causes excessive short circuit current to flow through the fault connection. A fault can be of high impedance type, with relatively small fault current flow, or low impedance type with relatively high current flow. As explained in Section 3, one ground fault in an ungrounded system will not cause abnormal system operation. Multiple ground faults, or phase to phase faults, can result in damage to an ungrounded power system. If the fault is not "cleared" by a protective device in sufficient time, the reduced power system voltage caused by the fault will cause motor damage; excessive loss of loads shutdown by low voltage protected controllers' generators will be damaged by the excessive current demand caused by the fault; fire hazards are created by excessive heating of electrical cable and bus work, and arcing at the location of the fault connection.

The maximum available fault current in any power system is a function of the generator electrical design characteristics and the connected motor loads. While a generator can be designed for minimum system fault currents, other system parameters, such as generator voltage transient response, may be adversely affected.

5.1 Fault Current Analysis. A fault current analysis is conducted to determine fault (short circuit) current magnitudes for selected points in a power system. These fault current magnitudes will provide the necessary information for the selection of proper protective devices and their settings. Design Data Sheets DDS300-2 (AC Fault Current Calculations) and DDS300-1 (Fault Current Calculations for DC Systems) set forth recommended methods of calculating fault currents.

5.2 Circuit Breakers. The most common shipboard protective device for fault current protection applications is the air circuit breaker with inverse time delay overcurrent protection. This provides for fast tripping time for large values of overcurrent (short time delay protective feature), and slow tripping time for smaller values of overcurrent (long time delay protective feature). A circuit breaker, depending upon its particular type and application, can have long or short time delay and instantaneous trip protective features. Inverse time delay protection is normally accomplished by magnetic devices.

a. <u>Circuit Breaker Types</u> - Common types of circuit breakers used on Navy ships are ACB, AQB, AQB-LF, NQB and ALB. The type ACB circuit breaker is an open frame circuit breaker. All other circuit breaker types noted are contained within insulated enclosures. A particular circuit breaker frame size can accommodate a number of different standard trip elements which allows for maximum flexibility in circuit breaker design applications. For example, a circuit breaker with a 100 amp frame, which indicates that the circuit breaker components (contacts, etc.) are designed to carry a maximum of 100 amps continuous current, can be used with 100, 75, 50, 25 or 15 amp, rated trip elements. The larger size circuit breakers have trip units which can be changed aboard ship. Smaller breakers have non-interchangeable trip units installed at the factory. The type ACB circuit breaker is used in large current capacity circuits, such as generator, bus-tie and major bus feeder circuits. The largest frame size of type ACB circuit breakers can carry a maximum continuous current of 4000 amps at 450 volts and can provide long time delay, short time delay and instantaneous overcurrent protection. The type AQB circuit breaker is normally utilized in bus feeder circuits, distribution feeders and branch circuits to individual or groups of power loads. The largest frame size of type AQB circuit breakers can carry a maximum continuous current of 1600 amps and provide long time delay and instantaneous overcurrent protection. The type AQB-LF circuit limiting fuses included which trip the circuit breaker when one or more fuses are blown. The current limiting fuses extend the fault current interrupting capacity of a type AQB breaker and will blow only if the currents are near the limit of the fault current interrupting rate of the circuit breaker. Type NQB circuit breakers are type AQB circuit breakers with no automatic overcurrent protection and operate essentially as heavy duty safety switches. Type ALB circuit breakers are utilized in 115 volt lighting circuits and provide instantaneous trip overcurrent protection.

5.3 Fuses. Fuses, operating alone, are not normally used for the protection of the ship's power distribution system. Problems with fuses in circuit protection applications include the possibility of blowing one fuse in a three phase circuit which would lead to phase unbalancing with possible damage to three phase motors, and the fact that replacing blown fuses takes more time than resetting a circuit breaker to restore power after a fault has been cleared. However, fuses can be used to protect branch circuits feeding non-vital loads under 30 amps. The most common shipboard application of fuses in distribution systems is in fused lighting distribution boxes.

