PROTECTION OF TRANSFORMERS IN A POWER SYSTEM

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DECLARATION

I, ANDILLO RABIOU of the Department of Electrical and Computer Engineering, F. U. T, MINNA, hereby declare that this project work was carried out by me under the supervision of Engineer M. D. ABDULLAHI of the Electrical and Computer Department, F. U. T MINNA, NIGER STATE.

.... 27/02/2002.

ANDILLO RABIOU 97/6436 EE **DATE**

CERTIFICATION

I hereby certify that this work was carried out by Mr. Andillo Rabiou of the Department of Electrical/Computer Engineering, Federal University of Technology, Minna, Niger State, Nigeria

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Date

DEDICATION

This project is dedicated to my parents, Andillo and Aminatu, for their moral and financial support in accomplishing my project.

ACKNOWLEDGEMENT

Glory be to Allah, the creator of everything who gave me the health and the power of doing my project in good conditions of peace and prosperity.

I am very grateful to my supervisor, Engr. M. D. Abdullahi, for his help, advice and encouragement in making sure this project is a success.

I am very thankful to my parents and my brothers and sisters who helped me in one way or the other throughout my course of study in the University.

I am also very thankful to my Uncle, Halilou Mage, for his support.

ABSTRACT

This project deals with the protection of transformers in a power system. Transformers require great attention and protection because of their valuable function in transmission and distribution of electric energy.

In this project, the importance of the transformer is noted as well as its operations and design.

Protective devices are also presented for the protection of transformers There are various methods of protecting transformers. The one used is the high-speed –biased differential protection. This scheme uses the permanent magnet moving coil relay as the operating coil. It provides fast clearance of internal faults and deals with magnetizing inrush current. Buchholz relay is also provided to clear faults, which occur under oil in a transformer.

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CHAPTER ONE

1.1 INTRODUCTION

A transformer is an electric component used to transfer electric energy from one alternating current (a. c.) circuit to another by magnetic coupling. Essentially, it consists of two or more multi-turn coils of wire placed in close proximity to cause the magnetic field of one to link the other. In general, a transformer accomplishes one of the following between two circuits:

a. a difference in voltage magnitude,

b. a difference in current magnitude

c. a difference in phase magnitude

d. a difference in voltage insulation either between the two circuits or to ground

Transformers are used to meet a wide range of requirements. Those used for transferring power between sub-circuits of an electrical power supply are called power transformers. One of the main advantages of AC power transmission and distribution is the ease with which an alternating voltage can be increased or reduced through power transformers. For instance, a generator transformer is a step-up transformer used to transfer power supplied by an alternator at about 20 kV into a higher voltage network, operating at a voltage up to say 750 kV, in order to reduce copper losses for long distance power transmission by operating at a lower current level. Transmission transformers are step-down transformers for reducing the voltage back down to a level more convenient for supply to a township at say 110 kV, or down to an even lower voltage of say 11 kV for distribution in a neighborhood. Distribution transformers are the final step-down transformers to the consumer at 110 to 240 volts.

Power transformers may be single phase or three phase transformers depending upon size and transport difficulties. A transformer is possibly the most important item of equipment in a power system.

All systems are liable to faults and these may cause many dangers. The high cost of power system equipment and the time required to repair or replace damaged equipment, such as transformers, cable, high voltage circuit breakers, etc, make it imperative that serious considerations be given to system protection design. Protective devices have to be used to provide protection. An important function of the system protective device is to initiate operation of the circuit interrupter responsible for isolating the fault so that the other equipment connected to the same circuit is not stressed beyond the safe limits. Otherwise the initial fault condition can affect far more than the specific circuit to be isolated, and a widespread outage can result.

The aim of this project is to provide protection for transformers in a power system.

1.2 LITERATURE REVIEW

To transfer energy from power station to consumers, the electrical transmission system has been developed from the earliest local distribution working at 200 volts, to modern national networks, which generally operate at about 400 KV. The transfer of this high voltage is impossible without the use of modern power transformers. These equipments as being very important have to be given great protection in order to avoid service interruption as well as fire and loss of personnel and equipment.

Generally, protection in an electric system is a form of insurance. It pays nothing as long as there is no fault or other emergency, but when a fault occurs it can be credited with reducing the extent and duration of the interruption, the hazards of property damage, and personnel injury. Economically, the premium paid for this insurance must be balanced against the cost of repairs and lost of production. Protection, well integrated with the class of service desired, may reduce capital investment by eliminating the need for equipment reserves in a power system.

While the protective devices are the watchmen of the power system, the electrical engineer must be the custodian of the protection system. Adequate and regular maintenance and testing must be done, as well as reanalysis of the protection scheme when major system changes occur.

CHAPTER TWO

2.1 IMPORTANCE OF POWER TRANSFORMER

It is impossible to transmit directly, even over modest distances, the electric power as it is being generated in the synchronous generator. Unacceptably, there would be high losses and voltage drops. The power transmission, even over short distances, is possible only if one can work with voltage levels far exceeding those that can be directly generated in rotating machines.

For instance, since the power transmitted is given by $P = V\ I\ \cos\theta$, it means that for a given amount of power, an increase in voltage will reduce the current. A lower current will result in reduction of the cable and switch gear size which also results in reduction of the line power losses given by $P = I^2R$.
Power transformers are used to make this possible. They transform the generator voltage to levels at which transmission becomes feasible over distances as high as about 1000 Km.

They are also used to reduce the voltage at the receiving end down through the various distribution voltage levels to safer working voltages. They also make the supply cost be reduced because, as a general principle, the higher the voltage the cheaper the supply. Power transformer is always designed for simple frequency, 60 HZ. It comes either single phase or three phase units. Size ranges from a few KVA for small distribution transformers to more than 1000 MVA for larges transmission transformers.

2.2 PRINCIPLE OF OPERATION

When the primary of a power transformer is connected to an alternating voltage, it produces an alternating flux in the core. The flux generates a primary electro-motive force, which is essentially equal and opposite to the voltage applied to it. It also generates a voltage in the other coil or coils, one of which is called secondary. This voltage generated in the secondary will supply alternating current to circuit connected to the terminals. A Current in the secondary winding requires an additional current in the primary. The primary current is essentially self-regulated to meet the power demand of the load connected to the secondary terminals. Thus, in normal operation energy can be transferred from the primary to the secondary electro magnetically. The figure below shows a transformer.

