DESIGN DATA SHEET

DEPARTMENT OF THE NAVY, BUREAU OF SHIPS

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Section DDS9620-4

Ship Service Electric Power System, Application and Coordination of Protective Devices
9620-4-a. References
(a) General Specifications for Ships of the U. S. Navy, Section 9620-5, Protective devices for electric circuits
(b) Design Data Sheet DDS9620-3—A.C. fault current calculations

9620-4-b. Scope

This Design Data Sheet covers a method of applying and coordinating the protective devices of ship service 60 and 400-cycle power systems.

9620-4-c. General

Overall protection of an electrical power system consists of system fault protection and thermal overload protection. The primary concern of this Design Data Sheet is system fault protection. This is achieved by applying protective devices to isolate faulted sections automatically with minimum damage and minimum disturbance to the remainder of the system. These protective devices include the circuit breakers in Tables I, II, and III and the fuses in Table IV. Circuit breakers with tripping elements in all 3 poles shall be provided for 4-wire grounded systems. Therefore, type AQB-A50 and type ALB-10 circuit breakers shall not be used for wye connected 4 wire grounded neutral systems.

To ensure continuity of service, a fully rated system as defined in reference (a) should be provided, and cascading should be restricted insofar as practicable. To avoid the necessity of using type ACB back-up breakers with type AQB breakers of inadequate interrupting capacity, type AQB-LF breakers should be used. This type breaker combines the standard type AQB breaker with a current limiting fuse unit which interrupts all values of current in excess of the interrupting rating of the breaker. Thus, the 60-cycle interrupting capacity of type AQB breakers is extended to 100,000 asymmetrical amperes at 500 volts. The protective coordination is such that the circuit breaker overcurrent devices perform their normal functions unless the magnitude of fault current reaches the fusing band of the current limiting fuses (crossover band). The thermal and magnetic trip devices protect against overloads and short circuit currents up to the region of the interrupting ratings of the breakers. The approximate cross-over bands for the AQB-LF circuit breakers are as follows:

	Symmetrical amperes	0.5 p.f.
	Fuse does not blow	Fuse blows
AQB-LF100		
Inst. setting 210 amperes or less	7150	7950
Inst. setting above 210 amperes	10,500	12,000
AQB-LF250	11,500	12,800

In applying type AQB-LF breakers, the time current characteristic of the current limiting fuses are not to be considered, and no attempt should be made to coordinate two sets of these fuses. When two type AQB breakers, fused or unfused, are installed in series in a circuit, selectivity cannot be assured for any value of current in excess of the highest pickup current setting of the magnetic trip elements. For this condition, both breakers may trip. Consequently, there is no advantage to be gained by obtaining coordination of fuses above the breaker interrupting ratings when coordination cannot be achieved for some values of current below the interrupting rating. In addition, the time current characteristics of the fuses have not been defined with sufficient accuracy to permit coordination. For the above reasons, in circuits having fault currents in excess of the ratings of unfused type AQB breakers, only the breaker nearest the source should be of the fused type. The single fused unit will act to protect the other type AQB breakers in series.

As indicated above, continuity of service may be lost for values of current in excess of the magnetic trip pick-up current setting of the largest unit. Therefore, not more than two type AQB breakers are installed in series. Selective tripping can more nearly be achieved by the use of type ACB breakers having time delay and adequate interrupting capacity. However, because of increases in cost, weight, and space, type ACB breakers can rarely be justified if type AQB breakers can be used.

Prevention of false non-tripping is of importance because of the difficulty of locating faults. False non-tripping may occur in some instances where the following protective devices are installed in series:

a. Two AQB or ALB breakers with the same instantaneous setting.

b. AQB or ALB breakers in series with fuses.

Because of the first possibility, two circuit breakers having the same instantaneous trip settings should never be installed in series. Table IV includes the instantaneous settings available on several types of AQB and ALB breakers, and the maximum fuse sizes which may be used if the possibility of false non-tripping is to be minimized.

Tables I, II, and VI of reference (a) specify the circuit breaker trip settings for ship service a.c. power and lighting systems. Examples 1, 2, 3, 4, and 5, which follow, have been prepared in order to illustrate the application of reference (a) to specific electrical systems. The examples are not intended to represent particular ships, but to serve as illustrations. In making the fault current analyses, the formulas derived in reference (b) were used. Circuit breaker and bus work impedances were not included in the calculations, since their inclusion has very little effect upon the value of fault current obtained.

Table I

Standard Navy Circuit Breakers Available for 60-Cycle Power Systems

Breaker	Maximum Line-to-Line Voltage (r.m.s. volts)	Continuous Current Rating of Copper (amperes)	Poles	Interrupting Rating (r.m.s. amperes)	Short Time Rating (r.m.s. amperes)	Operation	Time bands or Time Delay
ACB 640R	500	640	3	40,000	25,000	Manual or Electric	1, 2, and 3
1600R	500	1600	3	60,000	50,000	Manual or Electric	1, 2, and 3
1600HR	500	1600	3	100,000	100,000	Electric	1, 2, and 3
3200HR	500	3200	3	100,000	100,000	Electric	2, 3, and 4
4000HR	500	4000	3	100,000	100,000	Electric	2, 3, and 4
AQB-A50	500	50	3	5,000	....	Manual	
A100	500	100	2 or 3	15,000		Manual	
LF100	500	100	3	100,000		Manual	
A101	500	100	2 or 3	15,000		Manual	
A250	500	250	2 or 3	20,000		Manual or Electric	
LF250	500	250	3	100,000		Manual	
A400	500	400	2 or 3	30,000		Manual or Electric	
AT400	500	400	3	20,000	...	Manual or Electric	3 or 5 cycles

Table I—Continued
Standard Navy Circuit Breakers Available for
60-Cycle Power Systems

Breaker	Maximum Line-to-Line Voltage (r.m.s. volts)	Continuous Current Rating of Copper (amperes)	Poles	Interrupting Rating (r.m.s. amperes)	Short Time Rating (r.m.s. amperes)	Operation	Time bands or Time Delay
AQB LF100	500	400	3	100,000	....	Manual or Electric	3 or 5 cycles
A800	500	800	3	50,000	....	Manual or Electric	.....
A801	500	800	3	40,000		Manual or Electric	
AT801	500	800	3	40,000		Manual or Electric	3 or 5 cycles
ALB 1	125	50	1 (1)	5,000 (2)		Manual	
10	125	200	3	10,000		Manual	

Notes: (1) Can be connected by handle yokes for 2 or 3-pole operation.
(2) 1500 amperes with 5-ampere element.

TABLE II
Standard Navy Circuit Breakers Available for
400-Cycle Power Systems

Breaker	Maximum Line-to-Line Voltage (Volts)	Continuous Current Rating of Copper (Amperes)	Poles	Interrupting Rating (r.m.s. amperes)	Short Time Rating (r.m.s. amperes)	Operation
AQB A50	500	50	3	5,000		Manual
A100	500	100	2 or 3	(1)		Manual
A101	500	100	2 or 3	(1)		Manual
A250	500	250	2 or 3	(1)		Manual or Electric
A400	500	400	2 or 3	(1)		Manual or Electric
ALB 1	125	35	1 (2)	5,000 (3)		Manual
ALB 10	125	150	3	10,000		Manual

Notes: (1) Due to limited 400-cycle test facilities, this breaker has been tested and approved only through 10,000 amperes.
(2) Can be connected by handle yokes for 2 or 3-pole operation.
(3) 1500 amperes with 5-ampere element.

TABLE III
Standard Navy Circuit Breakers Available for
D.C. Power Systems

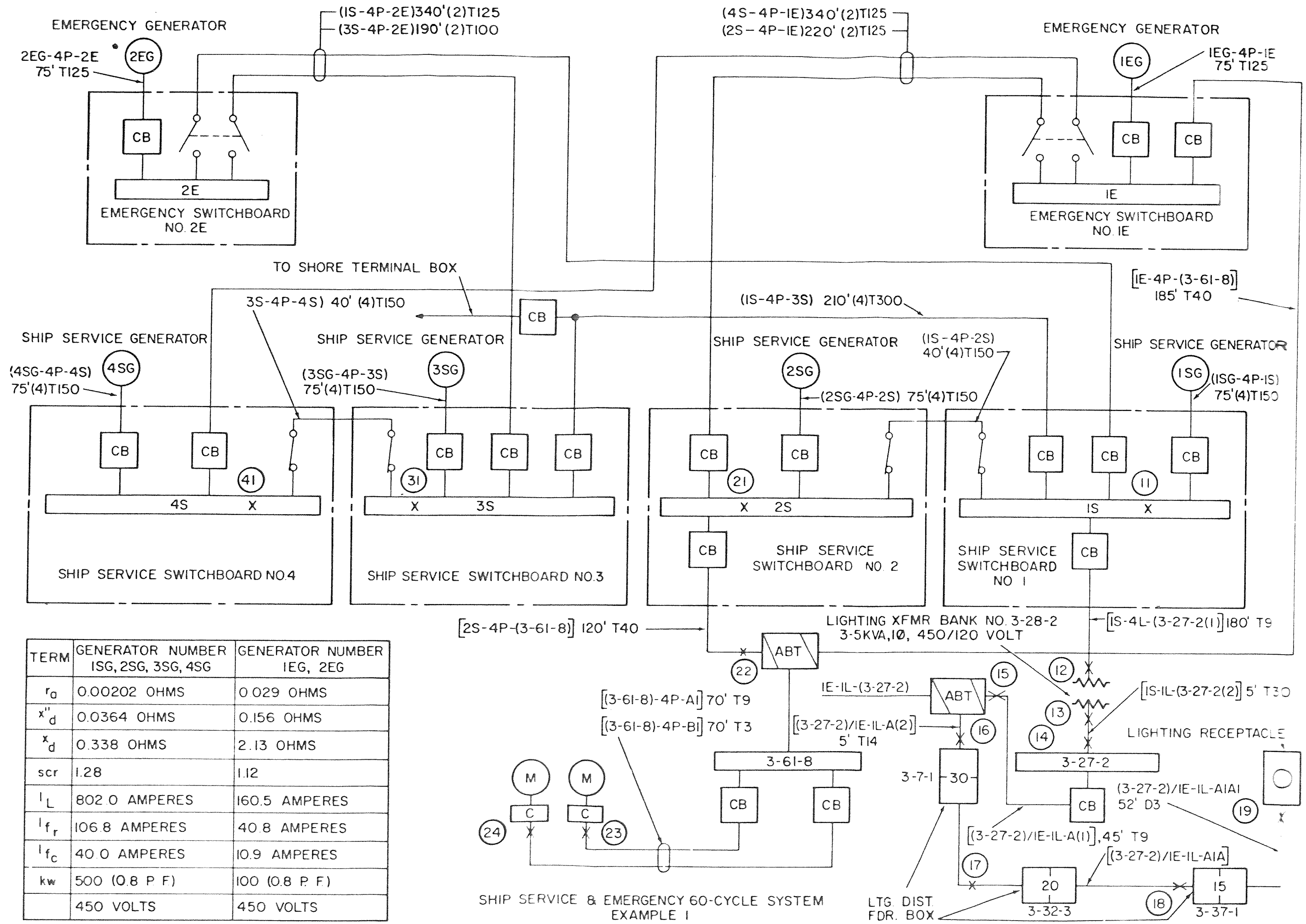
Breaker	Maximum Line-to-Line Voltage (Volts)	Continuous Current Rating of Copper (Amperes)	Poles	Interrupting Rating (Amperes)	Operation
AQB A50	250	50	3	2,500	Manual
AQB A100	250	100	2 or 3	10,000	Manual
A101	250	100	2 or 3	10,000	Manual
A250	250	250	2 or 3	15,000	Manual or Electric
A400	250	400	2 or 3	20,000	Manual or Electric
A600	250	600	2 or 3	20,000	Manual
ALB 1	125	50	1 (1)	2,500 (2)	Manual
10	125	200	3	5,000	Manual

Notes: (1) Can be connected by handle yokes for 2 or 3-pole operation.
(2) 1500 amperes for 5 ampere element.

