Electrical Systems - Course 135

COMPOSITE ELECTRICAL PROTECTIVE SCHEMES: PART I

BUSES AND TRANSFORMERS

1.0 INTRODUCTION

Following on from lesson 135.03-1, this lesson shows componte protective schemes for buses and large transformers. The actions of the **ac** part of the protection (fed from CT's) are described together with the **dc** tripping to the respective breakers.

2.0 PROTECTION OF CIRCUITS

2.1 Essential Features

All forms of electrical protection must:

(a) **Protect all sections** of the circuit in question. There must not be any section or sections which are not fully protected.

(b) Be **stable.** Operation of the protection is only permitted when a fault occurs within its designated **zone.** Operation is not permitted for faults occuring outside the designated zone.

(c) Have an adequate **sensitivity.** It must be able to distinguish between healthy and fault conditions, ie, to detect, operate and initiate tripping before serious damage occurs.

(d) Have an adequate operating **speed.** When electrical faults or short circuits occur, the damage produced is largely dependent upon the time the fault persists. Therefore electrical faults must be interrupted as quickly as possible.

3.0 PROTECTION SYSTEMS FOR BUSES

The previous lesson 135.03-1, sections 2.1 and 2.2 showed the principles of busbar protection when it is applied to single and teed busbars.

3.1 Generating Station Distribution Buses

Figure 1 shows a distribution bus similar to that used for the 13.8 kV system at Bruce NGS'A'. Note that the currents flowing into the bus from the supply transformers and the currents flowing to the load circuits are monitored by CT's, each CT having the same ratio. The bus will be healthy provided that the currents leaving the bus **exactly** equal the currents feeding the bus. Under this condition, the CT secondary currents will also balance and there will be no current in the differential relays (87 and 87N).

In the event of a fault on the bus, the differential relays (87 and 87N) will operate and trip all sources of infeed, ie, supply breakers #1 and #2 and the feeder breakers.

Note that the three 87 relays will operate for busbar to busbar (ie, line to line) faults within the bus while the 87 neutral relay will operate only when a line to ground fault occurs.

The actual tripping circuit and devices are covered in detail in the next few pages.

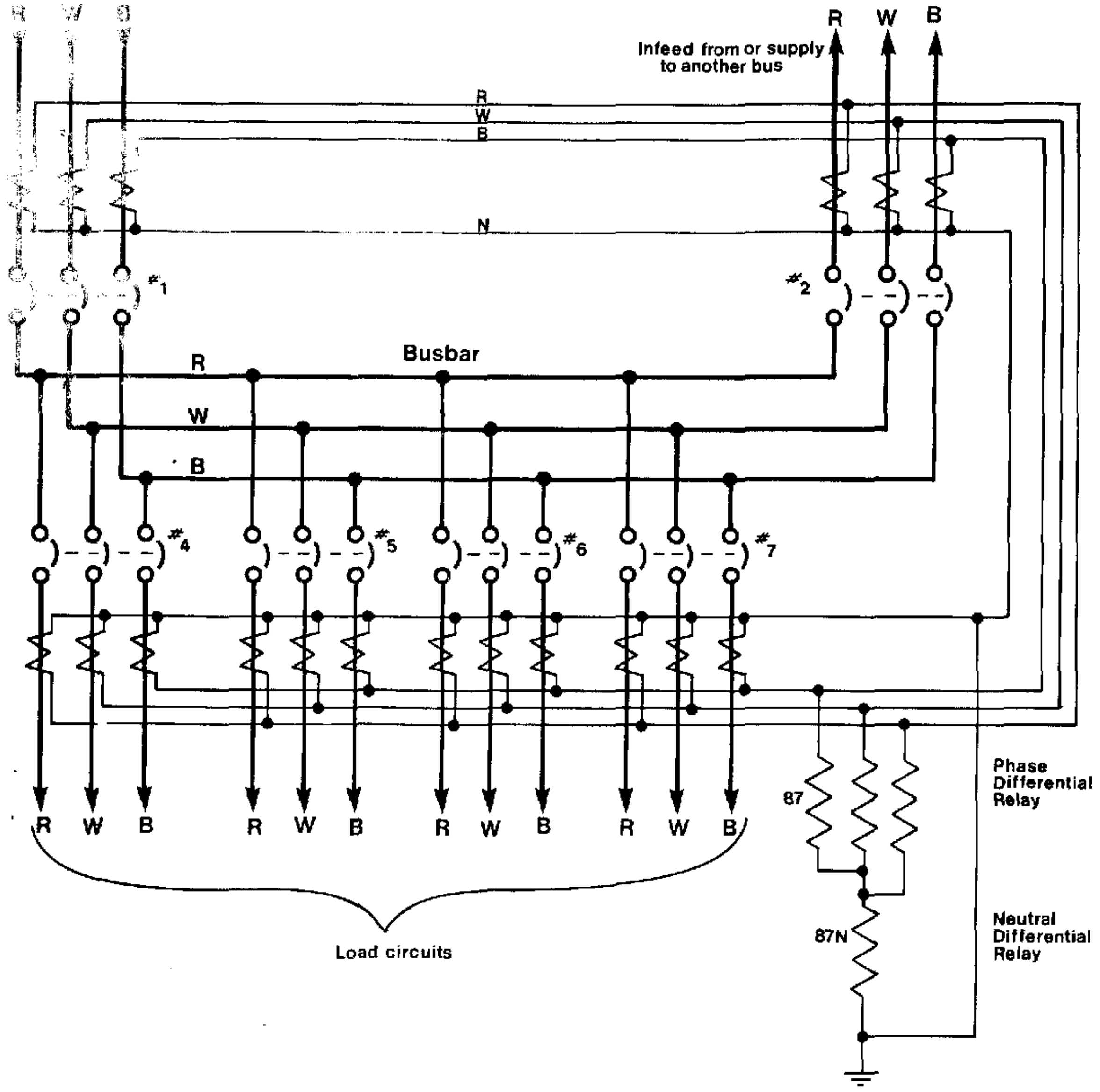


Figure 1: Differential busbar protection applied to a 13.8 kV station bus.

