

## NOTES &amp; REFERENCES

## Module 6

# POWER TRANSFORMER PROTECTION

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## OBJECTIVES:

After completing this module you will be able to:

- 6.1 Explain how each of the following protection schemes can be used to provide protection of a power transformer:
- a) Transformer gas relay,
  - b) Transformer winding temperature,
  - c) Differential protection,
  - d) Ground fault.
- 6.2 For each of the schemes listed in 6.1, give an example of a fault requiring the protection scheme to operate and the consequence to the transformer if the protection scheme failed to operate.

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## INSTRUCTIONAL TEXT

### INTRODUCTION

This module will discuss various protection schemes used for the protection of power transformers.

### TRANSFORMER GAS RELAY

The transformer gas relay is a protective device installed on the top of oil-filled transformers. It performs two functions. It detects the slow accumulation of gases, providing an alarm after a given amount of gas has been collected. Also, it responds to a sudden pressure change that accompanies a high rate of gas production (from a major internal fault), promptly initiating disconnection of the transformer.

*Pages 1–4* ⇔

*Pages 4–5* ⇔

*Pages 5–6* ⇔

*Pages 7–8* ⇔

*Pages 2–7* ⇔

*Obj. 6.1(a)* ⇔

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Obj. 6.2 ⇔

An **incipient fault**, or developing fault, usually causes slow formation of gas (the process of gas formation is discussed later in this section). Examples of incipient faults are:

- a) current flow through defective supporting and insulating structures;
- b) defective joints at winding terminals causing heating;
- c) minor tap changer troubles;
- d) core faults.

A **major fault** is one that results in a fast formation of a large volume of gases. Examples of such faults are:

- a) shorts between turns and windings;
- b) open circuits which result in severe arcing.

Failure to disconnect the transformer under fault conditions can result in **severe equipment damage from high gas and oil pressures and the effects of the electrical fault.**

### Generation of Gas Due to Transformer Faults

Internal transformer electrical faults result in the production of ionized gases. A significant volume of gas is frequently generated in the early stages of a fault by rapid oil breakdown. The generated gases rise through the oil to the top of the equipment and collect in the gas relay. Once a sufficient volume of gas has accumulated, an alarm is generated by contacts within the gas relay.

In the event of a gas alarm, it is necessary to sample and analyze the gas being generated. This analysis, together with knowledge of the rate at which gas is accumulating, will determine the proper course of action. If a fault is thought to be developing, the device must be removed from service. Ignoring this early warning sign can lead to severe equipment damage as the fault progresses.

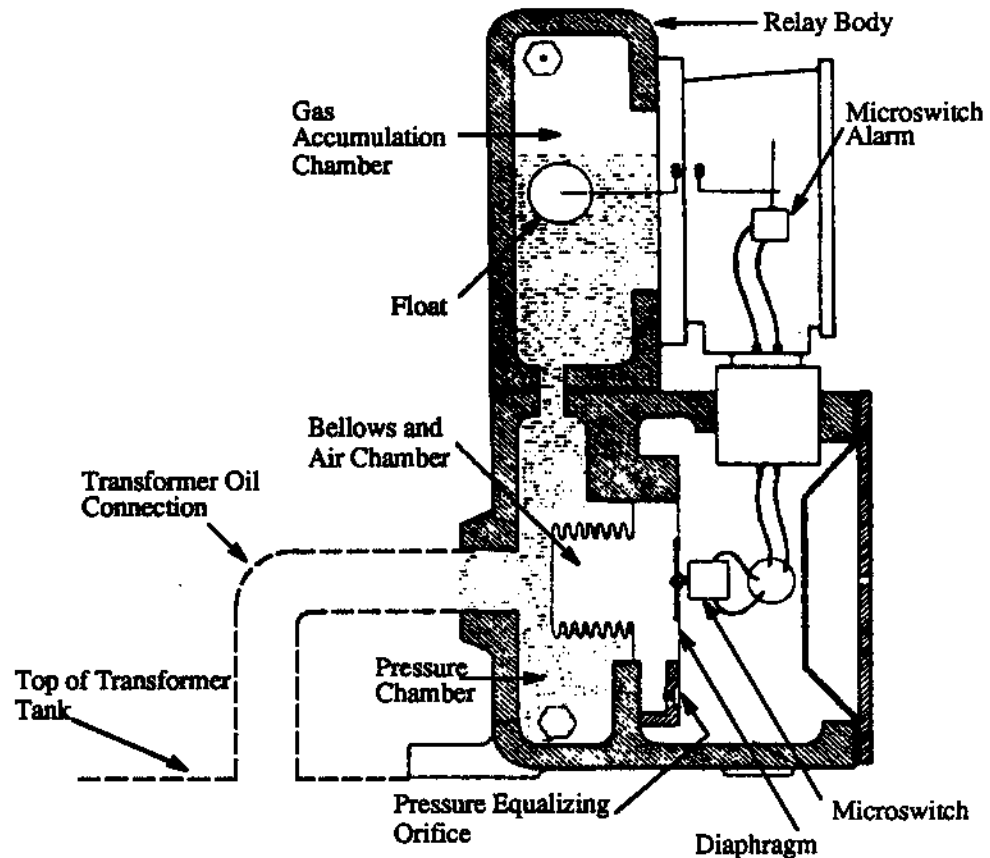
Several types of transformer gas relays are in use within Ontario Hydro. The next section describes the operation of a typical device.