Table IV
Maximum Fuse Sizes Which May be Used in Series With Type AQB-A101, AQB-A100, AQB-A50, or ALB Breakers to Eliminate the Probability of False Non-Tripping

Circuit Breaker Type	Trip Coil or Thermal Element	Instantaneous Trip Pick-up Settings (AMPS)	Maximum Fuse Rating on Load Side of Breaker	
			Type A (AMPS)	Type C (AMPS)
AQB-A101	15	75-120		3
Note (1)	15	175-220	2	5
	25	125-200	1	5
	25	290-365	3	10
	50	250-400	2	10
	50	575-725	10	25
	75	375-600	3	15
	75	865-1090	10	35
	100	500-800	5	25
	100	1150-1450	10	45
AQB-A100	15AF	90-105	--	3
	15A	180-210	2	5
	25AF	150-175	1	5
	25A	300-350	3	10
	50AF	300-350	3	10
	50A	600-700	10	25
	75AF	450-525	5	15
	75A	900-1050	10	35
	100AF	600-700	10	25
	100A	1200-1400	10	45
AQB-A50	10	300-800	3	10
	15	450-800	5	15
	20	600-800	10	25
	25	600-800	10	25
	35	600-800	10	25
	50	600-800	10	25
ALB-1	5	Note (2)	3	10
	10, 15	Note (2)	3	15
	20, 50	Note (2)	5	20
ALB-10	any	Note (3)	15	40

Notes: (1) Type AQB-A101 breakers have adjustable (Lo-Hi) instantaneous trip settings.
(2) Minimum current is 500 amps, except 400 amps for 10-15 amp breakers and 325 amps for 5 amp breakers.
(3) Minimum current is 1200 amps.



TERM	GENERATOR NUMBER 1SG, 2SG, 3SG, 4SG	GENERATOR NUMBER 1EG, 2EG
r_a	0.00202 OHMS	0.029 OHMS
x''_d	0.0364 OHMS	0.156 OHMS
x_d	0.338 OHMS	2.13 OHMS
scr	1.28	1.12
I_L	802.0 AMPERES	160.5 AMPERES
I_{f_r}	106.8 AMPERES	40.8 AMPERES
I_{f_c}	40.0 AMPERES	10.9 AMPERES
kw	500 (0.8 P. F.)	100 (0.8 P. F.)
	450 VOLTS	450 VOLTS

Ship Service & Emergency 60-Cycle System
Example 1

EXAMPLE I
Impedances from Switchboard 1S to Location 18
450-Volt Base

Section	Distance (feet)	Cable Size	Ohms per 1000 ft. R	Ohms per 1000 ft. X	Section Ohms R	Section Ohms X	Cumulative Ohms R	Cumulative Ohms X	Location
1. 11 12	180	T9	1.4	0.037	0.252	0.00666	0.252	0.00666	12
2. 12 13	Transf.				0.298	0.26800	0.550	0.275	13
3. 13 14 (1)	5	T30	5.75	0.407	0.0288	0.00204	0.579	0.277	14
4. 14 15 (1)	45	T14	12.40	0.449	0.568	0.0202	1.15	0.297	15
5. 15 16 (1)	5	T14	12.40	0.449	0.062	0.0022	1.21	0.299	16
6. 16 17 (1)	45	T9	19.7	0.520	0.886	0.0234	2.10	0.322	17
7. 17 18 (1)	15	T4	40.8	0.548	0.611	0.0082	2.71	0.330	18
8. 18 19 (1)	52	D3	66.1	0.575	3.44	0.030	6.15	0.360	19
Impedances from Ship Service Generators to Switchboard 1S									
9. Gen. 1G (X''_d)					0.003	0.0364	0.003	0.0364	1G
10. 1G-11 (2)	75	4T150	0.0205	0.0065	0.0015	0.0005	0.005	0.0369	11
11. Gen. 2G (X''_d)					0.003	0.0364	0.003	0.0364	2G
12. 2G 21 (2)	75	4T150	0.0205	0.0065	0.0015	0.0005	0.005	0.0369	21
13. 21 11 (2)	40	4T150	0.0205	0.0065	0.0008	0.00026	0.006	0.0372	11
14. Gen. 3G (X''_d)					0.003	0.0364	0.003	0.0364	3G
15. 3G 31 (2)	75	4T150	0.0205	0.0065	0.0015	0.0005	0.005	0.0369	31
16. 31 11 (2)	210	4T300	0.0108	0.0065	0.0023	0.0014	0.007	0.0383	11
17. Gen. 4G (X''_d)					0.003	0.0364	0.003	0.0364	4G
18. 4G 41	75	4T150	0.0205	0.0065	0.0015	0.005	0.005	0.0369	41
19. 41 31	40	4T150	0.0205	0.0065	0.00082	0.00026	0.006	0.0372	31
20. 31 11					0.0023	0.0014	0.008	0.0386	11

Note (1): Impedance calculated on 450-volt basis. Typical calculations for converting impedances on a 120-volt base to impedances on a 450-volt base are as follows:

Section (13-14)

$$R_{120} = 0.38\,\Omega/1000';\ R_{450} = 0.38\left(\frac{450}{120}\right)^2 = 5.33\,\Omega/1000'$$

$$X_{120} = 0.029\,\Omega/1000';\ X_{450} = 0.029\left(\frac{450}{120}\right)^2 = 0.407\,\Omega/1000'$$

Note (2): Impedances are based on the number of cables in parallel. Typical calculations for determining the impedance of cables in parallel are as follows:

Section (1G-11)—

$$\frac{1}{Z_{eq.}} = \frac{1}{Z_{T150}} + \frac{1}{Z_{T150}} + \frac{1}{Z_{T150}} + \frac{1}{Z_{T150}} = \frac{4}{Z_{T150}}$$

$$Z_{eq.} = \frac{0.081 + j0.026}{4} = (0.0205 + j0.0065)\,\Omega/1000'$$

I. Calculation of fault currents

A. Maximum RMS asymmetrical short circuit current from ship service generator No. 1G at switchboard No. 1S:

$$I_s'' = \frac{1.5\,E_g}{X_d'' + X_c} = \frac{1.5\,E_g}{\text{Impedance @ line 10}} = \frac{1.5(260)}{0.0369} = 10{,}580 \text{ amps}$$

B. Minimum sustained RMS short circuit current of ship service generator No. 1G at switchboard No. 1S:

$$I_s = \frac{\frac{I_{fr}}{I_{fc}}\,(\text{S.C.R.})\,X_d\,I_1}{X_d + X_c} = \frac{\left(\frac{108.6}{40.0}\right)(1.28)\,(0.338)\,(802)}{0.338 + 0.0005} = 2730 \text{ amps}$$

C. Maximum available RMS short circuit current at switchboard No. 1S:

$I_{m,generator} = 2/3\,(802) = 535$ amps (motor contrib./gen.)

(a) Average of the maximum asymmetrical RMS currents of the three phases at ½ cycle:

Assuming generators 1G, 2G, and 3G in parallel:

$$X\ parallel = \frac{1}{\frac{1}{X_{1G-11}}+\frac{1}{X_{2G-11}}+\frac{1}{X_{3G-11}}} = \frac{1}{\frac{1}{0.0369}+\frac{1}{0.0372}+\frac{1}{0.0383}} =$$

$$\frac{1}{27.1+26.9+26.1} = \frac{1}{80.1} = 0.0125\ ohm$$

$I_{m(total)} = 3\,(802)\,(2/3) = 1604$ amps

$$I_{avg} = 3.5\,(I_m) + \frac{1.25\,E_g}{X} = (3.5)\,(1604) + \frac{(1.25)\,(260)}{0.0125} = 31{,}600\ amp.$$

(b) Maximum available RMS asymmetrical short circuit current:

$$I_{max} = 4\,I_m + \frac{1.5\,E_g}{X} = 4\,(1604) + \frac{1.5\,(260)}{0.0125} = 37{,}600\ amps$$

D. Maximum available short circuit current at ⑪ (panel 3–27–2):

Resistance from switchboard to fault—r_f—R line 3 = 0.579 ohm

Reactance from switchboard to fault = X_f—X line 3 = 0.277 ohm

Equivalent resistance—$R - r_f$ = 0.579 ohm

Equivalent reactance = $X = X_f{}' X_{1G,\,2G,\,3G} = 0.277 + 0.0125 = 0.290$ ohm

$$\frac{X}{R} = \frac{0.290}{0.579} = 0.501;\ K_1 = 1;\ K_2 = 1$$

$$I_{avg} = \frac{0.71E_g}{\sqrt{\left(\frac{0.07E_g}{I_m}+r_f\right)^2+\left(\frac{0.19E_g}{I_m}+x_f\right)^2}} + \frac{K_1\,E_g}{\sqrt{R^2+X^2}}$$

$$R_f = \frac{0.07E_g}{I_m} + r_f = \frac{0.07\,(260)}{1604} + 0.579 = 0.590\ ohm$$

$$X_f = \frac{0.19E_g}{I_m} + x_f = \frac{0.19\,(260)}{1604} + 0.277 = 0.308\ ohm$$

