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INDUSTRIAL AND COMMERCIAL POWER SYSTEM APPLICATIONS SERIES

SYSTEM NEUTRAL GROUNDING AND GROUND FAULT PROTECTION

- CHARGING CURRENT

GOOD PAPER FOR APPLICATIONS

The Industrial and Commercial Power System Application Series offers Westinghouse suggested procedures for the protection of various types of electrical equipment. The protection shown will be applicable to the majority of cases.

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This application guide is a summary of Westinghouse recommendations on system grounding and ground fault protection for typical industrial and commercial power distribution systems. It applies to 3-phase ac power system between 208Y/120V and 69kV encountered in industrial plants and large commercial structures. Special situations involving safety codes other then NEC*, unusual process requirements, dc systems, etc. must receive individual attention, and will not be covered.

A. INTRODUCTION

1. The primary purposes of system grounding are the following:

   a. limitation of transient overvoltages, caused by restriking ground faults, to the level the equipment is designed to withstand

   b. personnel safety

   c. compliance with codes

   d. fast, selective isolation of ground faults.

2. Power distribution systems fall into the following catagories:

   a. Ungrounded system, (Figure 1) in which there is no intentional connection between the neutral or any phase and ground; i.e., the system is capacitively coupled to ground.

   b. High-resistance grounded system, (Figures 2, 3 and 4) in which the neutral is grounded through a predominantly resistive impedance whose resistance is selected to allow a ground fault current through the resistor equal to or somewhat more than the capacitive charging current of the system. The resistor can be connected either directly from neutral to ground, or in the secondary circuit of one or more transformers. Typical ground fault currents are 1 to 10 A on the primary system. A sample calculation for determining the charging current and selecting high-resistance grounding equipment is given in Appendix II and III. Curves 1 through 4 summarize the typical charging currents of power system components.

   c. Low-resistance grounded system, (Figures 5 and 6) in which the neutral is grounded through a considerably smaller resistance than used for high-resistance grounding. Typical ground fault currents are 50 to 600 A on the primary system.

   d. Solidly grounded system, (Figure 7) in which the neutral (or occasionally one phase) is connected to ground without intentional intervening impedance. Typical ground fault currents are several thousand amperes and may exceed the calculated 3-phase fault current.

   e. Reactance grounded system, (Figure 8) where a reactor is connected from neutral to ground. Typical ground fault currents are 60% to 100% of the 3-phase fault.

As a general rule, it is desirable to limit available ground fault currents to the minimum consistent with the limitation of transient overvoltages to acceptable levels (approximately 250%) and with the re-

*USA National Electrical Code (ANSI C1)

quirements of protective relaying. This is true because the energy released at the fault location is approximately proportional to the square of the fault current, and because ground faults are the most common type of fault in industrial and commercial power systems. Consequently, limiting the available ground fault current by resistance grounding is an excellent way to reduce personnel hazards, damage to faulted equipment, and electrical fire danger. Economic considerations, code requirements, or protective requirements as discussed in section B, often dictate the use of solid grounding despite its disadvantages.

Except in very restricted situations, reactance grounding has no advantages over solid grounding and it is almost never used in industrial and commercial systems.

B. SYSTEM GROUNDING RECOMMENDATIONS:

1. Low-voltage Systems, 1000 V and below:

Refer to Figure 9 for a summary of low-voltage grounding rcommendations.

National Electrical Code (1978) Article 250-5 REQUIRES the following classes of systems to be SOLIDLY GROUNDED:

"(1) Where the system can be so grounded that the maximum voltage to ground on the ungrounded conductors does not exceed 150 volts.

"(2) Where the system is nominally rated 480Y/277-volt, 3-phase, 4-wire in which the neutral is used as a circuit conductor.

"(3) Where the system is nominally rated 240/120-volt, 3-phase, 4-wire in which the midpoint of one phase is used as a circuit conductor.

"(4) Where a service conductor is uninsulated in accordance with Section 230-4."

MOST OTHER LOW-VOLTAGE SYSTEMS SHOULD ALSO BE SOLIDLY GROUNDED, because solid grounding is the least expensive way to limit transient overvoltages while obtaining enough ground fault current for fast, selective fault isolation. However, it is risky to depend on phase overcurrent protection alone to detect ground faults even in solidly-grounded low-voltage systems. High arc and ground return impedances may reduce the ground fault current for remote faults to levels not readily distinguishable from normal load current. Appendix IV illustrates a common example of the effect of arc impedance; the calculations show that primary fuses provide very poor protection against secondary arcing faults on low-voltage power systems.

HIGH RESISTANCE GROUNDING OF LOW-VOLTAGE SYSTEMS SHOULD BE CONSIDERED ONLY WHEN SERVICE CONTINUITY IS OF PARAMOUNT IMPORTANCE, AND A POLICY OF IMMEDIATELY LOCATING AND REPAIRING GROUND FAULTS IS ENFORCED.

Low-resistance grounding is not used on low-voltage systems, primarily because the limited available ground-fault current is insufficient to positively operate the series trip units and fuses depended upon for both phase-to-phase and phase-to-ground fault protection on some or all of the circuits.

Ungrounded operation of low-voltage systems is also not rcommended because of the potential overvoltage problems. Note that most such supposedly "ungrounded" systems are really high-resistance-grounded through the loading resistor of the ground detector circuit. This, together with the relatively high insulation level relative to the rated voltage of low-voltage equipment, explain the historical infrequency of overvoltage-failures in these systems.

UNGROUNDED OR LOW-RESISTANCE GROUNDED OPERATION OF LOW-VOLTAGE SYSTEMS IS NOT RECOMMENDED.

2. Medium-voltage systems, 1001 through 15000V:

Refer to Figure 10 for a summary of recommendations for grounding of systems in this voltage range.

THESE SYSTEMS SHOULD NOT BE OPERATED UNGROUNDED because of the high probability of failures due to transient overvoltages caused by restriking ground faults. Overvoltage limitation is particularly important in systems over 1000V, because equipment in these voltage classes is designed with less margin between 60 Hz test and operating voltages than low-voltage equipment. Any of the grounding methods can be applied, depending on technical and economic factors.

a. LOW-RESISTANCE GROUNDING IS PREFERRED FOR MOST SYSTEMS BETWEEN 1000 and 15000V, especially those which serve directly-connected rotating apparatus. To limit fault damage, the lowest ground fault current (highest resistance) consistent with adequate ground relay sensitivity should be used. As a rule of thumb, enough current must be available for the least-sensitive ground relay to respond to 10% of the maximum ground fault current under minimum ground source conditions.

With properly applied ground relaying, about 50 to 150A of ground fault current is adequate to obtain 10% relay sensitivity. For example, with the combination of the 50:5 type BYZ zero sequence ct and the 0.25-0.5A type ITH instantaneous current relay, which has a combination ct relay pickup of approximately 5A, a maximum ground fault of 50A is sufficient for 10% sensitivity. (Figure 11). By contrast, because of the high ratios of phase ct's, conventional residual relaying (Figure 12) would require hundreds or thousands of amperes of fault current to obtain the desired 10% relay sensitivity. The fault current necessary with residual relay can be reduced by the application of auxiliary ct's in the phase ct neutral circuits. (Figure 13). With ct's applied in conventional switchgear, an auxiliary ct with a ratio of 1:10 or lower will adequately improve the sensitivity of the residually connected ground relay. The performance should be checked with the current transformer excitation curve.

b. **High-resistance grounding:**

High-resistance grounding limits fault damage to a minimum. It SHOULD BE APPLIED in any of the following situations:

(a) when it is essential to prevent unplanned shutdowns; (b) when a single rotating machine is served by a captive transformer; (c) when an existing system has previously been operated ungrounded and no ground relaying has been installed; or (d) in any system where limitation of both fault damage and overvoltages is desired, but ground relay selectivity is not required. Appendix III provides an example of the calculations required to select high resistance grounding equipment, based on the calculated or preferably the measured capacitive charging current of the system.