### Operation of a Transformer Gas Relay

A typical transformer gas relay consists of two chambers, each performing a distinct function. A simplified cross-section of a gas relay is shown in Figure 6.1.

The relay assembly consists of a gas accumulation chamber mounted directly over a pressure chamber. The accumulation chamber collects slowly produced gases. A float located in this partially oil-filled chamber moves as the gas volume increases. It operates an alarm switch when the amount of gas

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**Figure 6.1: Cross Section of a Typical Transformer Gas Relay**

collected reaches a specified level. An indicator coupled to the float also provides a means to monitor the rate at which gas is being generated.

The second chamber, a pressure chamber, connects directly to the transformer oil circuit. It connects vertically to the accumulation chamber, providing a path for the rising gas. An air-filled bellows within the pressure chamber acts as the pressure change detector. A sudden pressure surge in the oil compresses the bellows and forces the air within to move a diaphragm. The moving diaphragm actuates a switch that initiates tripping of the transformer.

The relay must be configured in such a way as to act on pressure changes caused by internal faults, but compensate for pressure changes occurring under normal operating conditions.

“Steady state” pressure changes occur at a much slower rate than those resulting from internal faults, and a pressure equalizing orifice is provided on the relay to make it insensitive to these relatively slow pressure changes. This orifice is a very small opening in the diaphragm support. Should the bellows be compressed slowly, the pressure will not build up in the air chamber and the microswitch is not operated. If, however, a sudden pressure is applied,

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the pressure equalizing orifice is too small to relieve the pressure and the microswitch will operate.

Sudden pressures, such as oil circulating pump surges, are normal operating events and the relay must be set to ride through them. In practice, it is necessary to make sure the relay is set to operate at about 7 kPa (1 psi) above the maximum oil circulating pump surge pressure.

Dangerously high pressure increases from major faults are relieved by an explosion vent on the top of the transformer tank. This is basically a diaphragm sealed pipe with its open end directed away from the transformer. A significant increase in pressure bursts the diaphragm and discharges gases and hot oil with a possibility of resulting fire.

## TRANSFORMER WINDING TEMPERATURE

Heat is generated in a power transformer by current flow in the primary and the secondary windings as well as internal connections due to  $I^2R$  losses. At low loads, the quantity of heat produced will be small. But, as the load increases, the amount of heat becomes significant. At full load, the windings will be operating at or near their design temperature. The nameplate on a transformer will provide information on the maximum allowable “in-service” temperature rise for its windings and connections and will indicate what method of cooling is employed to remove the heat generated under load. A temperature of about 105° C is considered to be the normal maximum working value for large power transformers, based on an assumed maximum ambient temperature of 40° C.