3.2 Generating Station Switchyard Buses

Figure 2 shows the type of ring bus layout used at Pickering and other generating stations. The bus is shown divided into four sections, A, B, C, D. Breakers separate each section from the two adjacent sections.

Section 'A' of the busbars is protected by a differential protection relay (87-A). This relay compares the currents leaving breakers A-B, and A-D with the current entering the bus from generator G1.

Section 'D' of the busbars is directly connected to line L1, and as far as the protection is concerned, this bus is part of L1. Because the system services transformers SST-1 is also directly connected to bus 'D', any current taken from the bus by this transformer must be subtracted from the currents flowing through breakers A-D and C-D. Failure to do this will give incorrect measured values of current flowing down the line.

Section 'B' of the bus is protected in a similar manner to bus 'D' and L1. Section 'C' of the bus is protected in a similar manner to bus 'A'.

In the event of a fault at F1 on bus 'A' all sources of infeed to the fault must be tripped.

Because the fault is inside the zone of bus 'A', relay 87-A will operate and open breakers (A-B) and (A-D). Generator G1 and the unit services transformer also provide an infeed to the fault. Therefore they must both be tripped by relay 87-A.

For a fault at F2 on Bus 'D' or the line L1, the protection for line L1 and Bus 'D' will operate. Breakers C-D and A-D will trip. In addition, the systems services transformer SST T-1 LV breakers must trip and the line L1 must also trip at the remote end. The tripping of the line at the remote end is done by the protection at the far end of the line sensing the fault and/or the protection at the local end sending a signal (usually called a **transfer trip)**, to the breaker at the far end of the line.

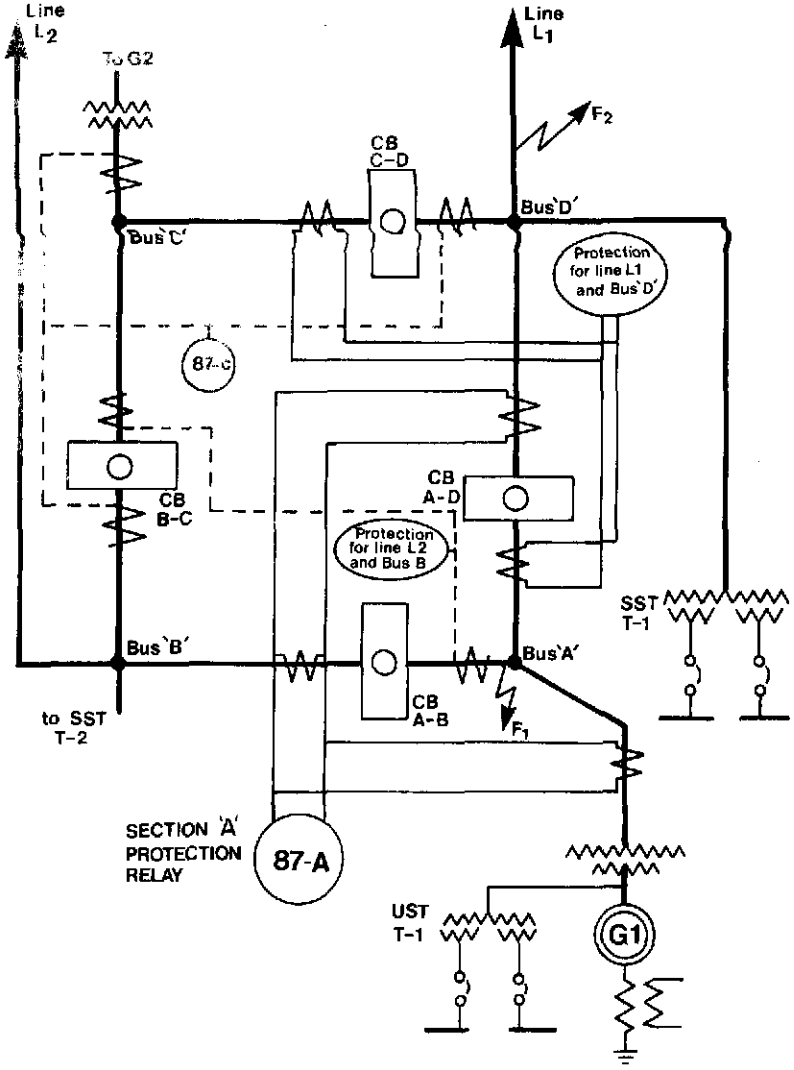


Figure 2: Differential and line protection protecting sections of a ring bus.

Figures 3(a) and 3(b) show the basic circuit of the dc tripping associated with bus 'A' and bus 'D', line L1 and systems services transformer SST T-1.

In Figure 3(a) note that the bus 'A' protection relay (87-A) operates its associated trip relay 94. This relay in turn trips breaker (A-B), Breaker (A-D) and the generator. Generator protection also feeds into the trip relay.

In Figure 3(b), the protection for Bus 'D' operates its associated trip relay 94. This relay in turn trips all sources of infeed to the fault, tripping breaker (C-D), breaker (A-D) and the system services transformer LV breaker. At the same time, a transfer trip is sent to trip the breaker at the remote end of the line.