5.4 Types of Power System Fault Protection. Functionally, a power system fault protection plan can be either of the fully rated selective trip type or the cascaded type. A fully rated system is one in which all protective devices are applied and coordinated within their individual interrupting capacity ratings. Fully rated systems are specified for new ship design. A cascade system is one in which protective devices are applied above their individual interrupting ratings to interrupt a fault current in excess of the rating of the protective device. The device opens together with a second or "back-up" protective device located nearer the power source and applied within its interrupting rating. For example, referring to Figure 1, if a fault occurs along an individual load cable, only the circuit breaker in the distribution panel protecting the cable will trip if fully rated selective tripping has been provided. If a cascaded protection scheme had been provided, the "back-up" load center circuit breaker protecting the feeder cable to the distribution panel would be disrupted. A selective tripping fault current protection system is preferred over a cascaded system since it causes a minimum amount of circuit interruptions.

5.5 Typical Circuit Protection Features. Design Data Sheet DDS311-3 sets forth a method of applying and coordinating the protective devices for a ship's power system. Described below are the typical protection features for major power system circuits. It should be realized that a specific ship's power system protection requirements may deviate from those presented below:

a. Generator Circuit Protection

- High speed clearing of bus faults combined with selective operation of the bus-tie and feeder circuit breakers accomplished by the short time delay protective feature of the generator circuit breaker.
- Prevention of excessive generator temperatures under extreme conditions of overload by long time delay protective feature of the generator circuit breaker.
- Clearing of faults in the generator and generator cables accomplished by the instantaneous trip feature of the generator circuit breaker when more than two generators are operating in parallel.
- Prevention of damage of the prime mover of a generator operating in parallel with one or more other generators if subjected to a rapid reduction in load, or a failure of the prime mover. When this situation occurs, a reverse power delay will sense current flow from the bus to the generator and will trip the generator circuit breaker. This prevents the generator from being driven as a motor by the other parallel generators which could damage the driven prime mover.

b. Bus-Tie Circuit Protection

- High speed clearing of bus-tie circuit and connected switchboard bus faults combined with selective operation of the generator and feeder circuit breakers accomplished by the short time delay protective feature of the bus-tie circuit breaker.
- Protection against overloads or high impedance faults by the long time delay protective feature of the bus-tie circuit breaker.
- Instantaneous trip feature is normally not required for a bus-tie circuit breaker.

c. <u>Shore Power Circuit Protection</u>

- o High speed clearing of shore power circuit and connected switchboard bus faults accomplished by the long time delay protective feature of the shore power circuit breakers. Short time delay protection is not normally required.
- o Clearing of low impedance faults on the switchboard bus, accomplished by the instantaneous trip feature of the shore power circuit breakers, is usually provided by a current limiting fuse unit which interrupts the circuit when the current is in excess of the interrupting rating of the breaker. This maximum fault current protection is required in order to ensure that a large volume of fault current does not enter the ship's distribution system from the shore power source.

d. <u>Feeder Circuit Protection</u>

- o High speed clearing of feeder circuit faults accomplished by the long time delay protective feature of the feeder circuit breaker.
- o Clearing of low impedance feeder circuit faults accomplished by the instantaneous trip feature of the feeder circuit breaker.
- o A short time delay feature is normally not required for feeder circuit breakers unless the feeder circuit is of large capacity and protected by a type ACB circuit breaker which feeds a distribution panel containing type AQB circuit breakers. In such a case, a short time delay feature is included to provide for high speed clearing of faults on the feeder circuit and selective operation between the feeder circuit breakers and distribution panel circuit breakers. Instantaneous trip is required only when the short time rating of the circuit breaker is exceeded.