*Obj. 6.1(b) ⇔*

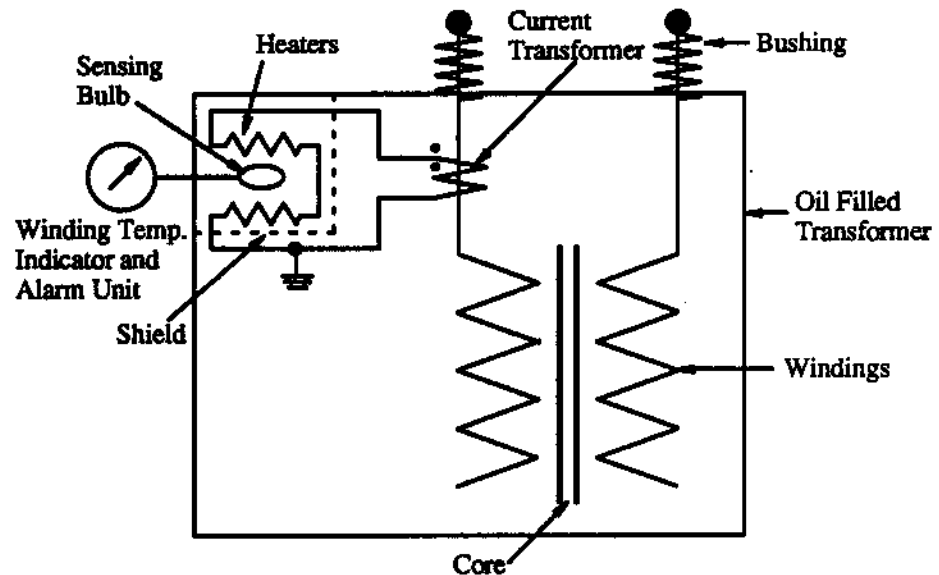
The winding temperature is sensed and indicated by a winding temperature gauge/alarm assembly. Figure 6.2 shows a typical arrangement. The purpose of this gauge is to provide a thermal image of the hottest point within the transformer. The sensing bulb of the assembly is placed in a well located near the top of the transformer tank. The well is immersed in the hot transformer oil. A heating coil, supplied from a load sensing current transformer, is installed around the sensing bulb to provide a local temperature rise above the general oil temperature. The effect of the heating coil, coupled with the heat of the oil on the bulb, allows the gauge to simulate the winding temperature “hot spots”.

*Obj. 6.2 ⇔*

Operation of the transformer above its rated voltage by even 10 % can cause a **significant temperature rise**, initiating an over-temperature alarm. Over voltage operation may be a result of tap changer or voltage regulation problems. Such over-temperature operation can lead to **physical insulation damage** reducing the useful life of the insulation and thus the life of the unit.

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A temperature rise of 8 – 10 °C beyond the normal maximum working value, if sustained, will halve the life of the unit. Unchecked overloading of a power transformer can cause a sufficient temperature rise to yield similar damage.

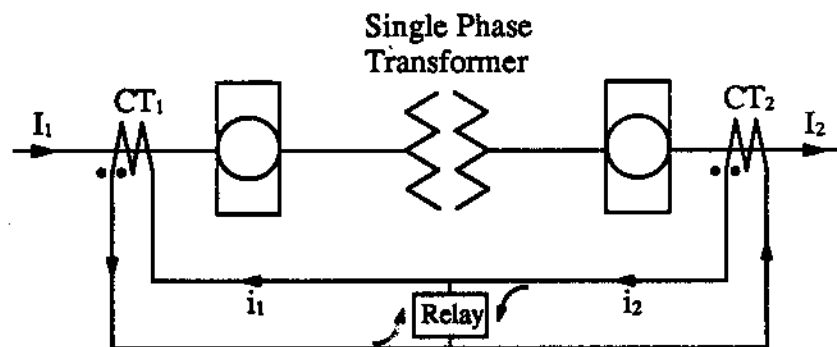


**Figure 6.2: Transformer Winding Temperature Sensor**

## DIFFERENTIAL PROTECTION

Obj. 6.1(c) ⇔

Transformer windings can be protected by differential protection methods. The concept of differential protection was introduced in Module 4. A simple transformer differential protection circuit is shown in Figure 6.3 .



**Figure 6.3: Simple Differential Protection for a Transformer**

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**Obj. 6.2 ⇔**

**Inter-winding faults** (short circuits) and ground faults within power transformers can be detected by this protection scheme. Failure to detect these faults and quickly isolate the transformer may cause serious damage to the device.

The transformer shown in Figure 6.3 is a single phase step-up transformer. Note that CT<sub>1</sub> and CT<sub>2</sub> will have ratios such that, under normal full load conditions on the power transformer, the currents  $i_1$  and  $i_2$  will be equal. Thus, the relay has no current flow and will not operate.