The protection tripping from SST T-1 also trips the same breakers. This is because a fault on SST T-1 requires the interruption of the same current infeeds or supplies.

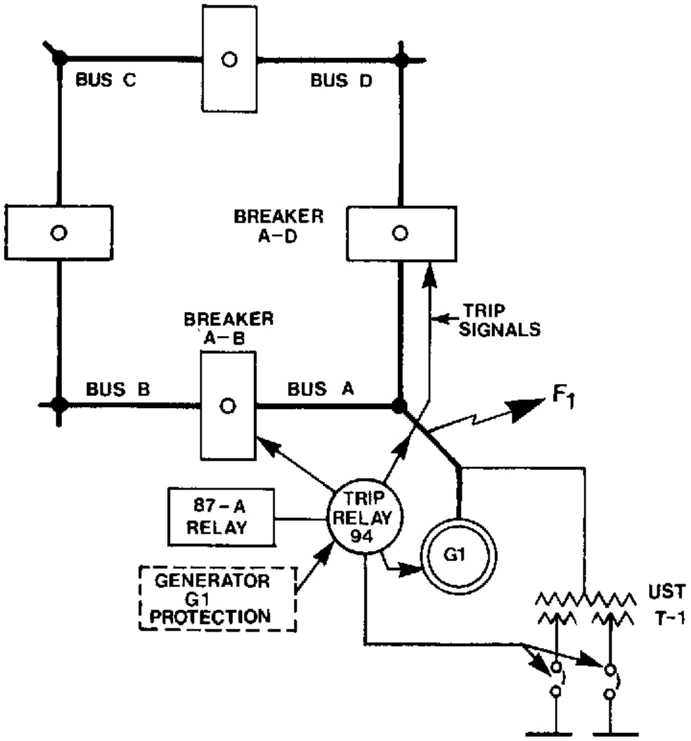


Figure 3(a): Tripping associated with Bus 'A' and Generator G1.

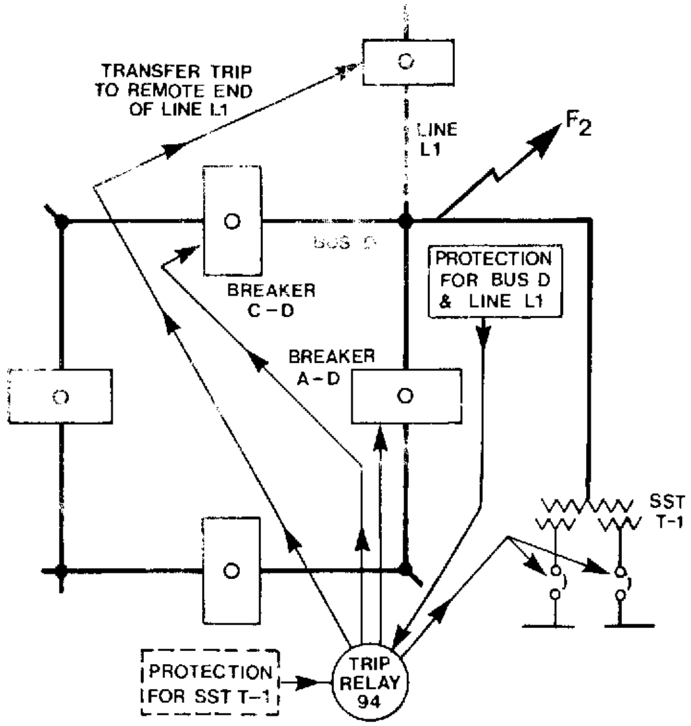


Figure 3(b): Tripping associated with Bus 'D' line L1 and SST T1.

4.0 PROTECTION OF TRANSFORMERS

With small transformers, (up to approximately 4 MVA, the cost of differential protection cannot be justified. Consequently small transformers are protected using one or more of the following:

(a) Fuses.
(b) Overcurrent relays (time delayed or instant aneous).
(c) Ground fault relays.
(d) Gas and oil relays.
(e) Oil or coolant temperature detecting devices.
(f) Winding temperature detecting device.
(g) Oil level detecting device.

4.1 Differential Protection Applied to Transformers

With larger transformers, (above approximately 4 MVA), the cost of differential protection is justified. The principle of differential protection, whether applied to buses or transformers is the same, ie, the current(s) entering the transformer must equal the current(s) leaving the transformer. Because the ratio between transformer windings is rarely 1:1, the ratios of the current transformers on the primary and secondary supply lines have to compensate for any change in current. To illustrate this, the following example is considered.

A single phase 20 MVA 230 kV/13.8 kV transformer is protected using differential protection.

(a) Taking the HV current transformer ratio to be 100/5, calculate the ratio of the LV current transformer.

(b) Draw a diagram showing the transformer, current transformer and differential relay. (See Figure 4.)

Solution

(a) For a single phase transformer

$$U = VI, \quad \text{VA.}$$

For the HV, $20 \text{ x } 10^6 = 230 \text{ x } 10^3 \text{ x } I$

$$I = 87 \text{ A}$$

On full load, this current will cause a current of

$$87 \text{ x } = \frac{5}{100} = 4.35 \text{ A}$$

to flow in the secondary of the current transformer.

