Electrical Equipment - Course 230.2

TRANSFORMERS: PART 1

RATINGS

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1. OBJECTIVE

The student must be able to:

1. From the information given on a transformer name-plate, explain the following ratings:

   (a) voltage.
   (b) current.
   (c) apparent power.
   (d) temperature rise.
   (e) impedance.

2. State the consequences of exceeding the following ratings:

   (a) voltage.
   (b) current.

3. From the information given on a transformer name-plate explain the winding connections and other relevant details.

2. INTRODUCTION

The previous NTD electrical course 226.0 explained the basic transformer theory and construction details. This lesson explains transformer ratings and connections by examining each relevant detail on a given transformer nameplate.

It must be clearly understood that the rating of any transformer is determined by the apparent power taken by the load, that is connected to the transformer secondary.

3. TRANSFORMER NAMEPLATE DETAILS

The following section describes a typical transformer nameplate which is shown in Figure 1. Marked on Figure 1 are encircled numbers (1) to (10). The reference numbers for the following sections correspond to these encircled numbers.

(1) The transformer has a rating of 10 000 kVa or 10.0 MVA. The transformer is able to supply a load up to this value, without exceeding its rated capacity.

(2) The transformer is able to supply a three phase load or loads whose current requirements do not exceed 1 390 A.

(3) The transformer has a rated secondary line to line voltage of 4 160 V when the windings are connected as shown. The line to neutral voltage is 4160 V $\div \sqrt{3}$, ie 2 400 V.

(4) When the transformer is supplied with 13 800 V, selected to tap position 2 and supplying full rated load of 10 000 kVA, the transformer will require an HV line current of 418 A. Note that if the supply voltage is greater than 13 800 V, tap 1 is used and when on full load the HV current is 408 A. When the supply voltage is less than 13 800 V taps 3, 4 or 5 should be used. In this case, because the supply voltage is lower, for the same load, the supply current will be higher.