As a rule, it is preferable to detect and clear the fault rather then letting it persist, to limit localized damage at the fault point. Alarm only schemes are often used when service continuity is very critical, although they present a risk that a sustained ground fault in a small space such as a rotating machine stator slot will progress to a catastrophic phase-to-phase fault.

c. **Solid grounding:**

Solid grounding has the lowest initial cost of all grounding methods. It is recommended for overhead DISTRIBUTION SYSTEMS AND FOR SYSTEMS SUPPLIED BY TRANSFORMERS WHICH ARE PROTECTED BY PRIMARY FUSES. This is necessary to provide enough fault current tc melt the primary fuses on a secondary ground fault. However, it is NOT THE PREFERRED SCHEME FOR MOST INDUSTRIAL AND COMMERCIAL SYSTEMS because of the severe damage potential of high magnitude ground fault currents.

3. With rare exceptions, SYSTEMS OVER 15000V SHOULD BE SOLIDLY GROUNDED to permit the use of equipment with insulation to ground rated for less than full line-to-line voltage, and because neutral grounding equipment in this voltage is prohibitively expensive.

C. GROUND FAULT PROTECTION:

The circuit diagrams in this publication illustrate the ground fault protection techniques most often used in industrial and commercial power systems, with general recommendations covering ratios, characteristics, etc. Refer to the other application guides in this series and to the **Applied Protective Relaying** Handbook (B7235E) for detailed recommendations on application of ground relaying to particular classes of equipment.

1. The NEC in Article 230-95 states that ground fault protection is required for LV solidly grounded systems, and that the minimum level of protection shall be applicable to service disconnecting devices rated 1000 amperes or more. The Article further states that the ground detection device shall have a maximum setting of 1200 amperes and shall function to open all ungrounded conductors of the faulted circuit in one second or less for ground fault currents equal to or greater than 3000 amperes. This requirement is considered minimum protection, and to obtain selective tripping with lower rated downstream devices it is recommended that these lower rated devices also be equipped for ground fault detection and interruption.

2. The zero sequence type CT (BYZ) and associated relay is the recommended scheme for sensitive detection of ground fault currents in medium voltage systems. For such application requiring time delay to coordinate with a downstream ground relay the use of the instantaneous ITH with a separate timing relay will usually provide more accurate timing than a CO relay. This is due to the burden imposed by the CO relay on the BYZ type CT.

APPENDIX I

TYPICAL CHARGING CAPACITANCES (C_0) PER PHASE OF POWER SYSTEM COMPONENTS

Abbreviations: uf = microfarads, (10^{-6})
pf = picofarads (10^{-12})

1. Overhead open-wire lines:

   Negligible for line lengths used in typical industrial/commercial distribution.

2. Shielded power cable, plastic insulation, dielectric constant = 3.3*

Size, AWG or KCMIL	Capacitance, uf/1000 ft. 5kV	15kV	23kV	34.5kV
8	0.0607	–	–	–
6	0.0709	–	–	–
4	0.0836	–	–	–
2	0.0993	0.0401	–	–
1	0.1096	0.0456	0.0345	–
1/0	0.1202	0.0524	0.0388	–
2/0	0.1321	0.0607	0.0441	0.0319
3/0	0.1452	0.0661	0.0504	0.0358
4/0	0.1600	0.0715	0.0546	0.0404
250	0.1598	0.0776	0.0588	0.0460
350	0.1846	0.0844	0.0634	0.0496
500	0.215	0.0920	0.0685	0.0532
750	0.241	0.0981	0.0743	0.0573
1000	0.274	0.1118	0.0789	0.0617

*Multiply capacitances by 1.75 for oiled-paper-insulated cables to account for higher dielectric constant.

3. Non-shielded cable in conduit: 0.02-0.06 uf/1000ft., typically 0.04 uf/1000ft.

4. Non-shielded cable in trays: 0.02-0.05 uf/1000ft., typically 0.03 uf/1000 ft.

5. Surge supression capacitors (values are those typically used; should be checked for each application):

Voltage	Capacitance, uf
480V	1.0
2400V	0.5
4160V	0.5
13.8kV	0.25

6. Turbine-Generators: See Figure 14.

7. Salient-Pole Generators and motors: See Figure 15.

8. Synchronous and induction motors:

Voltage	Capacitance, uf/1000 HP
480V	0.032

See figures 15, 16 and 17 for other voltage ratings

9. Outdoor apparatus bushings:

Voltage	Range	Typical Value
15kV	160-220pf	200pf
23kV	190-450pf	300pf
34.5kV	150-620pf	400pf

10. Outdoor CT's and PT's

Voltage	Device	Range	Typical Value
15kV	L-L PT	200-300pf	260pf
23kV	L-L PT	250-440pf	300pf
23kV	L-N PT	270-800pf	500pf
34.5kV	L-L PT	310-440pf	350pf
34.5kV	L-N PT	270-900pf	550pf
23kV	CT	180-260pf	220pf
34.5kV	CT	160-250pf	200pf

11. Segregated, Non-Segregated and isolated-phase bus:

Capacitances pf/ft.

Ampere Rating	Isophase 15kV	Isophase 23kV	Segregated phase 15kV	Non-Segregated 5-15kV
1200	14.3	12	10	10
2000	14.3	12	10	15
2500	14.3	12	–	–
3000	14.3	12	10	22
3500	14.3	12	–	–
4000	14.3	14	13	29
4500	14.3	14	–	–
5000	19	16	15	–
5500	19	16	–	–
6000	19	16	17	–

12. Transformers: Typically 4000 picofarads per phase.

APPENDIX II

SAMPLE CALCULATION OF CAPACITIVE CHARGING CURRENT (I_{OC}) FOR THE POWER SYSTEM SHOWN IN FIGURE 18

1. Because of delta-wye transformations, zero-sequence system is isolated to 13.8kV level, as shown by broken lines.

2. Itemize the equipment by classes with reference to Appendix I for appropriate charging capacitances, and add for the system total:

Equipment Class	Quantity	Appendix I Reference	C_O Per Unit Quantity	C_O For Equipment Class, uf
20MVA transformer 350kV BIL	1	12	4000pf	0.004
20MVA generator 3600 RPM, air-cooled	1	Fig. 14a	0.10uf	0.10
10,000 HP syn. motor, 1800 RPM, air-cooled (similar to 7500kVA generator)	1	Fig. 14a	0.05uf	0.05
0.25 uf motor surge capacitors	1	5.	0.25uf	0.25

Shielded 15kV cable:				
500KCMIL	1350'	2.	0.092 uf/1000'	0.1242
350KCMIL	1000'		0.0844uf/1000'	0.0844
Bus duct (similar to non-segregated phase)	75'	11	10pf/ft	0.00075
Swgr. bus (similar to non segregated phase), 8 36" cubicles	24'	11	10pf/ft	0.00024
12.5MVA transformer, 110kV BIL	1	12	4000pf	0.004
Power center transformers, 110kV BIL				
2000kVA	6		4000pf	0.024
1500kVA	4		4000pf	0.016
Other equipment	–		–	Negligible
Total charging capacitance, uf/phase				0.658

3. The capacitive charging current I_{OC} per phase is

$$I_{oc} = \frac{V_{LL}}{\sqrt{3}(X_{co})}$$

$$\text{where } X_{co} = \frac{10^6}{2\pi f C_o} = \frac{10^6}{2\pi(60)(.658)} = -j4031 \text{ ohms per phase}$$

$$Ioc = \frac{13{,}800}{\sqrt{3}\,(4031)} = 1.98 \text{ amperes per phase}$$

APPENDIX III

SAMPLE CALCULATIONS FOR APPLYING HIGH-RESISTANCE GROUNDING EQUIPMENT FOR THE POWER SYSTEM SHOWN IN FIGURE 18

1. Make the resistive component of current (I_{OR}) equal to the charging component of current (I_{OC}). Thus for figure 18 from Appendix II,

   $I_{OR} = I_{OC} = 1.98$ amperes per phase.

