

PI 30.22-1

Electrical Equipment - Course PI 30.2

TRANSFORMERS

OBJECTIVES

On completion of this module the student will be able to:

1. Briefly explain, in writing, the terms "hysteresis loss" and "eddy current loss".
2. Recall, in writing, two factors which make it necessary for a transformer to be cooled.
3. Briefly, state, in writing, two consequences of insufficient cooling in transformers.
4. Given a diagram, identify and briefly explain in one or two sentences the purpose of each component in a power transformer.
5. Briefly state, in writing, the methods used for the cooling of transformers.
6. In writing, identify which transformers within NGD, use oil-water-heat exchanger cooling.
7. Briefly explain, in writing, the operation of an oil-water heat exchanger type of cooling system.
8.
 - a) Recall, in writing, one problem which may occur with an oil-water heat exchanger type of cooling system;
 - b) Explain, in writing, what causes this problem to develop and how it can be eliminated.
9. Recall, in writing, two advantages and two disadvantages of using mineral oil for transformer cooling.
10. Recall, in writing, four contaminations which may occur in transformer oil.
11. Briefly explain, in writing, how each of four contaminants affects transformer performance.
12. Briefly explain, in writing how each of four contaminants in transformer oil is detected.
13. Briefly, in writing, explain the function of a tap changer and how a tap changer performs this function.
14. If given a tap changer schematic and a set of voltage variations, select the correct tap to be used.

1. Introduction

This lesson will introduce the reader to:

- (a) A short review of transformer theory.
- (b) Methods used for the cooling of transformers.
- (c) A sectional view of a power transformer.
- (d) The common problems associated with transformer insulating oil and the their respective detection methods.
- (e) Tap changers.

2. Transformer Theory Review

For a detailed discussion on transformer theory, refer to the PI 263 course notes.

$$\begin{aligned} \text{Turns ratio (a)} &= \frac{\text{Primary number of turns (N}_1\text{)}}{\text{Secondary number of turns (N}_2\text{)}} = \frac{\text{Primary Voltage (V}_1\text{)}}{\text{Secondary Voltage (V}_2\text{)}} \\ &= \frac{\text{Secondary current (I}_2\text{)}}{\text{Primary current (I}_1\text{)}} \end{aligned}$$

Total core loss = Eddy current loss + Hysteresis loss.
Core loss is a constant quantity. It does not vary with changes in the load current.

$$\begin{aligned} \text{Total copper loss} &= \text{Primary copper loss (I}_1^2\text{R}_1\text{)} + \text{Secondary copper loss (I}_2^2\text{R}_2\text{)} \end{aligned}$$

Copper loss is not a fixed quantity, it changes with the load current.

3. Transformer Cooling

3.1 Why Cooling is Needed

In the transformer, heat is produced by the following two factors:

- (a) Core loss (considered to be fixed).
- (b) I^2R loss, which is also referred to, as copper losses. The I^2R loss changes as the load current changes.

If the heat produced by the above two factors is not removed effectively then:

- (i) insulation failure will occur, or
- (ii) transformer will have to be derated to prevent damage to the transformer.

Since both of these circumstances mentioned are undesirable, effective cooling methods must be employed to remove this heat from the transformer.

3.2 Cooling Methods

The common cooling methods used in NGD are listed below.

- (a) For dry type transformers.
 - (i) Self-air cooled: The transformer is placed in its housing and the heat is removed by the natural convection of surrounding air and through heat radiation. This method is used for the transformers rated up to 3MVA.
 - (ii) Forced air cooled: The transformer is placed in its housing and air is circulated through it, by means of blowers. This method is used for transformers rated up to 15 MVA in size.

3.2 Cooling Methods (continued)

- (b) Oil-immersed type: In the oil immersed type, the transformer windings and the transformer core are immersed in a mineral oil which has good electrical insulating and thermal conductivity properties.
 - (i) Oil-immersed self cooled: Cooling in this type of transformer is provided by mineral oil, which is circulated by natural convection through a radiator that is cooled by the surrounding air. This type is normally used for distribution transformers.
 - (ii) Oil-Immersed forced air cooled: Cooling is provided by mineral oil, which in turn is cooled by forced air circulation. A bank of fans/blowers are used to force air through the cooling fins of the transformer radiator. This cooling method is normally used for large transmission transformers, which are situated outdoors, in power plants, or in transformer stations.
 - (iii) Oil-immersed, water cooled: Cooling is provided by mineral oil, which in turn is passed through an oil-water heat exchanger. This method is used on very large transformers. The main transformers in NGD are of this type. This method will be discussed in greater detail, later in this lesson.