A more complicated protection circuit is shown in Figure 6.4 (a fold out drawing at the end of the module). Here a generator and its transformers are protected by two separate differential schemes. For simplicity, both the main power circuit and the relay circuits have been drawn as single line diagrams (remember that there would be a CT and a relay for each phase).

An examination should be made of the zones of protection, noting the overlap of the zones on the unit service transformer connection.

Note again that when transformers are included in the primary circuit, the ratios of the CTs may *not* be the same but their secondary outputs *will be* the same for the same value of supply/load power.

Consider the case of a fault in line L1 at point A. The secondary currents through the Main Transformer Differential Relay will no longer be balanced and it will operate.

A similar situation arises for a fault at point B. In this case, only the Unit Service Transformer Differential Relay will operate.

For a fault at point C, which is in the overlap area of both protection zones, both differential protection circuits will have unbalanced current flows and thus, both relays will operate.

In any of the three cases discussed above, failure of the protective relays to operate would result in severe damage to the equipment.

Should a fault occur on the 4 kV bus bar at point D, *neither* relay will operate. The fault will be cleared by other protection on the 4 kV bus bar.

Because the differential relay will not operate with load current or faults outside the protected zones ("through faults"), it can be set to operate at a low value of current thereby giving rapid operation when a fault occurs. There is **no need to time delay** the operation of the relay and therefore a fast acting type of relay can be used.

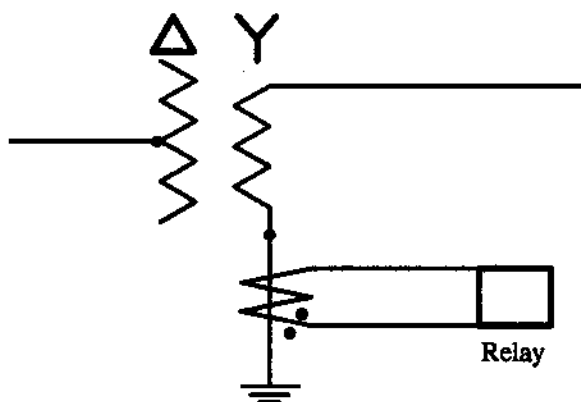
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Obj. 6.1(d) ⇔

**GROUND FAULT PROTECTION**

Large power transformers are protected from ground faults by the use of current transformers on the grounded neutral of their star or wye connections. The CT connects to a relay that detects any current flow (since this is the return path for fault current) and trips the power transformer. For example, a single CT is located on the grounded neutral of the high voltage side of the Main Transformer as the primary ground fault protection. Other power transformers, such as the Unit Service Transformer, employ a CT on the low voltage grounded neutral as a means of back-up ground protection. (The back-up relay will operate for ground faults outside of the differential protection zone for the transformer, if employed.)

Figure 6.5 shows a typical ground fault protection circuit for a power transformer star connection.



**Figure 6.5: Ground Fault Protection for a Star Winding**

More complete protection involves both differential and ground fault circuits on a given transformer. See Figure 6.6 (a fold out drawing at the end of the module). In this case, there is both ground fault protection on the secondary and differential protection for the entire transformer. The phase correcting transformer for both these protection circuits (delta-star creates a  $-30^\circ$  phase angle shift) has been omitted from the figure for clarity. A description of circuit operation follows below and considers the cases of two fault locations.

Obj. 6.2 ⇔

First, consider the case of a ground fault at point A. Since this fault occurs within the zone protected by the ground fault relay, this relay will sense the current flow in the secondary winding common (the return path for the fault current) and act to trip the circuit breaker. Note that the differential protection zone for the transformer as a whole will also sense an imbalance on its two CTs and *tend to act*. The operation of this relay will typically be

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slower than the ground fault relay since the operating current flowing through it is less than that through the ground fault relay. A ground fault that persists unchecked can result in severe damage to the device from high fault currents.

For a ground fault at point B, outside the differential protection zone, the situation is very different. No current imbalance is detected by the differential protection relay, therefore it doesn't act to clear the fault. The ground fault relay will detect the return flow of the fault current through the star winding common and *begin* to act. The protective relaying for the load bus should act to clear the fault but, should it fail, the ground fault relay would fully operate and trip the breaker.