2. The alternate 1 grounding shown in Figure 18 is detailed in Figure 19

a. Transformer ratio: the primary rating must be at least equal to system line-line voltage since system neutral is displaced during fault as illustrated in Figure 19c. The transformers on the unfaulted phase see approximately full V_{LL}. Lower voltage ratings are not recommended as they invite insulation failures and ferroresonance. Select distribution transformers rated 13.8kV:240/120V.

b. For purposes of this example, it is assumed immediate tripping for a ground fault cannot be tolerated. Therefore, to permit continuous operation with a ground fault, use a 199 volt CV-8 relay, 59G for alarm, and connect the transformer secondary for 120 volts.

c. For a solid ground fault, the transformer primary current I_{OR} will be 1.98 amperes. The circulating secondary current will be

$$I'_{OR} = I_{OR}\left(\frac{13{,}800}{120}\right) = 228 \text{ amperes}$$

d. Transformers on unfaulted phases have primary voltage of V_{LL} = 13.8kV; third transformer primary is shorted by the fault current path and sees zero voltage. Therefore voltage across open delta corner is vector sum of two 120V quantities 120° apart, or $3V_{OR}$ = 208 volts secondary approximately.

Alternately, $V_{OR} = I_{oc}(X_{oc}) = 1.98 \times 4031$

$= 7981$ volts primary

$$V'_{OR} = 7981\left(\frac{120}{13800}\right) = 69.4 \text{ volts secondary}$$

$3V_{OR}$ = 23,943 volts primary

$3V'_{OR}$ = 208.2 volts secondary

e. Resistor value must be

$$R = 3R_0 = \frac{3V'_{OR}}{I'_{OR}} = \frac{208.2}{228} = 0.913 \text{ ohms}$$

f. Resistor power dissipation must be

$$P_R = I'_{OR}{}^2 R = (228)^2 \times .913 = 47.46\text{kW}$$

g. Transformer kVA rating is

$$P_T = 1.98 \times 13.8 = 27.32\text{kVA per phase}$$

h. In this example, it is assumed operation with a ground fault will be permitted pending an orderly shutdown. Thus, the resistor and transformers should be rated for continuous duty. In other systems where the CV-8 is connected to trip the power sources, the required ratings can be decreased according to applicable overload capabilities.

3. The alternate 2 grounding shown in Figure 18 is detailed in Figure 20.

a. Transformer primary rating should be at least V_{LN}. The full line-line rating is not needed because transformer cannot see more than V_{LN} during a ground fault. Otherwise, the ratio depends on whether 59G will trip or alarm only, and on economics. Possibilities are:

Ratio	Max V_0	CV-8 Rating	Function	Relay Sensitivity $= \left(\frac{\text{Relay Pickup}}{V_o}\right)(100)$
ϕ 8kV:120V	119.5	67V	Trip*	4.5%
ϕ 8kV:120V	119.5	199V	Alarm	13.4%
8kV:240V	239.0	199V	Trip	6.7%
13.8kV:120V	69.3	67V	Alarm or Trip	7.8%
13.8kV:240V	138.6	67V	Trip*	3.9%
14.4kV:120V	66.4	67V	Alarm or Trip	8.1%
8kV:480V plus 480V:120V VT	119.5	67V	Trip*	4.5%
8kV:480V plus ϕ 480:120V VT	119.5	199V	Alarm	13.4%

67 volt CV-8 pickup is 5.4 volts; 199 volt CV-8 pickup us 16 volts.

*The 67 volt CV-8 can be used with an SV relay and resistor for sensitive ground fault alarms. This circuit is shown in Fig. 6-5 page 6-4 of the Applied Protective Relaying Book (B-7235E) 1976.

ϕ Selection for subsequent calculations.

b. For alarm service, select 8kV:120V transformer and 199V CV-8 relay, which provides adequate sensitivity at minimum equipment cost.

1) $3I_{OR} = 5.94\text{Amp (primary)}$

$$3I'_{OR} = (5.94)\left(\frac{8000}{120}\right) = 396 \text{ Amp. (secondary)}$$

$$R' = \frac{V'_o}{3I_{OR}} = \frac{119.5}{396} = 0.302 \text{ ohms.}$$

2) Resistor Power:

$$P_R = (3I'_{OR})2\ R' = (396)^2\ (0.302) = 47.36\text{kW}$$

3) Transformer kVA rating is determined by primary current and primary voltage selected.

$$P_T = (3I_{OR})\ (V_T) = (5.94)\ (8.0) = 47.52\text{kVA.}$$

c. For tripping service select 8kV:120V transformer and use a 67V CV-8 relay. Because of short-time loading, the power ratings of the resistor and transformer can be reduced to a minimum of 10% of the calculated power requirements, or about 5kW and 5kVA respectively.

Selection of the grounding system. Either of the two alternates shown in Figure 18 give adequate protection from transients and provide sensitive fault detection. Alternate 1 is preferred as only one set of transformers and one resistor are required. The economic comparison in the example is three 50kVA transformers and one 50kW resistor vs two 50kVA transformers and two 50kW resistors.

Both generator and transformer neutrals must be grounded in alternate 2 to ensure that the system will be grounded when one of the sources is out of service.

APPENDIX IV

SAMPLE CALCULATION ILLUSTRATING THE DIFFICULTIES OF PROTECTION AGAINST ARCING GROUND FAULTS WITH PRIMARY FUSES AND PHASE SERIES TRIPS

1. A typical system is shown in Figure 21. For a bolted single line to ground fault (F1) at the power center:

$$I_F = 3I_{OF} = \frac{3V_{LN}}{Z_1 + Z_2 + Z_o}$$

In per unit on a 750kVA base:

For the source $Z_1 = Z_2 = \frac{750}{250{,}000} = j.003\text{pu}$

For the transformer $Z_1 = Z_2 = Z_o = j.0575$ pu

Assuming no motor contributor at the 480Y/277 volt bus, the total sequence impedances to the fault F_1 are

$Z_1 = Z_2 = j.003 + j.0575 = j.0605$ pu

$Z_o = j.0575$ pu

$$I_F = \frac{j3}{j.0605 + j.0605 + j.0575} = \frac{j3}{j.1785}$$

= 16.81 per unit

The actual fault current at 480 volts is

$$I_F = 16.81 \text{ X } \frac{750}{\sqrt{3}\text{X}.48} = 16.81 \text{ X } 902.1$$

= 15,164 amperes

2. The effect of an arcing fault is to reduce the current significantly at this voltage level. A typical arc voltage for arcs in switchboard-type enclosures is about 150 volts, essentially independent of the current magnitude. Thus for an arcing fault in the secondary switchgear.

$$I_{F(arcing)} = (15{,}164)\left(\frac{277\text{-}150}{277}\right) = 6952 \text{ amperes}$$

3. As illustrated in Figure 22, the primary current flowing thru the fuses will be

$$I_{pri} = 6952\left(\frac{480}{\sqrt{3}\ 4160}\right) = 463 \text{ amperes}$$

The fuse curve indicates that the total clearing time is about 200 seconds for 463 amperes, a very long time to clear the fault.

4. To illustrate effect of this delay, the energy (E) released in faulted switchboard is

$$E = V_{ARC}\, I_{F(arcing)}\, T_{FAULT} = (150V)\,(6952A)\,(200\ SEC) =$$

$$= 2.09 \times 10^{8}\ \text{Joules} = (1.98 \times 10^{5}\ \text{B.T.U.})$$

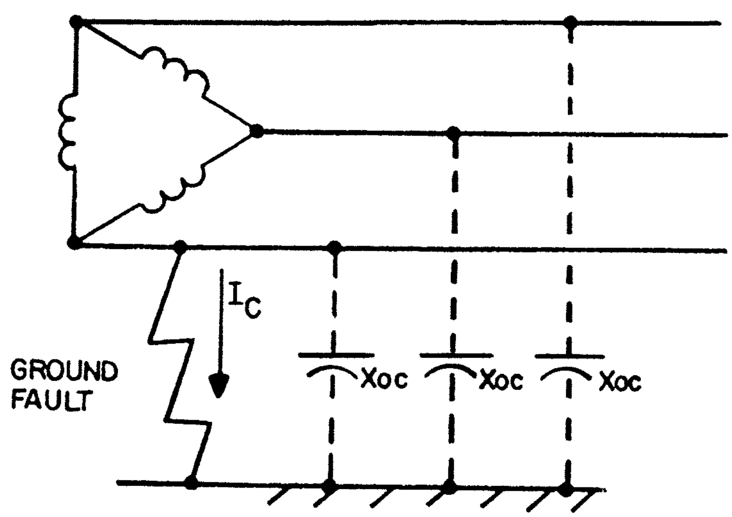
This is enough to melt 739lb. of copper, starting at 75°F and assuming no reduction of the heat.