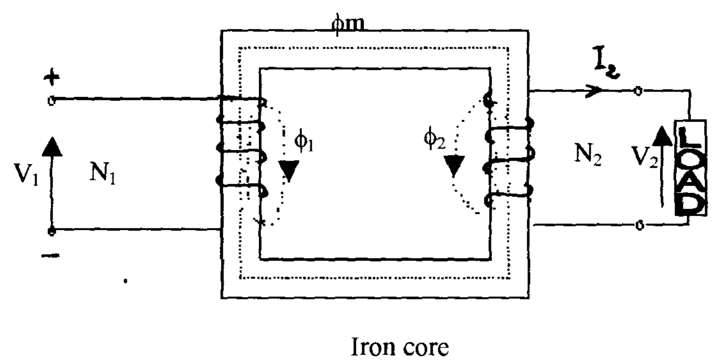


Fig 1. Basic transformer

The primary consists of N_1 turns and the secondary N_2 turns. Since all quantities shown are alternating, the arrows indicate only instantaneous polarities. The magnetic flux ϕ set up by the primary consists of two components. One part passes completely around the magnetic circuit defined by the iron, thus linking the secondary coil. This is the mutual flux ϕm. The second part is a smaller component of flux that links only the primary coil. This is the primary leakage flux ϕ_1. If the secondary circuit is completed through a load, a secondary current I_2 flows and in turn creates a secondary leakage flux ϕ_2. These leakage fluxes contribute to the impedance of the transformer. If the leakage is small, the coupling between the primary and secondary is said to be close. The use of iron core decreases the leakage flux by providing a low reluctance path for the flux.

In a power transformer the voltage drops due to winding resistance and leakage are small; therefore V_1 and V_2 are essentially in phase (or 180° out of phase, depending on the choice of polarity). Since the no load current is small, $I_1$and$_2$ are essentially in phase (or out of phase). Therefore $V_1I_1 = V_2I_2$..........(1)

From equation (1) the voltage ratio $V_1/V_2 = I_2/I_1 \cong a$ .....(2)

Where a is the transformation ratio.

Substituting equation (2) into equation (1) demonstrates that the current ratio is inversely proportional to the transformation ratio, $I_1/I_2 = 1/a$ .....(3)

A transformer therefore may be used to step up or down a voltage from a level V_1 to a level V_2 according to the transformation ratio a. Simultaneously the current will be transformed inversely proportional to a.

Equation (1) may be written as $I_1^2\, V_1/I_1 \cong I^2{}_2V_2/I_2$..........(4)

Since V_2/I_2 is the impedance Z_2 of the load on the secondary and $V_1/I_1$is the impedance $Z_1$of the load as measured on the primary, we have $I_1^2\, Z_1 = I^2{}_2\, Z_2$...........(5)

The transformer is thus capable of transforming circuit impedance levels according to the square of the transformation ratio.

The transmission of power from primary coil to secondary coil is via magnetic flux. The flux is proportional to the ampere-turns in either coil. Since the power in each coil is nearly the same, $N_1I_1 \cong N_2I_2$ from which $N_1/N_2 = I_2/I_1$. The transformation ratio is therefore approximately equal to the turns ratio.

2.3 E.M.F Equation of a Transformer

Suppose the maximum value to be Φ_m Wbs and the frequency to be f hertz (or cycle/ second).From figure 2 below , it is seen that the flux has to charge from $+\Phi_m$ to $-\Phi_m$ in half , namely in ½f second.

Therefore average rate of change of flux = $2\Phi_m/(1/2f) = 4f\Phi_m$ webers/second and verage e.m.f induced/ turn = $4f\Phi_m$ volts.

core losses due to hysteresis and eddy currents are allowed for by a resistor R of such value that it takes a current Ic equal to core loss of the actual transformer. The resultant of I_{mag} and I_c is I_o, namely the current which the transformer takes on no load. Since the noload current of a transformer is only about 3-5 per cent of the full-load primary current, the parallel circuit R and X can be omitted without an appreciable error when considering the behavior of the transformer on full load. The approximate circuit is shown in fig 4 below.

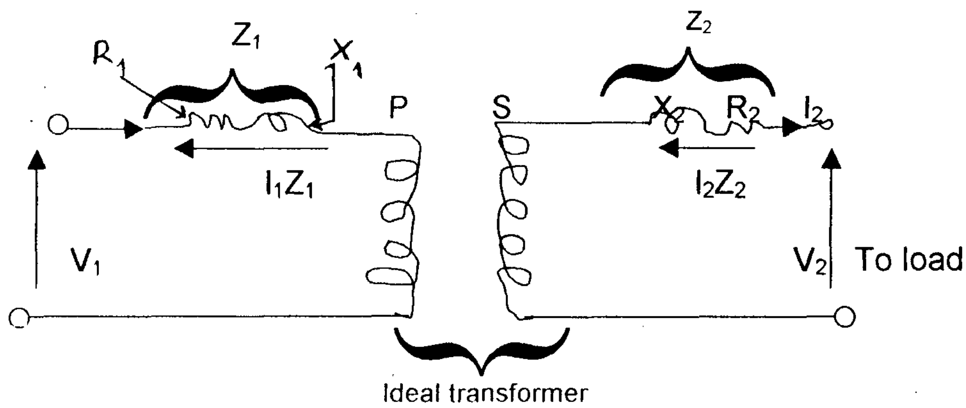


Fig. 4 approximate equivalent circuit of a transformer

The resistance R_2 can be replaced by inserting additional resistance R'_2 in the primary circuit such that power absorbed in R'_2 when carrying the primary current is equal is to that in R_2 due to the secondary current

i.e , $I^2_2R'_2 = I^2_2R_2$

$\therefore R'_2 = R_2(I_2/I_1)^2 = R_2(V_1/V_2)^2$

Hence if Re be a single resistance in he primary circuit equivalent to the primary and secondary resistances of the actual transformer, then $Re = R_1 + R'_2 = R_1 + R_2(V_1/V_2)^2$