$Z_f = \sqrt{(0.590)^2 + (0.308)^2} = 0.664$ ohm

$Z = \sqrt{R^2 + X^2} = \sqrt{(0.579)^2 + (0.290)^2} = 0.648$ ohm

(1) Average of the maximum asymmetrical RMS currents of the three phases at ½ cycle:

$$I_{avg} = \frac{0.71\,(260)}{0.664} + \frac{260}{0.648} = 278 + 401 = 679\ amps\left(\begin{array}{c}450\text{-V.}\\ base\end{array}\right)$$

$$= 679\left(\frac{450}{120}\right) = 2540\ amps\ (120\text{-V. base})$$

(2) Maximum available short-circuit current at ½ cycle in the phase having the maximum asymmetrical current:

$$I_{max} = \frac{0.81\ E_g}{\sqrt{\left(\frac{0.07E_g}{I_m} + r_t\right)^2 + \left(\frac{0.19E_g}{I_m} + X_t\right)^2}} + \frac{K_2\ E_g}{\sqrt{R^2 + X^2}}$$

$$\frac{0.81\ (260)}{0.664} + \frac{260}{0.648} = 317 + 401 = 718 \text{ amps} \left(\begin{matrix}\text{450-V.} \\ \text{base}\end{matrix}\right)$$

$$718\left(\frac{450}{120}\right) = 2690 \text{ amps (120-v. base)}$$

E. Minimum available RMS asymmetrical short-circuit current

(1) At ⑯ (Distribution feeder box No. 3–17–1)
Assuming only generator 4G in operation:

$$R = R4G-11 + R11-16 = 0.008 + 1.21 = 1.22 \text{ ohms}$$

$$X = X4G-11 + X11-16 = 0.0386 + 0.299 = 0.338 \text{ ohm}$$

$$I_{min} = \frac{E_g}{\sqrt{R^2 + X^2}} = \frac{260}{\sqrt{(1.22)^2 + (0.338)^2}} = 206 \text{ amps} \left(\begin{matrix}\text{450-V.} \\ \text{base}\end{matrix}\right)$$

$$206\left(\frac{450}{120}\right) = 772 \text{ amps} \left(\begin{matrix}\text{120-V.} \\ \text{base}\end{matrix}\right)$$

(2) At ⑲ (Lighting receptacle)

$$R = 0.008 + 6.15 = 6.16 \text{ ohms}$$

$$X = 0.0386 + 0.360 = 0.399 \text{ ohm}$$

$$I_{min} = \frac{0.866\ (260)}{\sqrt{(6.16)^2 + (0.399)^2}} = 36.6 \text{ amps (450-V. base)} = 137 \text{ amps (120 V. base)}$$

NOTE: SINGLE PHASE FAULT CURRENT IS FOUND BY MULTIPLYING THE THREE PHASE CURRENT BY

$$\frac{E}{2Z_e} \Big/ \frac{E}{\sqrt{3}Z_e} = 0.866$$

II. Selection of protective device

A. Ship service A.C. generators Nos. 1G, 2G, 3G and 4G

(1) Line-to-line voltage = 450 volts
Full load current of generator = 802 amps.
Maximum available fault current through generator breaker = 31,600 amps.
Consequently, breaker must be type ACB 1600 with an 800 amp. coil.

(2) Long time delay setting:
150 percent of full load current = 1203 amps.
LTD setting = 1280 amps.

(3) Short time delay setting:
80 percent of minimum sustained short circuit current = 0.8(2730) = 2184 amps.
STD setting = 2100 amps., time band No. 3

(4) Instantaneous trip setting:
120 percent of maximum generator asymmetrical short circuit current = 1.2 (10,580) = 12,700 amps.
Instantaneous setting = 13,000 amps.

(5) Reverse power relay:
5 percent of generator rating = 0.05 (500) = 25 KW
Shall trip in 10 seconds or less with reverse power of 25 KW.

B. Bus tie circuit breaker No. 1S–4P–3S

(1) Resultant current = 1200 amps.
I avg. at switchboard = 31,600 amps.
Use type ACB 1600 breaker with 1200 amp. coil.

(2) Long time delay setting: Not required for multi-generator switchgear groups.

(3) Short time delay setting:
150 percent of bus tie coil rating = 1.5 × 1200 = 1800 amps.
STD setting = 1800 amps., time band No. 2

(4) Instantaneous trip setting: 40,000 amps. Since GSS does not require an instantaneous trip, the maximum possible setting is used.

C. Shore connection circuit breaker

(1) Capacity of shore power system = 800 amps.
Use type ACB–1600 breaker with 800 amp. coil.

(2) Long time delay setting:
1.5 (800) = 1200 amps.
LTD setting = 1280 amps.

(3) Short time delay setting:
STD setting = 2100 amps., time band No. 3

(4) Instantaneous trip setting: 40,000 amps. Since GSS does not require an instantaneous trip, the maximum setting is used.

D. Feeder circuit breaker No. 1S–4P–(3–27–2)

(1) Maximum available fault current = 31,600 amps.

$$\text{Full load current of transformer bank} = \frac{15}{\sqrt{3}(0.450)} = 19.3 \text{ amps.}$$

Transformer inrush current = 12 (19.3) = 232 amps.
Use type AQB–LF100 with 25 amp. coil.

(2) Long time delay: 25 amp. coil rating.

(3) Short time delay setting: Not applicable.

(4) Instantaneous trip setting:
1200 percent trip element rating = 12 (25) = 300 amp.
80 percent minimum available current = 0.80 (5700) = 4560 amps.
Instantaneous trip setting = 300–350 amps.

E. Sub-branch lighting circuit fuse No. (3–27–2)/1E–1L–A1A1:
Sub-branch supplying receptacle = 15 amps.

F. Branch lighting circuit fuse No. (3–27–2)/1E–1L–A1A: 20 amps.

G. Sub-main lighting circuit fuse No. (3-27-2)/1E-1L-A1: **30 amps.**

H. Main circuit breaker No. (3-27-2)-1L-A(1):

Maximum available fault current = 2540 amps.
Use type ALB-5 breaker with 35 amps. coil
It was not necessary to calculate the maximum fault current since breaker 1S-4P-(3-27-2) provides adequate back-up protection.

I. Feeder circuit breaker No. 2S-4P-(3-61-8):

(1) Maximum available fault current = 31,600 amps.
Resultant load current = 79 amps.
Use type AQB LF100 breaker with 100 amp. coil.

(2) Instantaneous trip setting: 1200-1400 amps, since main breaker instantaneous setting is 600-700 amps.

J. Main circuit breaker No. (3-61-8)-4P-A(1):

(1) Maximum available fault current = 9290 amps.
Resultant load current, $I_R = 26.5$ amps.
Locked rotor current = 185 amps.
Use type AQB-A100 breaker with 50 amp. coil.
It was not necessary to calculate the maximum fault current since breaker No. 2S-4P-(3-61-8) provides adequate back-up protection.

(2) Instantaneous trip setting:

Minimum fault current from emergency generator No. 1E $= \dfrac{E_g}{\sqrt{R^2+X^2}}$

$R_{cable} = 0.185\ (0.32) = 0.0592$ ohm.
$X_{cable} = 0.185\ (0.029) = 0.00536$ ohm.
$R = 0.029 + 0.0592 = 0.0882$ ohm.
$X = 0.156 + 0.00536 = 0.161$ ohm.

$$I_{min} = \frac{(260)}{\sqrt{0.0882^2 + 0.161^2}} = \frac{(260)}{0.183} = 1420 \text{ amps.}$$

80 percent $I_{min} = 0.80\,(1420) = 1136$ amps.
1200 percent of overcurrent trip rating = 12 (50) = 600 amps.
I.T. setting = 600-700 amps.

K. Emergency bus tie breaker No. 2S-4P-1E:

(1) $I_{ave} = 31{,}600$ amps.
$I_R = 300$ amps. (rated capacity of emergency bus tie circuit)
Use type ACB-640 breaker with 320 amp. coil

(2) Long time delay setting:
80 percent ship service generator LTD = (0.80) (1280) = 1024 amps.
120 percent of the highest L.T.D. setting of the feeder breakers = (1.20) (338) = 405.6 amps.
150 percent $I_R = (1.50)\,(300) = 450$ amps.
LTD setting = 500 amps.

(3) Short time delay setting:
120 percent of the highest instantaneous setting of the AQB feeder breakers = (1.20) (1400) = 1680 amps.
80 percent ship service generator STD = (0.80) (2100) = 1680 amps.
STD setting = 1600 amps, time band No. 2

(4) **Instantaneous setting:**
I_{sc} = 31,600 amps.
Short time rating of breaker = 25,000 amps.
Instantaneous setting = 16,000 amps. (highest setting available for this coil size)

L. Emergency generator No. 1EG:

(1) Full load current of generator = 160.5 amps.
I''_s = 2460 amps.
Use type AQB–A250 with 160G coil