e. Main and Branch Circuit Protection

- o Clearing of high impedance main or branch faults on cable or overloads on cable accomplished by the long time delay protective feature of the main or branch circuit breaker.
- o Clearing of low impedance faults on main or branch cables or in equipment accomplished by the instantaneous trip feature of the main or branch circuit breaker.
- o Short time delay protective feature is not normally provided for main or branch circuit breakers.
- o Fuses may be used to protect non-vital main and branch circuits when disconnect features are not required. If selectivity with the circuit breakers can be obtained. Fuses cannot be used in circuits supplying motors in excess of 7.6 horsepower at 440 volts.

f. Lighting Mains and Branch Circuit Protection

- o Type ALB circuit breakers provide inverse time delay and instantaneous trip protection, similar to that obtained in power main and branch circuit protection.
- o As with non-vital power main and branch circuits, fuses may be used in lighting distribution boxes.

g. Special 400 Hertz System Protection - In addition to circuit breaker protection, similar to that provided for the 60 Hertz system, the 400 Hertz power system utilizes voltage or voltage and frequency monitors which sense deviations on each 400 Hertz system or portion of the system. The monitor trips an associated circuit breaker when the voltage or frequency transients exceed pre-set limits so as to prevent damage to connected equipment.

h. Protection of Motor Driven Auxiliaries - Motor controllers, both manual and magnetic types, have overload protective features. The manual type provides low voltage release and the magnetic type can be wired either for low voltage release or low voltage protection.

- o LVP (low voltage protection) type opens the motor circuit upon voltage failure and maintains an open circuit until reclosed by manual operation of the control pushbutton. LVR (low voltage release) type opens the motor circuit upon voltage failure, but reclose the circuit automatically upon voltage recovery. In a manual type motor controller, low voltage release type protection is provided by an LVR-E (low voltage release effect) type where the voltage is re-established automatically to the motor circuit, since there are no magnetic devices in a manual controller to become de-energized and open on voltage failure.
- o Overload protection is provided by means of either a thermal overload device, which has an inherent inverse time delay, or by a magnetic device with an inverse time delay attached. Manual controllers can also utilize fuses for overload protection.

6. PRACTICAL FACTORS

The following practical factors are included as part of the Electrical Power Distribution lesson plan:

a. Review a one line diagram for a ship having three ship generators, one of which is designated as an emergency generator. Study how power can be supplied to the distribution system from the ship's power generation plants and shore power via the main switchboards and their bus ties. Study the electrical power distribution scheme from the main switchboards to individual loads (e.g., were load centers are utilized or is power fed directly from the main switchboards to distribution panels; where were manual bus transfer (MBT) switches or automatic bus transfer (ABT) switches are utilized?).

b. Review an electric load power analysis for ship having three ship generators, one of which is designated as an emergency generator. Study the load summaries for the various operating conditions and compare with the ship's generation plant capacities. Study the load factors selected for individual equipment under the various operating conditions.

c. Review DOD-STD-1399, Section 300, Interface Standard for Shipboard Systems, Electric Power, Alternating Current. Study the electrical power system characteristics for Types I, II, and III power.

7. QUESTIONS:

a. Sketch a one line diagram, including circuit breakers, for the following electric plant:

- o 3-1000 KW Ship Service Turbine Generator Set with associated switchboard connected in a ring bus configuration.
- o 1-750 KW Emergency Diesel Generator Set with bus ties to two of the three ship service switchboards.
- o 1-Shore Power Connection.
- o 3-Load Centers, one fed from each ship service switchboard. Two of the load centers have a normal and emergency supply; one via an ABT and the other via an MBT. The load center supplied from only one source feeds a three phase bank of single phase 450/120 volts lighting transformers which, in turn, feed lighting distribution panels.

b. Discuss the design features of a ship's electrical distribution system which provide maximum continuity of service to equipment, consuming electrical power.

c. Differentiate between an ungrounded electrical system and the grounding of electrical power equipment for personnel safety. Discuss the advantages of using an ungrounded electrical system.

d. Describe the relationships between the ship's service power, lighting, emergency, casualty and 400 hertz power distribution systems. Explain how each system interfaces with the others.

e. Describe the various protective devices used in electrical power distribution systems and specify in what type of circuits they would be utilized.

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