Similarly, since the inductance of a coil is proportional to the square of the number of turns, the secondary leakage reactance X_2 can be replaced by an equivalent reactance X'_2 in the primary circuit, such that:

$X'_2=X_2(N_1/N_2)^2=X_2(V_1/V_2)^2$

If Xe be the single reactance in the primary circuit equivalent to X_1 and X_2 of the actual transformer,

$$Xe = X_1+ X'_2 = X_1+ (V_1/V_2)^2$$

If Ze be the equivalent impedance of the primary and secondary and secondary windings referred to the primary circuit ,

$$Ze = \sqrt{(R^2e + X^2e)}$$

If ϕe be the phase difference between I_1 and I_1Ze, then $Re = Ze\cos\phi_e$ and $Xe = Z\sin\phi e$

The simplified circuit of the transformer is given in fig 5

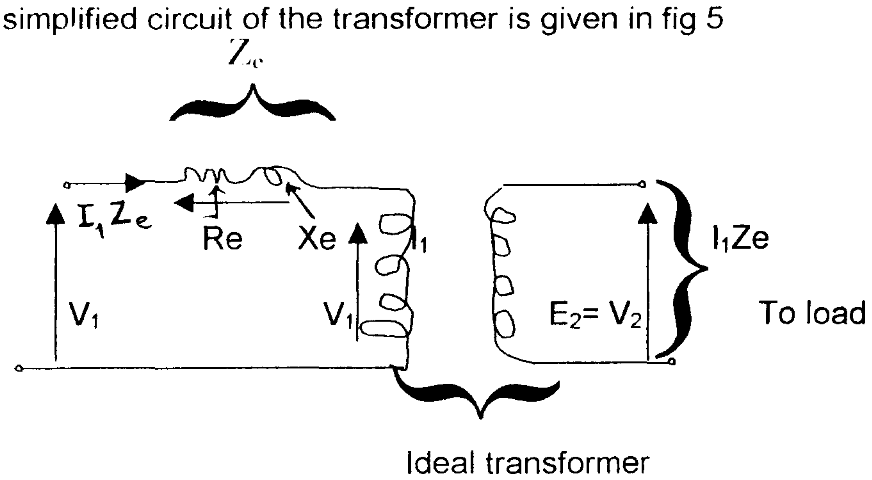


Fig. 5 Simplified Equivalent circuit of a transformer

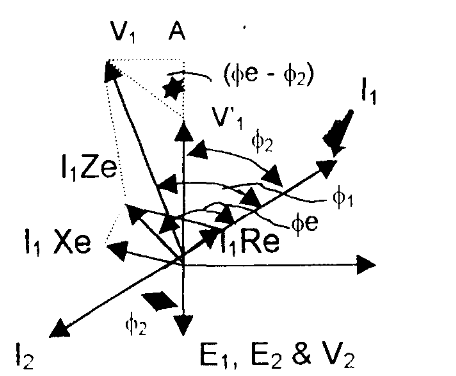


Fig 6 Phasor diagram for Fig 5

2.5 VOLTAGE REGULATION

The voltage regulation of a transformer is defined as the variations of the secondary voltage between no-load and full load expressed as either per unit or a percentage of the no load voltage, the primary being assumed constant, i.e.

$$\text{Voltage regulation} = \frac{\text{No load voltage - full-load voltage}}{\text{No load voltage.}}$$

If V_1 =primary applied voltage,

Secondary the voltage on no load = $V_1 \times N_2/N_1$,

Since the voltage drop in the primary winding due to the no-load current is negligible

If V_2= secondary voltage on full-load,

$$\text{Voltage regulation} = \frac{V_1(N_2/N_1)-V_2}{V_1(N_2/N_1)}$$

$$= \frac{V_1-V_2(N_2/N_1)}{V_1} \text{ per unit}$$

$$= \frac{V_1-V_2(N_1/N_2)}{V_1} \times 100$$

From fig 6 N_1 and N_2 were assumed equal, so that $V'_1=V_2$

In general, $V_1' = V_2 (N_1/N_2)$

Therefore per unit voltage regulation $= \frac{V_1-V'_1}{V_1}$

From fig $V_1^2=(V'+V'_1A)^2+(V_1A)^2$

$$=[V'+I_1Z_e\cos(\phi_e-\phi_2)]^2+[I_1Z_e\sin(\phi_e-\phi_2)]^2$$

In actual practice, $I_1Z_e\sin(\phi_e-\phi_2)$ is very small compared with V'_1,so that:

$$V_1= V'_1+I_eZ_e\cos(\phi_e-\phi_2)$$

Hence, per unit voltage regulation $= \frac{V_1-V'_1}{V_1}$

$$= \frac{I_1Z_e\cos(\phi_e-\phi_2)}{V_1}$$

2.6 EFFICIENCY OF A TRANSFORMER

The iron core and copper coils of a transformer both convert some electric energy into heat energy. This is of course, why a transformer heats up when in operation. The purpose of a transformer is not to provide heat but to transfer energy from the primary to the secondary. Therefore, any heat produced by the transformer represents inefficiency. This heat causes power losses.

The copper loss in the primary and secondary are $I^2_1R_1 + I^2_2R_2$. The iron losses in the core are due to hystersis and eddy currents. Since the maximum value of the flux in normal transformer do not vary by more than about 2 percent between no-load and full, it is usual to assume the iron loss constant at all loads. Hence, if Pc = total iron loss the core , total losses in the transformer = $Pc + I^2R_1 + I^2_2R_2$

$$\text{And efficiency} = \frac{\text{Output power}}{\text{input power}}$$

$$= \frac{\text{output power}}{\text{output power} + \text{losses}}$$

$$= \frac{I_2V_2 \text{ x power Factor}}{V_2I_2 \text{ xpf} + Pc + I^2R_1 + I^2_2R_2}$$

Greater accuracy is possible by expressing the efficiency thus :

$$\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}}$$

$$= \frac{\text{Input power - losses}}{\text{Input power}}$$

$$= 1 - \frac{\text{Losses}}{\text{Input Power}}$$

2.7 OPEN-CIRCUIT AND SHORT-CIRCUIT TESTS ON A TRANSFORMER.

These two tests enable the efficiency and the voltage regulation to be calculated without actually loading the transformer and with an accuracy far higher than is possible by direct measurement of input and output powers and voltages.