Further experience with back-up ground fault protection has led to the design of the HIROP (High Resistance ground and Open Phase) protection scheme. This scheme is being installed throughout the Bulk Electricity System (BES) to detect either an open phase or a high resistance ground fault and selectively isolate the faulted zone.

### SUMMARY OF THE KEY CONCEPTS

- A transformer gas relay can provide protection for a power transformer by detecting the build up of gases within the transformer and/or by reacting to sudden pressure surges due to major faults.
- The winding temperature of a power transformer can be monitored by a sensor to protect from prolonged over-temperature operation which can lead to reduced transformer life.
- Differential protection techniques can be used to protect transformers and associated equipment from faults within defined zones.
- A single current transformer and relay can be placed on the grounded neutral of a star winding to protect the transformer from ground faults.

Pages 9-11 ⇔

You can now do assignment questions 1-5.

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**ASSIGNMENT**

1. How does a transformer gas relay provide protection for a power transformer ?

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2. What can cause over temperature operation of a power transformer ?

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3. What effect can this have on the transformer ?

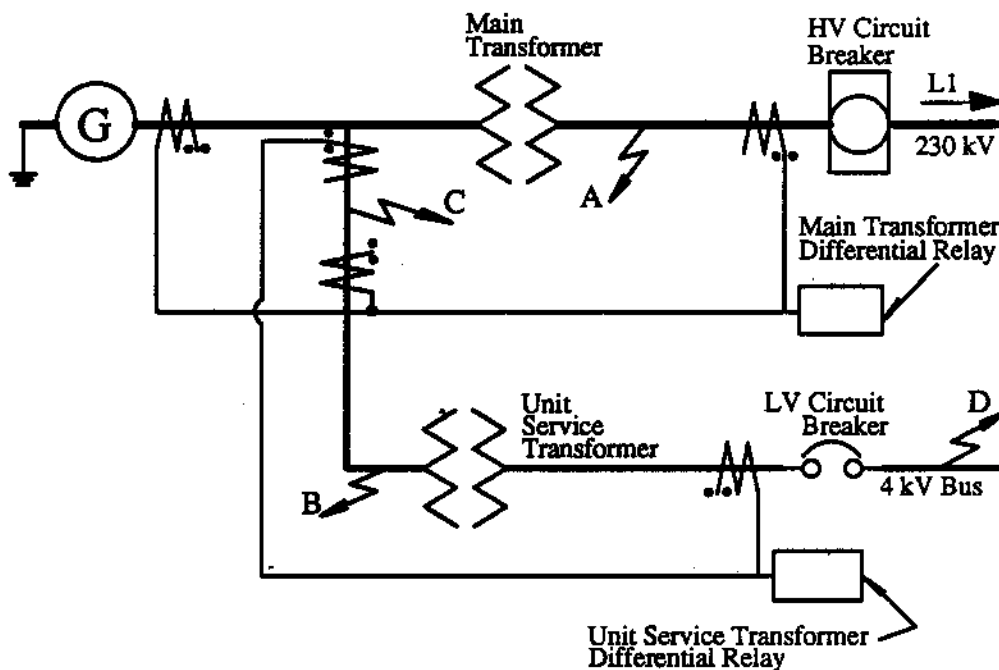
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## NOTES &amp; REFERENCES

4. For the differential protection circuit shown below,



Explain:

a) Circuit operation for a fault at point A.

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b) Circuit operation for a fault at point B.

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c) Circuit operation for a fault at point C.

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d) Circuit operation for a fault at point D.

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**NOTES & REFERENCES**

5. Explain the operation of transformer ground fault protection.

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Before you move on to the next module, review the objectives and make sure that you can meet their requirements.