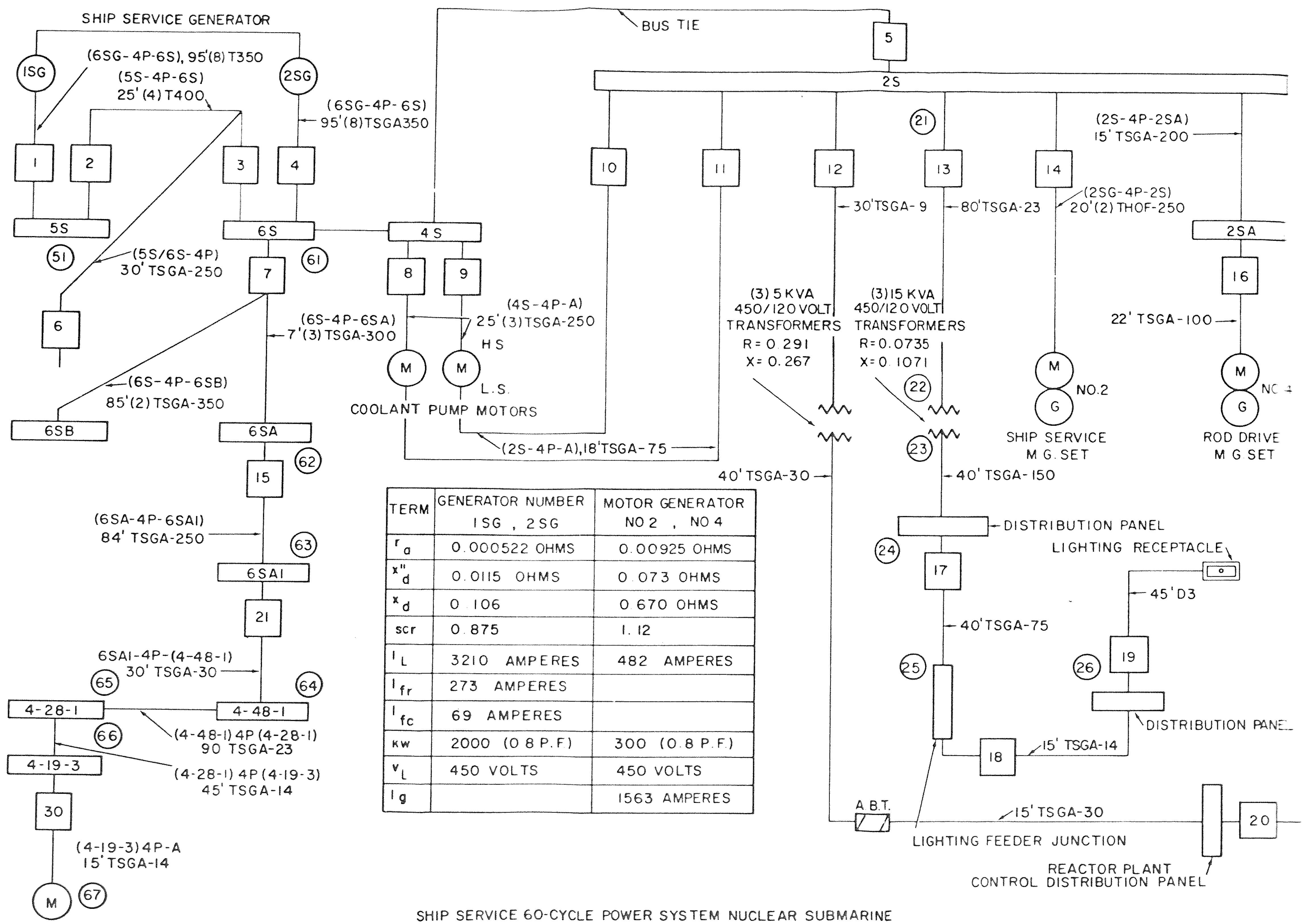
(2) Long time delay setting: 160G coil

(3) Short time delay setting: not applicable.

(4) Instantaneous trip setting:
120 percent I''_s = (1.20) (2460) = 2952 amps.
I.T. setting = 3200 amps.

TABULATION OF BREAKERS AND SETTING FOR EXAMPLE 1

Breaker or Fuse No.	Type	Frame Size	Fuse Size or Coil Rating (Amps.)	LTD Pickup (Amps.)	STD Pickup (Amps.)	Time Band	Instantaneous Pickup (Amps.)	Maximum Fault Current (Amps.)	Minimum Fault Current (Amps.)
Gen. No. 1G	ACB	1600R	800	1200	2100	3	12,000	31,600	
1S-4P-3S	ACB	1600R	1200	N.A.	1800	2	40,000	31,600	
Shore Power	ACB	1600R	800	1200	2100	3	40,000	31,600	
1S-4P-(3-27-2)	AQB-LF	100	25	N.A.	N.A.	N.A.	300-350	31,600	
(3-27-2)-1L-A(1)	ALB	5	35	N.A.	N.A.	N.A.	N.A.	2,540	667
(3-27-2)-1E-1L-A1	Fuse	N.A.	30	N.A.	N.A.	N.A.	N.A.		
(3-27-2)-1E-1L-A1A	Fuse	N.A.	20	N.A.	N.A.	N.A.	N.A.		
(3-27-2)-1E-1L-A1A1	Fuse	N.A.	15	N.A.	N.A.	N.A.	N.A.		127
(2S-4P-(3-61-8))	AQB-LF	100	100	N.A.	N.A.	N.A.	1200-1400	28,600	
(3-61-8)-4P-A1	AQB-A	100	50	N.A.	N.A.	N.A.	600-700	N.A.	1250
(2S-4P-1E)	ACB	640R	320	500	1000	2	16,000		
Gen. 1E	AQB-A	250	160G	N.A.	N.A.	N.A.	3,200		



TERM	GENERATOR NUMBER 1SG , 2SG	MOTOR GENERATOR NO 2 , NO 4
r_a	0.000522 OHMS	0.00925 OHMS
x''_d	0.0115 OHMS	0.073 OHMS
x_d	0.106	0.670 OHMS
scr	0.875	1.12
I_L	3210 AMPERES	482 AMPERES
I_{fr}	273 AMPERES	
I_{fc}	69 AMPERES	
KW	2000 (0.8 P.F.)	300 (0.8 P.F.)
V_L	450 VOLTS	450 VOLTS
I_g		1563 AMPERES

SHIP SERVICE 60-CYCLE POWER SYSTEM NUCLEAR SUBMARINE
EXAMPLE 2

EXAMPLE 2
Impedances from Switchboard 2S to Location 26
450-Volt Base

Section	Distance (Feet)	Cable Size	Ohms per 1000 Ft. R	Ohms per 1000 Ft. X	Section Ohms R	Section Ohms X	Cumulative Ohms R	Cumulative Ohms X
21-22	80	T23	0.55	0.030	0.044	0.0024	0.044	0.0024
22-23	Transf.				0.0735	0.1071	0.1175	0.1095
23-24 (1)	40	T150	1.14	0.366	0.0456	0.0146	0.163	0.124
24-25 (1)	40	T75	2.39	0.380	0.0956	0.0152	0.259	0.139
25-26 (1)	15	T14	12.40	0.449	0.186	0.00675	0.445	0.146

Impedances from Generators to Switchboards
450-Volt Base

Section	Distance (Feet)	Cable Size	Ohms per 1000 Ft. R	Ohms per 1000 Ft. X	Section Ohms R	Section Ohms X	Cumulative Ohms R	Cumulative Ohms X
Gen. 2G (X''_d)					0.0005	0.0115	0.0005	0.0115
2G-61	95	8T350	0.0046	0.00313	0.0004	0.00029	0.0009	0.0118
Gen. MG2 (X''_d)					0.00925	0.073	0.00925	0.073
MG2-21	20	2T250	0.026	0.013	0.00052	0.0026	0.00977	0.0756
Gen. 1G (X''_d)					0.0005	0.0115	0.0005	0.0115
1G-51	95	8T350	0.0046	0.00313	0.0004	0.00029	0.0009	0.0118
51-61	25	4T100	0.0078	0.00625	0.0002	0.00016	0.0011	0.0120

Impedances from Switchboard 6S to Location 67
450-Volt Base

Section	Distance (Feet)	Cable Size	Ohms per 1000 Ft. R	Ohms per 1000 Ft. X	Section Ohms R	Section Ohms X	Cumulative Ohms R	Cumulative Ohms X
61-62	7	3T300	0.0143	0.0087	0.0010	0.00061	0.0010	0.0006
62-63	84	T250	0.051	0.026	0.0043	0.0022	0.0053	0.0028
63-64	30	T30	0.41	0.029	0.0123	0.00087	0.0176	0.0037
64-65	90	T23	0.55	0.030	0.0495	0.0027	0.0671	0.0064
65-66	45	T14	0.88	0.032	0.0396	0.0014	0.1067	0.0078
66-67	15	T14	0.88	0.032	0.0134	0.0005	0.1201	0.0083

Note (1) Impedance calculated on 450-volt basis. To convert from an impedance on a 120-volt base to an impedance on a 450-volt base, the following formulas are used:

$$R_{450} = R_{120}\left(\frac{450}{120}\right)^2 ; X_{450} = X_{120}\left(\frac{450}{120}\right)^2$$

I. Calculation of fault currents

A. Maximum RMS asymmetrical short circuit current of ship service generator No. 2G at switchboard 6S:

$$I''_g = \frac{1.5\ E_g}{x''_d + x_c} = \frac{1.5\,(260)}{0.0118} = 33{,}100 \text{ amps.}$$ (Used to determine the instantaneous setting of the generator breaker)

$$I_{avg} = \frac{1.25 E_g}{x''_d + x_c} = \frac{1.25\,(260)}{0.0118} = 27{,}500 \text{ amps.}$$ (Used to determine the interrupting requirements of the generator breaker)

B. Minimum sustained RMS short circuit current of ship service generator No. 2G at switchboard No. 6S:

$$I_c = \frac{\frac{I_{fr}}{I_{fe}}(\text{S.C.R.})\,x_d I_L}{x_d + x_c} = \frac{\frac{273}{69}(0.875)\,(0.106)\,(3210)}{0.106 + 0.00029} = 11{,}100 \text{ amps.}$$

C. Maximum available fault current at switchboard No. 6S
$I_m = 2/3(3210)$ $= 2140$ amps.

(a) Average of the maximum asymmetrical RMS currents of the three phases at 1/2 cycle:
Assuming one turbine generator and one motor generator in paralllel.

$$\frac{1}{x_{parallel}} = \frac{1}{x_{20\text{-}21}} + \frac{1}{x_{MG\text{-}21}} = \frac{1}{0.0118} + \frac{1}{0.0756} = 98.0 \quad x_{parallel} = 0.0102 \text{ Ohm}$$

$x_{parallel} = 0.0102$ Ohm

$$I_{avg} = 3.5\ I_m + \frac{1.25 E_g}{x} = 3.5(2140) + \frac{1.25(260)}{0.0102} = 39{,}290 \text{ amps.}$$

(b) Maximum available RMS asymmetrical short circuit current:

$$I_{max.} = 4\ I_m + 1.5\ E_g = 4(2140) + \frac{1.5(260)}{0.0102} = 8560 + 38{,}200 = 46{,}760 \text{ amps.}$$