Also, the power required to carry out these tests is very small compared with the full-load out put of the transformer.

2.7.1 OPEN-CIRCUIT TEST

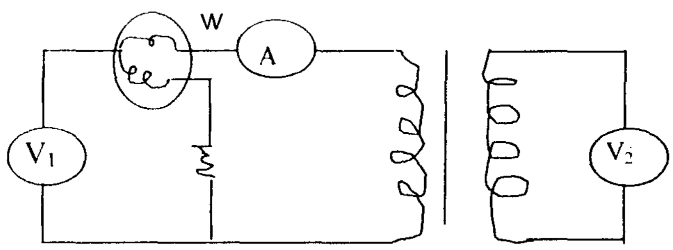


Fig 7 Open-circuit test on a transformer

The transformer is connected to a supply at the rated voltage and frequency, namely the voltage and frequency given on name plate. The ratio of the voltmeter readings, V_1/V_2, gives the ratio of the number of turns. Ammeter A gives the no-load current, and its reading is a check on the magnetic quality of the iron core and joints. The primary current on no-load is usually less than 5 per cent of the full-load current,so that I^2R loss on no-load is less than 1/400 of the primary I^2R loss on full load and is so negligible compared with the iron loss. Hence, the wattmeter reading can be taken as the iron loss of the transformer

2.7.2 SHORT-CIRCUIT TEST

The secondary is short-circuited through a suitable ammeter A_2 as shown in fig. 8 and a low voltage is applied to the primary circuit. This voltage should, if possible, be adjusted to circulate full-load currents in the primary and secondary circuits.

Assuming this to be the case, the copper loss in the windings is the same as that on full load. On the other hand, the iron loss is negligibly small, since the applied voltage and therefore the flux are only about one-twentieth to one-thirtieth of the rated voltage and flux, and the iron loss approximately proportional to the square of flux. Hence, the power registered on wattmeter W can be taken as the copper loss in the windings.

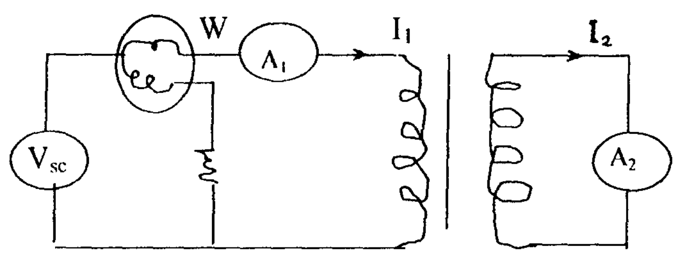


Fig 8 short circuit test on a transformer

2.7.3 CALCULATIONOF EFFICIENCY FROM THE OPEN- CIRCUIT AND SHORT- CIRCUITTESTS

If Pc=input power in watts on the open-circuit test = iron loss,

And Psc = input power in watts on the short-circuit test with full-load currents,= total copper loss on full load, then total loss on full load = Poc +Psc and efficient

$$\text{on full load} = \frac{\text{Full-load VA x pf}}{\text{(full-load x p.f + Poc + Psc}}$$

Also, for any load equal to n x full-load, corresponding total loss = Poc + n^2Psc and

$$\text{Corresponding efficiency} = \frac{\text{n x Full-load VA x pf}}{\text{n x Full-load x p.f + Poc + } n^2\text{Psc}}$$

2.7.4 CALCULATION OF THE VOLTAGE REGULATION FROM THE SHORT –CIRCUIT TEST

Since the secondary voltage is zero, the whole of the applied voltage on short-circuit test is absorbed in sending currents through the impedance of the primary and secondary windings, and since ϕe in fig is the phase between the primary current and the voltage drop due to the equivalent impedance referred to the primary circuit,

$\cos\phi e$ = power factor on short-circuit = Psc/ I_1Vsc

If V_{sc} be the values of the primary applied voltage on the short-circuit test when full-load currents are flowing in the primary and secondary windings, then per unit voltage regulation = ($V_{sc}\cos(\phi e - \phi_2)$)/V_1

2.8 POWER FACTOR

In ac work the product of the r.m.s value of the applied voltage and current is VI volt-amperes, the latter term being used to distinguish this quantity from the power, expressed in watts. The number of watts is equal or less than the number of volt-amperes and the latter has in general, to be multiplied by a quantity termed power factor to give the power in watts: i.e

Power in watts = number of volt-amperes x power factor

= VI x power factor

or power factor = {power in watts}/ product of r.m.s values of voltage and current

For sinusoidal voltage and current,

Power factor = cos ϕ where ϕ is the angles between voltage and current .

$\cos\phi$ = IR/V = IR/IZ = Resistance / Impedance

It has become the practice to say that the power factor is lagging when the current lags the supply and leading when the current leads the supply.

2.9 Per unit Analysis

In the work of analysis, electric power prefers to use per unit (P.U) or percent measures of all types of system variables. These measures generally give a better relative sense of the variables in question.

$$P.U = \frac{\text{Actual value of quantity}}{\text{Base value or reference value of the same quantity.}}$$

$$\text{Base current (Ib)} = \frac{\text{Base voltage Ampere}}{\text{Base voltage}}$$

$$\text{Base impedance} = \frac{\text{Base voltage}}{\text{Base voltage}}$$

$$\text{Per unit current} = \frac{\text{Actual current}}{\text{Base current}}$$

$$\text{Per unit impedance} = \frac{\text{Actual impedance}}{\text{Base impedance}}$$

2.10. TRANSFORMER DESIGN

A transformer consists of two or more coils of wire placed near each other so that most of the magnetic field generated by one coil passes through the other coil.

