
Problems

These practical problems, developed over many years from actual experience, provide the opportunity to apply the material in the book by practicing the basic techniques. Problems involving application choices are generally so subjective that I have avoided them whenever possible. Each problem has a message to be unlocked with a reasonable minimum of labor—that is, with a good RH factor, where R denotes relative minimum labor and H denotes high educational value.

CHAPTER 2

- 2.1** A wye-connected generator has a nameplate rating of 200 MVA, 20 kV, and its subtransient reactance (X''_d) is 1.2 pu. Determine its reactance in ohms.
- 2.2** The generator of Problem 2.1 is connected in a power system where the base is specified as 100 MVA, 13.8 kV. What is the generator reactance (X''_d) in per unit on this system base?
- 2.3** Convert the per-unit answer calculated in Problem 2.2 to ohms. Does this match the value determined in Problem 2.1?
- 2.4** Three 5 MVA single-phase transformers, each rated 8:1.39 kV, have a leakage impedance of 6%. These can be connected in a number of different ways to supply three identical $5\ \Omega$ resistive loads. Various transformer and load connections are outlined in Table P2.4. Complete the table columns. Use a three-phase base of 15 MVA.

TABLE P2.4

Case No.	Transformer Connection		Load Connection to Secondary	Line-to-Line Base kV		Total Z as Viewed from the High Side	
	Primary	Secondary		HV	LV	Per unit	Ω
1	Wye	Wye	Wye				
2	Wye	Wye	Delta				
3	Wye	Delta	Wye				
4	Wye	Delta	Wye				
5	Delta	Wye	Wye				
6	Delta	Wye	Delta				
7	Delta	Delta	Wye				
8	Delta	Delta	Delta				

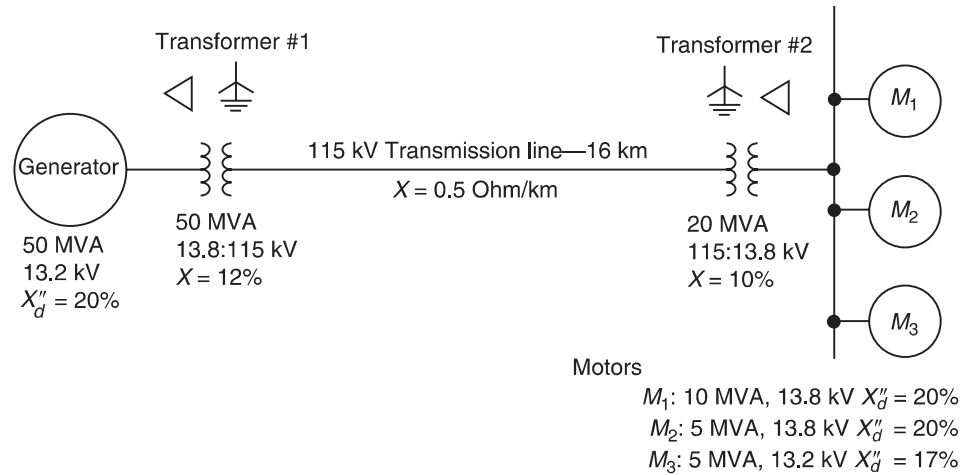


FIGURE P2.5

- 2.5** A three-phase generator feeds three large synchronous motors over a 16 km, 115 kV transmission line, through a transformer bank, as shown in Figure P2.5. Draw an equivalent single-line reactance diagram with all reactances indicated in per unit of a 100 MVA, 13.8, or 115 kV base.
- 2.6** In the system of Problem 2.5, it is desired to maintain the voltage at the motor bus of $1. \angle 0^\circ$ per unit. The three motors are operating at full rating and 90% pf.
- Determine the voltage required at the generator terminals assuming that there is no voltage regulating taps or similar equipment in this system.
 - What is the voltage required behind the subtransient reactance?
- 2.7** The percent impedance of a transformer is typically determined by a short circuit test. In such a test, the secondary of the transformer is shorted and the voltage on the primary is increased until rated current flows in the transformer windings. The applied voltage that produces rated current divided by the rated voltage of the transformer is equal to the per-unit impedance of the transformer.

A short circuit test on a 150 KVA, 7200–240 V transformer provides the following results:

Primary voltage at 20.8 primary amperes = 208.8 V

- Determine the %Z of the transformer.
- Calculate the ohmic impedance of the transformer in primary and secondary terms.

- c. How much current would flow in the transformer if its secondary would become shorted during normal operating conditions? (Consider source impedance to be zero.)

CHAPTER 3

- 3.1** Four boxes represent an AC generator, reactor, resistor, and capacitor and are connected to a source bus XY as shown in Figure P3.1. From the circuit and phasor diagrams, identify each box.
- 3.2** Two transformer banks are connected to a common bus as shown in Figure P3.2. What are the phase relations between the voltages V_{AN} and $V_{A'N'}$; V_{BN} and $V_{B'N'}$; V_{CN} and $V_{C'N'}$?
- 3.3** Reconnect transformer bank 2 of Problem 3.2 with the left windings in wye instead of delta, and the right windings in delta instead of wye so that V_{AN} and $V_{A'N'}$ are in phase, V_i and $V_{B'N'}$ are in phase, and V_{CN} and $V_{C'N'}$ are in phase.
- 3.4** The power transformer connections shown in Figure P3.3 are non-standard and quite unusual with today's standardization. However, this connection provides an excellent exercise in understanding phasors, polarity, and directional sensing relay connections.

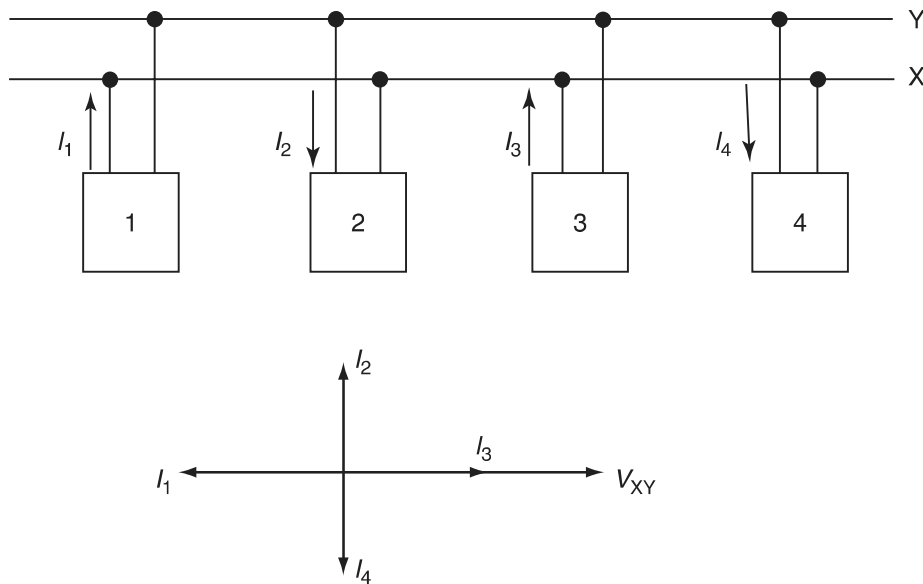


FIGURE P3.1

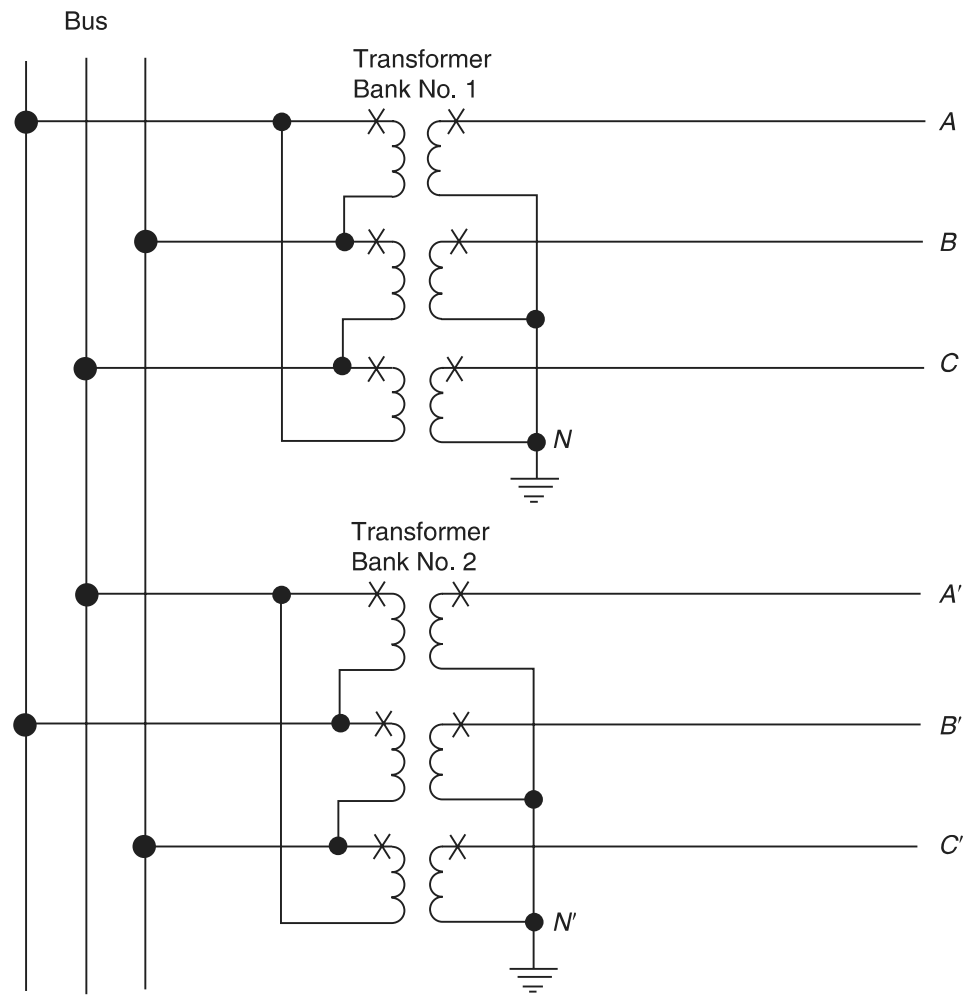


FIGURE P3.2

Connect the three-directional phase relays *A*, *B*, *C* to line-side CTs and bus-side VTs for proper operation for phase faults out on the line. Use the 90° – 60° connection. Each directional relay has maximum torque when the applied current leads the applied voltage by 30° . The auxiliary VTs should be connected to provide the relays with equivalent line-side voltages.