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Notes

4. Components of a Power Transformer

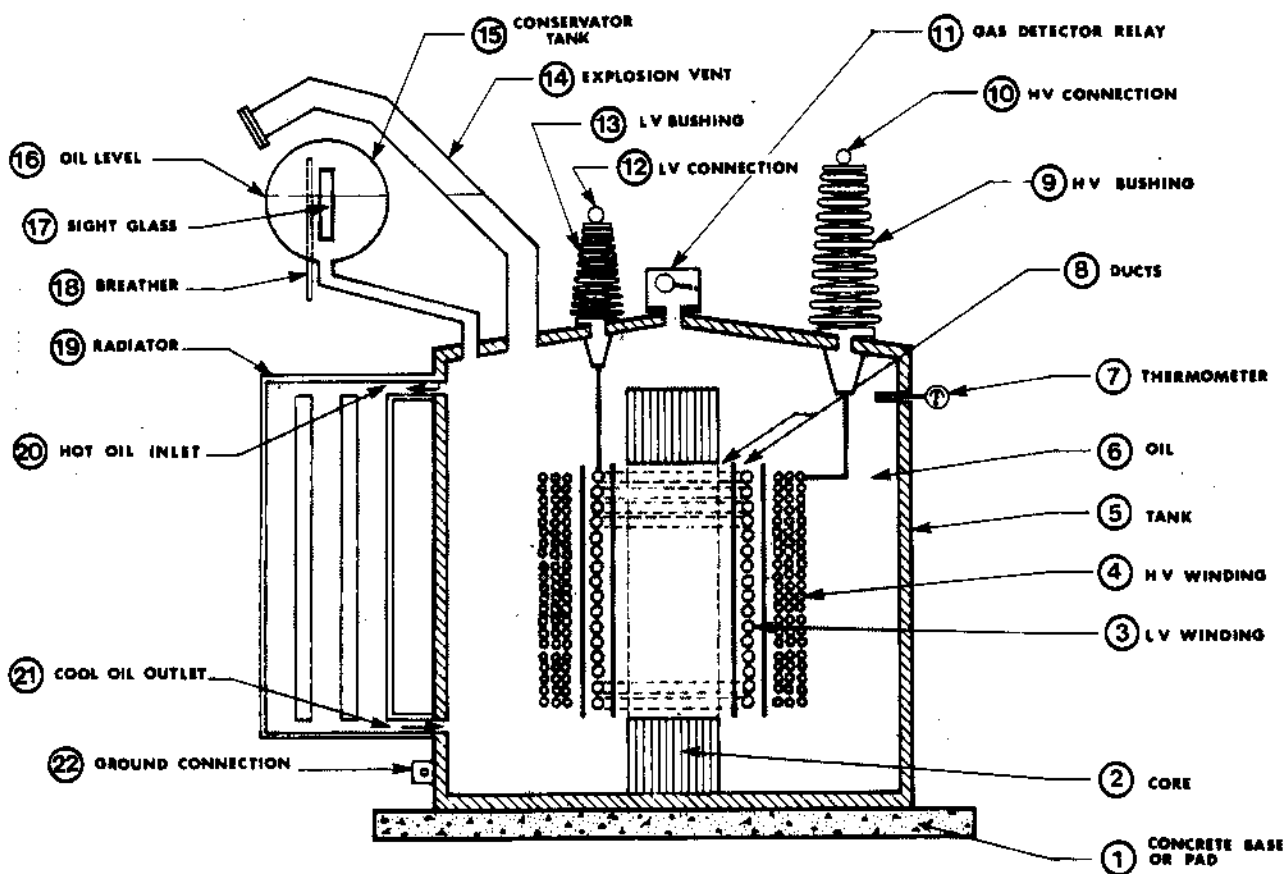


Figure 1: Cross Section of a Power Transformer

4. Components of a Power Transformer (continued)

ITEM	DESCRIPTION	REMARKS
1	Concrete base	Needed to provide proper support for the large weight of the power transformer. Base must be solid, properly levelled & fire resistant.
2	Core	Provides a path for the magnetic flux. Provides mechanical support for the windings.
3	LV Winding	It has fewer turns, as compared to HV windings. The conductor diameter is relatively larger, since it carries more current, as compared to the high voltage winding.
4	HV Winding	High voltage winding has a larger number of turns. Its conductor diameter is relatively smaller, since it carries less current. The HV winding is usually wound over the low voltage winding.
5	Tank	The transformer tank acts as a housing for the windings, core and the oil. It must be mechanically strong enough to withstand high gas pressures and electromagnetic forces that develop when a fault occurs.
6	Oil	It is high quality mineral oil. Provides an insulation between the windings, core and transformer tank. It also removes heat from the windings and the core.