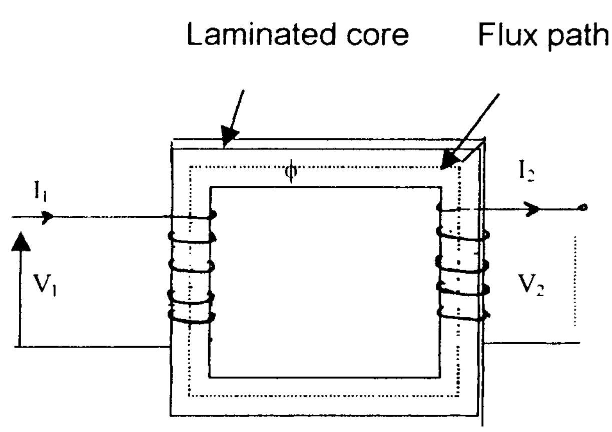


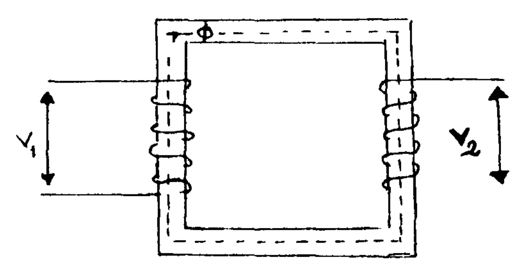
Fig. 3 Two windings Transformer

The magnetic circuit,or core , is made from steel to reduce the reluctance of the flux path and gives a low magnetizing current. If a solid core were used it would act as a shorted turn enclosing the flux path, permitting a circulating to flow and producing a very high eddy current loss. To reduce this loss, the core is made up of thin steel laminations insulated from each other to reduce the magnitude of circulating currents, which flow. The steel is usually a silicon-iron alloys which has been cold reduced to increase the degree of grain orientation within laminations and give a lower hysteresis loss due to the smaller area of hysteresis loop.

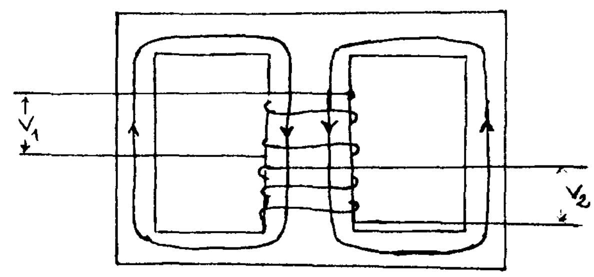
The core cross-sectional area is chosen to maintain the flux density below saturation point. Above this point the core becomes less effective as a low reluctance path and the magnetizing current rises dramatically.

Constrcucally, the transformers are of two general types, distinguished from each other merely by the manner in which the primary and secondary coils are placed around the laminated core. The two types are core-type and shell-types. Another recent development is spiral-core or wound core-types, the trade name being SPIRAKORE Transformer.

In the core type transformers, the windings surround a considerable part of the core where as in the shell-type transformers, the core surrounds a considerable portion of the windings as shown schematically in fig 10 below.



(a) Core type



(b) Shell type

Fig 10 Types of Transformers

The windings are made with a low resistivity material such as copper or aluminum in strip or foil form. The cross-sectional of conductors must be sufficient to reduce the loss caused by resistive heating of the windings when carrying load current, to an acceptable level. The winding conductors must also be large enough to withstand any mechanical forces to which the transformer may be subjected in services, because of short circuits, when the fault current may be several times they normal full -load current. As the current in primary and secondary windings flow in opposite directions round the core, the windings will repel each other, causing the conductors to bend in an inadequately designed winding.

moisture formation. Unlike mineral oil, it shows no rapid burning .The oil carries the excess heat by means of convection currents to the cooling tubes where the heat is passed to the atmosphere. By circulating this oil, it not only keeps the coils reasonably cool, but also provides the transformer with additional insulation not obtainable when the transformer is left in the air. To ensure the trouble free operation, it is necessary to control the temperature of oil, timely replace the contaminated oil, and periodically dry and clear it. Variations in temperature of a transformer lead to changes in the level of oil in the tank.

To keep a transformer always immersed in oil, the transformer tank is equipped with an oil conservator. The oil conservator is a steel drum mounted on the tank cover and connected with the tank through a tube. The oil level charges only in the conservator, which reduces the oil surface in contact with air and gards the oil against pollution and moisture. The fig 11 shows an oil-immersed thee phase Power transformer.

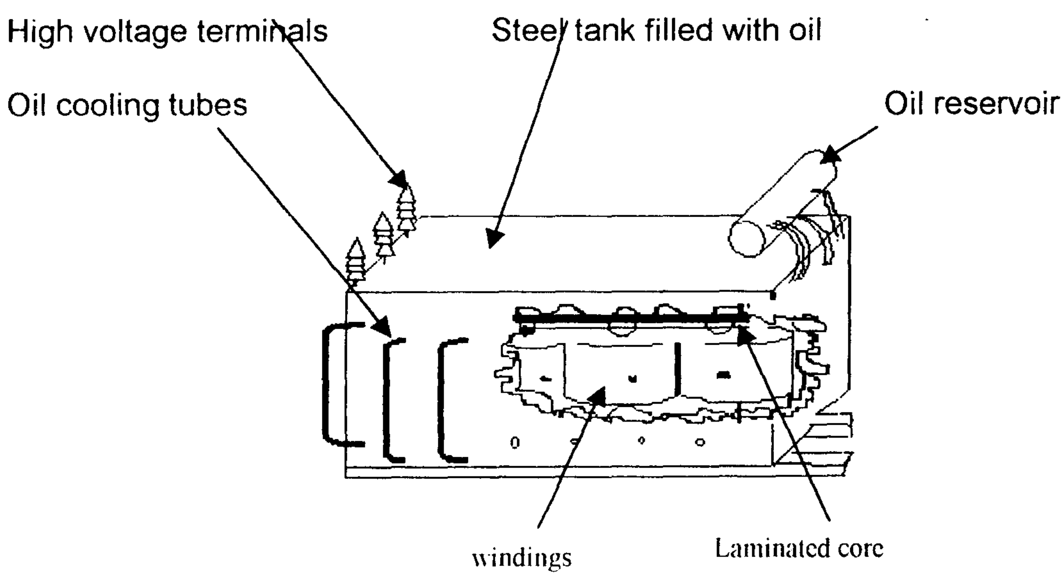
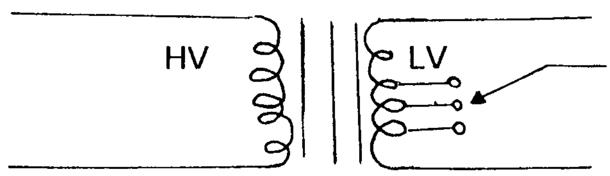