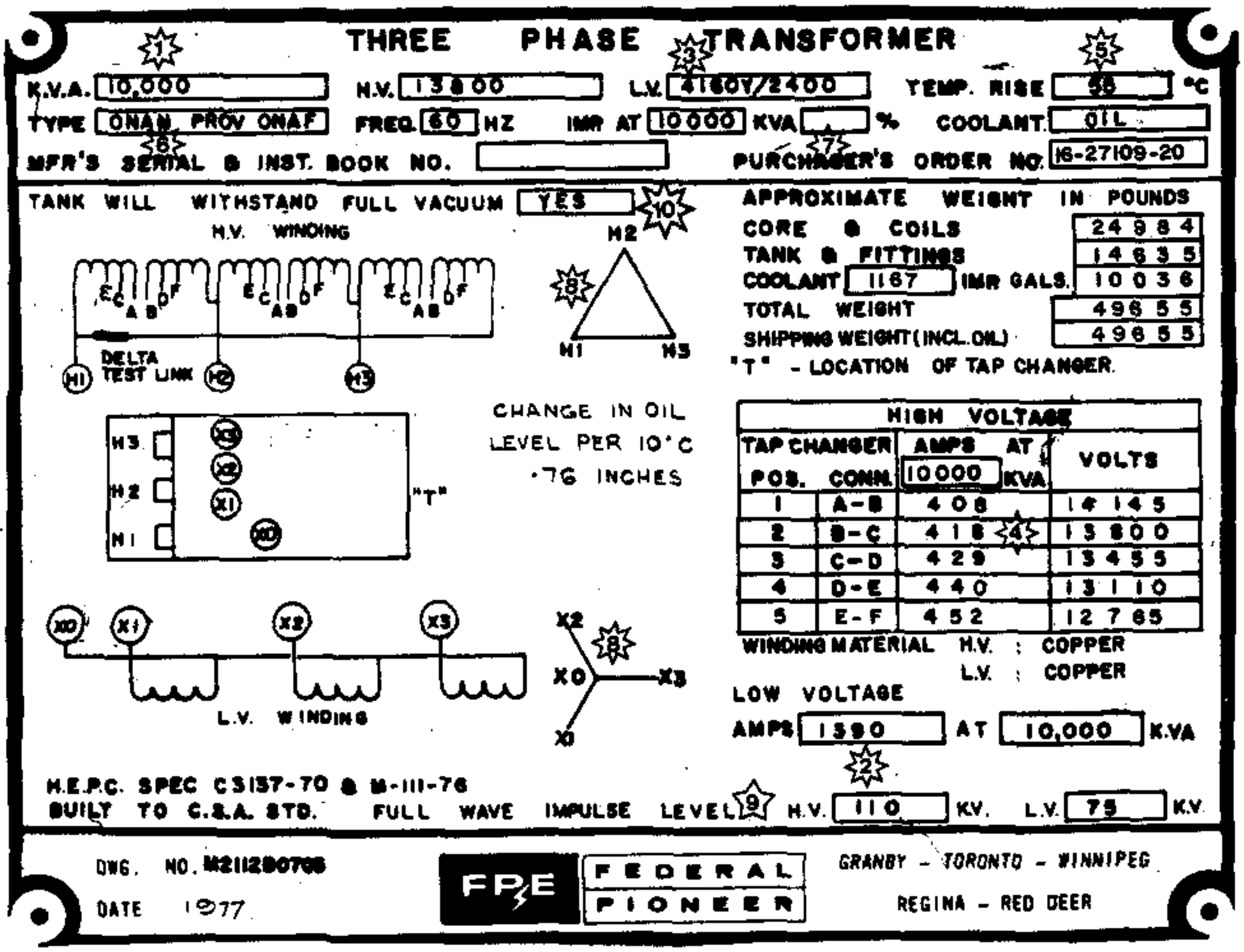

Figure 1

This *transformer* is *supplied with an off* circuit tap changer and therefore tap changing can only be done while the transformer is de-energized. The nameplate does not specifically state that the tap changer is OFF CIRCUIT and therefore the tap changer should, from a safety point of view, be assumed to be an off circuit type. On load tap changers are specifically call ON LOAD.

Operation of this OFF CIRCUIT tap changer, when the transformer is energized (or worse still on load), will result in severe arcing in the tap changer and will almost certainly destroy the transformer.

3.2 Thermal Ratings

The thermal ratings of a transformer are determined by the following three factors.

(a) the amount of heat produced in the windings and connections.

(b) the amount of heat produced in the iron core.

(c) how effectively the heat can be removed from the transformer when the thermal rating of the transformer is reached. At this point, the heat being produced must equal the heat being removed or dissipated - thermal equilibrium.

3.2.1 Heat Produced in the Windings and Connections. As the transformer is loaded, heat is produced in the primary and secondary windings and connections due to I^2R. At low loads, the quantity of heat produced will be small but as load increases, the amount of heat produced becomes significant. At full load, the windings will be operating at or near their design temperature. Figure 2 shows the relationship between load current and the heat produced in transformer windings and connections.