For the LV, $U = VI$

$$20 \text{ x } 10^6 = 13800 \; I$$

$$I = 1449 \text{ A}$$

For the LV current transformer to balance with HV current transformer, it must also give an output of 4.35 A when the 20 MVA transformer is on full load. Consequently the LV current transformer must have a ratio of 1449/4.35. However the ratio if usually quoted with a 5.0 ampere secondary and this will give a primary current value of

$$\frac{5.0}{4.35} \text{ x } 1449 = 1666 \text{ A}$$

The CT ratio will therefore be 1666/5.

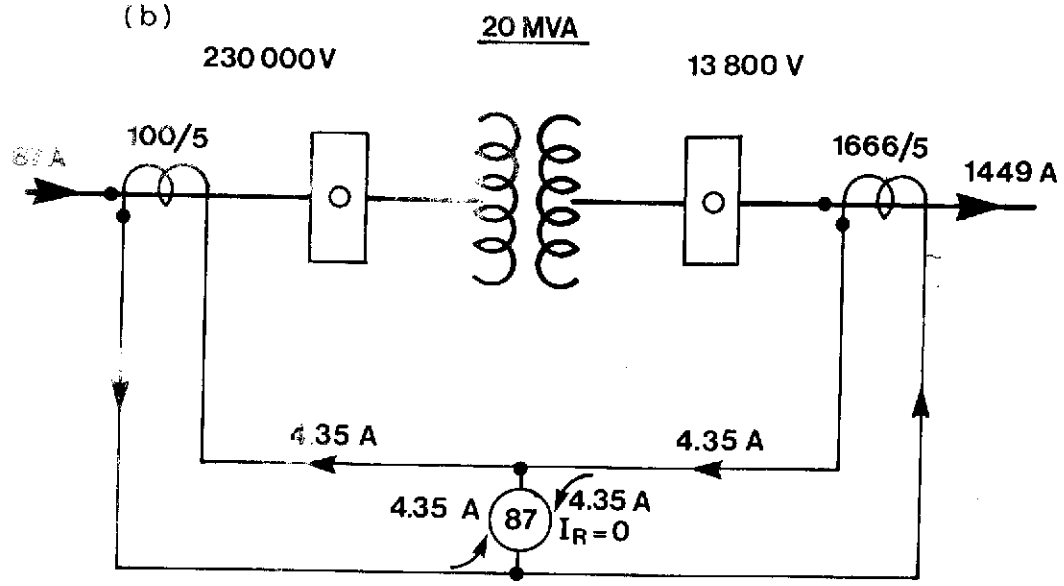


Figure 4: 20 MVA single phase transformer protected by a simple differential scheme.

In the case of a three phase transformer, three CT's are required on the HV and three are required on the LV. Three relays are also required. If there is a phase shift through the transformer because of star and delta connections, the CT circuits will have to compensate by having the same phase shift. This is done by connecting the CT's in delta and star.

4.2 Tripping Schemes for Large Transformers

For the purpose of this lesson, consider a 50 MVA star HV, star LV transformer. In order to protect this transformer fully, the following protection is required:

(a) Overcurrent (50, 51), HV and LV.

(b) Differential (87) to cover the complete transformer and the HV and LV cables.

(c) Ground fault (64) HV and LV.

(d) Winding temperature (49).

(e) Gas and oil (63G).

(f) Oil level (63L).