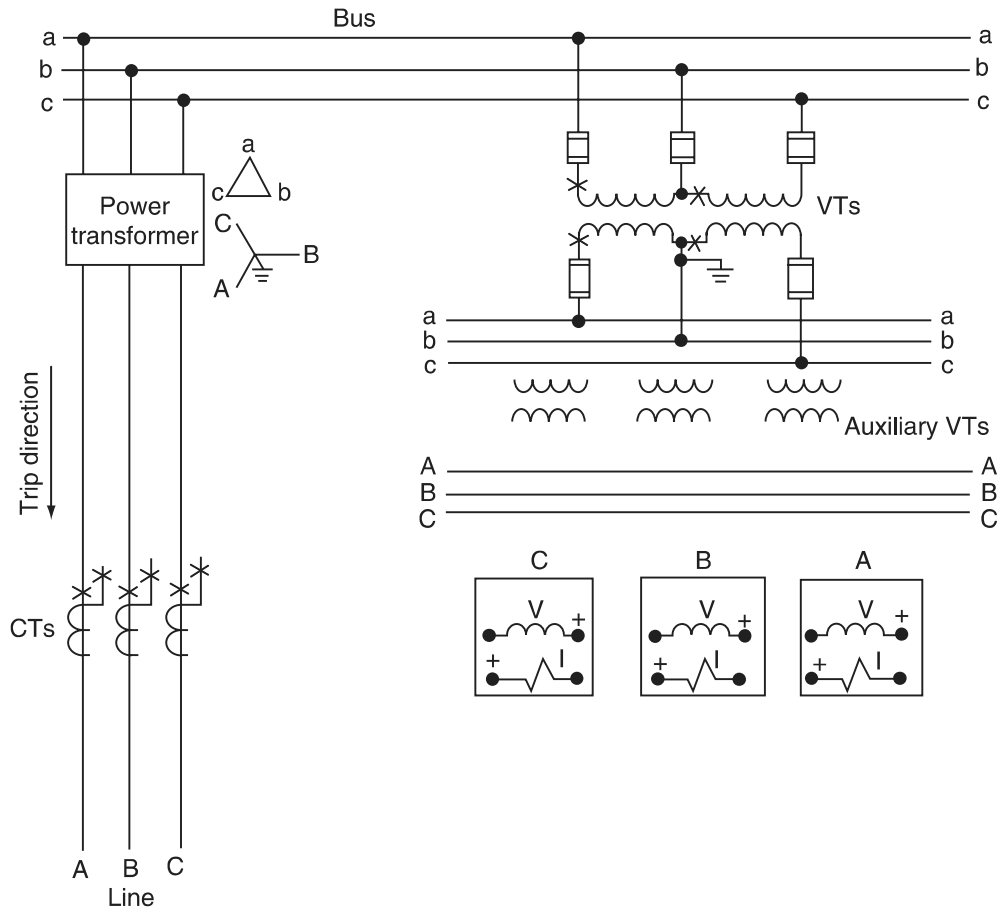


FIGURE P3.3

CHAPTER 4

- 4.1** The per-unit currents for a phase-*a*-to-ground fault are shown in the diagram of Figure P4.1. Assume that the system is reactive with all resistances neglected and that the generator(s) are operating at $j = 1.0$ per-unit voltage.

Draw the positive, negative, and zero sequence diagrams and describe the system that must exist to produce the current flow as shown.

- 4.2** For the system shown in Figure P4.2
- Determine the source and equivalent star reactances of the transformer on a 30 MVA base.
 - Set up the positive, negative, and zero sequence networks. There are no fault sources in the 13.8 and 6.9 kV systems. Reduce these

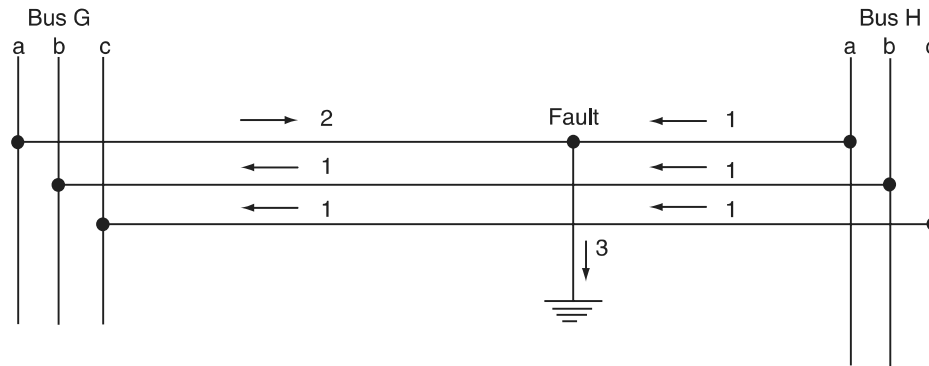


FIGURE P4.1

networks to single-sequence reactances for faults on the 13.8 kV side.

- c. Calculate a three-phase fault at the 13.8 kV terminals of the transformer.
- d. Calculate a single-phase-to-ground fault at the 13.8 kV transformer terminals.
- e. For the fault of part d, determine the phase-to-neutral voltages at the fault.
- f. For the fault of part d, determine the phase currents and the phase-to-neutral voltages on the 115 kV side.
- g. For the fault of part d, determine the current flowing in the delta winding of the transformer in per unit and amperes.
- h. Make an ampere-turn check for the fault currents flowing in the 115, 13.8, and 6.9 kV windings of the transformer.

4.3 For the system shown in Figure P4.3

- a. Determine the current flowing to the load. Assume that the generators of the equivalent source behind the 13.8 kV bus are operating at 1 per-unit voltage at 0° .

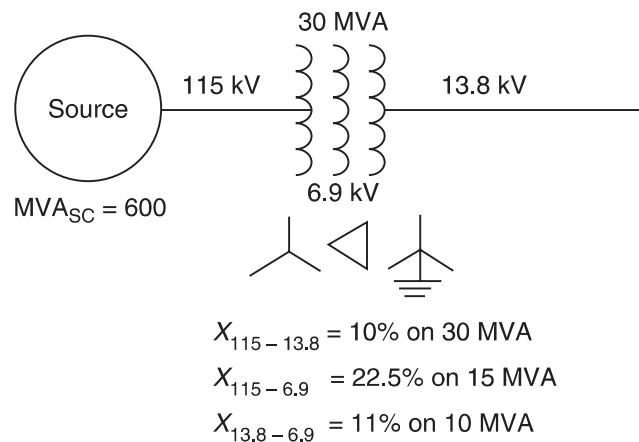


FIGURE P4.2

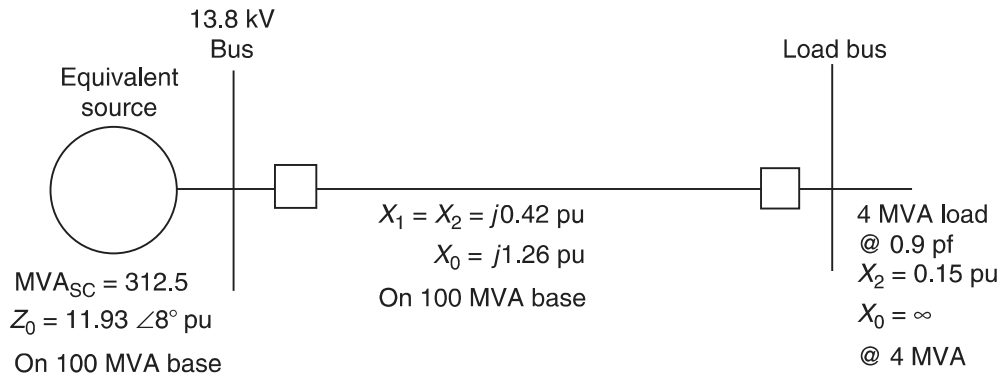


FIGURE P4.3

- b. Calculate the voltage at the load bus.
 - c. Calculate the fault current for a solid phase-*a*-to-ground fault at the load bus. Neglect load for this part.
 - d. Calculate the currents flowing in the line when an open circuit occurs in the line just at the load bus. Assume that phase *a* opens while carrying the load as indicated.
 - e. Calculate the currents flowing when the open phase of a conductor of part d falls to ground on the source side of the open. Assume a solid fault.
 - f. Repeat part e but for the case when the opened conductor falls to ground on the load side.
- 4.4** Repeat the example of Section 4.14 for a solid phase-to-ground fault on the 161 kV terminals of the autotransformer. Compare the directions of the currents in the bank neutral and the tertiary with those for the fault on the 345 kV side.

CHAPTER 5

- 5.1** A 13.8 kV feeder circuit breaker has a 600:5 multiratio current transformer with characteristics as shown in Figure 5.11. The maximum load on the feeder is 80 A primary. Phase time inverse overcurrent relays are connected to the CT secondaries. The relay burden is 3.2 VA at the tap values selected, and the lead burden is 0.38 Ω.
- a. If the 100:5 CT ratio is used, then a relay tap of 5 A is required in order for the relay pickup to be 125% above the maximum load. With these, determine the minimum primary current to just operate the relays.
 - b. For the selection of part a what is the approximate maximum symmetrical fault current for which the CTs will not saturate (use the ANSI/IEEE knee point)?
 - c. If the 200:5 CT ratio is used so that the 2.5 A relay tap can be used, determine the minimum primary current to just operate the relays.