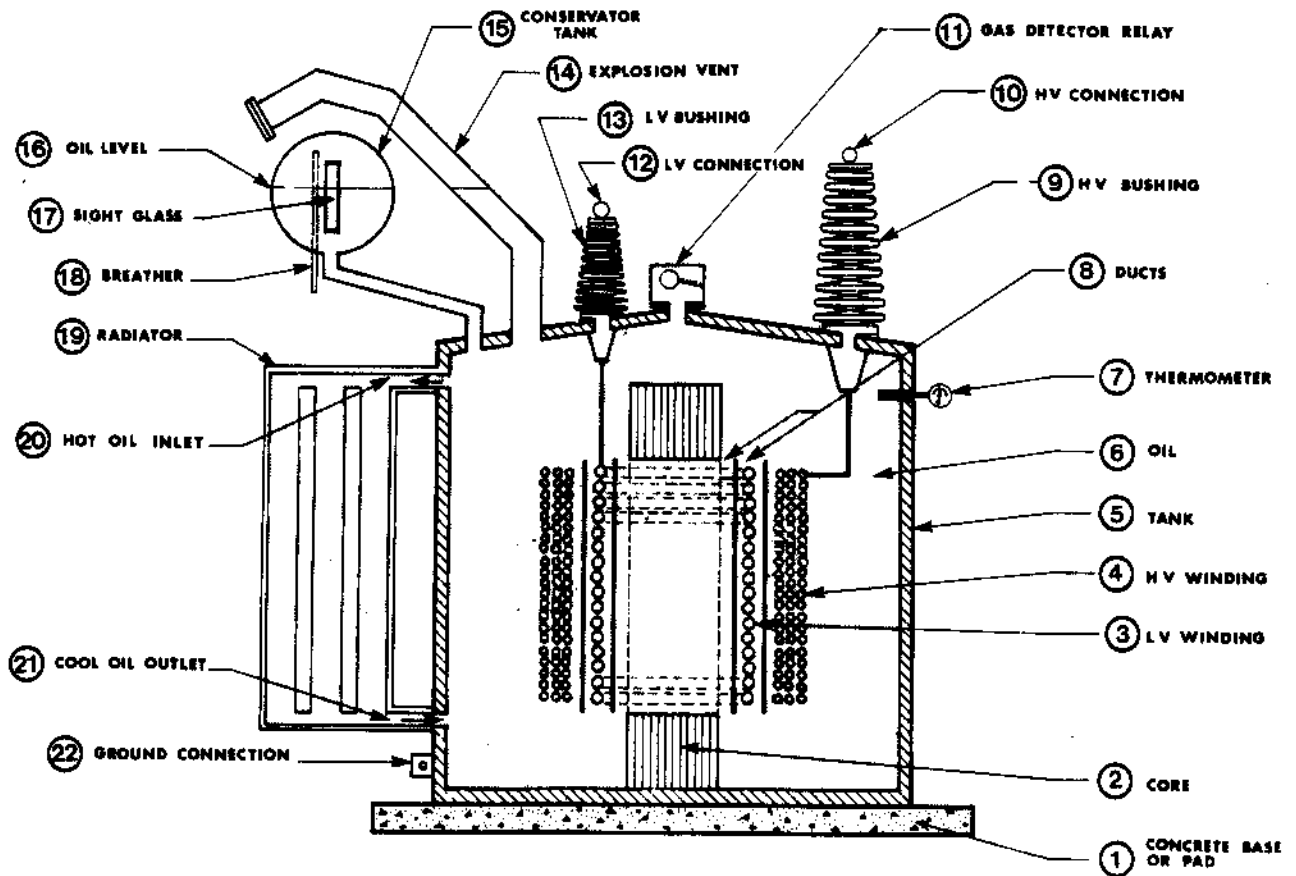


Figure 2: Cross Section of a Power Transformer

4. Components of a Power Transformer (continued)

ITEM	DESCRIPTION	REMARKS
7	Thermometer	Monitors the oil temperature and initiates an alarm, if the temperature exceeds a predetermined level.
8	Ducts	Remove heat from inside of the windings, to improve the cooling.
9	HV Bushing	Ceramic bushing which carries the HV conductor. It also insulates the HV conductor from the tank.
10	HV connections	Connects the HV winding to the HV side of the circuit.
11	Gas Detector relay	Detects gas buildup in the tank. It has two sections. One detects large rate of gas production, which may be produced due to a major fault and the other detects the slow accumulation of air/gases which are released from the oil, when it gets warm or from minor arcs. It can initiate an alarm or trip the transformer off the line, if excessive gas pressure is detected.
12	LV connection	LV conductor which connects the LV winding to the circuit.
13	LV bushing	Ceramic bushing which carries the LV conductor & insulates it from the tank which is at ground potential.