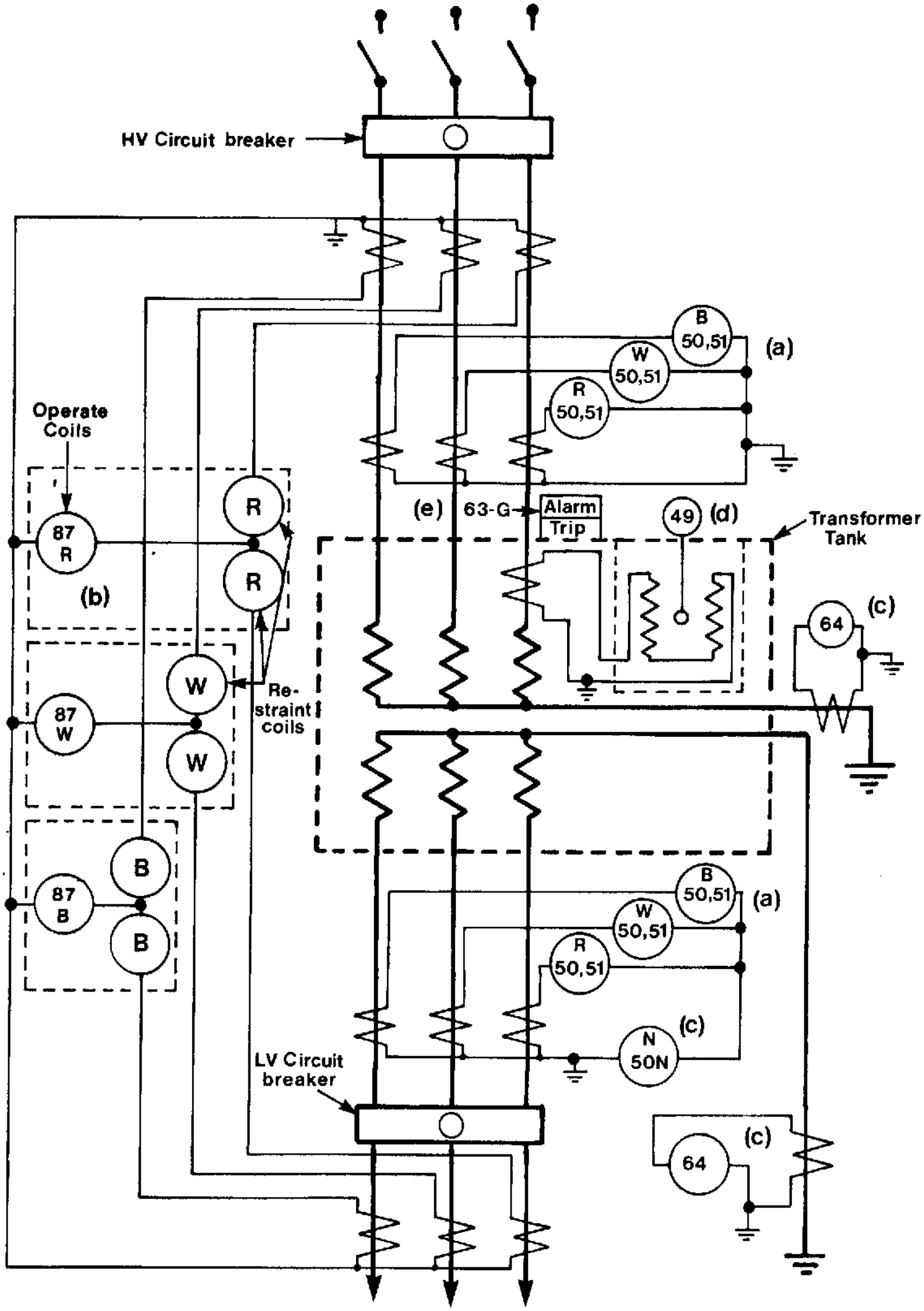


Figure 5: A 50 MVA transformer with its protective devices.

4.2.1 Detailed Protection Schemes. The circuits associated with the transformer and its CT's are shown in Figure 5, Figure 6 shows the dc tripping.

(a) Overcurrent Protection (50, 51) is provided on the HV and LV sides of the transformer. In the event of an overcurrent occurring on the LV side of the transformer, for example due to overload, then this protection must trip the LV breaker. There is no need to trip the HV breaker, and the transformer can remain energized ready for re-loading after the overloading problem has been cleared. It should be appreciated that to ensure correct operation, the HV overcurrent relay must have a higher current setting and longer time setting than the LV overcurrent relay.

In the event of the HV overcurrent relay operating, it is assumed that either the LV breaker has failed to clear the fault and/or the fault is inside the transformer. Under this condition, the HV and LV breakers must be tripped to take the transformer off line.

(b) Differential Protection (87) is provided to cover the complete transformer and the HV and LV cables. Note the location of the CT's. Restraint coils are installed in the relays to allow for current unbalances due to tap changing and CT errors. Lesson 135.03-1 gives the reasons for this requirement. Differential protection trips both HV and LV breakers.

(c) Ground Fault Protection is provided on the HV and LV sides of the transformer.

On the HV Side, a current transformer supplies the relay (64). If a ground fault occurs on the HV system, current must flow in the HV neutral connection. The relay will sense this current and will operate if the current exceeds the relay setting in **time and current magnitude.**