5. Similar calculations including impedance of cable to remote bus give arcing ground fault current of only 2100 Amp. at remote bus. This current takes 60 sec. to trip typical LA molded-case breaker, releasing 4.0×10^{7} joules in remote panel, enough to melt 95 lb. of copper, assuming no reduction of the heat.

6. **CONCLUSIONS**

   a. Primary fuses selected to permit full use of transformer capabilities provide very little protection against secondary arcing ground faults. Main secondary breaker, preferrably with ground trips, is strongly recommended.

   b. Secondary phase protection also provides poor protection for remote arcing ground faults and sensitive ground protection is recommended.



During a ground fault, the charging current is:

$$I_c = 3I_0 = \frac{\sqrt{3}\, V_{LL}}{X_{oc}} = \frac{3V_{LN}}{X_{oc}}$$

where I_0 is the zero sequence current.

Fig. 1. Ungrounded system is capacitively coupled to ground thru distributred capacitances of cables, equipment, etc.

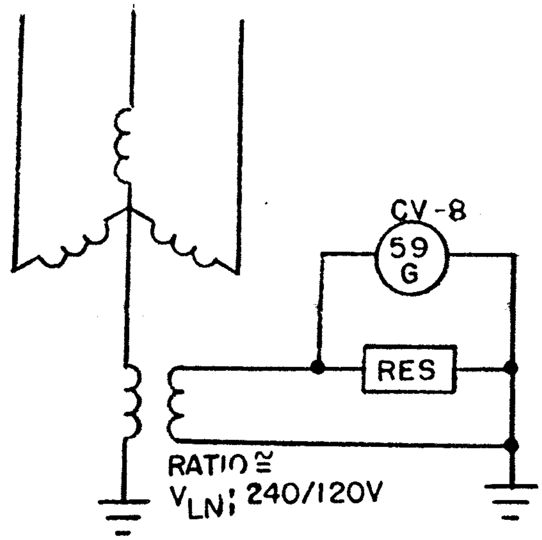


Fig. 2. High-resistance grounding of the neutral of medium voltage wye-connected transformer or generator winding through distribution or equivalent type transformer, with ground-sensing voltage relaying.

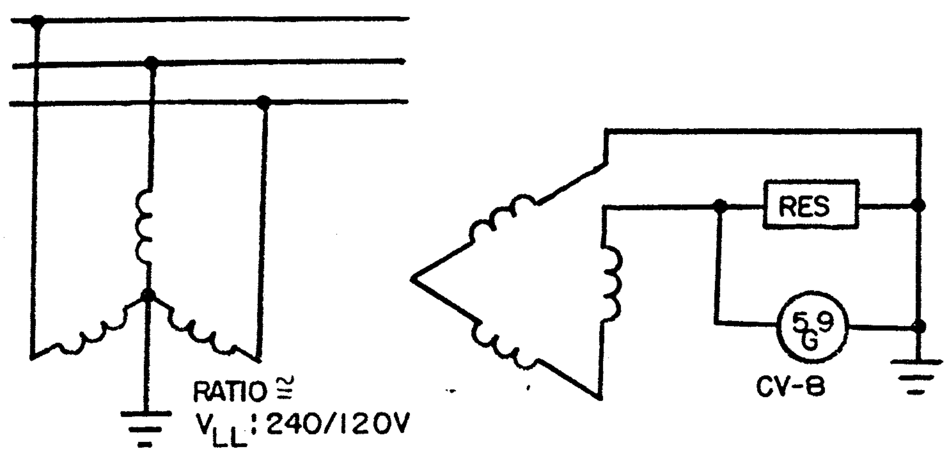


Fig. 3. High-resistance grounding of system (when neutral is not available) through three single-phase distribution or equivalent type transformers connected wye-open-delta, with ground-sensing voltage relaying.

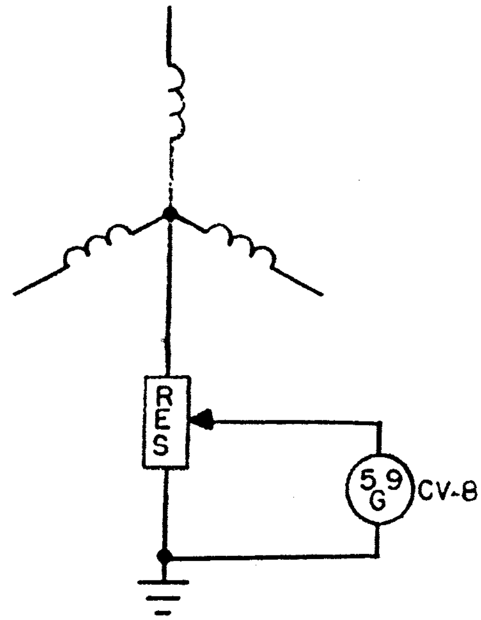


Fig. 4. Direct high-resistance grounding of a generator or transformer neutral in low voltage systems, with ground sensing voltage relaying.

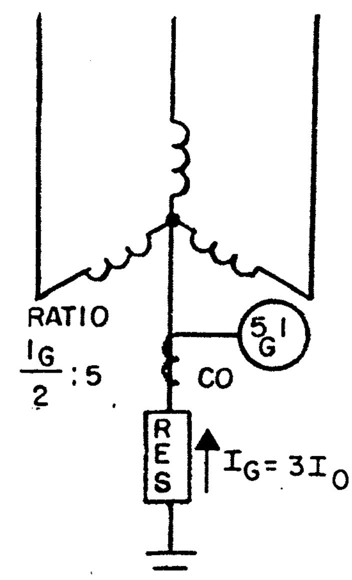


Fig. 5. Low-resistance grounding of neutral of a wye-connected generator or a delta-wye connected transformer with neutral ground relaying

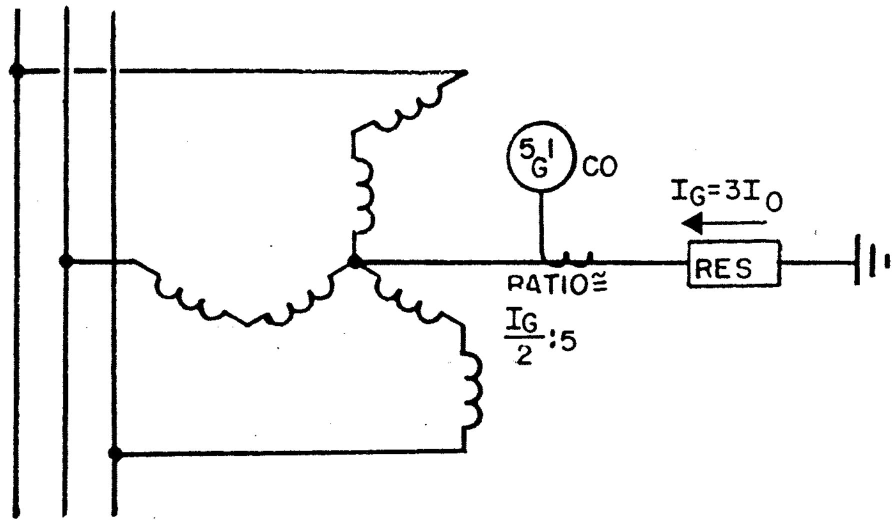


Fig. 6. Low-resistance grounding of system through zig-zag grounding transformer, with neutral ground relaying.

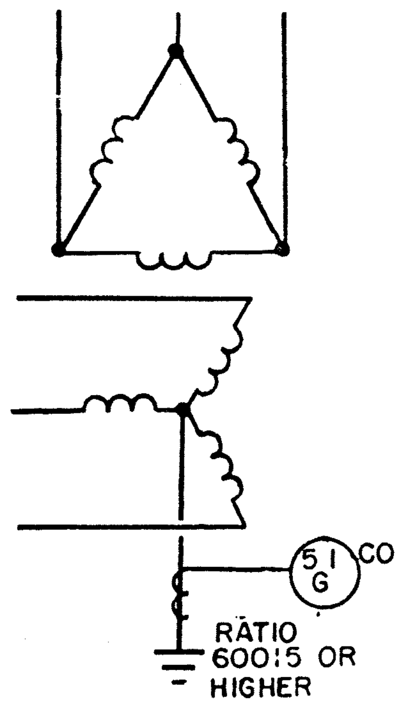


Fig. 7. Solid neutral grounding of secondary of power transformer, with neutral ground relaying.