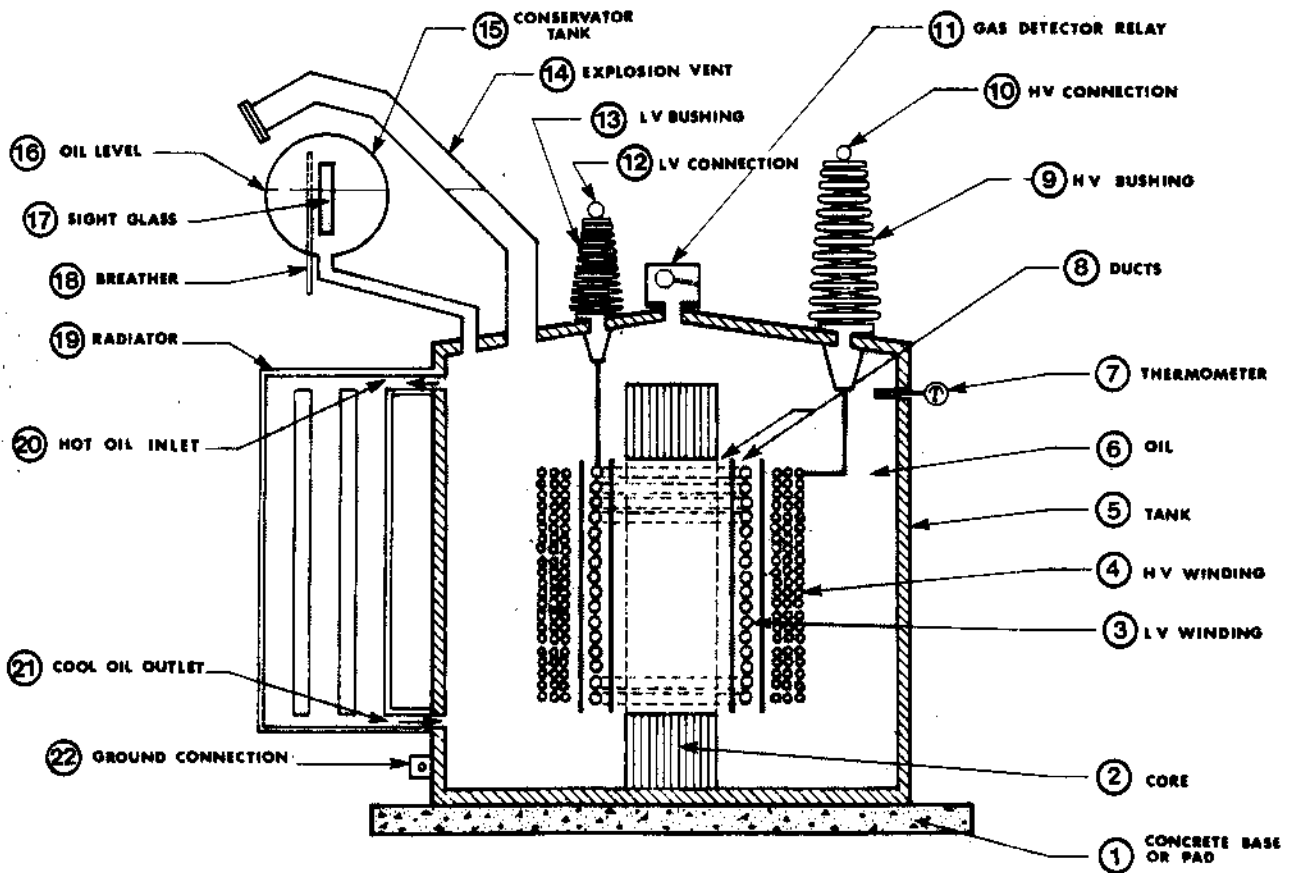


Figure 3: Cross Section of a Power Transformer

4. Components of a Power Transformer (continued)

ITEM	DESCRIPTION	REMARKS
14	Explosion vent	Explosion vent prevents buildup of high pressure in the tank. When a fault occurs, oil disintegrates and forms gases. If the gas pressure is above a predetermined value, the relief diaphragm at the end of explosion vent, ruptures and vents the tank to atmosphere.
15	Conservator tank	It acts as a reservoir of oil. When the oil is hot it expands and the excess oil goes in the conservator tank. When oil cools, it contracts and returns to the transformer tank. This maintains the transformer tank fully filled with oil.
16	Oil level	Oil level in the conservator tank varies depending on the expansion or the shrinkage of oil volume. Oil must always immerse the core and the windings, to ensure there is adequate cooling and insulation.
17	Sight glass	Provided as a visual means to check the level of oil in the conservator tank.
18	Breather	Allows the air to get in or out of the conservator tank upon the shrinkage or expansion of oil. It is fitted with an air drier (silica gel) to remove the moisture from the air going into the conservator tank.