Fig 11 OIL IMMERSED THREE-PHASE POWER TRANSFORMER

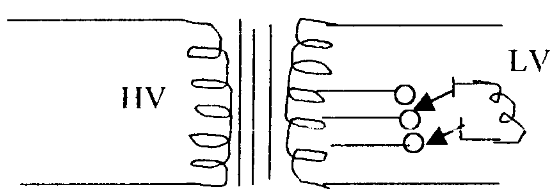
For safety of servicing, the transformer is bonded by steel trip to the earth of the transformer.

2.11 TAP CHAGING

The application of a transformer to a power system involves a correct choice of turns ratio for average operating conditions, and the selection of proper taps to obtain improve voltage levels when average conditions do not prevail. Tap changes are frequently used in the high voltage side of the transformer They are arranged in the middle of the winding on each leg of the core. In general the tapings recommended are standard at ± 2 ½ and ± 5 percent. These ranges are sufficient for normal requirements to cater for load variations. The tapings are generally connected via removable links, with the transformer disconnected from the supply. When transformer have their tapping arrangements on the low-voltage side a tapping switch is used. Large transformers have special arrangements for on-load tap changing which are necessary to ensure continuity Of the supply



(a.)Simple off-load tap changing circuit



b.) On-load tap-charging circuit using reactor to prevent any heavy circulating current due to short-circuiting a number of turns on the secondary winding.

Fig 12 Tap changing

2.12 TRANSFOMER RATINGS

To properly use a transformer, one must know its ratings. The transformer core losses depend upon the magnitude of the core flux which is proportional to the voltage. The transformer ohmic, or copper losses depend upon the winding.

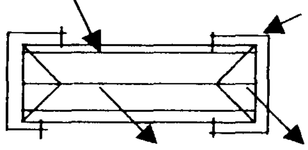


Fig. 13 Fuse

3.2 CIRCUIT BREAKER

It is a device to open or close an electrical power circuit either during normal power system operation or during abnormal conditions. A circuit breaker serves in the course of normal system operation to energize or de-energize loads. During abnormal conditions, when excessive current develops, a circuit breaker opens to protect equipment and surrounding s from damage due to excess current. These currents are usually the result of short-circuit created by lighting, accidents, deterioration of equipment, or sustained over loads.

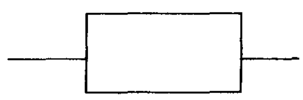


Fig. 14 Circuit breaker

3.3 RELAY

It is an electromechanical or solid-state device operated by variations in the input, which, in turn, operate or control other devices connected to the output. They are used in wide variety of applications.

3.3.1 PROTETIVE RELAY

A protection relay is a device, which responds to abnormal conditions in an electrical power system to operate a circuit breaker to disconnect the faulty section of the system with the minimum interruption of the supply. These relays range from the simple overload unit on housebreakers to complex systems used to operate extra-high-voltage power transmission lines. Heavy-duty protective relay system detect all intolerable system conditions such as faults caused by

CHAPTER THREE

3.0 PROTECTION DEVICES

Protective devices provide the intelligence and initiate the action, which enables circuit-switching equipment to respond to abnormal or dangerous system conditions. They guide against excessive voltage, current and certain changes, which can damage devices.

3.1.1 FUSE

It is an expendable device for opening an electric circuit when the current there in becomes excessive. An electric fuse consists principally of a section of conductor, known as a fusible element, of such properties and proportions that excessive current melts it and thereby severs the circuit. A fuse has the following requirements:

1. It must carry continuously the device rated current

2 .The fuse voltage during arcing must be high enough to force the current down and dissipate the circuit energy.

3. Its thermal storage capacity must be less than that of the device being protected.

4. After breaking the current, the fuse must be able withstand any retricking voltage which appears across it. Voltage ratings of fuse range from a few volts to more than 100,000 volts; current ratings extend from a fraction of ampere to several thousand amperes. At lower voltage interrupting rating may be hundreds of thousands of amperes. The schematic diagram of a fuse is shown below.

currents. As the total losses determine the maximum transformer temperature, its ratings must include information on both voltage and current. The product of current and voltage would evidently be meaningful rating measure. This explains why it is customary to rate a transformer in terms of KVA (or MVA) load.

For example, the ratings of a particular transformer may be read:

Voltage = 50/60KV, 60HZ

Power = 6000KV

From these ratings, we immediately learn that the maximum current load is as follows

6000/5o=120A(on HV side)

6000/10=600A(on LV side)

2.13 THREE PHASE TRANSFORMER CONNECTIONS

The windings of a three phase transformer may be connected in star-star, star-delta, delta-star, or delta-delta, depending upon the conditions under which the transformer is to be used. In star to delta or delta to star connection the line, voltage is smaller or greater than the transformation ratio by a factor of $\sqrt{3}$. Hence, by interchanging the interconnection of winding, we can always vary the secondary line voltage of the transformer.

The electrical insulation of windings is of great importance; not only must the conductors turns be insulated from each other, but there must be adequate insulation strength between windings and from each winding to earth.

No other feature in the construction of a transformer is given more attention and care than the insulating materials, because the life of the unit depends almost solely on the quality, durability and handling of these materials.

All insulating materials are selected on the basis of their high quality material are selected on the basis of their high quality and ability to preserve high quality and ability to preserve high quality even after many years of normal operation. The insulation must withstand not only the normal service voltage, but also over voltages that may occur in service due to lighting strikes and switching operations.