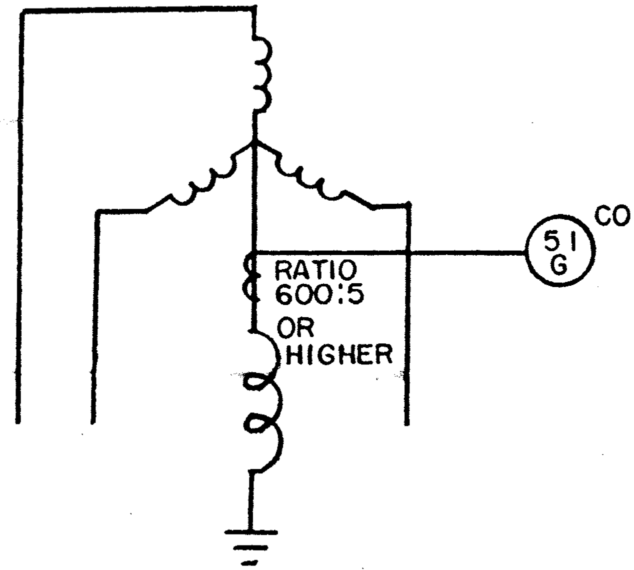
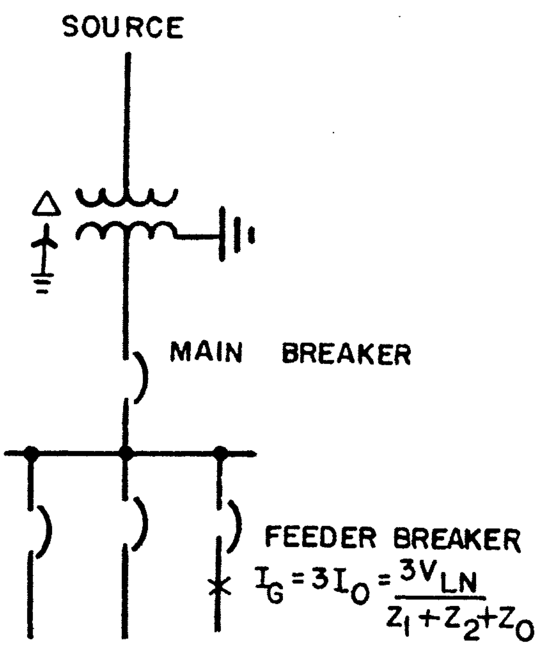
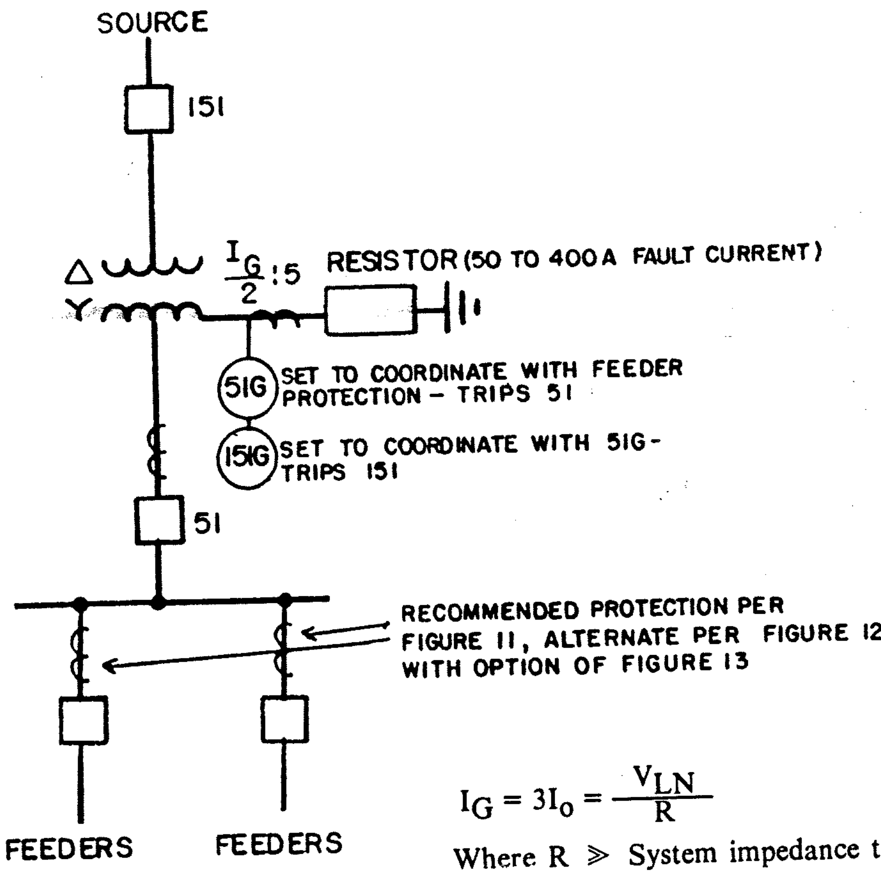


Fig. 8 Reactance grounding of neutral of wye-connected generator. With neutral ground relaying.



Preferred residual detection for main and feeder breakers in Amptector or Type SCB units integral with breaker. Alternate is zero sequence detection using Type GFP, GFR or ITH units.

Fig. 9. Recommended System Grounding for Low Voltage Systems.



$$I_G = 3I_0 = \frac{V_{LN}}{R}$$

Where R $\gg$ System impedance to the fault.

Fig. 10. Recommended System Grounding for Medium Voltage Systems.

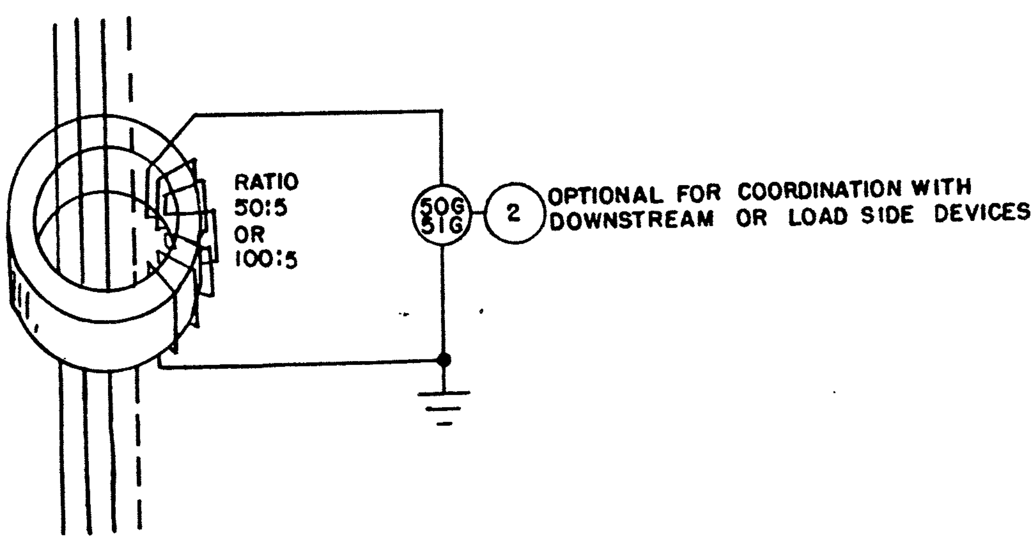


Fig. 11. Ground relaying utilizing type BYZ or similar window-type ct. In four-wire systems, neutral conductor must pass through window.