D. Maximum available short circuit current at twenty-four:
Resistance from switchboard to fault = r_f = 0.163 ohm
Reactance from switchboard to fault = x_f = 0.124 ohm
Equivalent resistance = R = r_f = 0.163 ohm
Equivalent reactance = $X = X_f + X_{20} = 0.124 + 0.0118 = 0.136$ ohm

$$\frac{X}{R} = \frac{0.136}{0.163} = 0.834;\ K_1 = 1;\ K_2 = 1$$

$$I_{avg} = \frac{0.71\ E_g}{\sqrt{\left(\frac{0.07\ E_g}{I_m} + r_f\right)^2 + \left(\frac{0.19\ E_g}{I_m} + x_f\right)^2}} + \frac{K_1\ E_g}{\sqrt{R^2 + X^2}}$$

$$R_f = \frac{0.07 E_g}{I_m} + r_f = \frac{0.07(260)}{2140} + 0.163 = 0.40851 + 0.163 = 0.172 \text{ ohm}$$

$$X_f = \frac{0.19(260)}{2140} + 0.124 = 0.1471 \text{ ohm}$$

$$I_{avg} = \frac{0.71(260)}{\sqrt{(0.172)^2 + (0.147)^2}} + \frac{260}{\sqrt{(0.163)^2 + (0.136)^2}} = 2046 \text{ amps (450V.base)}$$

$$= 2046\left(\frac{450}{120}\right) = 7690 \text{ amps (120 volt base)}$$

$$I_{max} = \frac{0.81 E_g}{\sqrt{\left(\frac{0.07 E_g}{I_m} + r_f\right)^2 + \left(\frac{0.19 E_g}{I_m} + X_f\right)^2}} + \frac{K_2 E_g}{\sqrt{R^2 + X^2}} = 2164 \text{ amps. (450V.base)}$$

$$= 2164\left(\frac{450}{120}\right) = 8100 \text{ amps. (120 V.base)}$$

E. Minimum available RMS asymmetrical short circuit current:
At twenty-six, assuming only MG set No. 2 in operation:
$R = R_{MG\text{-}21} + R_{21\text{-}26} = 0.00977 + 0.445 = 0.455$ ohm
$X = 0.0756 + 0.146 = 0.222$ ohm

$$I_{min} = \frac{0.866 E_g}{\sqrt{R^2 + X^2}} = \frac{0.866(260)}{\sqrt{(0.455)^2 + (0.222)^2}} = \frac{0.866(260)}{0.507} = 445 \text{ amp. (450 volt)}$$

$$= 445\left(\frac{450}{120}\right) = 1670 \text{ amps. (120-volt base)}$$

II. Selection of protective devices

A. Ship service A.C. generators Nos. 1G and 2G

(1) Line-to-line voltage = 450 volts
Full load current of generator = 3210 amps.
Maximum available fault current = 27,500 amps.
Use type ACB-3200H breaker with 3200 amp. coil

(2) Long time delay setting:

150 percent full load current	=4815 amps.
LTD setting	=4800 amps.

(3) Short time delay setting:
80 percent of sustained short circuit current = 0.8(11,100) = 8880 amps.
STD setting = 8000 amps, time band No. 4

(4) Instantaneous trip setting: 80,000 amps. max. value

(5) Reverse power relay:
5 percent generator rating = 100 KW
Shall trip in 10 seconds or less with reverse power of 100 KW.

B. Bus tie breaker No. 5S–4P–6S:

(1)

I_{asc} at switchboard	=35,100 amps.
Resultant current	=1605 amps

Use type ACB–1600A breaker with 1600 amp. coil

(2) Long time delay setting:
80 percent generator LTD = 0.80(4800) = 3840 amps.
150 percent resultant current = 1.50(1605) = 2407.5 amps.
LTD setting = 3200 amps.

(3) Short time delay setting:
80 percent generator STD = 0.80(8000) = 6400 amps.
STD setting = 6000 amps. time band No. 3

(4) Instantaneous setting: 40,000 amps. (maximum available)

C. Pressurizer heater circuit breaker:

(1) Maximum available fault current = 27,400 amps.

$$\text{Full load current} = \frac{200\ \text{Kw}}{\sqrt{3}\ (440)} = 263\ \text{amps.}$$

Use type AQB-A400 breaker with 300 amp. coil

(2) Long time delay: 300 amp. coil

(3) Short time delay: not applicable

(4) Instantaneous: 600 percent coil rating = 6(300) = 1800 amps.
Instantaneous setting = 1820 amps.

D. Feeder circuit breaker No. 13:

(1) Maximum available fault current = 35,100 amps.

$$\text{Full load current} = \frac{45}{\sqrt{3}\ (0.450)} = 57.7\ \text{amps.}$$

Transformer inrush current = 12(57.7) = 691 amps.
Use type AQB–LF100 breaker with 75 amp. coil

(2) Long time delay: 75 amp. coil

(3) Short time delay: not applicable

(4) Instantaneous setting:
1200 percent coil rating = 12(75) = 900 amps.
Minimum current at twenty-four = 850 amps.
80 percent minimum current = 0.8(850) = 680 amps.
Instantaneous setting = 900 = 1050 amps.

In this case, the instantaneous setting of 1200-1400 percent of coil rating was chosen even though greater than 80 percent of minimum current. This setting was chosen to prevent tripping on transformer inrush current.

When a transformer is first energized, a transient exciting current flows to bridge the gap between the conditions existing before the transformer is energized and the conditions dictated by steady-state requirements. For any given transformer this transient current depends upon the magnitude of the supply voltage at the instant the transformer is energized, the residual flux in the core and the impedance of the supply circuit. Often the magnitude of this transient current exceeds full-load current and may reach 8-10 times full-load current.

With a fault at location 24 and only MG set No. 2 feeding bus No. 2S, breaker No. 13 should trip on long time delay, rather than instantaneous, since sufficient fault current is not available for instantaneous tripping. Several seconds may elapse before circuit interruption but no damage should result other than the original fault. The time-current characteristics of the 75 amp. coil in breaker No. 13 will protect the cable from damage. Should any of the other loads drop out during this period because of low voltage, duplicate equipment on bus 1S would still be in operation. Consequently, the breaker setting chosen should provide selective operation with the turbo-generators in operation, provide adequate protection with only the MG set in operation and prevent false tripping on transformer inrush current.

Under different circumstances, however, the 600-700 percent instantaneous setting may be necessary and the possibility of false tripping accepted. This could occur with a load fed from a small transformer which is in turn supplied through a normal feed from the ship service switchboard or an emergency feed from a small emergency generator. Faced with the choice of having either false tripping because of transformer inrush current when the ship service generators are on the line or selectivity when the emergency generator is on the line, the latter is preferred. Although the transformer transient inrush current may reach 8 to 10 times full load current, the probability of achieving the maximum value is not great. Thus, the 600-700 percent instantaneous setting is accepted with the knowledge that the breaker may have to be reclosed occasionally because of false tripping on transformer inrush current.

E. Circuit breaker No. 17:

(1) Maximum available fault current = 7690 amps.
Resultant current = 80 amps.
Use type ALB-10 breaker with 100 amp. coil

(2) Long time delay and magnetic trip are not adjustable.

F. Circuit breaker No. 18:

(1) Maximum available fault current = 5110 amps.
Resultant current = 33 amps.
Use type ALB-5 breaker with 35 amp. coil

(2) Long time delay and magnetic trip are not adjustable.

G. Circuit breaker No. 19:

(1) Maximum available fault current = 3490 amps.
Use type ALB-1 breaker with 15 amp. coil.

(2) Long time delay and magnetic trip are not adjustable.

H. Circuit breaker No. 8 (high speed coolant pump):

(1) Maximum available fault current = 35,100 amps.
Full load current = 700 amps.
Use type ACB–1600 breaker with 800 amp. coil.

(2) Long time delay setting:
150 percent full load current = 1.50 (650) = 975 amps.
LTD setting = 1280 amps. (minimum available setting)

(3) Short time delay setting: Not required

(4) Instantaneous trip setting:
Twice locked-rotor starting current = 2(2200) = 4400 amps.
Instantaneous setting = 4400 amps.

I. Ship service motor-generator sets Nos. 1 and 2:

(1) Full load current of generator = 482 amps.
Maximum available fault current = 29,800 amps.
Use type ACB–640 breaker with 560 amp. coil.

(2) Long time delay setting:
150 percent full load current = 1.50 (482) = 723 amps.
LTD setting = 840 amps.

(3) Short time delay setting:
80 percent of sustained short circuit current = 0.80(1563) = 1250.4 amp.
STD setting = 1120 amps., time band No. 3

(4) Instantaneous setting
120 percent I''_g = 1.20(5160) = 6190 amps.
Instantaneous setting = 6200 amps.
With the above setting and a ship service generator operating, a fault on the motor-generator side of the breaker will allow the MG breaker to trip without tripping the MG-TG tie breaker. Since the setting is above the maximum current which can be supplied by the motor-generator set, the breaker will not trip on instantaneous because of a fault on the bus side of the MG breaker.

J. Circuit breaker No. 16 (rod drive MG set):

(1) Maximum available fault current = 28,400 amps.
Full load current = 118 amps.
Use type AQB–LF250 breaker with 125 LM coil.

(2) Long time delay: 125 amp. coil

(3) Short time delay: not applicable

(4) Instantaneous setting:
1200 percent coil rating = 12(125) = 1500 amps.
Instantaneous setting = 1950 amps.

K. MG-TG tie breaker No. 5:

(1) Maximum available fault current = 35,100 amps.
Resultant load current = 850 amps.
Use type ACB–1600 breaker with 1000 amp. coil.

(2) Long time delay setting:
150 percent resultant load current = 1.50 (850) = 1275 amps.
LTD setting = 1600 amps.

(3) Short time delay setting:
120 percent instantaneous of breaker No. 16 = 1.20(1950) = 2340 amps.
80 percent short time delay of bus tie = 0.80(6000) = 4800 amps.
STD setting = 2400 amps., time band No. 2.

(4) Instantaneous setting: 40,000 amps. (maximum value).

Ordinarily, the long time delay setting for a bus tie breaker is 80 percent of the generator circuit breaker LTD pickup setting. In this case,an LTD setting of 0.80(840) = 672 amps. would result. Since the resultant load current of the bus tie circuit is 850 amps., the above setting is not practical.

Similarly, the short time delay setting for a bus tie breaker is 80 percent of the generator STD pickup. This would result in an STD setting of 0.80(1120) = 896 amps. The above setting is also impractical since the instantaneous trip of a feeder breaker on the MG bus is 1950 amps.

The above settings for the MG-TG tie breaker could be raised by raising the motor-generator pick-up points. However, the STD of the MG breaker would then be above the generator sustained current and the breaker would not trip for faults on the bus side.

For the above reasons, the MG-TG bus tie breaker is set as though it were a feeder breaker supplying load from the turbo-generator and the MG breaker is set to protect the motor generator.

L. Circuit breaker No. 7:

(1) Maximum available fault current = 35,100 amps.
Resultant load current = 1520 amps.
Use type ACB–1600 breaker with 1600 amp. coil.

(2) Long time delay setting:
150 percent resultant load current = 1.50 (1520) = 2280 amps.
LTD setting = 2400 amps.

(3) Short time delay setting:
80 percent STD of bus tie breaker = 0.80(6000) = 4800 amps.
STD setting = 4800 amps., time band No. 1

(4) Instantaneous setting: 40,000 amps. (maximum setting available)

M. Circuit breaker No. 15 (6SA–4P–6SA1):

(1) Maximum available fault current = 31,860 amps.
Resultant load current = 230 amps.
Use type AQB–LF250 breaker with 250 amp. coil.