- d. Repeat part b for the selection of part c.
- e. Which of these two CT and relay selections would you recommend?
- 5.2** Determine the minimum CT ratio that might be used with a 0.5–2.5 A ground relay with an instantaneous trip unit set at 10 A. The total ground relay burden is 285 VA at 10 A. See Figure 5.10 for CT characteristics.
- 5.3** A circuit has 800:5 wound-type CTs with characteristics as shown in Figure 5.7. The maximum symmetrical fault for which the associated relays are to operate is 15,200 A. Approximately what will be the error in percent if the total connected burden is 2.0 Ω ? What will it be if it is 4.0 Ω ?
- 5.4** The feeder of Problem 5.1 has a ground relay connected in the CT circuit which has a burden of 4.0 VA at tap value. The taps available are 0.5, 0.6, 0.8, 1.0, 1.5, 2.0, and 2.5, which represent the minimum pickup current. What is the maximum sensitivity that can be obtained in primary amperes for a phase-*a*-to-ground fault? Assume that $I_b = I_c = 0$ for the fault and that the phase relay burden is 0.032 Ω if 50:5 CT ratio is used, 0.128 Ω with 100:5 tap, 0.261 Ω with 150:5 tap, and 0.512 Ω with 200:5 tap.
- 5.5** Phase and ground relays are connected to a set of voltage transformers (VTs) as shown in Figure P5.5. The secondary winding voltages are 69.5 for the phase relays and 120 V for the ground relays. The

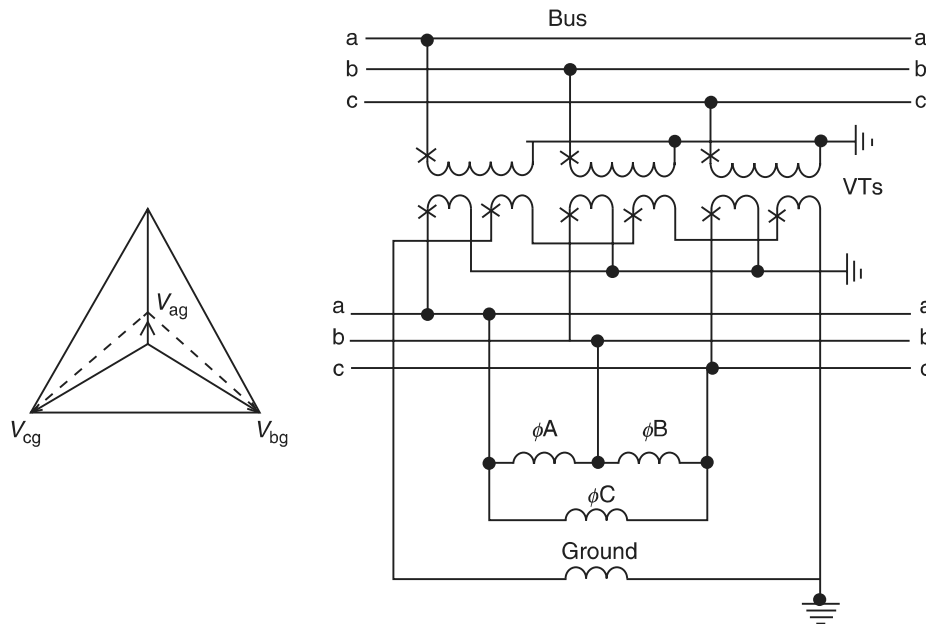


FIGURE P5.5

equivalent line-to-neutral burden of the phase relays is 25 VA resistive each phase at 69.5 V. The burden of the ground relays is 15 VA, 120 V at 25° leading pf angle.

- a. Calculate the total burden on each of three voltage transformers during a phase-*a*-to-ground fault, which reduces the phase *a* voltage to 0.15 per unit.
- b. What is the minimum-capacity voltage transformer that can be used for this application?

CHAPTER 7

7.1 Phase *a* of a three-phase 4.16 kV ungrounded system is solidly grounded. For this fault, calculate the magnitude of the positive, negative, and zero sequence voltages at the fault. Explain your answers with reference to the sequence networks and interconnections used to calculate line-to-ground faults on three-phase systems.

7.2 An ungrounded 4.16 kV system has a capacitance to ground of 0.4 μF per phase. In this system:

- a. Calculate the normal charging current in amperes per phase.
- b. Calculate the fault current for a phase-*a*-to-ground fault.
- c. Will this fault current operate a ground overcurrent relay set at 0.5 A pickup and connected to 100:5 current transformer or a ground sensor connected to a toroidal type CT with a primary pickup of 5 A?
- d. It has been decided to ground this system with a zig-zag transformer and neutral resistor. The source to the 4.16 kV bus has $X_1 = 10\%$ on 5000 kVA. If in this system X_1 is 2.4% on the zig-zag bank rating, what is the kVA of the zig-zag bank?
- e. In order to limit the overvoltage on the unfaulted phases to a maximum of 250% for possible restriking ground faults, it is necessary that

$$\frac{X_0}{X_1} \leq 20 \quad \text{and} \quad \frac{R_0}{X_0} \geq 2.0.$$

This requires a zig-zag transformer reactance of 6.67% and a ground resistor of $0.292 + j0.124$ per unit, all on the zig-zag transformer rating. Verify that these ratios requirements have been met.

- f. Calculate the solid phase-*a*-to-ground fault current in the 4.16 kV system with the zig-zag transformer and resistor grounding.
 - g. Provide specifications for purchasing the zig-zag transformer and resistor.
 - h. Will the relays in part c operate for ground faults of part f?
- 7.3** Verify that the unusual connection of voltage transformers shown in Figure P7.3 provides zero sequence voltage during a ground fault on

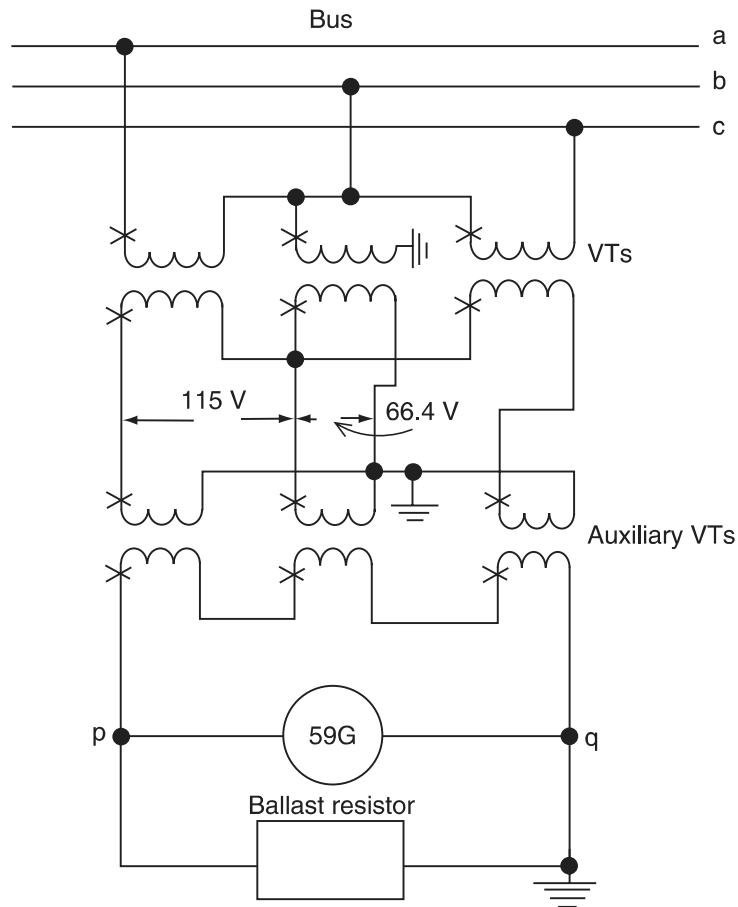


FIGURE P7.3

an ungrounded system for operation of the overvoltage relay 59G. (This connection used by a large power system for ground detection on ungrounded systems supplied from delta tertiary.)

Open-delta connected VTs are used for three-phase voltage, and the desire was to use these with minimum additions. Figure 7.5a connections using three auxiliary VTs in broken delta had a tendency in their system to go into ferro-resonance, probably because the resistor was not effective with the high leakage impedance of the auxiliaries. The scheme shown was evolved using the two existing VTs and adding a VT-connected phase to ground. This added VT is either a 60 Hz rated twice line-to-line voltage unit or a 25 Hz unit rated line-to-line so that they operate low on the saturation curve. No ferro-resonance has been encountered with this scheme.

- 7.4 a.** To limit ground faults, a reactor is to be connected in the grounded neutral of the 13.8 kV winding of the transformer (Figure P7.4). Calculate the value of the reactor in ohms required to limit the solid single-phase-to-ground current on the 13.8 kV side to 4000 A.

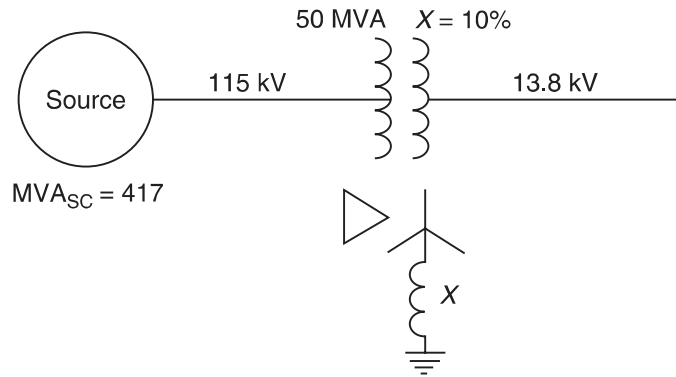


FIGURE P7.4

- b. What percentage reduction would this represent if the wye winding were solidly grounded instead of being grounded through the reactor?
- c. Repeat part a except using a resistor instead of a reactor. Determine the resistor value in ohms.