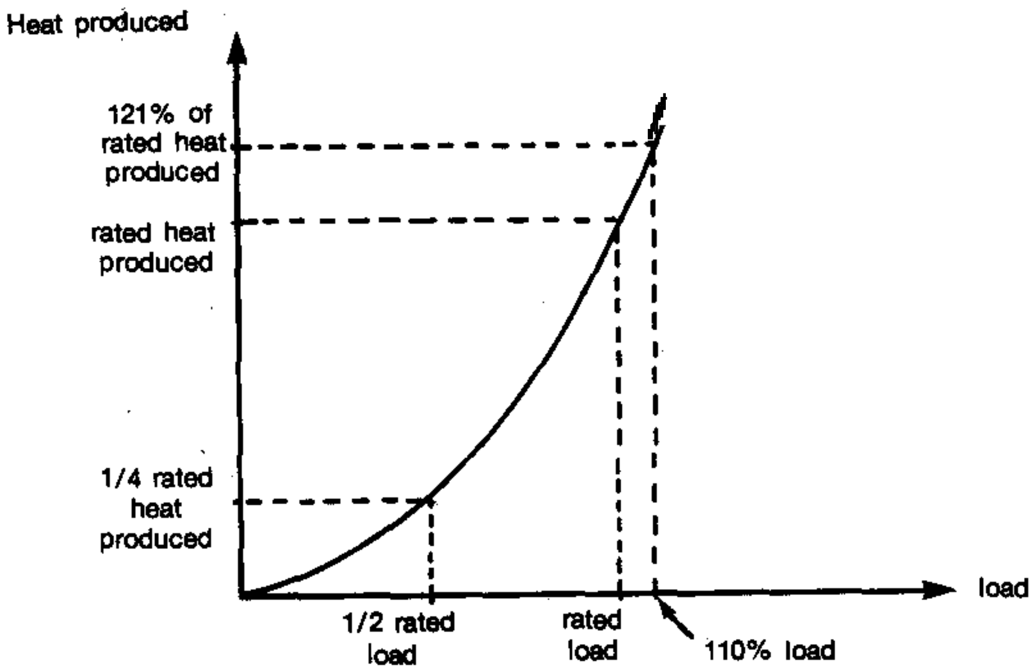

Figure 2: Relationship Between Load and Heat Produced in Transformer Windings.

3.2.2 Heat Produced in the Core. For a given frequency and number of turns, the flux in a transformer core is proportional to the applied voltage V and inversely proportional to the frequency. This is explained by the relationship:

$V \propto N\Phi_m f$ where N = Number of turns.
f = Frequency.
Φ_m = Maximum Value of Flux.

or, $\Phi_m \propto \frac{V}{Nf}$

It follows that if the number of turns and frequency are constant.

$\Phi_m \propto V$

and if the number of turns and voltage are constant

$\Phi_m \propto \frac{1}{f}$

When the transformer is operating at its rated voltage and frequency it will be operating with its rated value of flux Φ_m in the core. If the voltage rises while the frequency remains constant or the frequency falls while the voltage remains constant, the flux Φ_m is the core will **increase.** Because the flux is alternating, the core will heat due to the effects of hysterisis and eddy currents in the core. A voltage increase of 10% above the rated value will give a flux level of 10% above its rated value. From Figure 3, it can be seen that if the flux level is 10% above normal, the iron has commenced to saturate. As soon as iron begins to saturate, the heating, due to the eddy currents and hysterisis effects increases rapidly, see Figure 4.

For this reason, the voltage applied to a transformer should never be allowed to exceed the rated value by more than 10%. Failure to observe this precaution will cause overheating of the core. This overheating may cause the insulation which coats each of the laminations to fail, larger eddy currents will flow and extreme heating will follow. This can lead to a core failure, where in extreme cases, there will be melting of the iron laminations.

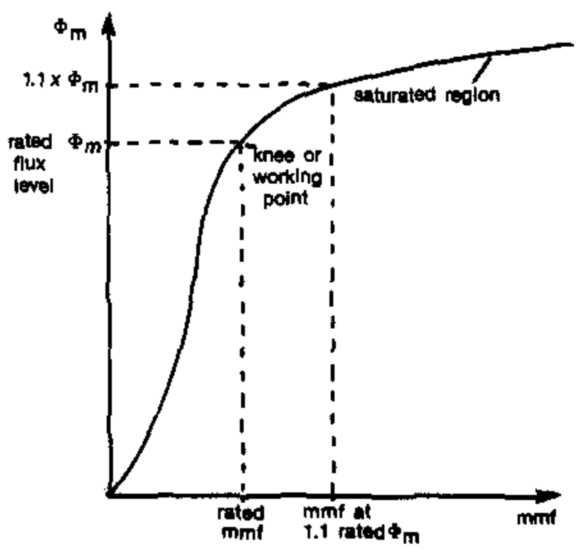

Figure 3: Typical Magnetization Curve for a Transformer Core.

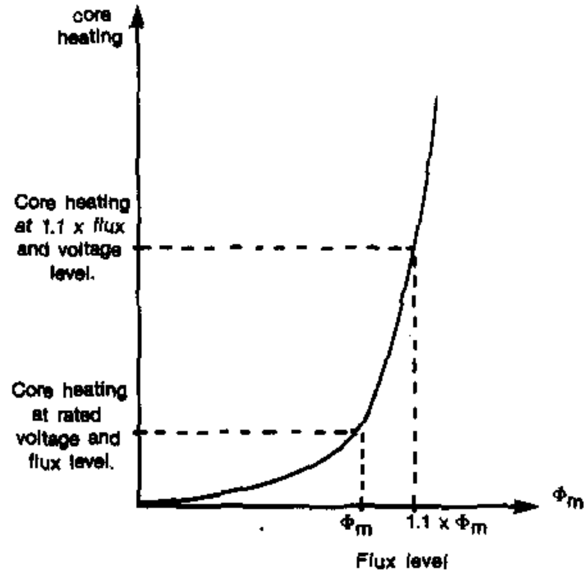

Figure 4: Relationship Between Core Flux Φ_m and Core Heating.