(2) Long time delay setting: 250 amp. coil.

(3) Short time delay setting: not required

(4) Instantaneous setting:
Sum of 1.6 times starting current of largest motor plus full load current of the balance of the loads = 361 amps.
80 percent minimum current = 0.80(2720) = 2176 amps.
Highest instantaneous setting of any AQB breaker in series = 900-1050 amps.
Instantaneous setting of breaker No. 15 = 1300 amps. which is the HI (high) setting for a 250L coil.

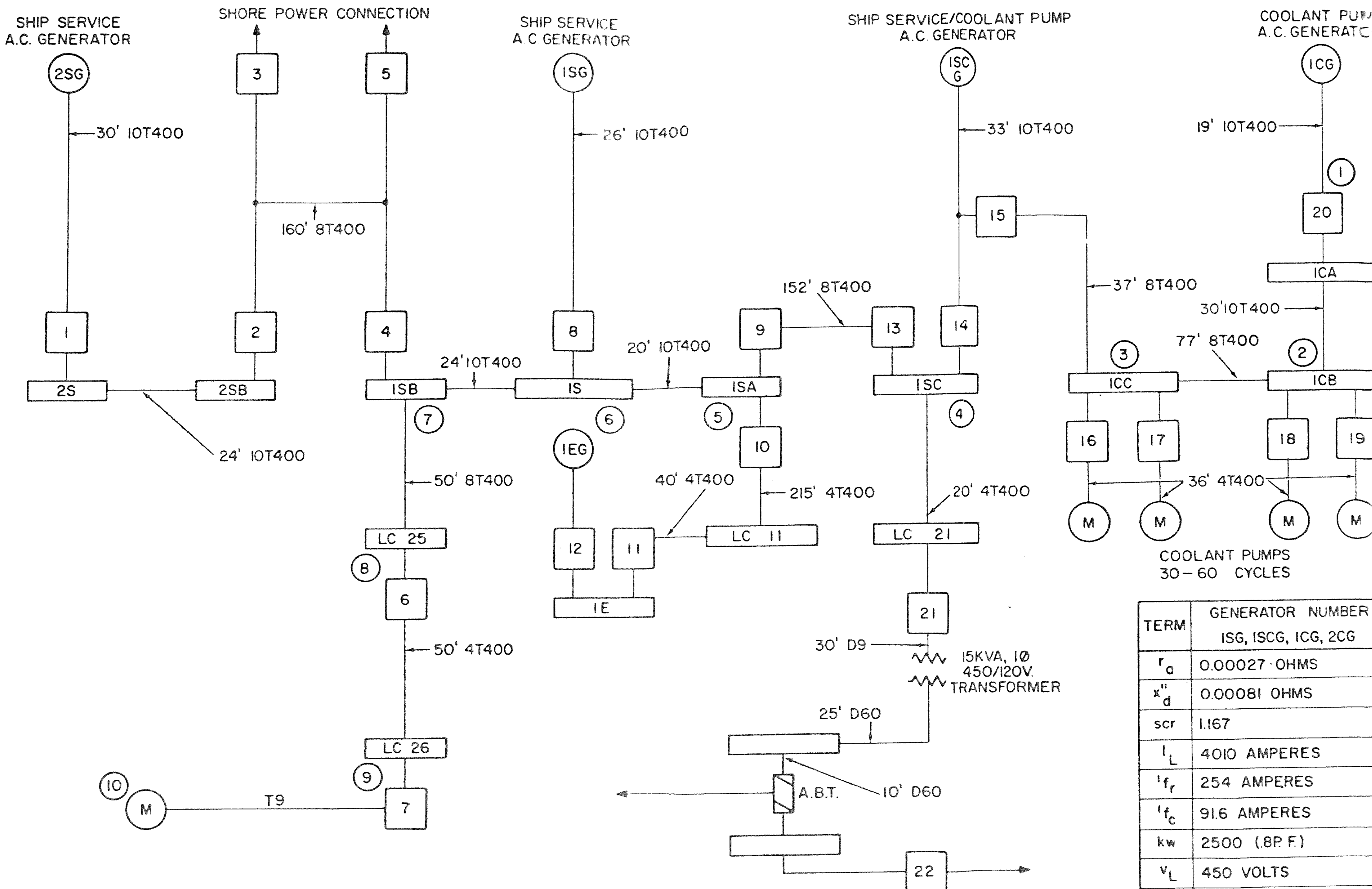
N. Circuit breaker No. 21 (6SA1–4P–(4–48–1):

(1) Resultant load current = 68 amps.
Use type AQB-A100 breaker with 75 amp. coil.

(2) Instantaneous setting:
Sum of 1.6 times starting current of largest motor plus full load current of the balance of the load = 126 amps.
Instantaneous setting = 900-1050 amps.

This instantaneous setting is used to prevent false non-tripping for a fault on circuit No. (4-19-3)-4P-A, which requires a 30 amp. fuse.

O. Fuse No. (4-19-3)–4P–A:
Maximum available fault current — 3930 amps.
Full load current of motor = 7.5 amps.
350 percent full load rating = 3.5(7.5) = 26.25 amps.
400 percent full load rating = 4(7.5) = 30 amps.
Use characteristic C fuse rated 30 amps.



TERM	GENERATOR NUMBER 1SG, 1SCG, 1CG, 2CG
r_a	0.00027 OHMS
x''_d	0.00081 OHMS
scr	1.167
I_L	4010 AMPERES
I_{f_r}	254 AMPERES
I_{f_c}	91.6 AMPERES
kw	2500 (.8P. F.)
V_L	450 VOLTS
x_d	0.0822 OHMS

SHIP SERVICE & REACTOR COOLANT PUMPING POWER SYSTEM OF NUCLEAR POWERED SURFACE SHIP
EXAMPLE 3

EXAMPLE 3

1. Fault current calculations for coolant pump system

Since maximum fault current will occur at 60 cycles, the calculations will be made on the 60-cycle basis.

Impedance from Coolant Pump Generators to Switchboard ICC
450-Volt Base

Section	Distance (Feet)	Cable Size	Ohms per 1000 Ft. R	Ohms per 1000 Ft. X	Section Ohms R	Section Ohms X	Cumulative Ohms R	Cumulative Ohms X
Gen. 1SCG (X''_d)		—	—	—	0.00027	0.0081	0.00027	0.0081
1SCG-3	37	10T400	0.0031	0.0025	0.00011	0.0001	0.00038	0.0082
Gen. 1CG (X''_d)	...	—	—	—	0.00027	0.0081	0.00027	0.0081
1CG-1	19	10T400	0.0031	0.0025	0.00006	0.00005	0.00033	0.0081
1-2	30	10T400	0.0031	0.0025	0.00009	0.0001	0.00042	0.0082
2-3	77	8T400	0.0039	0.0031	0.0003	0.0002	0.00072	0.0084

A. Average of the maximum asymmetrical RMS currents of the three phases at 1/2 cycle through coolant pump generator breaker No. 1CG:

The maximum current through the generator breaker would occur with two generators and four coolant pumps operating at 60 cycles. The maximum current would result from a fault between generator and generator breaker with the remaining generator and four coolant pump motors feeding the fault.

$I_m = 4(1220) = 4880$ amps.

$$I_{avg} = 3.5\ I_m + \frac{1.25 E_g}{x} = 3.5(4880) + \frac{1.25(260)}{0.0083} = 17{,}100 + 39{,}200 = 56{,}300 \text{ amps.}$$

B. Minimum sustained RMS asymmetrical short circuit current of coolant pump generator No. 1CG:

$$I_g = \frac{\frac{I_{fr}}{I_{fe}}(\text{S.C.R.})\, x_d I_r}{x_d + x_e} = \frac{\frac{254}{91.6}(1.167)(0.0822)(4010)}{0.0822} = 12{,}900 \text{ amps. (60 cycle)}$$

C. Average of the maximum asymmetrical RMS currents of the three phases at 1/2 cycle at switchboard No. ICC with generators 1SCG and ICG in parallel:

The maximum current through a coolant pump breaker would result from a fault between motor and motor breaker with two generators and three motors feeding current through the breaker.

$I_m = 3(1220) = 3660$ amps.

$$\frac{1}{x_{parallel}} = \frac{1}{x_{1SG-3}} + \frac{1}{x_{1CG-3}} = \frac{1}{0.0082} + \frac{1}{0.0084} = 241$$

$$X = \frac{1}{241} = 0.00415 \text{ ohm}$$

$$I_{avg} = 3.5\ I_m = \frac{1.25 E_g}{x} = 3.5(3660) + \frac{1.25(260)}{0.00415} \quad 91{,}100 \text{ amps.}$$

II. Fault current calculation for ship service system:

Impedances from Switchboard 1S to Location 10
450-Volt Base

Section	Distance (Feet)	Cable Size	Ohms per 1000 Feet R	Ohms per 1000 Feet X	Section Ohms R	Section Ohms X	Cumulative Ohms R	Cumulative Ohms X
6-7	24	10T400	0.0031	0.0025	0.0001	0.0001	0.0001	0.0001
7-8	50	8T400	0.0039	0.0031	0.0002	0.0002	0.0003	0.0003
8-9	50	4T400	0.0078	0.0062	0.0004	0.0003	0.0007	0.0006
9-10	50	T9	1.40	0.037	0.0700	0.0019	0.0707	0.0025

Impedances from Ship Service Generators to Switchboard 1S

Section	Distance (Feet)	Cable Size	Ohms per 1000 Feet R	Ohms per 1000 Feet X	Section Ohms R	Section Ohms X	Cumulative Ohms R	Cumulative Ohms X
Gen. 1SG (X''_d)	—	—	—	—	0.00027	0.0081	0.0003	0.0081
1SG 6	26	10T400	0.0031	0.0025	0.0001	0.0001	0.0004	0.0082
Gen. 1SCG (X''_d)		-			0.00027	0.0081	0.0003	0.0081
1SCG 4	33	10T400	0.0031	0.0025	0.0001	0.0001	0.0004	0.0082
4 5	152	8T400	0.0039	0.0031	0.0006	0.0005	0.0010	0.0087
5-6	20	10T400	0.0031	0.0025	0.0001	0.0001	0.0011	0.0088

A. Average of the maximum asymmetrical RMS currents of the three phases at 1/2 cycle at switchboard No. 1S:

$I_m = 2/3(4010) = 2670$ amps.

$$\frac{1}{X} = \frac{1}{X_{1SG-6}} + \frac{1}{X_{1SCG-6}} = \frac{1}{0.0082} + \frac{1}{0.0088} = 122 + 114 = 236$$

$$X = \frac{1}{236} = 0.00424 \text{ ohm}$$

$$I_{asy} = 3.5\ I_m + \frac{1.25E_g}{X} = 3.5(2670) + \frac{1.25(260)}{0.00424} = 9{,}340 + 76{,}700 = 86{,}040 \text{ amps.}$$

B. Minimum available RMS asymmetrical short circuit current at ten:

Assuming only generator 1SCG in operation:

$R = R_{1SCG-6} + R_{6-10} = 0.0011 + 0.0707 = 0.0718$ ohm

$X = X_{1SCG-6} + X_{6-10} = 0.0088 + 0.0025 = 0.0113$ ohm

$\sqrt{R^2+X^2} = 0.0725$ ohm

$$I_{min} = \frac{E_g}{\sqrt{R^2+X^2}} = \frac{(260)}{0.0725} = 3600 \text{ amps.}$$

III. Selection of protective devices

A. Ship service and coolant pump generators Nos. 1SG, 1SCG, 1CG, 2SG, 2SCG and 2CG

(1) Line-to-line voltage — 450 volts
Full load current of generator — 4010 amps.
Maximum available fault current through breaker = 56,300 amps.
Use type ACB–4000H breaker with 4000 amp. coil

(2) Long time delay setting:
150 percent of full load current = 1.5(4010) = 6015 amps.
LTD setting = 6000 amps.