7.5 The directional ground relay has been connected (Figure P7.5) for operation on ground faults out on the line. The relay has maximum

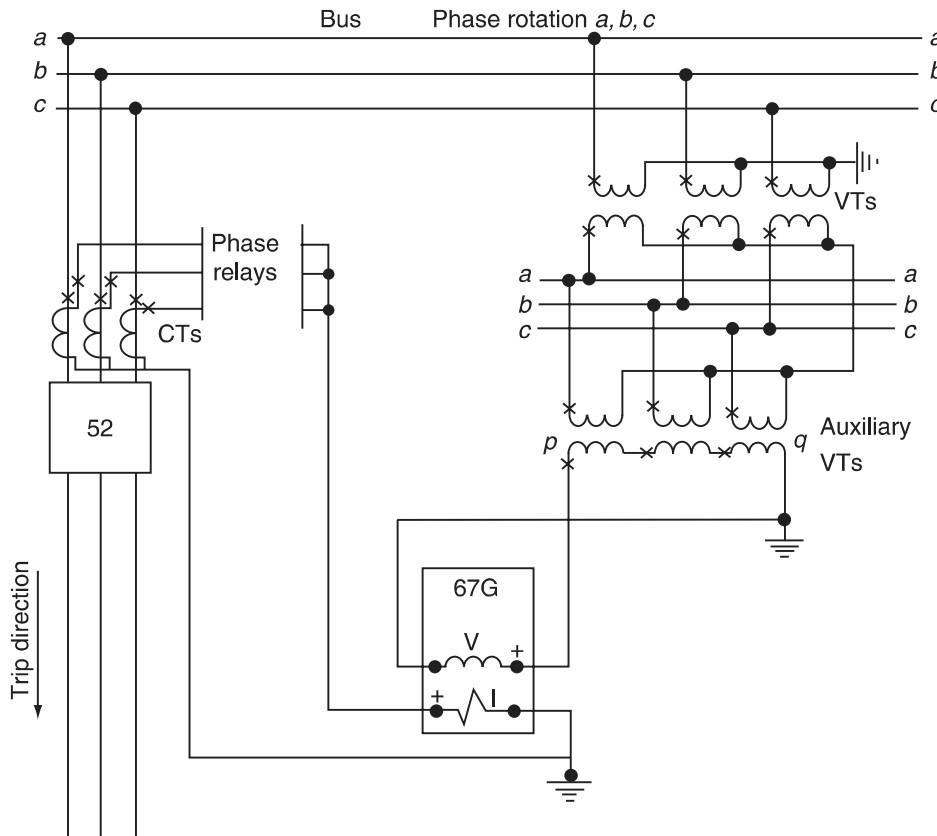


FIGURE P7.5

torque when the current lags the voltage by 60° , with the relative instantaneous polarities as shown.

- Are the connections correct? Check by assuming a line-to-ground fault in the tripping direction. Make any corrections as required.
- With the correct connections of a, field checks are to be made to verify the connections. Assuming 100% pf load, determine whether these checks provide relay-directional unit operation or not. Support your answer with a phasor diagram: Test A—Short phase c current transformer and open the secondary lead. Open phase a voltage transformer lead and short the secondary winding of that transformer. Restore connections after test; Test B—Short phase b current transformer and open the secondary lead. Open phase c voltage transformer lead and short the secondary winding of that transformer. Restore connections after test.

CHAPTER 8

8.1 Three 21,875 kVA, 13.8 kV generators with $X_d'' = 13.9\%$ are connected to individual buses, from which various loads are supplied. These buses are connected to another bus through 0.25Ω reactors as shown in Figure P8.1. The generators are all ungrounded. In this system:

- Calculate a three-phase fault at the terminals of one of the generators.

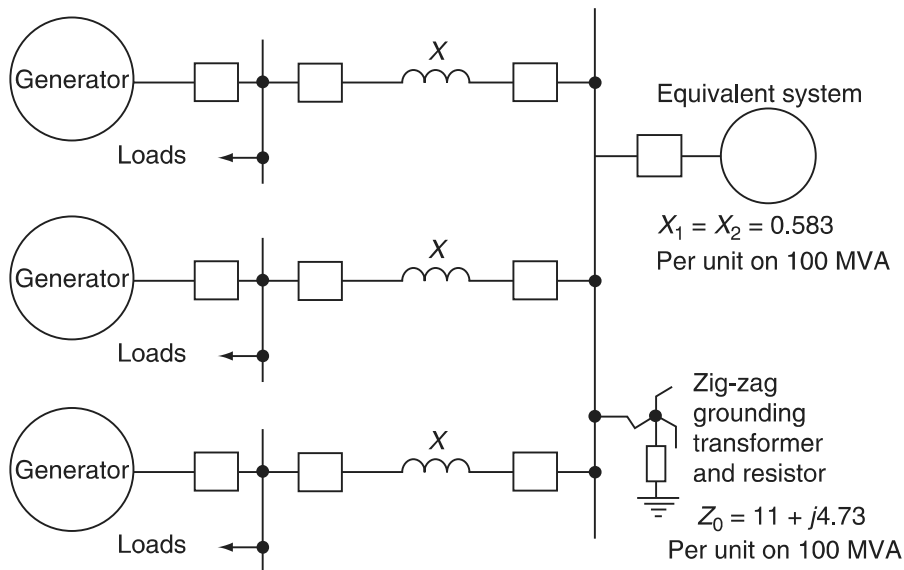


FIGURE P8.1

- b. Choose a current transformer ratio for differential relays to protect the generators. If the generator differential relays have a minimum pickup of 0.14 A, how many times pickup does the three-phase fault provide?
 - c. Calculate a single-phase-to-ground fault at the terminals of one of the generators.
 - d. Will this ground fault operate the generator differential relays? If so, how many times pickup will the ground fault provide?
- 8.2** The unit generator shown in Figure P8.2 has the following capacitance-to-ground values in microfarads per phase:

Generator-surge capacitors	0.25
Generator-to-transformer leads	0.004
Power transformer low-voltage windings	0.03
Station-service-transformer high-voltage windings	0.004
Voltage-transformer windings	0.0005

The ground resistor R has a 64.14 kW rating at 138 V.

- a. Determine the fault current magnitude for a single-line-to-ground fault between the generator and the power transformer.
- b. Determine the three-phase fault current magnitude for a fault between the generator and the power transformer.
- c. Choose a CT ratio for the generator differential protection. Compare the fault currents of parts a and b with the generator relay pick-up value of 0.15 A.

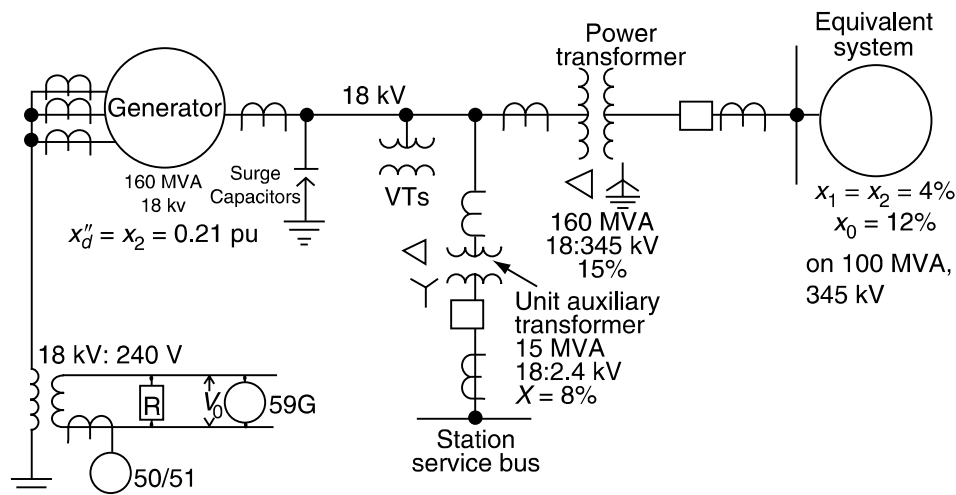


FIGURE P8.2

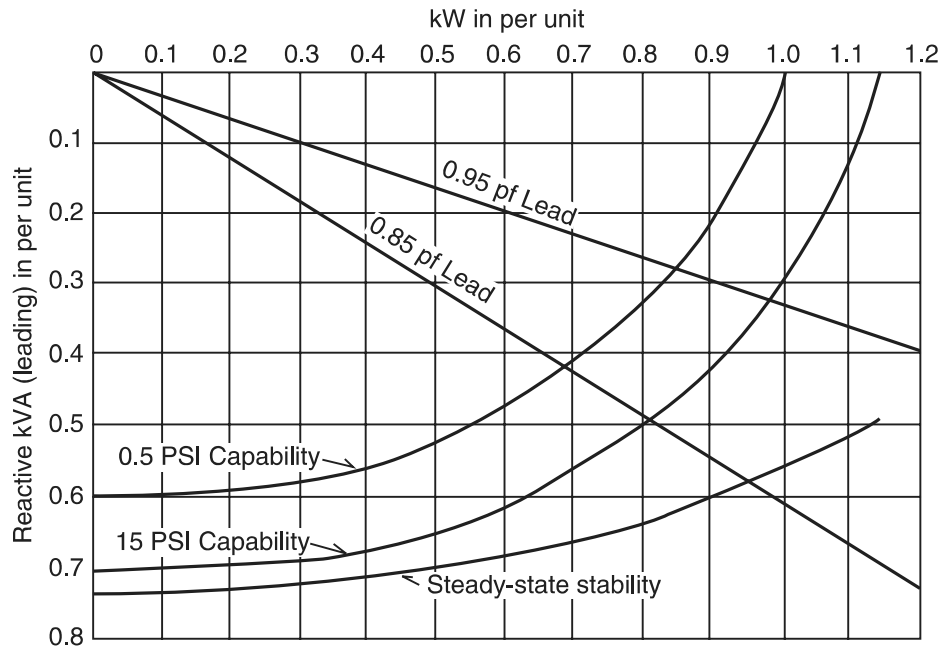


FIGURE P8.3

- d. How much voltage is available to operate an overvoltage relay 59G when connected across the grounding resistor? What is the multiple of pickup if 59G minimum operating value is 5.4 V.
 - e. How much current flows through the resistor? Select a CT and suggested overcurrent pickup values for the 50/51 relay.
- 8.3** The per-unit kVA capability and steady-state stability curves at rated terminal voltage for a 50 MVA, 13.2 kV, 60 Hz generator are shown in Figure P8.3. The current transformers used are 3000:5. For loss-of-excitation protection:
- a. Translate the steady-state stability limit to a per-unit $R-X$ diagram for a terminal voltage of 1.0 per unit.
 - b. Translate the 15 psi capability curve to a per-unit $R-X$ diagram for a terminal voltage of 1.0 per unit.
 - c. With these limits plotted on an $R-X$ diagram, draw a distance relay offset mho circle to provide protection for low or loss of excitation on this machine.
 - d. For the relay mho circle selected in part c, determine the per-unit offset (distance of the circle center from the $R-X$ origin) and the per-unit circle radius. Translate these values to relay ohms for setting a loss-of-excitation relay, $R_c = 3000:5$, $R_v = 120$.
- 8.4** A 100 MW generator is connected at the end of a radial 32 mile, 138 kV line. The 138 kV bus at which the line terminates is regulated to maintain a constant bus voltage of 138 kV. The impedance of the 138 kV line is $0.25 + j0.80 \Omega/\text{mile}$. Desired operation is such that

100 MW and 20 MVAR are to be delivered from the line into the bus at the 138 kV bus location. (This represents a lagging angle for current flow from the line into the bus.) There is no other load on the line. It is the policy of the utility to limit the operating voltage on its lines to 6% above nominal. As such, the overvoltage relay connected on the 138 kV side of the generator unit transformer at the generator location is set at 121.9 V. (115 V base)

- For the above operating condition, calculate the voltage on the 138 kV side of the generator unit transformer along with the MW and MVAR flow at this location. What are the MW and MVAR losses in the line?
- Based on the calculation made in (a), will the desired operation be possible if the overvoltage relay is connected to trip the generator?
- If operation is changed such that 100 MW and 0 MVAR is to be delivered at the 138 kV bus, will the overvoltage relay setting be exceeded?