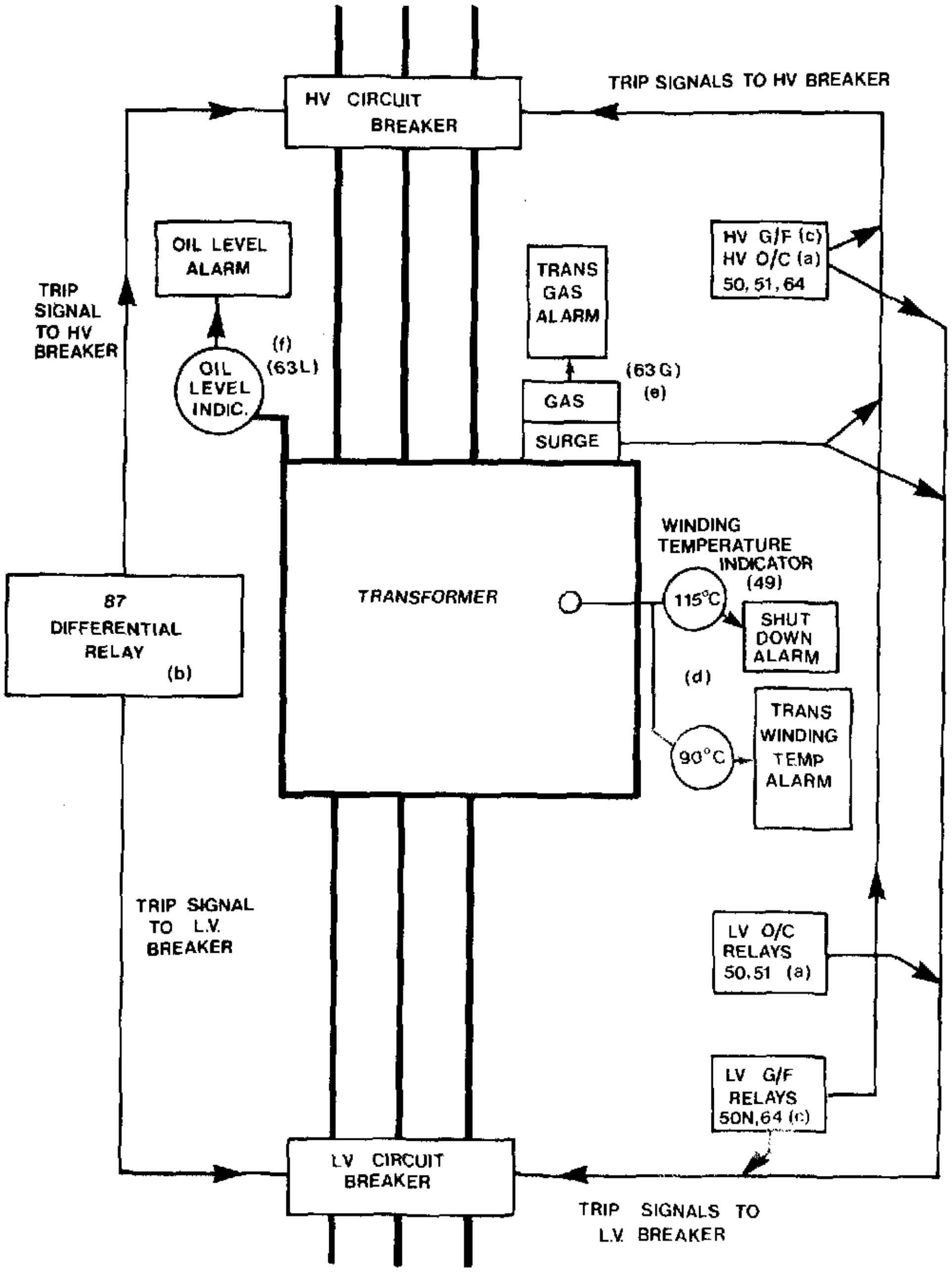


Figure 6: Diagram showing tripping from relays to breakers. Alarms are also shown.

On the LV Side, the ground fault protection is provided by relays 50N and 64. The 50N relay is connected in the neutral of the LV overcurrent CT's. In the event of a ground fault occurring, the CT's will not give a balanced output and the out of balance current will cause relay 50N to operate.

Relay 64 is connected in the neutral connection, in a similar manner to the HV ground fault relay. This relay is provided to trip the LV circuit breaker when a ground fault of low current magnitude persists for a longer period of time. An example of this type of fault would be an uncleared ground fault on a motor circuit which is supplied from the LV bus.

(d) A Winding Temperature Instrument (49) measures the top tank oil temperature and has a heater to give "thermal image". The operation of this device is described in Lesson 135.03-1. The setting of the winding temperature instrument, if connected for alarm is 90°C to 105°C. At the 115°C a shutdown alarm is given. At this temperature the operator must de-load or shut down the transformer.

(e) The Gas Collection and Oil Surge Relay (63G) is attached at the top of the tank. Gases formed by arcing and sparking will collect in the top of the relay and when sufficient has been collected, the alarm will operate. If an explosion occurs within the tank, the resulting oil surge will cause the microswitch in the pressure chamber to operate and trip the transformer.

(f) An Oil Level Alarm (63L) is commonly provided. The alarm is taken from contacts on a microswitch which is operated by the conservator level monitoring indicator. An alarm is given whenever the conservator. level is dangerously low.

Figure 7 is provided to show the tripping from the relays to the breakers. The alarm initiating devices are also shown.

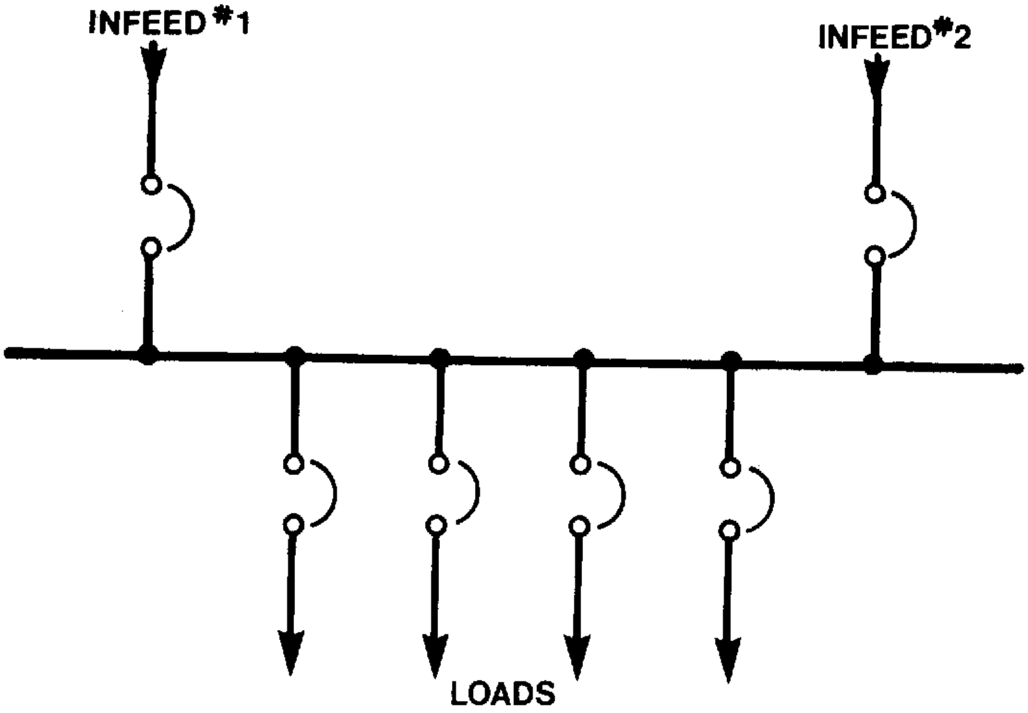
ASSIGNMENT

1. The diagram below shows a single line diagram for a three phase HV bus. Show on the diagram:

   (a) The positions of the bus protection current transformers.

   (b) How the bus protection relays are connected to the CT's. A detailed diagram is not necessary, a single line diagram is sufficient.

   (c) The breakers that are tripped by the bus protection.