(3) Short time delay setting:
80 percent sustained short circuit current = 0.8(12,900) = 10,320 amps.
STD setting = 10,000 amps, time band No. 4

(4) Instantaneous trip setting: 80,000 amps. (maximum available)

B. Coolant pump breakers:

(1) Full load current = 1220 amps.
Maximum available fault current = 91,100 amps.
Use type ACB–1600H breakers with 1200 amp. coil

(2) Long time delay setting:
150 percent full load current = 1.5(1220) = 18,300 amps.
LTD setting = 1800 amps. (Not set to protect coolant pump)

(3) Short time delay: not required

(4) Instantaneous setting:
Twice locked-rotor current = 2(5800) = 11,600 amps.
Instantaneous setting = 12,000 amps.

C. Bus tie breakers Nos. 2, 4, 9, and 13:

(1) $I_{s.c.}$ at switchboard = 86,040 amps.
Resultant current = 3200 amps.
Use type ACB–3200H breaker with 3200 amp. coil.

(2) Long time delay setting:
150 percent resultant current = 1.5(3200) = 4800 amps.
80 percent generator LTD = 0.8(6000) = 4800 amps.
LTD setting = 4800 amps.

(3) Short time delay setting:
80 percent generator STD=0.8(10,000) = 8000 amps.
STD setting = 8000 amps., time band No. 3

(4) Instantaneous setting: 80,000 amps. (maximum available)

D. Shore connection circuit breaker No. 3 and 5:

(1) Capacity = 1600 amps.
$I_{s.c.}$ = 86,000 amps.
Use type ACB–1600H breaker with 1600 amp. coil

(2) Long time delay setting:
150 percent rating = 1.5(1600) = 2400 amps.
LTD setting = 2400 amps.

(3) Short time delay setting:
Generator STD = 10,000 amps., time band 4
STD setting = 8000 amps., time band 3 (Maximum available)

(4) Instantaneous trip setting = 80,000 amps. (Maximum available)

E. Circuit breaker No. 6

(1) Maximum available fault current = 74,000 amps.
Resultant current = 1300 amps.
Use type ACB–1600H breaker with 1400 amp. coil

(2) Long time delay setting:
80 percent of LTD of bus tie breaker = 0.8(4800) = 3840 amps.
150 percent resultant current = 1.5(1300) = 1950 amps.
LTD setting = 2100 amps.

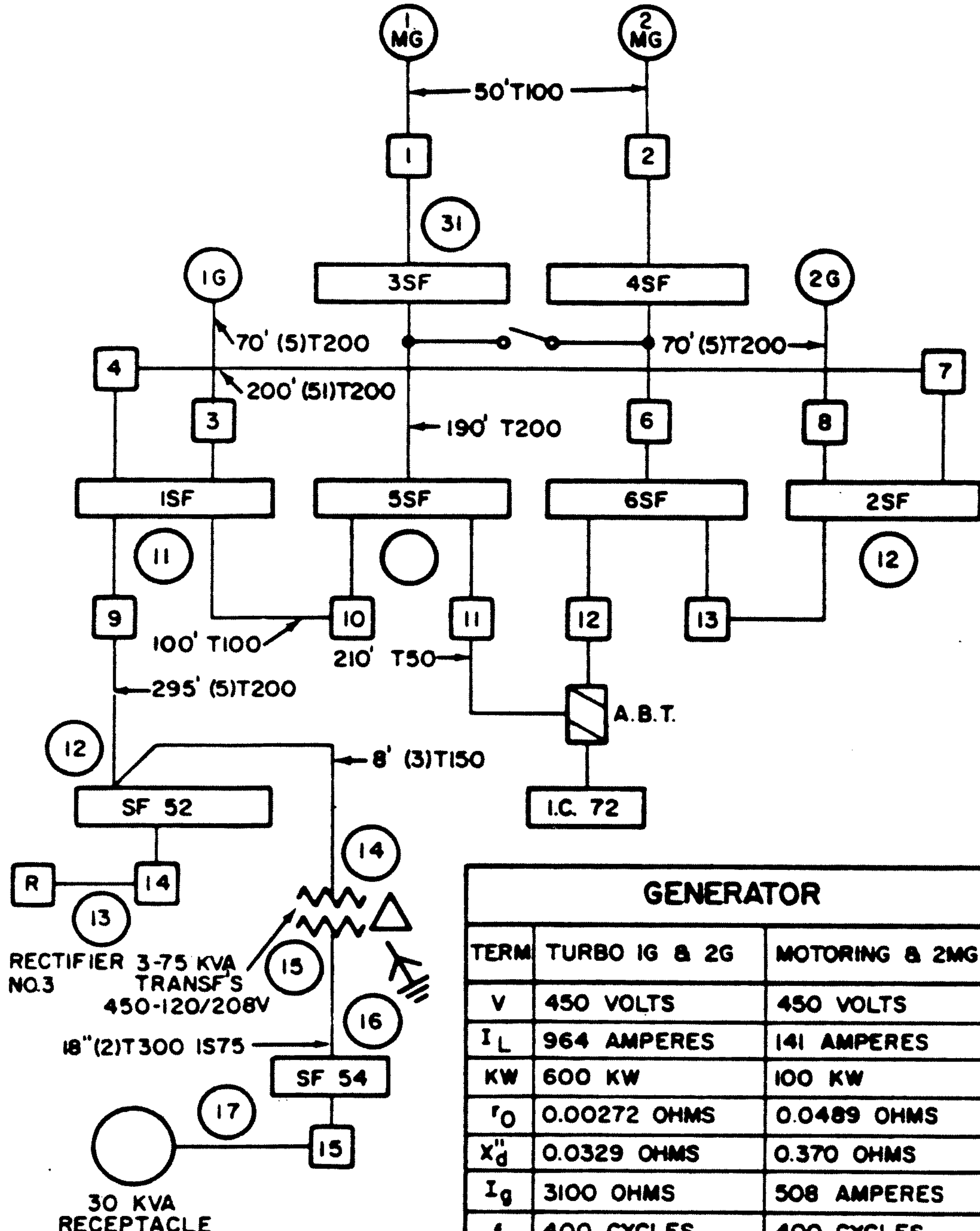
(3) Short time delay setting:
80 percent of STD of bus tie breaker = 0.8(8000) = 6400 amps.
120 percent highest AQB instantaneous = 1.2(3900) = 4680 amps.
STD setting = 4800 amps., time band No. 2

(4) Instantaneous setting: 80,000 amps. (maximum available)

F. Circuit breaker No. 7

(1) Maximum available fault current = 72,000 amps.
Full load current = 26 amps.
Use type AQB-LF100 breaker with 50D coil

(2) Instantaneous setting:
80 percent of minimum current = 0.8(3110) = 2488 amps.
Instantaneous setting = 600-700 amps.



GENERATOR		
TERM	TURBO 1G & 2G	MOTORING & 2MG
V	450 VOLTS	450 VOLTS
I_L	964 AMPERES	141 AMPERES
KW	600 KW	100 KW
r_O	0.00272 OHMS	0.0489 OHMS
X''_d	0.0329 OHMS	0.370 OHMS
I_g	3100 OHMS	508 AMPERES
f	400 CYCLES	400 CYCLES

NOTE:
(3)6SGA-200 CABLES MAY BE SUBSTITUTED FOR GENERATOR, BUS TIE AND FEEDER CABLE INSTEAD OF (5)TSGA-200 CABLES. ALTHOUGH CALCULATIONS WERE BASED ON (5)TSGA-200 CABLES, THE DIFFERENCE IN THE RESULTS USING (3)6SGA-200 CABLE WOULD BE NEGLIGIBLE.

SHIP SERVICE 400-CYCLE POWER SYSTEM
EXAMPLE 4

Example 4

EXAMPLE 4

Impedances from Switchboard 1SF to Locations 13 and 17
450-Volt Base

Section	Distance (Feet)	Cable Size	Ohms per 1000 feet R	Ohms per 1000 feet X	Section Ohms R	Section Ohms X	Cumulative Ohms R	Cumulative Ohms X
11-12	295	5T200	0.015	0.034	0.0044	0.0100	0.0044	0.0100
12-13	25	T60	0.220	0.180	0.0006	0.0045	0.0050	0.0145
12-14	8	3T150	0.030	0.057	0.0002	0.0005	0.0046	0.0105
14-15	Transf.				0.0376	0.0724	0.0422	0.0829
15-16 (1)	18	2T300	0.145	0.375	0.0026	0.0067	0.0448	0.0896
16-17 (1)	70	2F50	0.610	0.422	0.0427	0.0296	0.0875	0.1192
11-51	100	T100	0.140	0.170	0.0140	0.0170	0.0140	0.0170
Gen. 1G (X''_d)					0.0027	0.0329	0.0027	0.0329
1G-11	70	5T200	0.015	0.034	0.0010	0.0024	0.0037	0.0353
1MG(X''_d)					0.0489	0.570	0.0489	0.570
1MG-31	50	T100	0.140	0.170	0.0070	0.009	0.0559	0.579
31-51	190	T200	0.075	0.170	0.0143	0.323	0.0702	0.902
Gen. 2G (X''_d)					0.0027	0.0329	0.0027	0.0329
2G-12	70	5T200	0.015	0.034	0.0010	0.0024	0.0037	0.0353
12-11	200	5T200	0.015	0.034	0.0030	0.0068	0.0067	0.0421

(1) $Z_{450} = Z_{208}\left(\frac{450}{208}\right)^2$

I. Calculation of fault currents

A. Maximum available short circuit current at switchboard No. 1SF (Location Eleven):

Motor contribution is considered negligible since power is used for aircraft servicing and electronics.