Power transformers handle huge quantities of electrical energy and require special cooling arrangement. Air natural cooling is applied to dry transformers. In this case, the heat generated in a transformer is directly transferred to the surroundings. Because heat transfer is poor, the temperature distribution in a dry transformer may be all but uniform. Also the low electric strength of air (2.1 MV m^{-1}) impairs their insulation still more. For these reason, air natural cooling is mostly used on small-sized, low- voltage transformers.

The most commonly used type of transformers are oil-immersed transformers. They are high power transformers in which the core and coils assembly is placed in a steel tank filled with insulating oil.

Instead of natural mineral oil, now -a- days synthetic insulating fluids known as ASKARELS (trade name) are used. They are non-inflammable and, under the influence of electric arc do not decompose to produce inflammable gases. One such fluid commercially known as PYROLOR is being extensively used because it posses remarkable stability as dielectric and even after long service shows no deterioration through seldging , oxidation acid or

Lightning and equipment insulation failure, and initiate tripping of power circuit breakers within 6-10 milliseconds. The performance of a protective relay system is stated in terms of selectivity, speed of response, reliability and sensitivity.

A relay protection scheme has two groups of electric circuits: a c circuit connecting the relays to sources of data about the status of the equipment to be protected, and control current circuits responsible for the operation of circuit-opening devices in a desired sequence and with a desired selectivity. Control-current sources (dc or ac) may be dependent on or independent of the operating duty and condition of the primary (power) circuits of the protected plant. Dependent control current sources are potential transformers. Independent control-current sources are storage batteries.

Great majority of relays are in one of the following groups: (induction relays, attracted-armature relays, moving coil relays and timing relays.

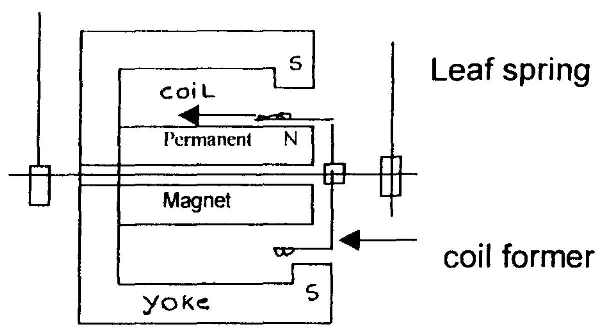


Fig. 15 Axial moving-coil relay

3.4 CURRENT TRANSFOMER

The current transformer is generally regarded merely as a device, which reproduces a primary current at a reduced level.

A current transformer designed for measuring purposes operates over a range of current up to a specific value, which usually corresponds to the circuit normal rating and has a specific error at that value. On the other hand, a protection current transformer is required to operate over a range of current many times the circuit rating and is frequently subjected to conditions greatly exceeding those which it would be subjected to as a measuring current transformer.Current transformers have two important qualities:

1. They produce the primary current conditions at a much lower level so that the current can be varied by the small cross-sectional cable associated with panel wiring and relays.

2. They provide an insulating barrier so that relays which are being used to protect high voltage equipment need only be insulated for a nominal 600V.

The schematic diagram of a current transformer is shown below

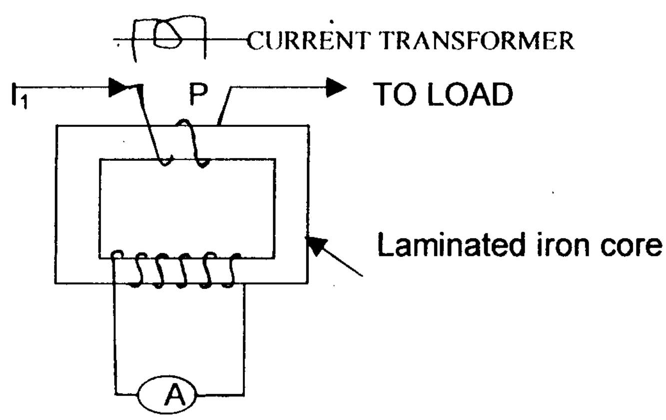


Fig. 16 Current Transformer

3.5 **TRANSFORMER PROTECTION**

Because of its static nature the power transformer can be regarded as a very reliable unit. Nevertheless there is a possibility of failure because of internal faults as well as being subjected to stresses from external sources, which could cause the internal fault condition. In order to avoid the loss of the unit as well as serious consequences, the transformer has to be given great protection.

3.5.1 **TYPES OF FAULTS**

Internal faults

1. Failure of insulation of windings, laminations or core bolts from damage in erection, inadequate quality or brittleness through ageing or over loading. Failure of the winding insulation resulting in inter-turn or earth faults.

stress in the end turns of the winding and a risk of partial winding flashover though the insulation is usually in this area.

4. Lightning

This is only a risk where the transformer is connected to an overhead line and is usually protected by arrests or spark gaps.

3.52 **FAULT DETECTION**

Fault detection is accomplished by a number of techniques., some of the common method are the detection of charges in electric current or voltages levels, power direction, ratio of voltage to current, temperature, and comparison of electrical quantities flowing into a protected area with the quantities flowing out. The last mentioned is known as differential protection.

Differential relay is applied to protect a piece of electrical equipments as shown in fig below