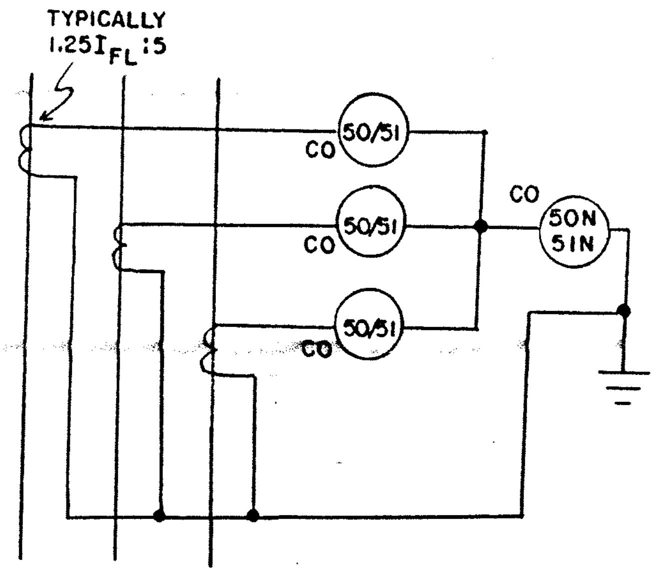


Fig. 12. Residual-type ground relaying utilizing phase current transformers.

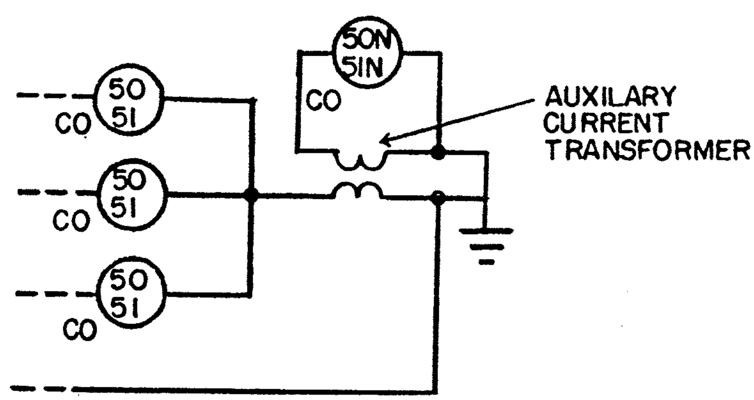
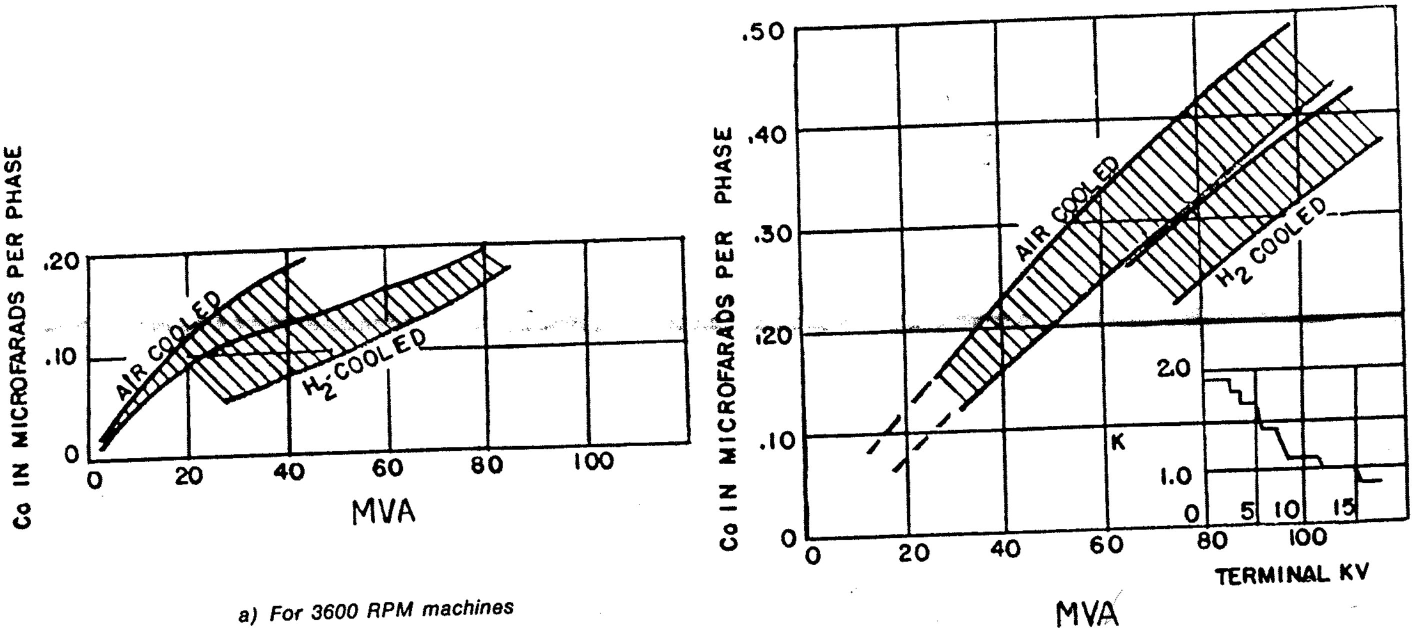


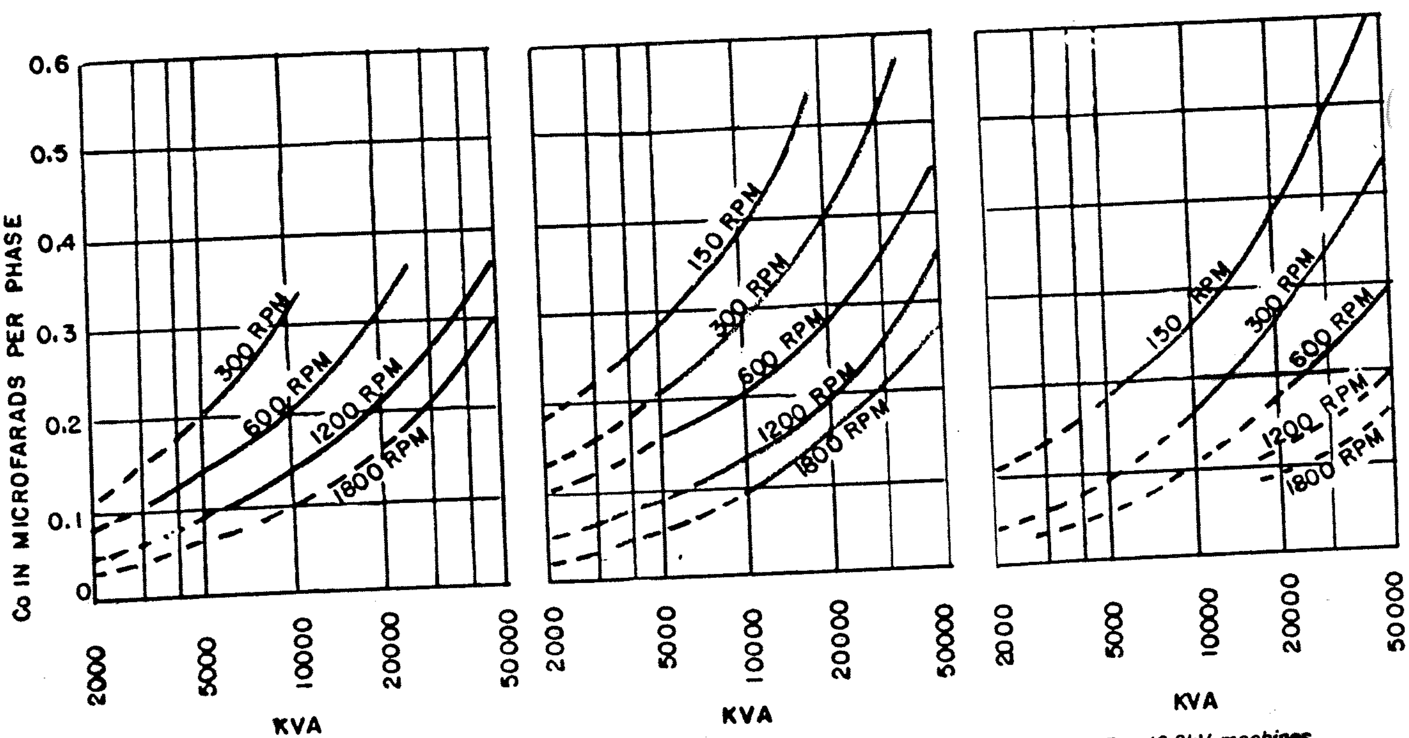
Fig. 13. Residual ground relaying with sensitivity enhanced by auxiliary ct in residual circuit.



a) For 3600 RPM machines

b) For 1800 RPM machines

Fig. 14. Capacitance to ground of TURBINE-GENERATOR windings for 13.2kV machines in microfarads per phase. For other voltages multiply by factor K in insert.



a) For 2300 volt machines

b) For 6900 volt machines

c) For 13.8kV machines

Fig. 15. Capacitance to ground of SALIENT-POLE GENERATORS AND MOTORS in microfarads per phase.