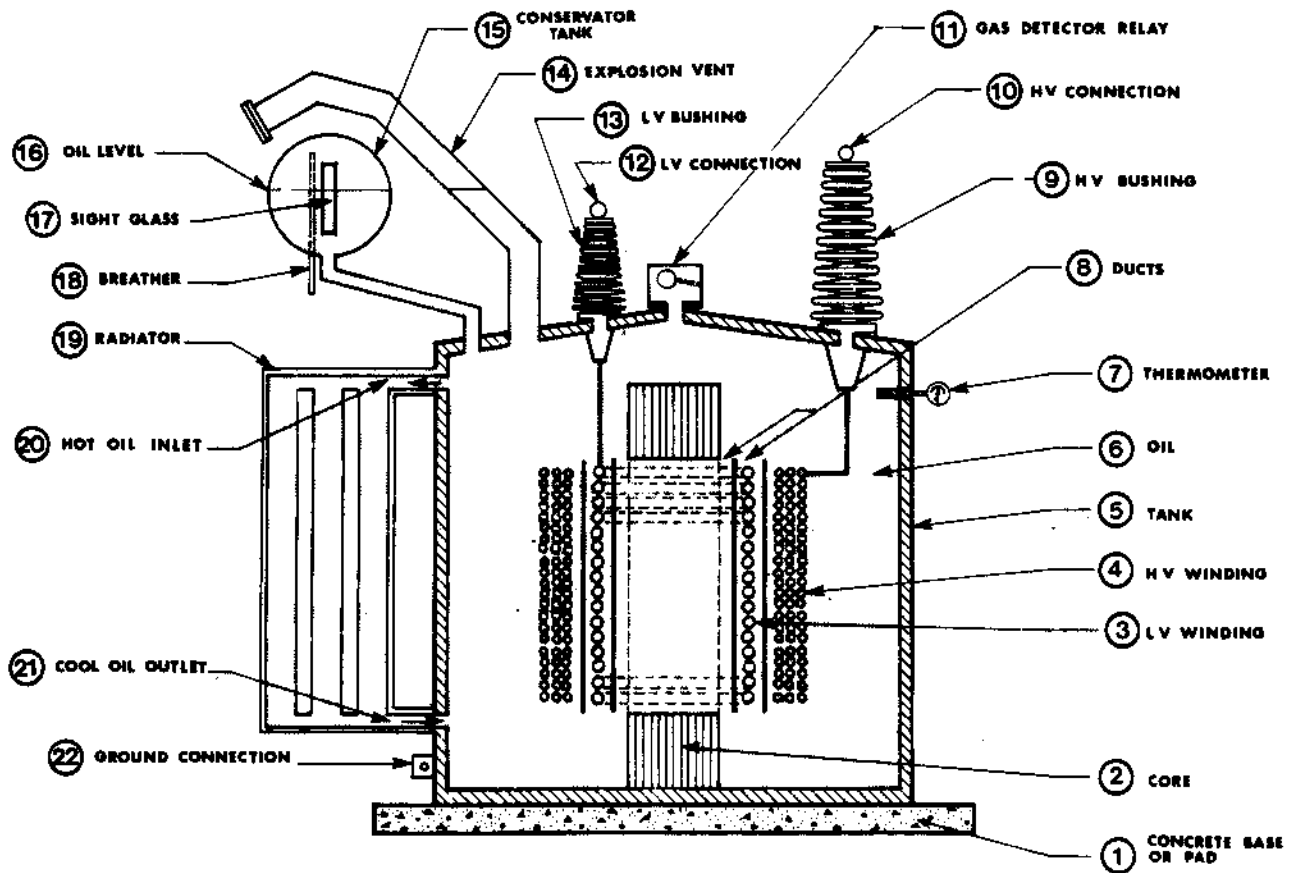


Figure 4: Cross Section of a Power Transformer

4. Components of a Power Transformer (continued)

ITEM	DESCRIPTION	REMARKS
19	Radiator	This is a type of heat exchanger which is used to provide cooling for the hot oil. Hot oil circulates through the cooling fins and air circulation around the radiator provides the cooling.
20	Hot oil inlet	Hot oil enters the radiator here from the transformer tank, due to convection.
21	Cool oil outlet	After oil circulates through the radiator it becomes cool and returns to the tank at this point.
22	Ground connection	Transformer tank is connected to the ground(earth) at this terminal, to provide safety to personnel.

5. Oil-Water Heat Exchanger Cooling

In NGD the main transformers are cooled by oil-water heat exchangers. Figure 5 shows a functional arrangement for such a system.

5.1 Operation (Refer to Figure 5)

- (a) Hot oil from the transformer is circulated through the heat exchanger by two, 100% capacity oil circulation pumps. Each pump is operated at 50% capacity.
- (b) Service water is circulated through two 100% duty heat exchangers. Each is operated at 50% capacity.
- (c) Heat transfer occurs from oil to water in the heat exchanger.
- (d) Flow switches (FS) are provided to detect an absence or reduction of service water flow. If the flow of water is lower than a predetermined set value, a flow switch initiates an alarm in the control room. The transformer can still be operated at 100% capacity, if one cooler is out of service. However, if both coolers are inoperative, then immediate action is required to trip the transformer and prevent overheating. Station instructions are provided to deal with such circumstances.