Prepared by: Paul Bird, WNTD

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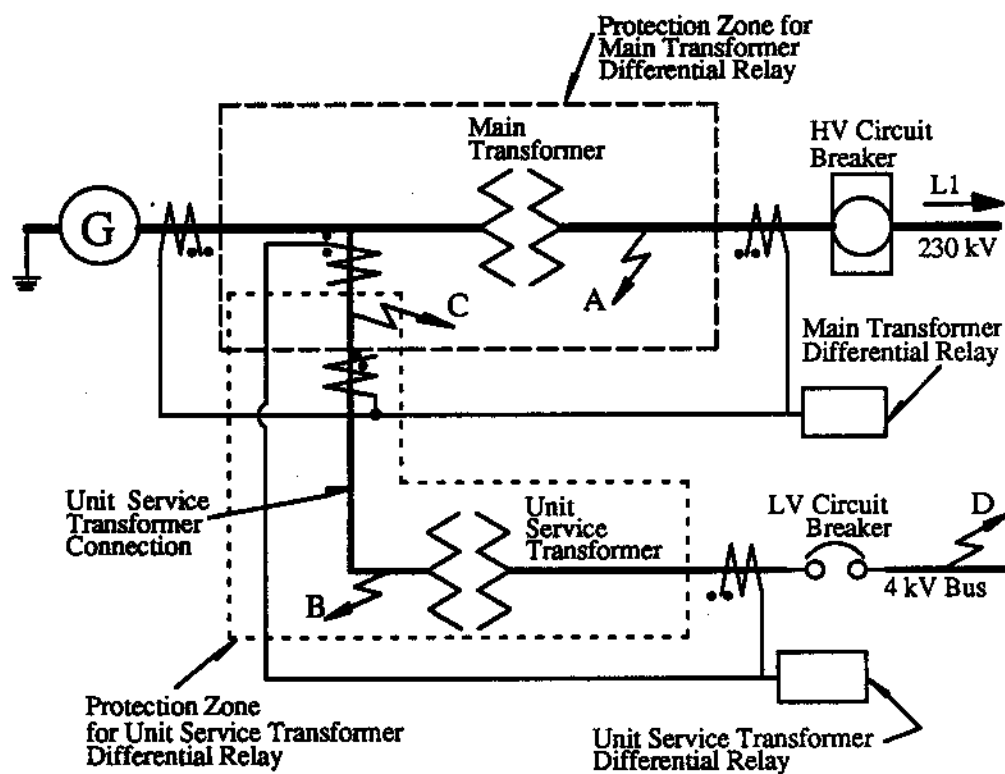
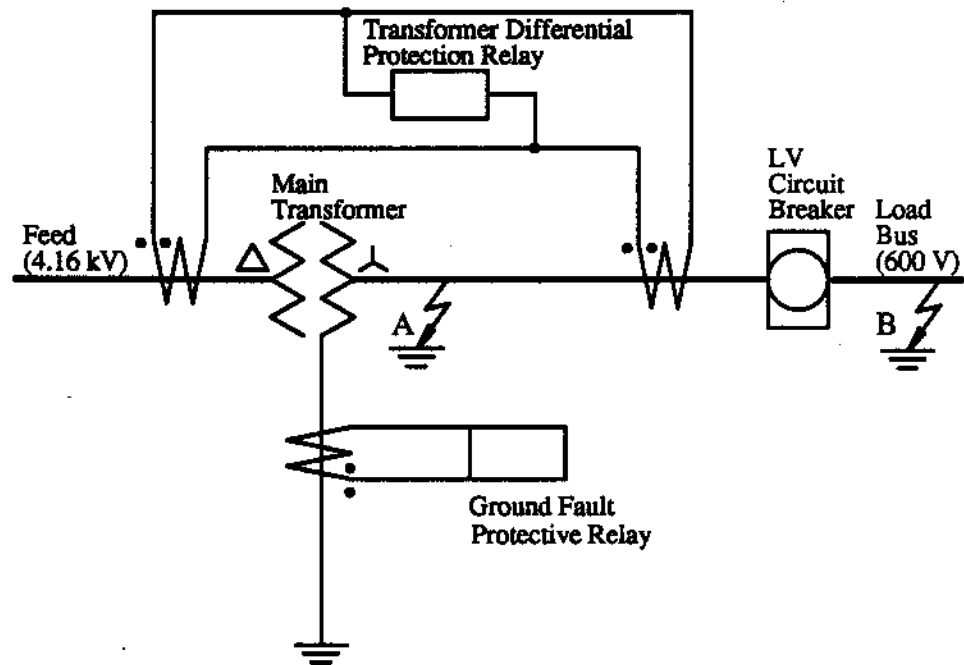


Figure 6.4:

**Typical Protection Diagram Showing Differential Protection Schemes for Main and Unit Service Transformers**

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**Figure 6.6:****Distribution Transformer Protection Loop With Ground Fault Protection**