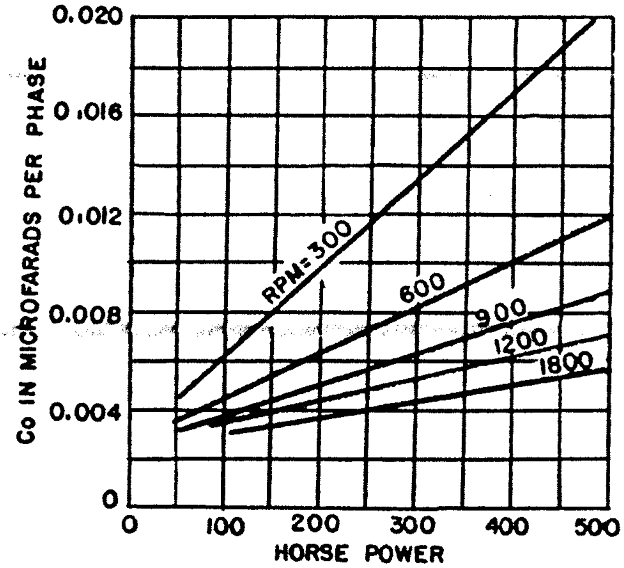


Fig. 16. Capacitance to ground of 2300-volt SYNCHRONOUS MOTORS in microfarads per phase to ground. For voltages between 2300 and 6600, the capacitance will not vary more than ± 15 percent from the values for 2300 volt.

USED

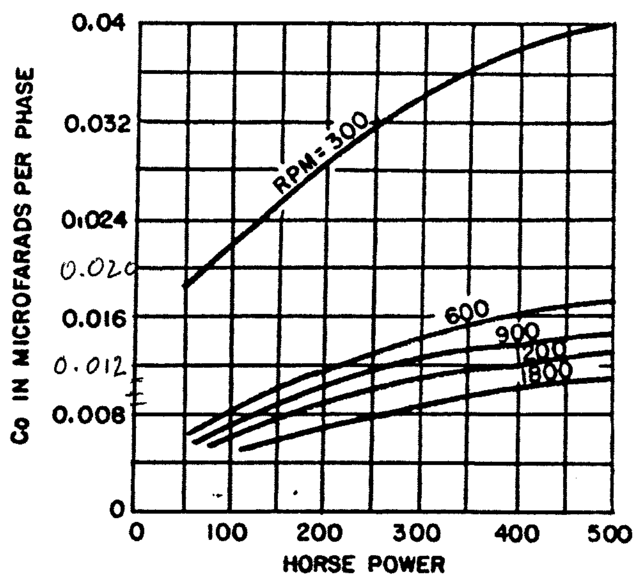


Fig. 17. Capacitance to ground of 2300-volt INDUCTION MOTORS in microfarads per phase. For voltages between 2300 and 6600, the capacitance will not vary more than ± 15 percent from the values for 2300 volts.

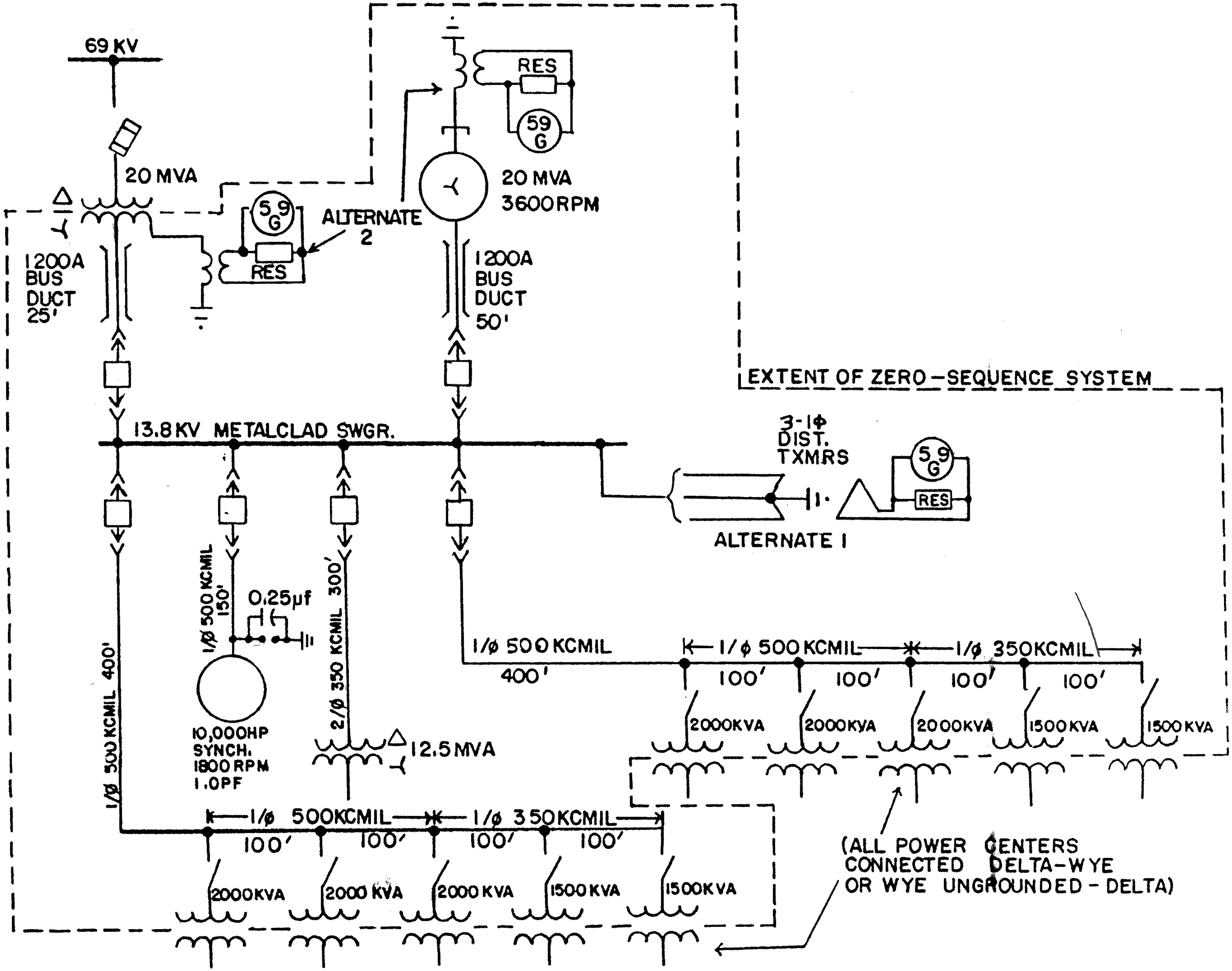
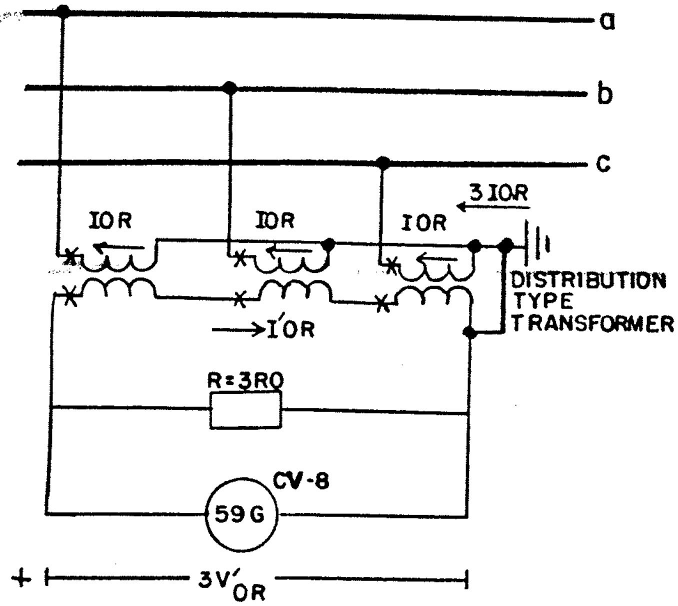
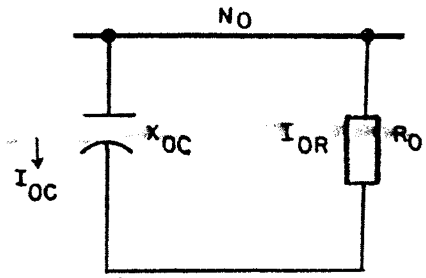