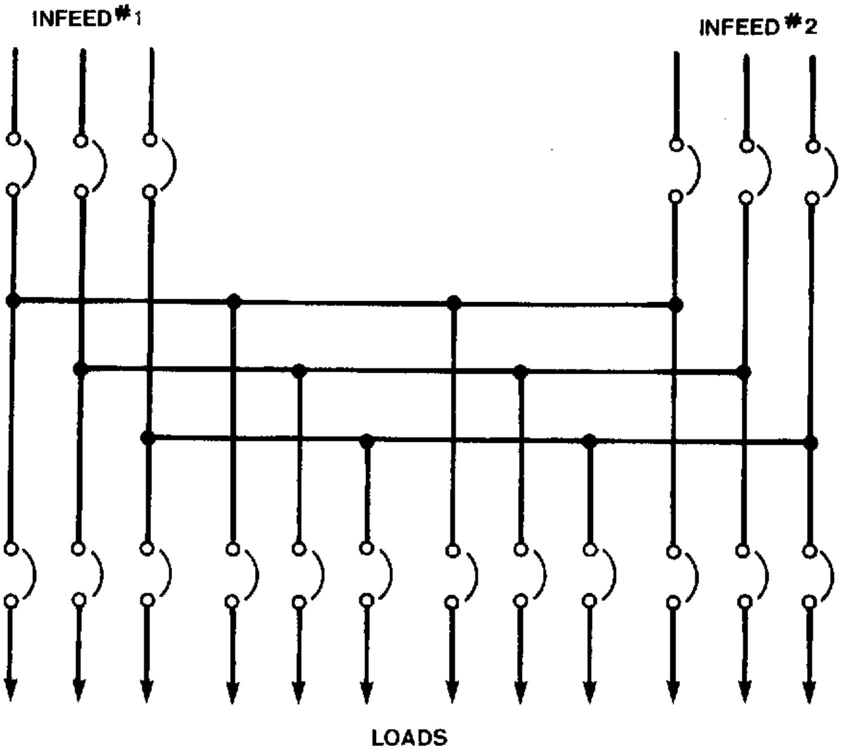


2. The diagram below shows a three phase bus. Show on the diagram.

   (a) The positions of the bus protection current transformers.

   (b) How the bus protection relays are connected to the CT's. Single line information is sufficient.

   (c) The breakers that are tripped by the bus protection.



3. The accompanying single line diagram shows a power station HV bus. The bus is supplied by a generator which in turn feeds a power line and a system services transformer. Show on the diagram:

   (a) The protection used for bus 'A' and the positions of the current transformers.

   (b) The protection used for bus 'D' and the line. Show the positions of the current transformers.

   (c) The breakers that are tripped when faults occur at the F1 and F2 positions, respectively.