Average of the maximum asymmetrical RMS currents of the three phases at 1/2 cycle:

Assuming generators 1G and 2G in parallel:

$$x_{parallel} = \frac{1}{\frac{1}{0.0353}+\frac{1}{0.0421}} = \frac{1}{28.3+23.8} = \frac{1}{52.1} = 0.0102 \text{ ohm.}$$

$$I_{avg} = \frac{1.25E_g}{x} = \frac{1.25(260)}{0.0192} = 16{,}900 \text{ amps.}$$

B. Minimum available RMS asymmetrical short circuit current

At seventeen, assuming only generator No. 1MG in operation:
R = 0.0702 + 0.0140 + 0.0875 = 0.1717 ohm
X = 0.902 + 0.0170 + 0.1192 = 1.0382 ohms

$$I_{min} = \frac{E_g}{\sqrt{R^2+X^2}} = \frac{(260)}{\sqrt{.0172^2+1.04^2}} = \frac{(260)}{1.04} = 250 \text{ amps. at 450 V.}$$

$$= 217\left(\frac{450}{208}\right) = 540 \text{ amps.}$$

II. Selection of Protective Devices.

A. Turbo-generator breakers No. 1G and 2G:

(1) Line-to-line voltage = 450 volts.
Full load current = 964 amps

Maximum fault current = 16,900 amps
Use type ACB – 1600 breakers with 1000 amp coils

(2) Long time delay setting:
150 percent – full load current = 1.5(964) = 1450 amps
LTD setting = 1600 amps

(3) Short time delay setting:
80 percent sustained short circuit current = 0.8(3100) = 2480 amps
STD setting = 2400 amps, time band No. 3

(4) Instantaneous setting: 40,000 amps (maximum available)

B. Bus tie breakers Nos. 4 and 7

(1) Full load current = 640 amps
Maximum fault current = 16,900 amps
Use type ACB–610 breaker with 640 amp coil

(2) Long time delay setting:
80 percent generator LTD = 0.8 (1600) = 1280 amps
LTD setting = 1280 amps.

(3) Short time delay setting:
80 percent generator STD = 0.8(2400) = 1920 amps
STD setting = 1600 amps, time band No. 2

(4) Instantaneous setting: 20,000 amps (maximum available)

C. Feeder breaker No. 9:

(1) Maximum fault current = 16,900 amps
Full load current = 290 amps
80 percent bus tie LTD = 0.8(1280) = 1024 amps
Use type AQB–A400 breaker with 300 amp coil

(2) Instantaneous setting:
1200 percent coil rating = 12(300) = 3600 amps
LTD = 3725 amps

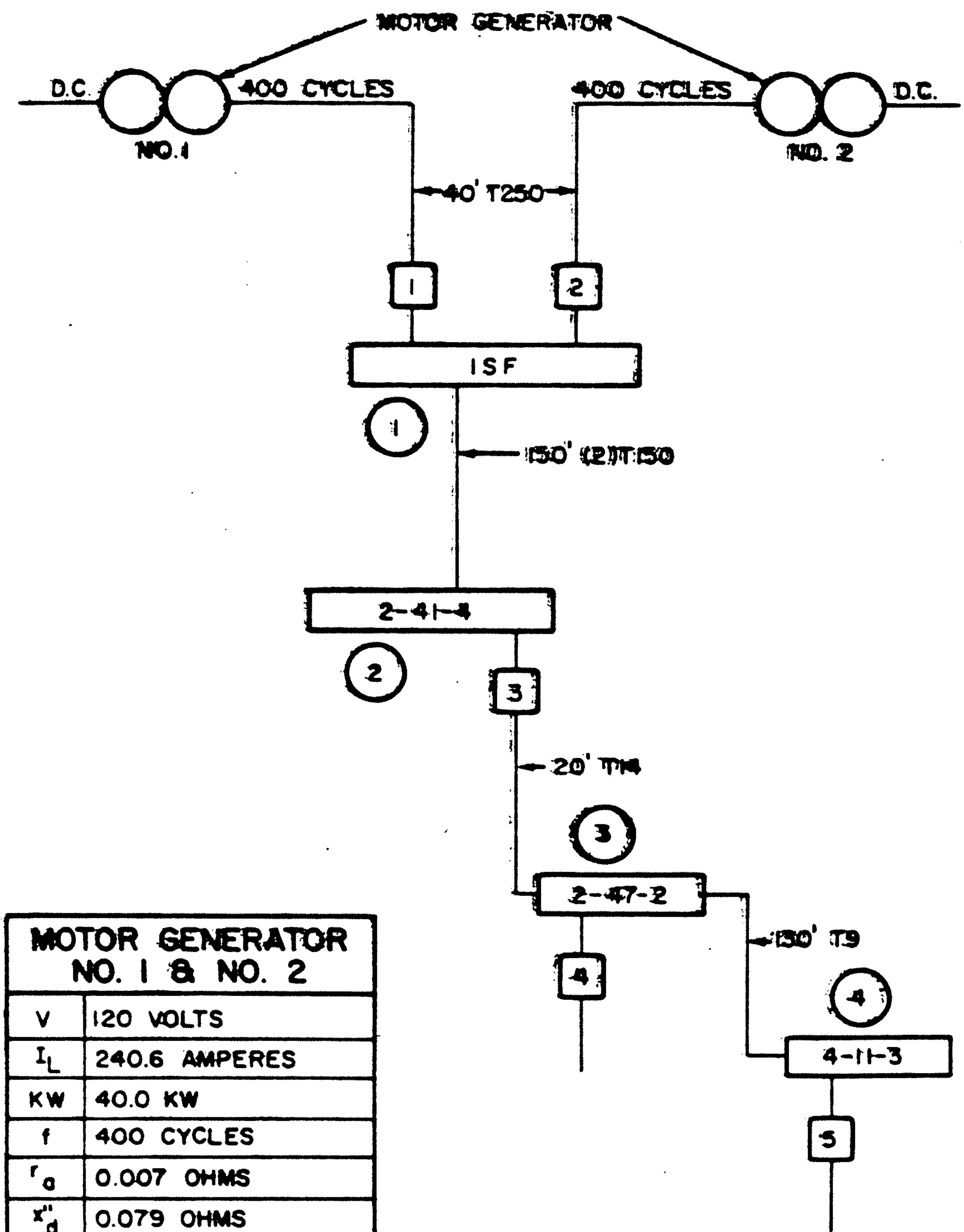
D. Circuit breaker No. Fourteen:

(1) Maximum fault current = 10,400 amps
Full load current = 20 amps
Use type AQB A100 breaker with 25 amp coil

(2) Instantaneous setting: 300–350 amps

E. Circuit Breaker No. Fifteen:
Voltage = 120/208 grounded wye
Full load current = 84 amps
Maximum fault current = 4800 amps
Minimum fault = 469 amps
Use type AQB 100 or A101 breaker with 100 amp coil

F. Motor-generator breaker No. 1
Line-to-line voltage = 450 volts
Full load current = 141 amps
Use type AQB–A250 breaker with 160G amp coil



MOTOR GENERATOR NO. 1 & NO. 2	
V	120 VOLTS
I_L	240.6 AMPERES
KW	40.0 KW
f	400 CYCLES
r_a	0.007 OHMS
x''_d	0.079 OHMS
I_g	1050 AMPERES

SHIP SERVICE 400-CYCLE SYSTEM
EXAMPLE 5

Example 5

EXAMPLE 5

Impedances from Switchboard 1SF to Location (4)
120-Volt Base

Section	Distance (Feet)	Cable Size	Ohms per 1000 feet R	X	Section Ohms R	X	Cumulative Ohms R	X
1-2	150	2T150	0.045	0.085	0.0068	0.0128	0.0068	0.0128
2-3	20	T14	0.88	0.20	0.0176	0.0040	0.0244	0.0168
3-4	130	T9	1.4	0.24	0.182	0.0312	0.2064	0.0480
Gen								
1MG (X''_d)					0.007	0.0790	0.0070	0.0790
1MG-1	40	T250	0.068	0.16	0.0027	0.0064	0.0097	0.0854
Gen								
2MG (X''_d)					0.007	0.079	0.0070	0.0790
2MG-1	40	T250	0.068	0.16	0.0027	0.0064	0.0097	0.0854

Assuming generators 1MG and 2MG in parallel:

$$\frac{1}{X_{parallel}} = \frac{1}{0.0854} + \frac{1}{0.0854} = \frac{2}{0.0854}$$

$$X_{parallel} = \frac{0.0854}{2} = 0.0427 \text{ ohm}$$

I. Calculation of fault currents

A. Average of the maximum asymmetrical RMS currents of the three phases at 1/2 cycle at switchboard 1SF (location 1):

Motor contribution is considered negligible since power is used for electronics.

$$I_{avg} = \frac{1.25\ E_g}{x} = \frac{1.25\,(69.3)}{0.0427} = 2030 \text{ amps}$$

B. Minimum available RMS asymmetrical short circuit current.
At four assuming only generator 1MG in operation:
$R = 0.0097 + 0.2064 = 0.2161$ ohm
$X = 0.0854 + 0.0480 = 0.1334$ ohm

$$I_{min} = \frac{E_g}{\sqrt{R^2+X^2}} = \frac{(69.3)}{\sqrt{0.2161^2+0.1334^2}} = 254 \text{ amps.}$$

II. Selection of Protective Devices

A. Motor-generator breakers Nos. 1MG and 2MG:
Line-to-line voltage = 120 volts
Full load current = 240.6 amps
Maximum fault current = 2030 amps
Use type AQB–A250 circuit breaker with 250G coil

B. Circuit breaker No. 3
Full load current = 15 amps
Use type ALB–10 breaker with 20 amp coil.
A type ALB–5 breaker is not used since the maximum instantaneous trip of 800 amps is the same value as the type ALB–1 breaker and false non-tripping may occur.

C. Circuit breaker No. 5
Full load current = 2 amps
Use type ALB-1 breaker with handles yoked together.
Use 5 amp coil
1 min = 275 amps
Instantaneous setting = not adjustable