3.2.3 Temperature Rise and Temperature Limitations

A "hot spot" winding temperature limit of 95°C is imposed on this oil filled transformer. Assuming that the maximum ambient temperature is 40°C, then the maximum permitted "in service" temperature **rise** for this transformer's windings and connections is 95° - 40° = 55°C. Transformers cooled by Askarel (PCB) have similar temperature limitations to transformers insulated with mineral oil. Some transformers now have a maximum "hot spot" temperature **rise** of 65°C.

A temperature limit of 155°C is imposed on dry (air cooled) transformers which have their windings insulated with silicone resin. These transformer are cooled by allowing air to circulate through the windings and over the core. Again, assuming a maximum ambient temperature of 40°C, then the temperature **rise** is limited to 155° - 40° = 115°C.

6 ONAN cooling. ONAN is an abbreviation for Oil Natural (thermosyphon) circulation with Air Naturally circulated for cooling. The PROV ONAF abbreviation denotes that the transformer has provision for Oil Natural Air Forced cooling. Forced air cooling would allow the rating to be increased by a small amount.

The main transformers at large generating stations are OFW types which have Oil Forced cooling. The oil is in turn cooled by Water.

3.3 Impedance

7 As a transformer, having a fixed supply voltage, is loaded the secondary voltage will fall due to the effects of winding resistances and reactances. For example, a transformer having an impedance of 5% will have a secondary voltage drop of 5% between no load and full load. At half load the voltage drop will be half, ie, 2.5%.

3.4 Winding Connections

8 The primary and secondary windings on a three phase transformer are connected in either star or delta formation. The "star point", X_0 (see Figure 1) of a star winding is connected to ground and this ensures the line terminals have equal and balanced voltages to ground. The delta winding, because it does not have a common (star) point, is not connected to ground at the transformer. (A delta winding is grounded by connecting it to a system which is grounded at some other point, see course 235 for details.)

In the case of this transformer, the high voltage (13 800 V) winding is connected in delta and brought out to terminals H_1, H_2 and H_3. The low voltage winding is connected in Star (Wye) and brought out to terminals X_1, X_2, X_3 and X_0. X_0 is the star point and is connected to ground.

3.5 Insulation Levels

9 Transformer insulation is designed to continually withstand its rated voltage and operate within its temperature limits. It is also designed to a "full wave impulse level". This impulse or surge voltage level is to allow for high voltage surges that can occur due to lightning, for example. These surges are of very short duration (typically 100 microseconds) and can puncture the insulation. To allow an adequate (and economic) safety margin, the HV insulation has been designed for and impulse tested at 110 kV. The LV insulation has been designed for and tested at 75 kV.

3.6 Tank Details

10 This transformer tank has been designed to withstand full vacuum without distortion. When drying out a transformer, it is often necessary to pull a vacuum. In this case, the tank will allow this vacuum treatment.

ASSIGNMENT

1. What factor determines the apparent power rating of a transformer? (Section 2)

2. Explain the two ways that a transformer can be damaged, if its voltage rating is exceeded. (Sections 3.2.2 and 3.5)

3. Explain how a transformer can be damaged if:

   (a) its current rating is exceeded.
   (b) its cooling is inadequate.

   (Section 3.2.1)

4. Explain how a transformer can be damaged if it is operated at its rated voltage but **below** its rated frequency. (Section 3.2.2)

5. A transformer has an "impedance of 7.5%". Explain the significance of the "7.5% impedance" with reference to:

   (a) full load operation.
   (b) half load operation.
   (c) off load operation.

   (Section 3.3)

6. From the information given on the accompanying transformer nameplate, (see Figure 5) explain the significance of the following ratings and details.