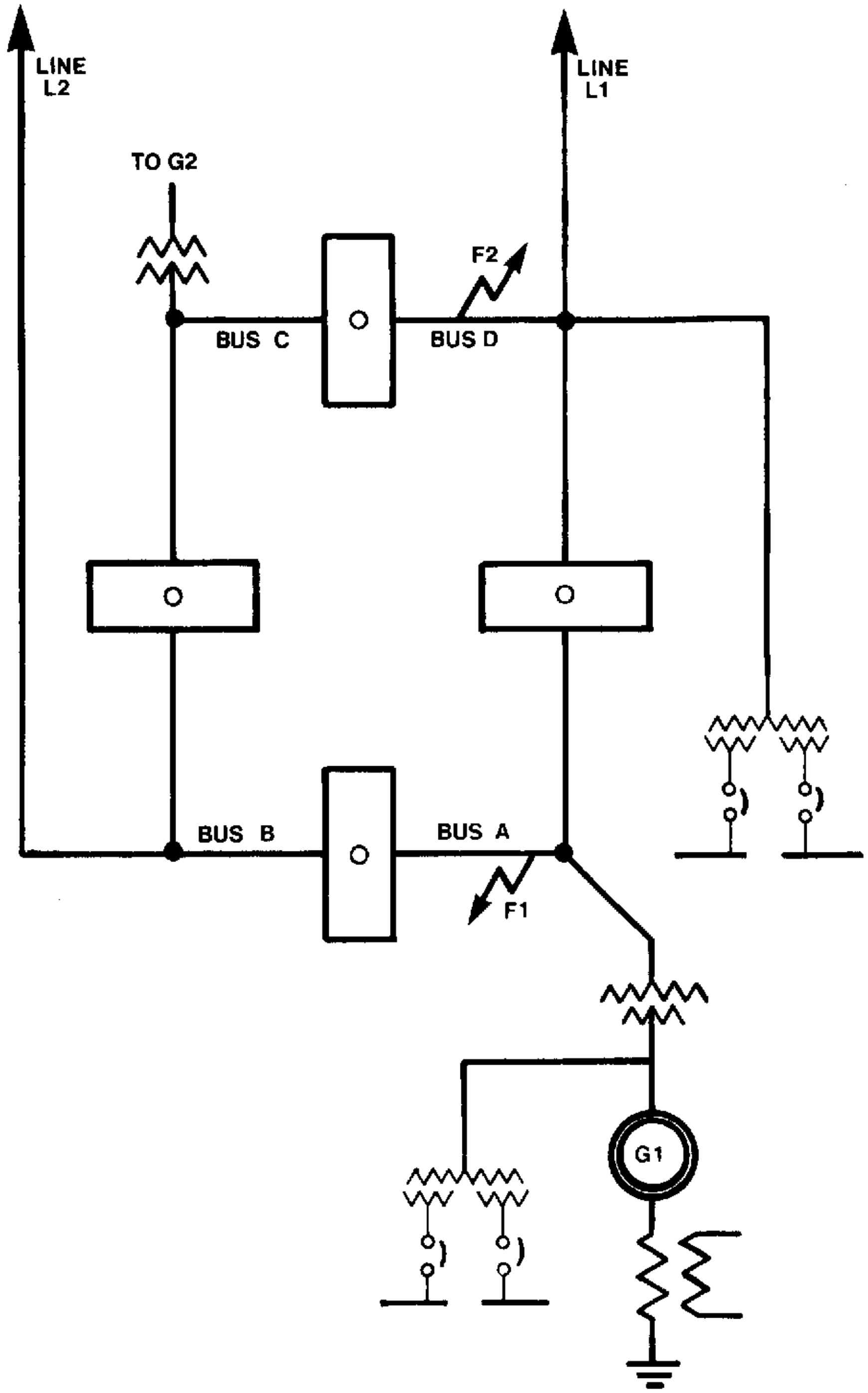


Diagram for Question #3

4. Figure 6 shows the protection applied to a transformer. For each of the protective devices:

   (a) State the name of the protection.

   (b) Briefly explain <u>how</u> and <u>when</u> each device operates.

   (c) State which breaker each relay trips.

5. The accompanying diagram shows a star/star transformer. The transformer has the following protection.

   (a) Overall differential (87).

   (b) HV overcurrent (50, 51).

   (c) HV ground fault (64).

   (d) LV ground fault (64).

   (e) LV overcurrent (50, 51, 50N).

   (f) Gas and oil (63G).

   (g) Winding temperature.

   (h) Oil level (63L).

   On the diagram:

   (a) Mark the designated number for each relay.

   (b) Show how each relay is connected.

   (c) Show the grounding of each CT circuit.

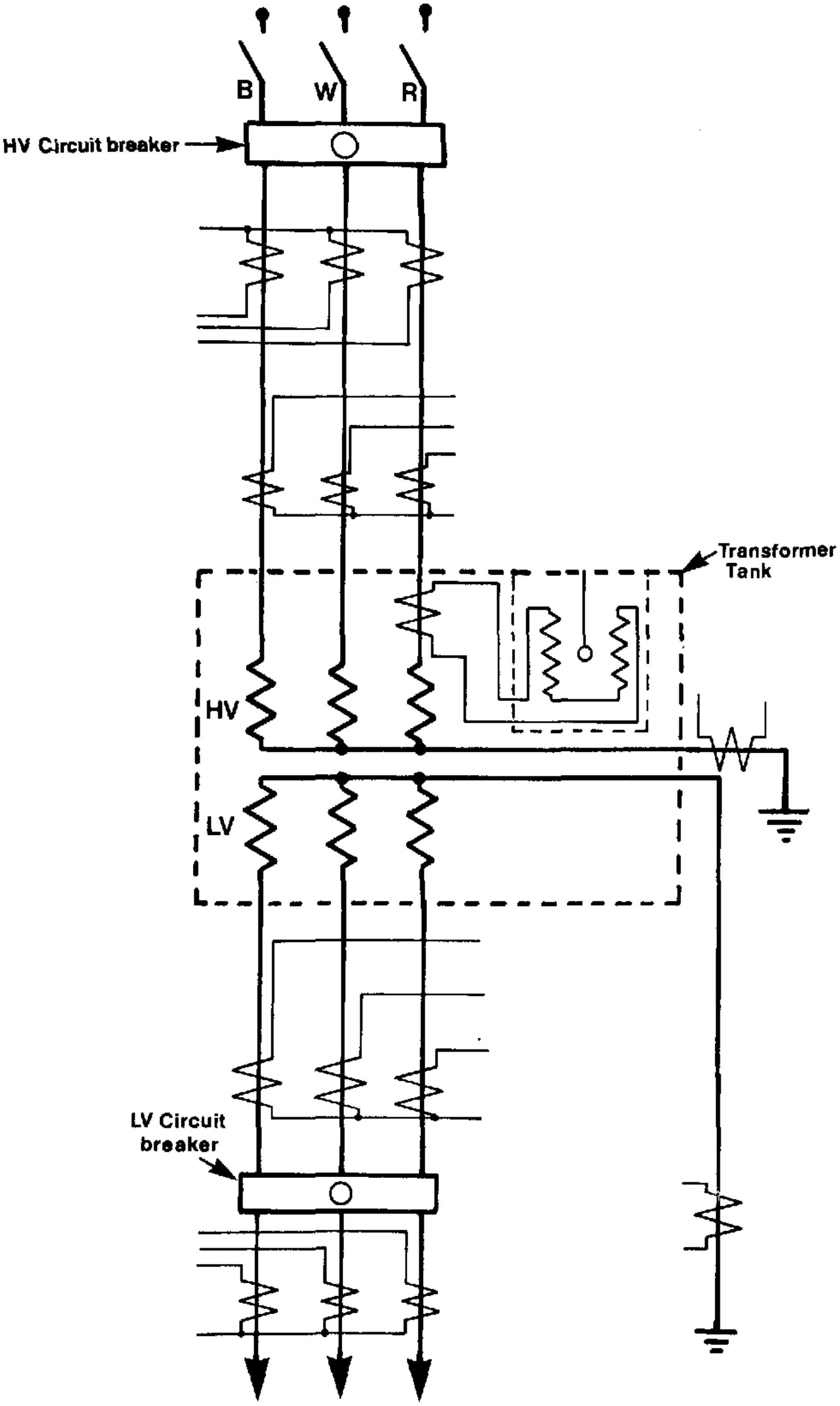


Diagram for Question #5