CHAPTER 9

9.1 Assume for this problem that the 69 kV system (Figure P9.1) is open and make the following calculation:

- Calculate the fault current in the three phases for a solid phase-*a*-to-ground fault on the 69 kV terminals.
- Calculate the three-phase voltages existing at the fault.
- For this 69 kV ground fault, determine the currents flowing in the 13.8 kV system.

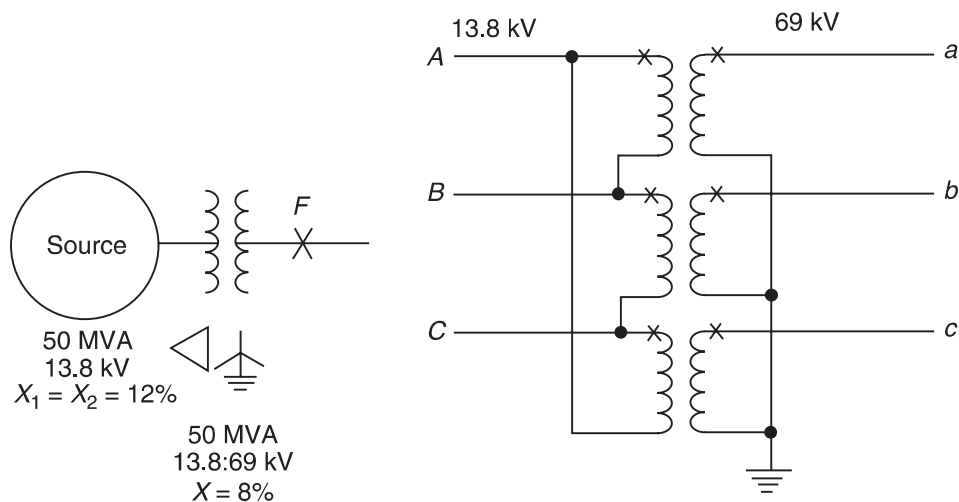


FIGURE P9.1

- d. What are the voltages for the three phases at the 13.8 kV transformer terminals for the 69 kV fault?
 - e. Compare the current and voltage phasors on the two sides of the bank for the 69 kV ground fault.
- 9.2** For the transformer bank of Problem 9.1, assume that phases *A*, *B*, *C* on the 13.8 kV side have 3000:5 CTs with taps at 1500, 2000, 2200, and 2500 A, and that the 69 kV circuits *a*, *b*, *c* have 600:5 multiratio CTs with taps, as indicated in Figure 5.10.
- a. Show the three-phase connections for transformer differential relays to protect this bank.
 - b. Select suitable 69 kV and 13.8 kV CT ratios for this transformer differential application.
 - c. If the differential relay has taps of 4, 5, 6, and 8, select two taps to be used with the CT ratios selected in part b so that the percent mismatch is less than 10%.
 - d. With this application and setting, how much current can flow to operate the differential relay(s) if the phase-*a*-to-ground fault of Problem 9.1 part a is within the differential zone? How many of the three relays operate for this ground fault?
- 9.3** The transformer bank (Figure P9.3) shown connected between the 13.8 and 2.4 kV buses, consists of three single-phase units, each rated 1000 kVA 13.8:2.4–1.39 kV.

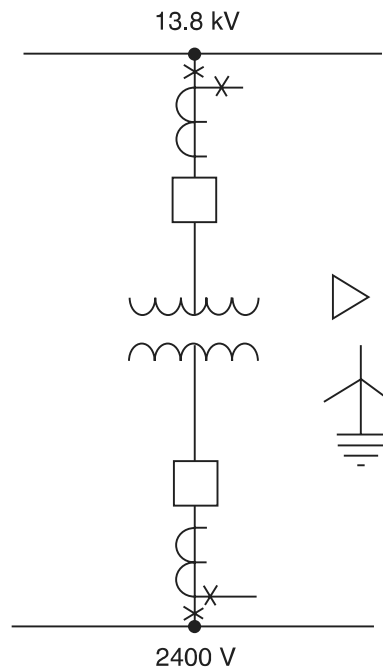


FIGURE P9.3

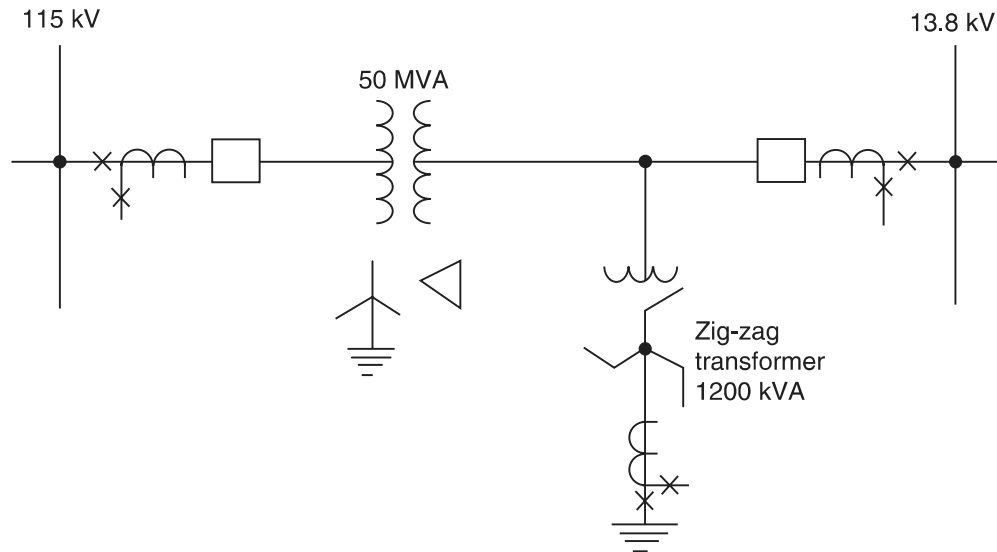


FIGURE P9.4

- Connect a two-restraint type differential relay for protection of the transformer bank.
- Select proper current transformer ratios and relay taps. Assume that the differential relay has ratio adjusting taps of 5:5 to 5:10 with the ratios of 1, 1.1, 1.3, 1.5, 1.6, 1.8, and 2.0. The CTs on the 13.8 kV breaker are 200:5 with 150, 100, and 50:5 taps, and on the 2.4 kV breaker; 2000/1500/1000/500:5 CTs.
- If one of the single-phase transformers is damaged, can service be continued with the remaining two banks? If so, show the connections, including any modifications required for the differential relaying.
- What is the maximum three-phase load that can be carried with any temporary connections?

- 9.4** A 50 MVA transformer bank (Figure P9.4), wye-grounded to a 115 kV bus, and delta to a 13.8 kV bus, supplies power to the 13.8 kV system. Transformer breakers are available on both sides of the bank with 300:5 (115 kV side) and 2200:5 (13.8 kV side) current transformers. To ground the 13.8 kV system, a 1200 kVA zig-zag transformer has been connected between the power transformer and the 13.8 kV bus and within the differential zone. For this arrangement as shown:
- Connect three two-restraint type transformer differential relays to protect the 50 MVA bank using the two sets of CTs on the breakers. Only these are available.
 - The system $X_1 = X_2$ reactance to the 13.8 kV bus is 13% on 50 MVA, and the zig-zag bank reactance is 6% on its rating base. Calculate the current for a solid single-phase-to-ground fault on

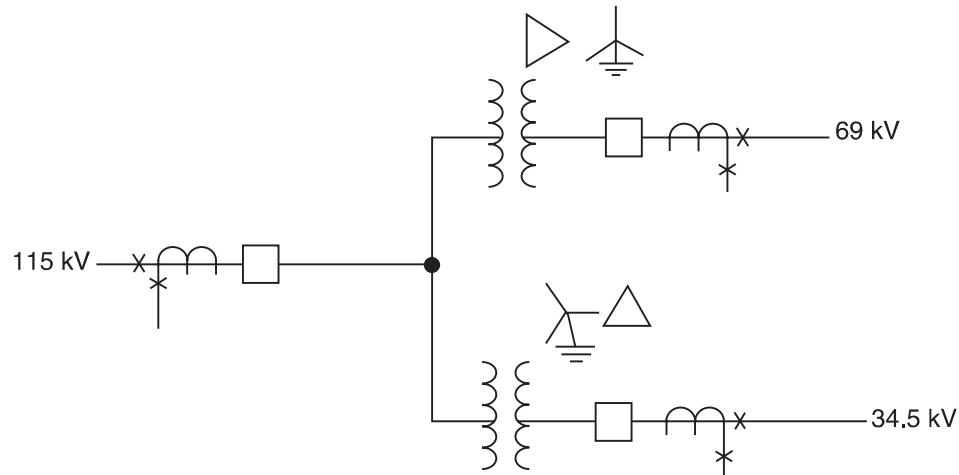


FIGURE P9.5

the 13.8 kV system. If the transformer differential relays have a pickup of 1.8 A, will they operate for a ground fault within the differential zone? What would you recommend for protection of the zig-zag bank?