   (a) 1000 kVA. (Section 3 (1))
   (b) 55°C rise. (Section 3.2.3)
   (c) 4160 V HV. (Section 3 (4))
   (d) 600 V/347 LV. (Section 3 (3))
   (e) Three phase. (Section 3 (2))
   (f) 60 Hertz. (Section 3.2.2)
   (g) Type ONAN. (Section 3.2.3)
   (h) Imp 6%. (Section 3.3)
   (i) High voltage delta 3 942 V, 146.1 A tap changer position 3, connects 3 - 6 on leads H_1, H_2 and H_3. Low voltage Wye 600 V, 962.2 A on leads X_0, X_1, X_2, X_3. (Section 3.4)
   (j) Do not operate no load tap changer with transformer energized. (Section 3 (4))
   (k) Tank withstand pressure. (Section 3.6)

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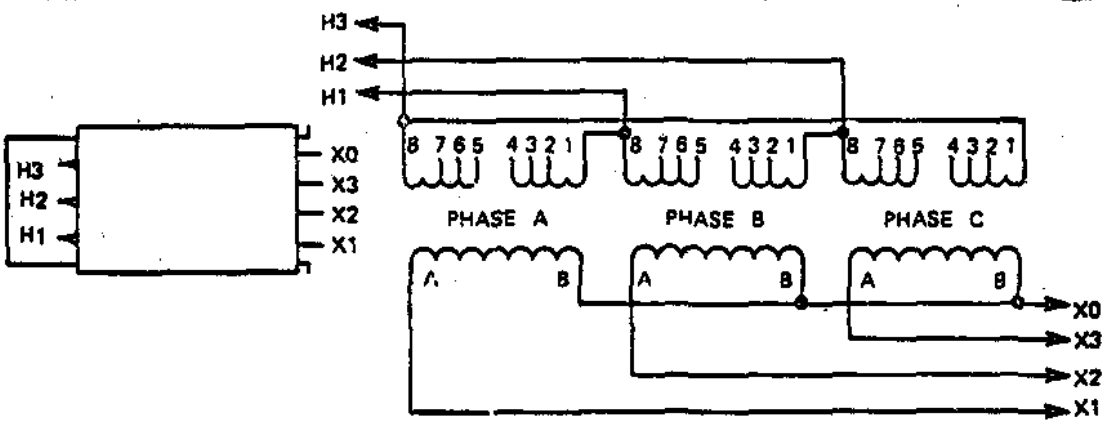
Westinghouse

INSULATION **INSULDUR** SYSTEM

1000 KVA	THREE PHASE	IMP % ONAN
55° C RISE	60 HERTZ	GAL OIL ______ IMP.
4160 HV	**TRANSFORMER**	LITRES OIL ______
600Y/347 LV	TYPE ONAN	MFG SERIAL ______
		CUST SERIAL ______
		INST BOOK ______

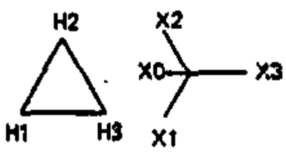
BASIC IMPULSE LEVEL: HV 75 KV, LV 45 KV



WINDING	VOLTS	AMPERES		TAPCHANGER		ON LEADS
		ONAN		POS	CONNECTS	
HIGH VOLTAGE DELTA	4160	138.8		1	4-5	H1, H2, H3
	4056	142.3		2	3-5	
	3952	146.1		3	3-6	
	3848	150.0		4	2-6	
	3744	154.2		5	2-7	
LOW VOLTAGE WYE	600	962.2		----	----	X0, X1, X2, X3

COOLING LIQUID MUST BE MAINTAINED AT THE PROPER LEVEL.
DO NOT OPERATE NO LOAD TAPCHANGER WITH TRANSFORMER ENERGIZED.
AMPERE RATING GIVEN IS CURRENT IN OUTLET LEADS.
TANK WITHSTAND PRESSURE: 69 KILOPASCALS POSITIVE OR 101 KILOPASCALS NEGATIVE.
10 PSI POSITIVE OR 14.7 PSI NEGATIVE.
INSULDUR INSULATION PERMITS CONTINUOUS OPERATION, WITH NORMAL LIFE EXPECTANCY, AT APPROXIMATELY 1120 KVA WITH A 65° C WINDING RISE.

CORE AND WINDINGS ______ kg ______ (LB)
TANK AND FITTINGS ______ kg ______ (LB)
INSULATING LIQUID ______ kg ______ (LB)
TOTAL ______ kg ______ (LB)



BUILT ______

MADE IN CANADA
Westinghouse Canada Limited
Hamilton, Ontario

PATENTED: 1966

230P832-1

Figure 5