5.2 Problems and Precautions

A problem that may occur with the coolers is freezing and bursting of the water cooling tubes, during winter months. (These tubes are located outdoors). This can occur due to two conditions.

- (a) If water is allowed to stand still in the cooling lines, during cold weather, it may freeze and burst the piping. To prevent this, the coolers must be drained of water, if the transformer is removed from service for an extended period of time. Station Instructions must be followed.
- (b) If oil at subzero temperatures is allowed to circulate through the coolers, the cooling water may also freeze. The oil temperature in the tank can be below zero if the transformer is removed from the line for extended period of time in the cold weather. To prevent this when the transformer is brought back on the line the oil must be allowed to warm up through normal copper and core loss heat before water is circulated through the coolers.

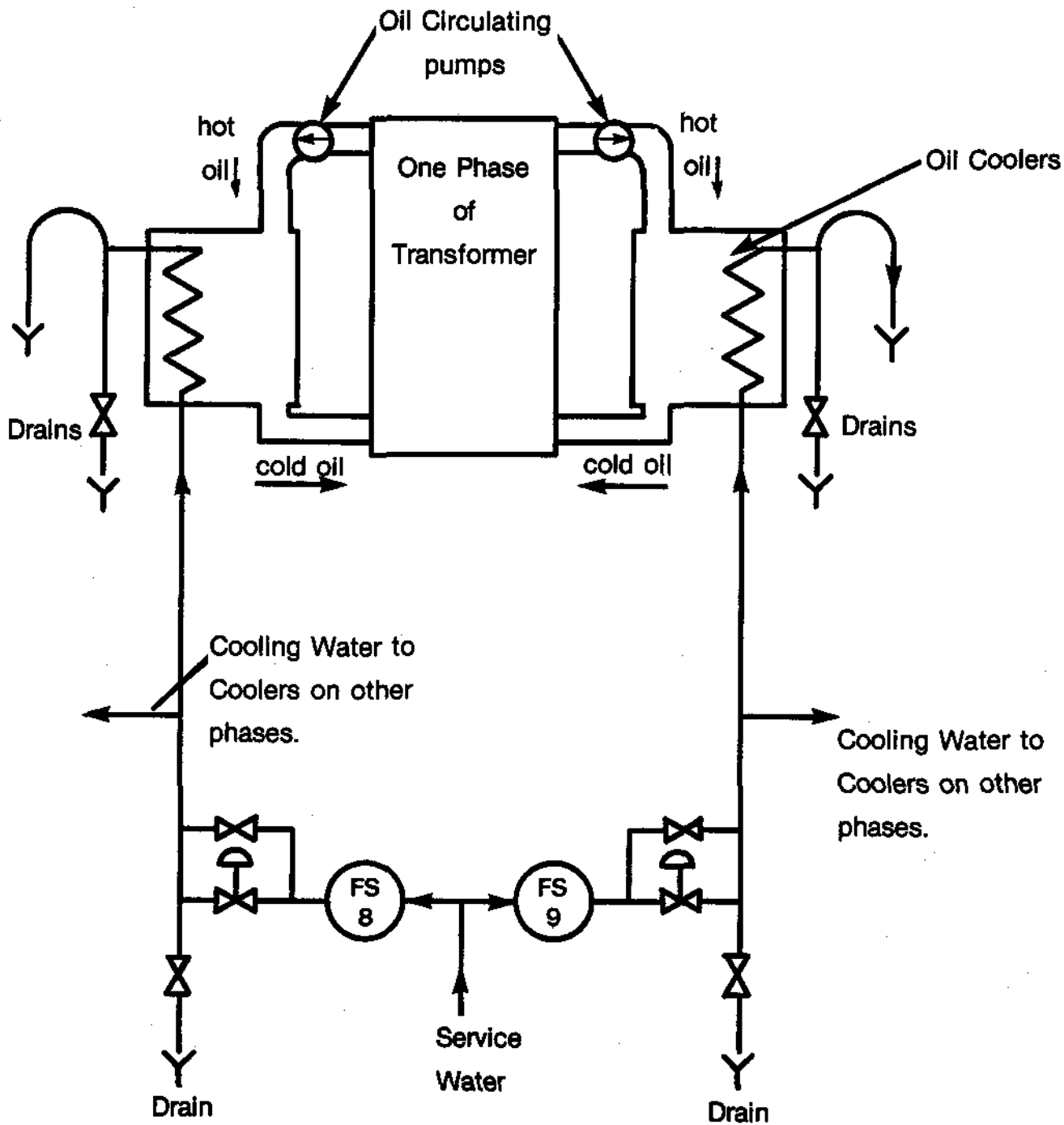


Figure 5: Cooling System for Main Transformers at Bruce "A" NGS.