- 9.5** Two separate transformer banks are connected as shown in Figure P9.5, without high-side breakers for economy. High-side transformer CTs are not available. The banks are connected per ANSI Standards. For this arrangement:
- Show complete three-phase connections for protecting these two transformer banks using three three-winding type transformer differential relays and the three sets of CTs shown.
 - Discuss the advantages and disadvantages of this protection compared with separate transformer differentials if separate 115 kV transformer CTs had been available.
- 9.6** For the application shown in Figure 9.12 and Figure 9.13, determine the currents that will flow in the relays for an 800 A ground fault. The neutral CT ratio is 250:5 and the line CT ratios are 1600:5. In the following determinations, choose a value of n to provide a good level of current in the 87G relay windings:
- For the ground fault external to the differential protection zone.
 - For the ground fault internal and within the differential protection zone. Assume the low-voltage feeders supply zero current to the internal fault.
- 9.7** A 1 MVA transformer bank, 13.8 kV delta, 480 V wye, solidly grounded with $X = 5.75\%$, supplies a group of induction motors. The source $X_1 = X_2$ is 0.0355 per unit on 5 MVA, 13.8 kV. The 13.8 kV, 65 A fuses are used to protect the transformer bank and the 480 V arcing faults, determine the following:
- What is the maximum possible ground-fault current at the 480 V bus?

- b. With a typical arc voltage of 150 V essentially independent of current magnitude, determine the magnitude of the arcing fault at the 480 V bus.
- c. What is the magnitude of this arcing fault on the 13.8 kV primary?
- d. Estimate the total clearing time for the 13.8 kV, 65 A fuses used in the primary supply to the bank for the 480 V arcing fault. The total clearing time for these fuses is as follows:

150	500
175	175
200	115
250	40
300	20
350	9
400	6

- 9.8** A 1200 kvar capacitor bank is to be connected on a 12.47 kV distribution line. The bank will be connected wye-grounded and will be made up of capacitor units rated at 20 kvar. Each phase will consist of one parallel group of capacitor units. The capacitor bank will be protected with fuses connected into each phase that supplies the bank. Ampere ratings of available fuses—10 through 100 A in 10 A increments.
- a. How many capacitor units need to be paralleled per phase?
 - b. What size fuse should be used to protect the bank?
- 9.9** A three-phase capacitor bank is being connected on a 138 kV system. Each phase of the bank will be made up of 12 series groups with 18 units per group. The bank will be protected with a mid-tapped voltage differential relay. Base voltage supplied to the relay is 115 V. (Under normal balanced conditions, the relay measures 0 V. When an unbalance occurs, the voltage seen by the relay = per-unit unbalance \times 115 V.)
- a. Determine the alarm setting for the voltage differential relay.
 - b. Determine the trip setting for the voltage differential relay.

CHAPTER 10

- 10.1** High-impedance voltage-differential relays are to be applied to protect a three-breaker bus, as shown in Figure 10.9. The CTs are all 600:5 multiratio type with characteristics per Figure 5.10. For this application, determine the relay-pickup setting voltage and the minimum primary-fault current for which the relays will operate. The maximum external fault is 8000 A rms. Assume that the lead resistance $R_L = 0.510 \Omega$ for the maximum resistance from any CT to the junction point.

For the particular relays applied, the pickup setting voltage is

$$V_R = 1.6k(R_S + pR_L)\frac{I_F}{N}V, \quad (10.3)$$

where 1.6 is a margin factor, k is a CT performance factor (assume $k=0.7$ for this problem), $p=1$ for three-phase faults and $p=2$ for single-phase-to-ground faults (Figure 5.9), I_F is the primary rms external maximum fault current, and N and CT ratio. R_S is the CT resistance. $p=2$ should be used to determine the value of the V_R setting. The maximum setting of the relay voltage element should not exceed 0.67 times the secondary exciting voltage of the poorest CT in the differential circuit at 10 A exciting current.

The minimum internal fault primary current to operate the relays is

$$I_{\min} = (nI_e + I_R + I_T)N \text{ primary amperes}, \quad (10.4)$$

where n is the number of circuits, I_e is the exciting current of the individual CT at the pickup voltage, I_R is the relay current at the pickup setting voltage, and I_T is the current required by a high voltage protective device across the relay coil (not shown in Figure 10.9). For this problem, assume $I_T=0.2$ A. The relay impedance and generally negligible resistance of the leads from the junction to the relay is 1700Ω . nI_e is applicable in this problem since all three breaker CTs are the same; otherwise this is a summation of the different CT exciting currents at the V_R pickup voltage.

- 10.2** A feeder circuit is added to the bus of Problem 10.1, making a four-circuit bus. The new breaker has the same type 600:5 multiratio CTs. With this addition, the maximum external fault increases to 10,000 A rms. All other circuit values remain the same. For this change, calculate the relay-pickup setting voltage and the minimum primary-fault current for which the relays will operate.

CHAPTER 11

- 11.1** A 2850 hp, 4 kV induction motor is connected to the supply system through a 2.5 MVA transformer, 13.8:4 kV with a reactance of 5.6%. The motor full-load current is 362 A and its locked-rotor current is 1970 A. The supply system short-circuit MVA at the 13.8 kV terminals of the transformer is 431 maximum, 113 minimum, on 100 MVA base. Determine if a phase-instantaneous overcurrent relay can be applied if it is set at half the minimum fault current and twice the locked-rotor current.

- 11.2** Review the application of Problem 11.1 if a time-delayed instantaneous unit is applied and set at 1.1 times locked-rotor current.
- 11.3** Another feeder is supplied by the same source as in Problem 11.1 through a 2.5 MVA, 13.8:2.4 kV transformer with 5.88% reactance. The largest motor connected to this bank is rated at 1500 hp, 2.3 kV, with a full load current of 330 A, locked rotor current of 2213.5 A. Can an instantaneous phase overcurrent relay be applied set at half the minimum fault current and twice the locked-rotor current?
- 11.4** The same source supplies a 460 V feeder through a 2 MVA transformer, 13.8 kV:480 V transformer with 5.75% reactance. The largest motor on this feeder is 125 hp, 460 V with 90.6 A full-load, 961 A locked-rotor current. Can a phase-instantaneous overcurrent be applied if set at half the minimum fault current and twice the locked-rotor current?
- 11.5** In the system shown in Figure P11.5:
- Calculate the fault currents flowing for a solid three-phase fault on the 4160 V bus. For this problem, consider the 500 hp induction motor as one of the sources.

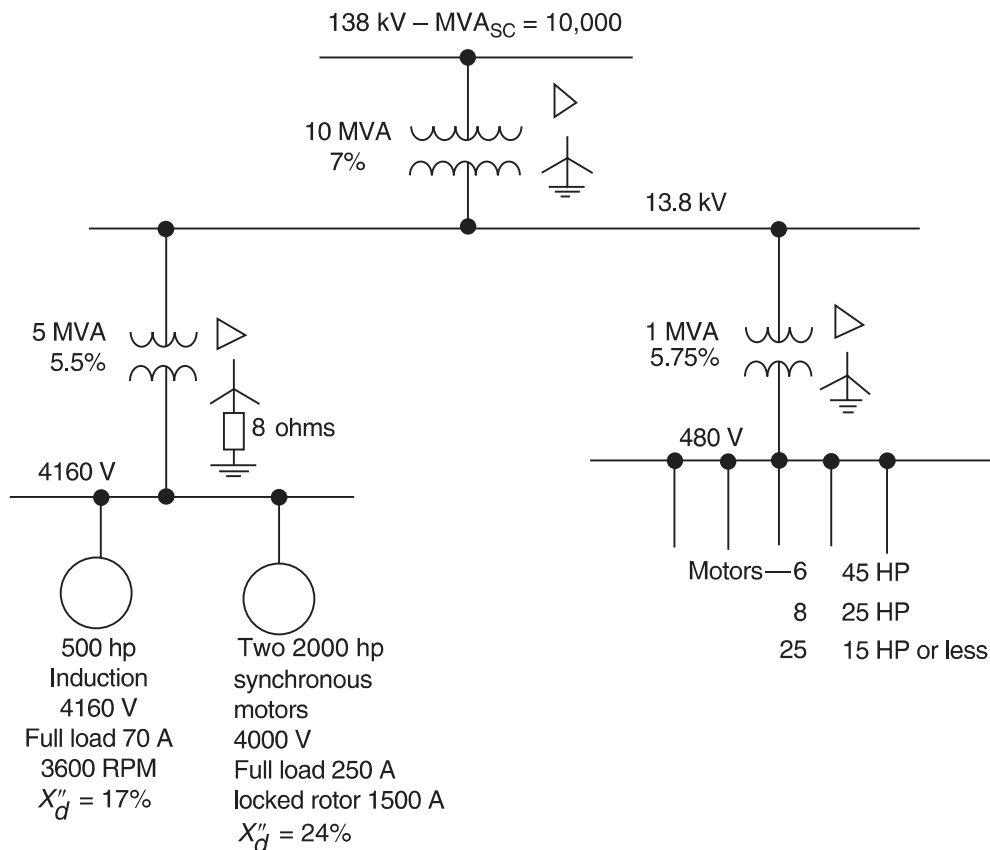


FIGURE P11.5

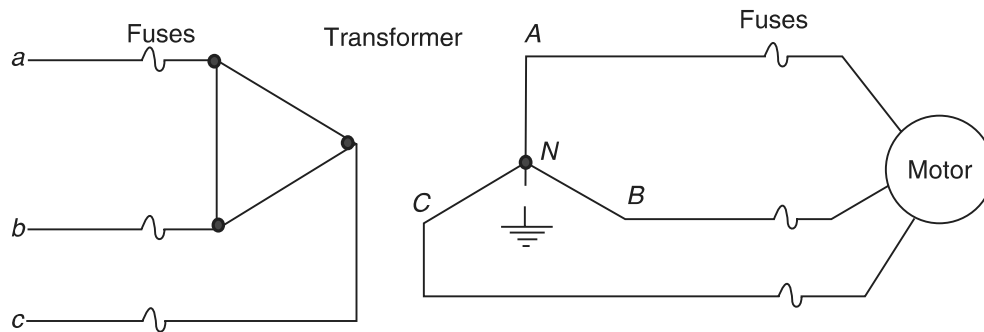


FIGURE P11.6

- b. What percent of the fault current does this induction and each of the two synchronous motors supply?
 - c. Calculate the current flowing for a solid single-line-to-ground fault on the 4.16 kV bus.
 - d. Select CT ratios and instantaneous overcurrent relay settings for protecting the motors for both phase and ground faults.
- 11.6** A fully loaded motor is connected to a supply source through a transformer as shown in Figure P11.6. The phase sequence is different on the two sides. Assume that the positive sequence current into the motor does not change after the fuse operations.
- a. For phase *b* fuse open on the source side, plot the sequence and total currents existing on both sides of the transformer. With one per unit positive sequence current, determine the magnitudes of the phase currents on both sides.
 - b. Repeat part a with all source side fuses in service but with the phase *A* fuse on the motor side open.
 - c. What effect does grounding the transformer neutral have?