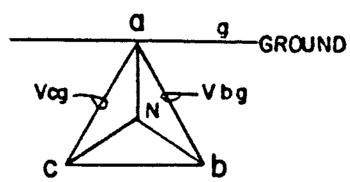
Fig. 18. Typical Power Distribution System with two alternate high-resistance grounding schemes for the example of Apendix III.



a) Three phase connections

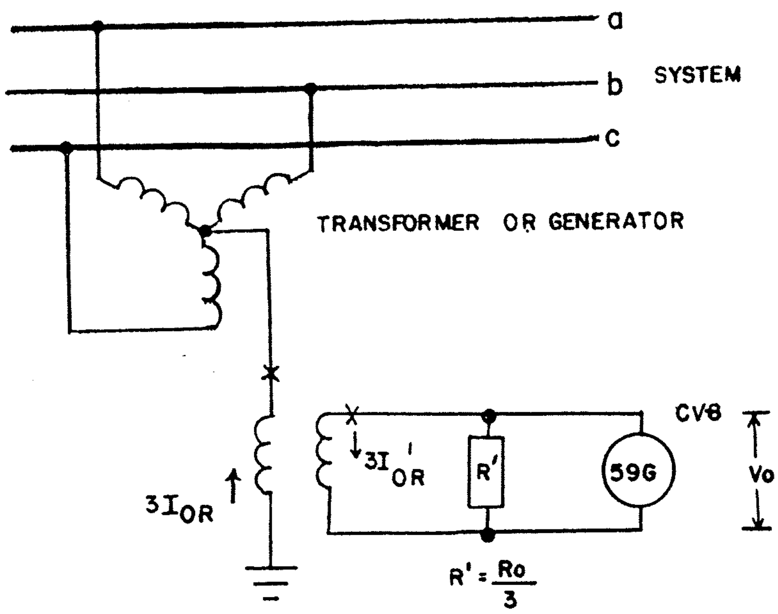


b) Zero sequence network

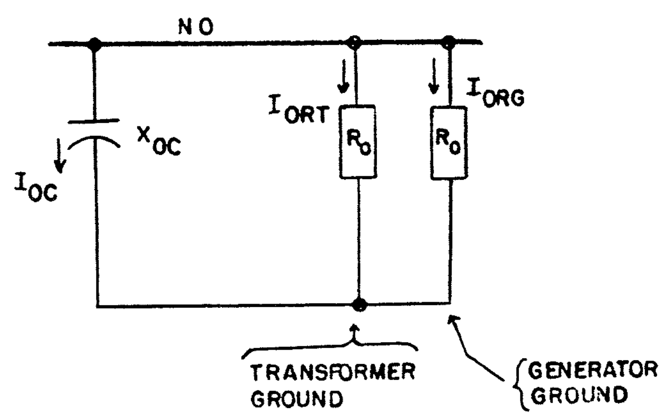


c) Phases for a phase a-to ground fault.

Fig. 19. Detail of High-Resistance Grounding through three single phase distribution or equivalent type transformers.



a) Three phase connections



b) Zero sequence network

Fig. 20 Details of High-Resistance Grounding through a neutral distribution or equivalent type transformer.

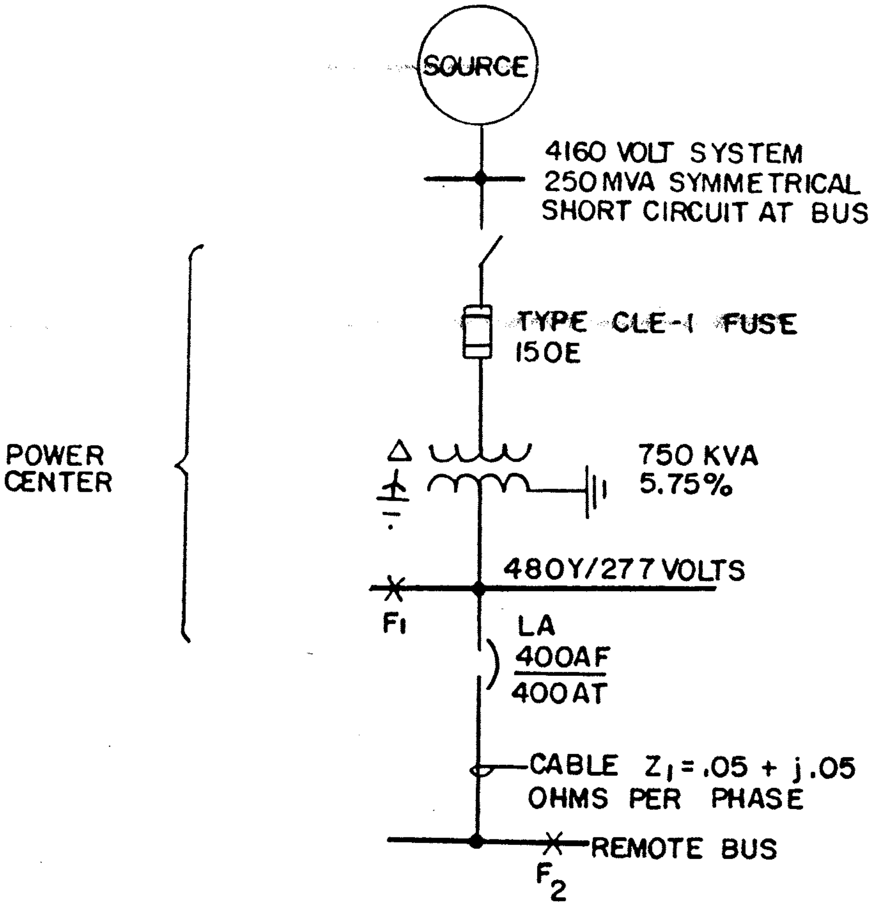


Fig. 21. Typical Power Center System with Primary Fuses.

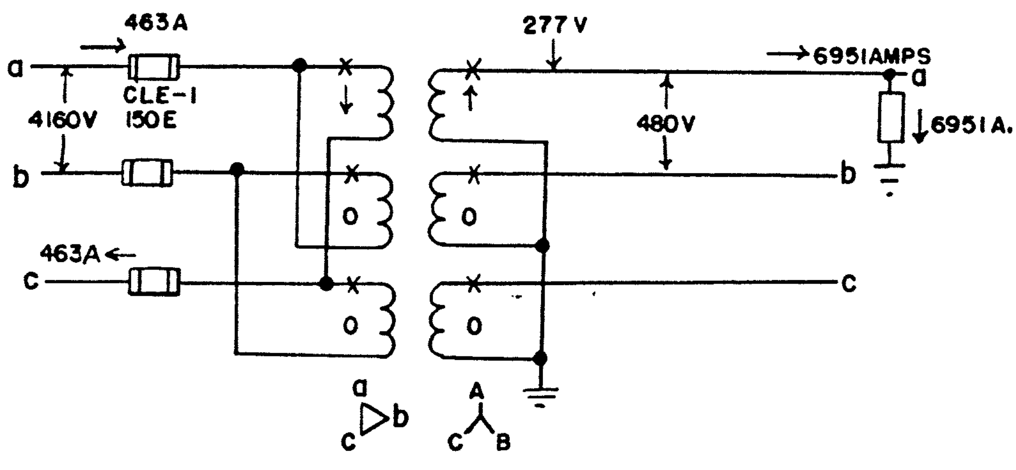


Fig. 22. Current flow thru the TransformerBank for the example of Fig. 21.