Note: Only One Phase is Shown

6. Advantages and Disadvantages of Transformer Oil

(a) Advantages:

- (i) Transformer oil is a good electrical insulator.
- (ii) Transformer oil has good thermal conductivity which allows efficient removal of heat.

(b) Disadvantages:

- (i) Mineral oil is a fire hazard, hence, indoor transformers should not be of the oil immersed type.
- (ii) Oil is a pollution hazard. Any leaks in the tank or during oil handling can result in pollution of the of the environment.
- iii) Synthetic oil, called "Askerel", is non-flammable, but it is linked to serious health problems. Its use has been banned and restricted to existing installations, only.

7. Oil Contamination and Detection Methods

Oil must be kept clean and free of contamination in order for it to perform as an insulator. The following factors will affect oil performance.

7.1 Moisture

Moisture is a major problem with oil which is used as an insulation for in electrical equipment. An excess of moisture greatly reduces the insulating properties of oil. Moisture contents of 0.06% reduce the insulating ability of oil to half. The maximum acceptable moisture level in oil is 35 parts per million. Extensive care is taken to prevent moisture contamination. Some of these are listed below;

- (a) During shipping and assembly, care is taken to prevent moisture from getting into the tank, or the windings, or the oil.
- (b) Air dryers are installed on the breather of the conservator tank. These dryers can be of a chemical or dehumidifier type.
- (c) In an oil-water heat exchanger, oil pressure is maintained above the water pressure to prevent the water from leaking into the oil.

- (d) Regular checks are made on oil samples in order to detect moisture. One method uses a dielectric tester. During this test the oil sample is subjected to a fixed potential difference for a given amount of time. If arcing does not occur, then the oil is considered to be satisfactory.

7.2 Oxidation of Oil

When oil is heated above 75°C and exposed to oxygen, it oxidizes and forms sludge. Oxidation presents the following problems.

- (a) Sludge formed in the oil restricts the flow of oil in the cooling ducts and reduces the cooling efficiency.
- (b) Oil becomes acidic which reduces its insulation quality and life.

Oxidation is detected by an acidity test of the oil. The result of this test is compared to the value found in a previous test. A progressively increasing acidity content indicates that oxidation of the oil is taking place. Once the acidity increases over a set, acceptable limit, the oil must be refiltered or replaced.

7.3 Dissolved Gases

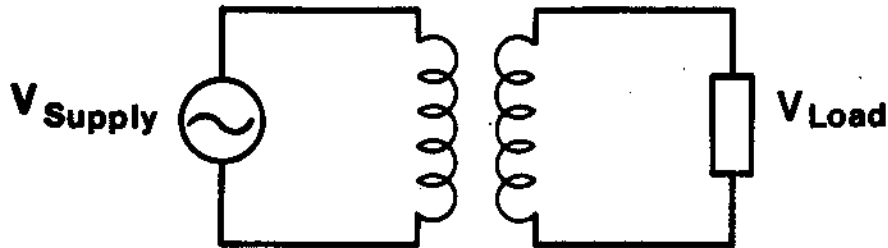
Localized hot spots, due to the burning of insulation or sparks causes oil temperature, in localized areas, to become high enough to cause oil disintegration. The formation of carbon and other gases occurs. Some of this gas is dissolved in the oil and causes the conductivity of oil to increase. In order to determine if localized hot spots are present in the transformer, a chemical analysis of the oil is performed. The presence of carbon and other gases can thus be detected. A presence of these, indicates localized burning of insulation and the transformer tank must be opened to correct this problem.

7.4 Oil Level

Oil level in the transformer may drop due to evaporation or leaks. A low oil level can damage the transformer. A sight glass or level indicator is provided on the transformer tank or the conservator tank. Regular checks are made on the oil level.

8. Transformer Tap Changes

8.1 What is a Tap Changer



A Transformer with No Tap Changer

Figure 6

On the load side of a transformer, it is desired to have voltages which are constant, or as close to the required voltage, as possible. However, load voltages can change if there is a change in the load current or the supply voltage.

Secondary voltage = Supply voltage/turns ratio "a".

In this condition, to maintain a constant secondary voltage or as close to the desired value as possible, the turns ratio is changed. A **tap changer** on a transformer performs the job of changing the turns ratio. A tap changer can be located on the primary or the secondary side. However, it is normally on the high voltage side because:

- (a) The HV winding is usually wound over the low voltage winding. Hence, it is easier to access the turns in the HV winding.
- (b) Current through the high voltage winding is lower. Hence, there is less "wear" on the tap changer contacts. The size of the tap changer contacts can be smaller.

Taps are normally provided at $\pm 2.5\%$ intervals. Some fine adjustment tap changers, on distribution transformers, could have taps at $\pm 1\%$ intervals.

8.2 Tap Changer Operation: Tap Changer in Primary

Consider the tap changer in Figure 7(A) and follow the steps below.