CHAPTER 12

- 12.1** The 12.5 kV distribution feeder (Figure P12.1) has two taps. One is protected by three oil circuit reclosers with 70/140 A coils set as in Table P12.1. The other tap is a single-phase circuit protected by one 30 A fuse operating as shown in Table P12.2. The data for the 46 kV fuse is in Table P12.3. The phase and ground relays are very inverse time overcurrent with instantaneous units. Their time–overcurrent characteristics are shown in the typical curves of P12.11. Fault currents are in amperes at 12.5 kV.
- a. Determine the 46 kV fuse time–current characteristics in terms of 12.5 kVA for 12.5 kV three-phase, phase-to-phase and phase-to-ground faults. Draw these high-side fuse curves along with the

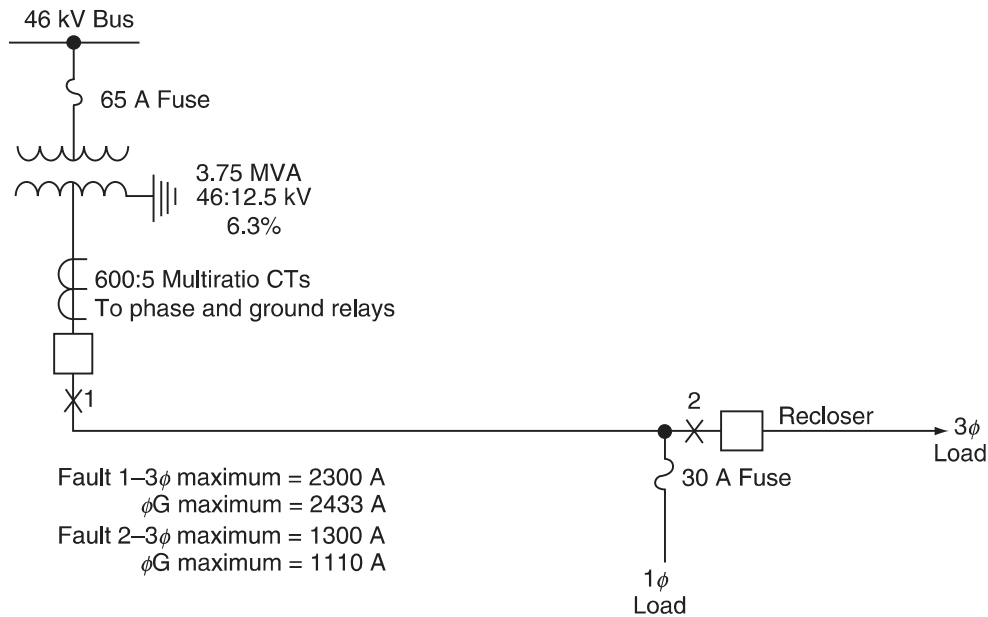


FIGURE P12.1

recloser and 30 A fuse curves on time–current log paper, such as K & E 48 5257, with 12.5 kVA as the abscissa and time in seconds as the ordinate.

TABLE P12.1
Circuit Reclosers

Current (A)	Time (sec)
140	20
185	10
200	7.5
275	5
320	4
400	3
480	2
600	1
650	0.8
720	0.7
800	0.6
900	0.5
1200	0.4
1600	0.3
2200	0.25

TABLE P12.2
30 A Fuse

Approximate by a 120° line
passing through 1000 A at
0.06 sec for the minimum melt curve
0.11 sec for the maximum clearing curve

- b. Select a suitable ratio for the current transformers to the phase and ground relays.
 - c. Set and coordinate the phase and ground relays. Provide a minimum 0.2 sec coordination interval between the recloser and the relays, and a minimum 0.5 sec between the 46 kV fuse and the relays. Specify the time–overcurrent relay tap selected (available taps are 1-1.2-1.5-2-2.5-3-3.5-4-5-6-7-8-10), the time dial, and the instantaneous current pickup for both phase and ground relays. Plot the coordination on the curve of part 1.
- 12.2** In the loop system of Figure 12.4, set and coordinate the phase overcurrent type relays around the loop in the counterclockwise direction for breakers 4, 6, and 9. Use criteria and the settings for the other relays involved from the example in the text.
- 12.3** Apply and set phase-instantaneous relays where they are applicable for the breakers 4, 6, and 9 in the system of Figure 12.4.
- 12.4** A 12/16/20 MVA transformer is connected to a 115 kV source through a high-side 125E fuse and through a low side recloser to supply a 12.5 kV feeder. The transformer is delta-connected on the high side and solidly wye-grounded on the low side. The total reactance to the 12.5 kV bus is $X_2 = X_2 = 0.63$ per unit, $X_0 = 0.60$ per unit on 100 MVA. The lines from the 12.5 kV bus have a positive sequence impedance of 0.82 Ω /mile and a zero sequence impedance of 2.51 Ω /mile. Ignore the line angle in this problem.

TABLE P12.3
65 A Fuse, Minimum Melt

46 kV (A)	Time (sec)
130	300
260	10
500	1
1500	0.1

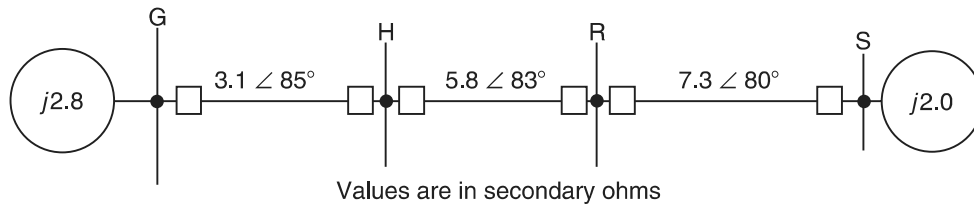


FIGURE P12.5

As a result of a problem it is necessary to operate temporarily with the low side recloser bypassed. Determine how many miles out on the line can be protected by the high-side fuse for solid line-to-ground faults. The minimum current to open the fuse is 300 Ω .

12.5

- Apply and set distance-type relays at Stations H and R for the protection of line HR in the system in Figure P12.5. Set zone 1 units for 90% of the protected line, zone 2 to reach 50% into the next line section beyond the protected line, and zone 3 for 120% of the next line section.
- Plot this system on an R - X diagram with the origin at bus H. Plot the relay settings of part 1 using mho-type characteristics. The mathematical formula for a circle through the origin or relay location is where Z_s is the relay setting at 75° :

$$Z = \frac{1}{2}(Z_s - Z_s \angle \phi).$$

The first term is the offset from the origin at 75° and the second term is the radius. This when ϕ is 75° , $Z = 0$, the relay location; when ϕ is 255° , $Z = Z_s$ the forward reach.

- What is the maximum load in MVA at 87% pf. that can be carried over line HR without the distance relays operating? Assume that the voltage transformer ratio $R_v = 1000$ and the current transformer ratio $R_c = 80$.

12.6

- Apply and set distance relays for line HR as in Problem 12.5 except set the zone 3 unit in the reverse direction to reach 150% of the line section behind the relay.
- Plot these settings (zone 1 and 2 as in Problem 12.5) and zone 3 as given earlier on the R - X diagram with the origin at bus H.
- For this application, what is the maximum load in MVA at 87% pf. that can be carried over line HR without the distance relays operation? $R_v = 1000$ and $R_c = 80$.

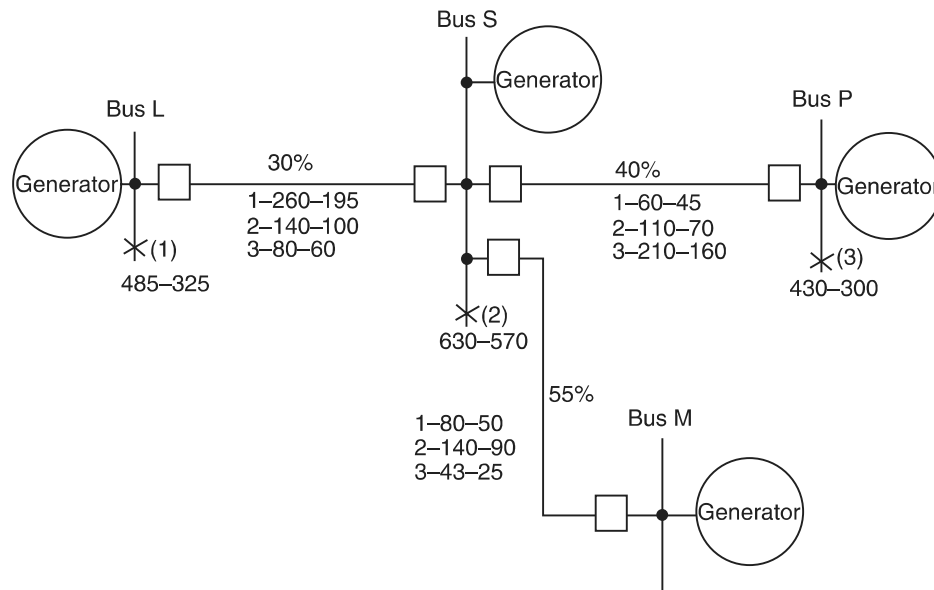


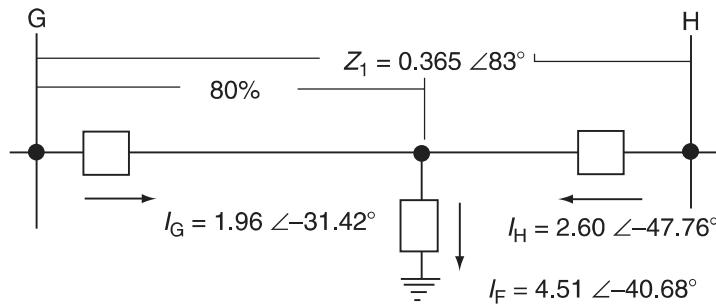
FIGURE P12.7

12.7 The line impedance values for the system in Figure P12.7 are in percent on a 100 MVA, 161 kV base. The fault values are in MVA at 161 kV for three-phase faults at the buses as indicated. The first value is for maximum conditions, and the second for minimum conditions.

- the zone 2 distance relay at station M is set for 70% impedance reach for the protection of line MS and into the lines SL and SP. The zone 3 distance relay is set for 100% impedance also into the line MS and the lines SL and SP. Determine the apparent impedance seen by these units at M under the maximum and minimum operation.
- What percentage of the lines SL and SP are protected during these two operating conditions.
- Determine the maximum load in MVA at 87% pf. that can be transmitted over line MS without operating the distance relays set as in part 2. Assume that the voltage transformer ratio $R_v = 1400$ and the current transformer ratio $R_c = 100$. Assume that the distance relay mho characteristic has a circle angle of 75° .

12.8 The 60 mile, 115 kV line GH (Figure P12.8) is operating with the voltages at each end 30° out of phase when a three-phase fault occurs at 80% of the distance from bus G. This fault has 12Ω arc resistance. The currents flowing to the fault are as shown and are in per unit at 100 MVA, 115 kV.

- Determine the apparent impedance seen by the distance relays at G for this fault.



All values in per unit on 100 MVA, 115 kV.

FIGURE P12.8

- Determine if the zone 1 mho unit at G set for 90% of the line GH can operate on this fault. Assume that the angle of the mho characteristic (Figure 6.12b) is 75° .
- Determine the apparent impedance seen by the distance relays at H for this fault.
- Determine if the zone 1 mho unit at H set for 90% of the line GH can operate for this fault. Assume that the angle of the mho characteristic is 75° .
- Describe how this three-phase fault can be cleared by the line distance relays.

12.9 The 40 MVA transformer bank (Figure P12.9) has tap changing under load (TCUL) with low voltage $\pm 10\%$ taps. The reactances at the high-, mid-, and low-voltage taps are 7.6% at 38 kV, 8% at 34.5 kV, and 8.5% at 31 kV respectively. This bank is connected directly to a 115 kV transmission line without a high-side breaker. There are no 115 kV voltage or current transformers available at G. To provide phase distance line protection, the relays must be set to

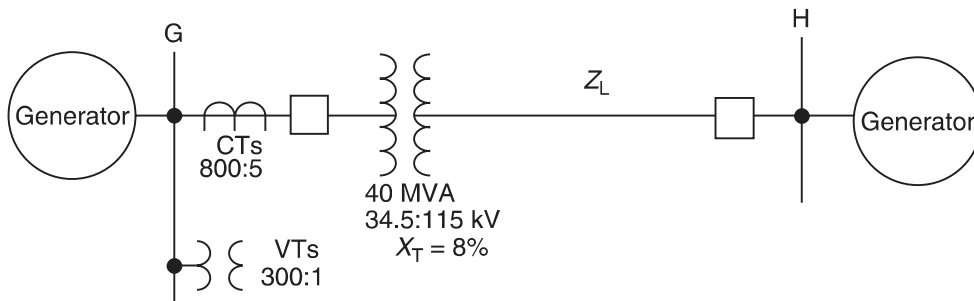


FIGURE P12.9

look through the transformer into the line. Assume that any phase shift through the transformer does not change the relay reach by either the connections or relay design.

- Set zone 1 phase distance relays at G for a 12 mile line GH where $Z_L = 10 \angle 80^\circ \Omega$. Note that it is necessary to determine which transformer bank tap gives the lowest value of ohms to bus H as viewed from bus G to prevent the relays from over-reaching bus H as taps are changed. Set zone 1 for $99\%X_T + 90\%Z_L$.
- With this setting of part 1, what percent of the line is protected by zone 1?
- What percent of the line will be protected when the other taps are in service with the setting of part 1?
- In view of the preceding analysis, what recommendations would you make for line protection?

12.10 Repeat Problem 12.9 but with a 50 mile, 115 kV line where $Z_L = 40 \angle 80^\circ \Omega$. Compare the protection for the 12 mile line or Problem 12.9 with the protection for the 50 mile line.

12.11 Ground directional overcurrent relays are to be applied to the 69 kV and 138 kV breakers for the protection of the 138 kV line that includes the autotransformer as shown in Figure P12.11. To determine the best method of directional sensing fault $I_1 = I_2$ and I_0 currents and V_2 and V_0 voltages are indicated for the three different line-to-ground faults.

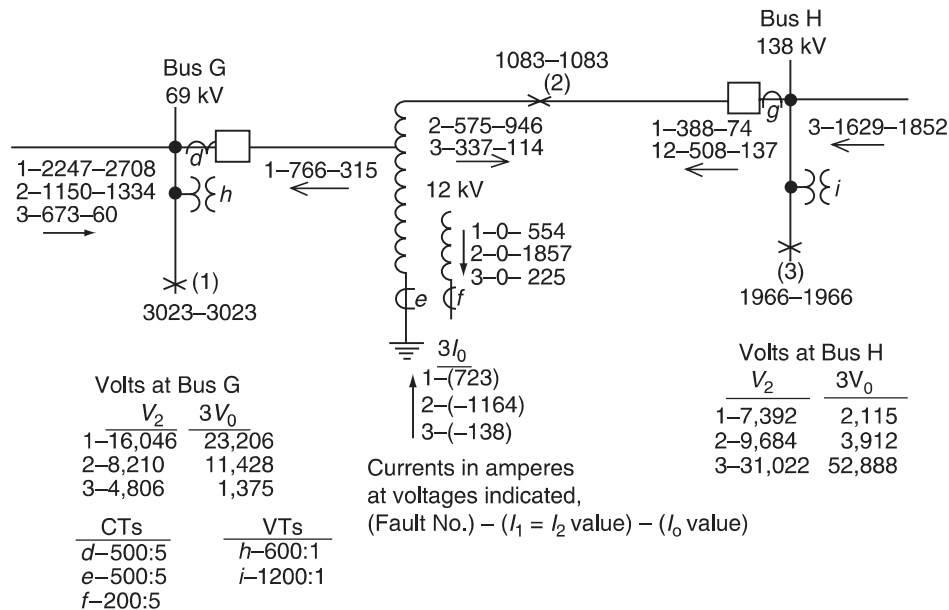


FIGURE P12.11.A

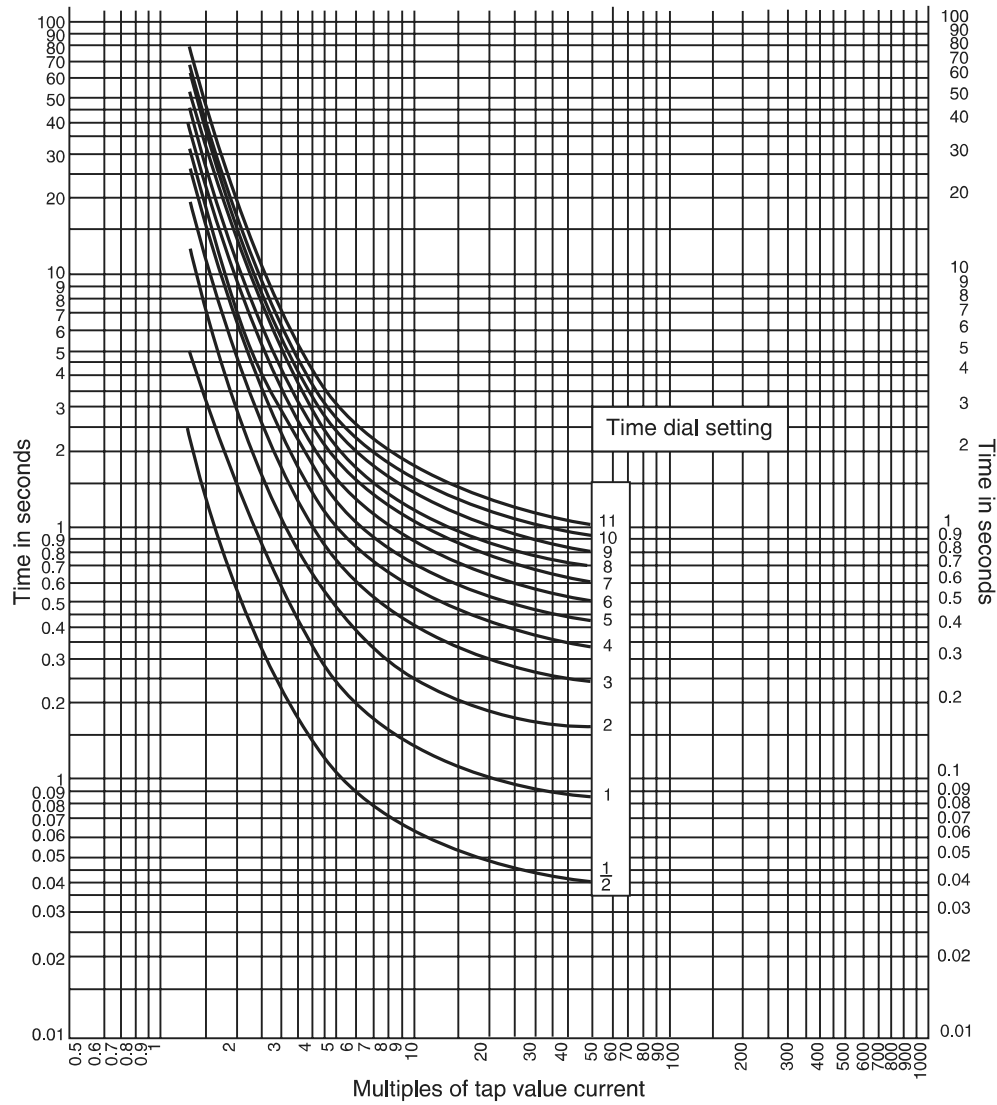


FIGURE P12.11.B

- a. Determine the secondary (relay) quantities that could be used to polarize and operate ground relays at both the G and H terminals.
- b. Make recommendations for the preferred method to polarize and operate the ground relays at G and H.

CHAPTER 14

14.1 For the system of Problem P12.5:

- a. Draw the locus of the surge ohms seen by the relays at H and R as the generators at the two ends of the system slip a pole. Assume

that the two generator voltages remain equal in magnitude throughout the swing. Locate the 60° , 90° , 120° , 180° , 240° , 270° , and 300° points.

- b. What is the magnitude of impedance as seen from bus H and from bus R for a 120° swing?
- c. With the distance settings applied in Problem 12.5, determine which distance relays will operate on the swing and at what swing angle this will occur.
- d. Repeat part c but with the distance settings as applied in Problem 12.6.