- (a) When the supply voltage is nominal, the tap changer will be at the tap marked 0%.
- (b) Consider the secondary voltage increasing 2-1/2% above its nominal value. To maintain the secondary voltage constant, the tap changer shifts to the tap marked + 2-1/2%. This increases the number of turns in the primary by 2-1/2%. Hence, the turns ratio increases. The secondary voltage therefore decreases.
- (c) Consider the load voltage decreasing by 2-1/2% from nominal. The tap changer shifts to the - 2-1/2% tap. This decreases the number of turns in the primary by 2-1/2%. The turns ratio, "a" decreases. Hence, the secondary voltage increases.

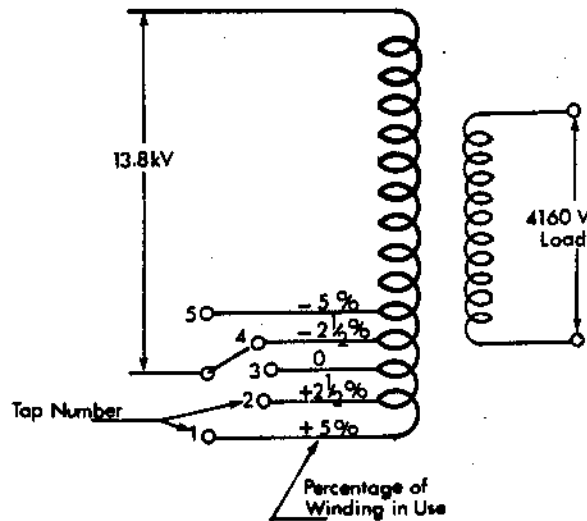


Figure 7(A): Tap Changer in the Primary

Note: If the tap changer is on the secondary side the shifting of taps will be reversed as compared to the above discussion.

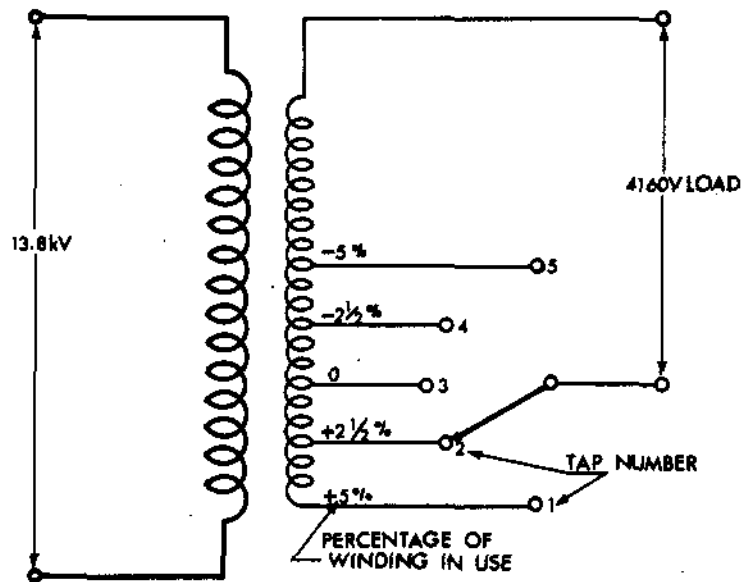


Figure 7(b): Tap Changer in Secondary

8.3 Types of Tap Changers

There are two types of tap changers.

(a) Off-load tap changer

In NGD, most of the tap changers in transformers are of the off-load type. Off-load tap changers, have contacts which are not designed to break any current, including the no-load current. Transformers with this type of tap changing mechanism must be electrically disconnected from the circuit before the tap is changed. Tap changing can be manual or motorized.

(b) On-Load Tap Changer

In on-load tap changers, the taps can be changed while the transformer is supplying the load. Mechanisms are provided to prevent damage to the transformer or to the tap changer.

4. List three cooling methods used for oil-immersed type transformers and briefly explain each. (Section 3.2)

5. List the components of a power transformer and give the function of each. (Section 4 Figure 1)
Use separate sheets.

6. State what type of transformers, in NGD, use an oil-water heat exchanger for cooling. Briefly explain the operation of such an arrangement. (Sections 5, 5.1)

7. What problem may develop with oil-water heat exchangers, what factors contribute to it and how can it be eliminated? (Section 5.2)

8. List two advantages and two disadvantages of transformer oil. (Section 6).

9. List three contaminants which may be detected in transformer oil. State how each affects transformer performance and how each is detected. (Section 7.1, 7.2, 7.3)

10. State what a tap changer does and how it achieves this.
(Section 8.1)

11. From Figure 7(B) indicate the tap position to be used
if:
(a) the secondary voltage increases by 5%.

(b) the secondary voltage decreases by 5%.

12. List the two types of tap changers used and differentiate between them. (Section 8.3)

S. Rizvi

Notes