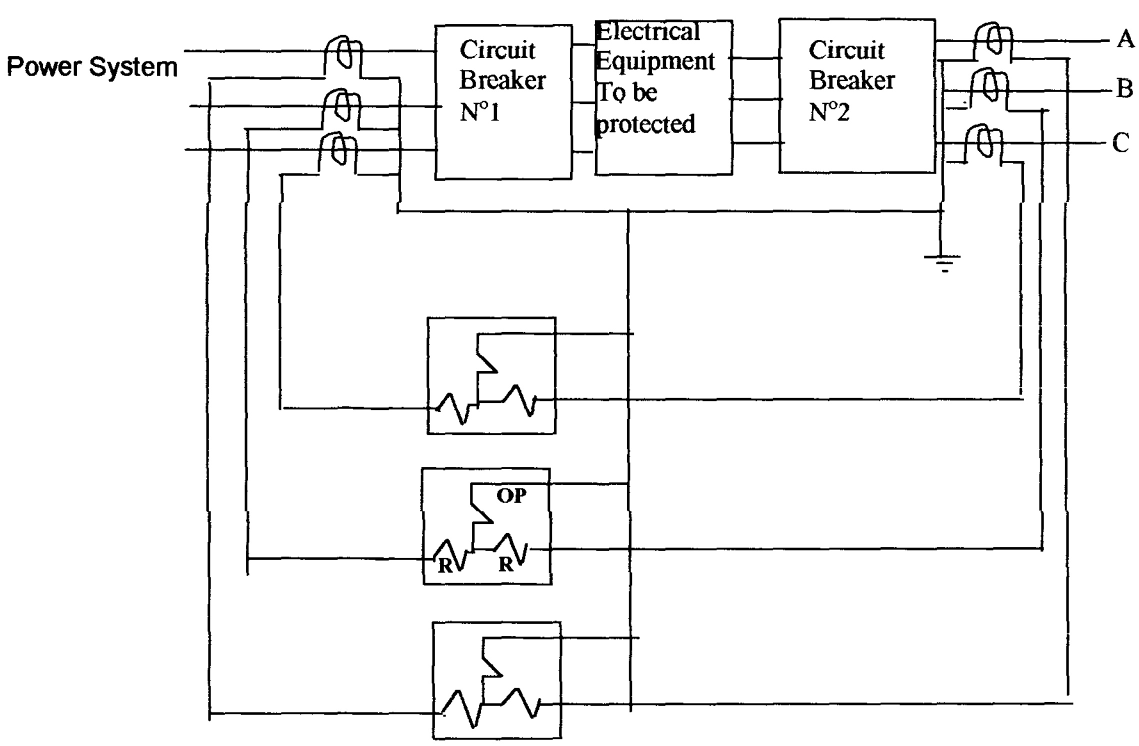
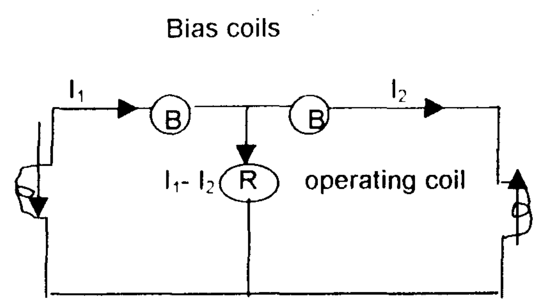


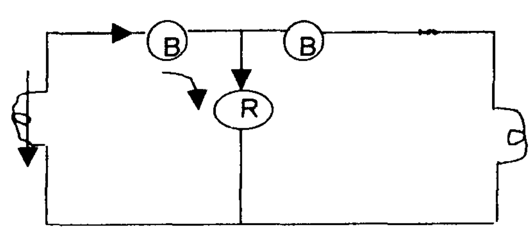
Fig. 17: Typical arrangement for electrical equipment

A differential relay functions by reason of difference between two quantities of the same kind (two currents, two voltages, etc) .The method to be used for protection of transformer is the high speed biased differential protection. But it is important to explain the differential protection as applied to the biasing coils to restrain the relay from operation and although a fairly large spill current may flow in operating coil of the relay it will be well below the value required to overcome the restraining force. The strength of the scheme lies in the fact that when the spill current is likely to be high, the restraining force is at its greatest. The most onerous condition under which the relay would be required to operate is an internal fault fed from one end only. Under this circumstance, the operating force greatly exceeds the restraining force.

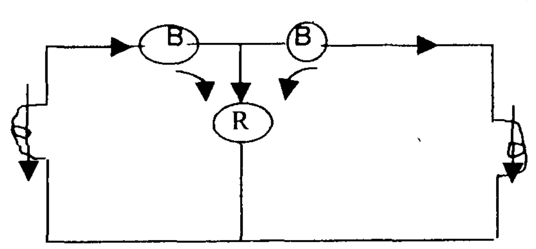
When the system is fed from both ends the net effect of the restraining force is reduced and the operating current is increased. The processes are shown below



a. Through fault



b. Internal fault fed from one end



c. Internal fault fed from both ends

Fig 18. Biased-Differential Protection

Failure of the lamination or core-bolt insulation leading to increased eddy current causing heating of the core.

2. Oil deterioration, which could be caused by:

- Poor-quality oil,
- Penetration of moisture,
- Decomposition because of over heating or the formation of sludge by oxidation as a result of bad electrical joints.

3. Loss of oil by leakage

4. Inability to withstand fault stress

This may be due to poor design or where repeated heavy currents set up severe mechanical stresses, which causes packing and wedges to be loosened and finally shaken out.

5 Tap changers faults

6 Cooling system faults.

External conditions, which could cause faults to develop :

1. Heavy through faults

The high current would produce severe mechanical stresses in the transformer windings and insulation.

2. Over loads

This would also produce mechanical stress in the windings and insulation and although these would be much less than under fault conditions they would be of much longer duration.

3. Switching surges

These surges, which may be several times the rated system voltage, have a very steep front therefore a high equivalent frequency. This causes stress current transformer secondary to protect the rectifier. Adjustment of the bias section is by means of the variable resist connected across the main restraint coil. The range is from 0 to 40% and will normally bet set at a value 10% above the maximum percentage difference between the power transformer ratio at the extremities of its tap range and the ratio of the current transformer primary ratings. A filter arrangement in series with the operating coil circuit filters off the harmonic currents which are then passed through the harmonic restraint coil. The harmonic circuit is proportioned so that 30% of second harmonic will just balance the operating force produced by the fundamental current. The amount of a higher harmonic which is required to balance the fundamental is slightly less.

An instantaneous high-set over current element is usually incorporated in the relay with a setting above the maximum magnetizing inrush current. For load through the equipment or for fault either the right or left of the current transformers, the secondary current flows through the restraining coils, and little or no-current flows through the operating coils so that operation is prevented. For fault between the current transformers, secondary current flows through the restraining windings and in the operating coils to operate the relay, trip the circuit breakers.

The high-speed Biased-differential -Protection scheme is a good means of protecting either large transformers or distribution transformers. This method detects the earth-faults and the fault will be cleared quickly. Thus, if use, the earth-fault relay will be of secondary importance.

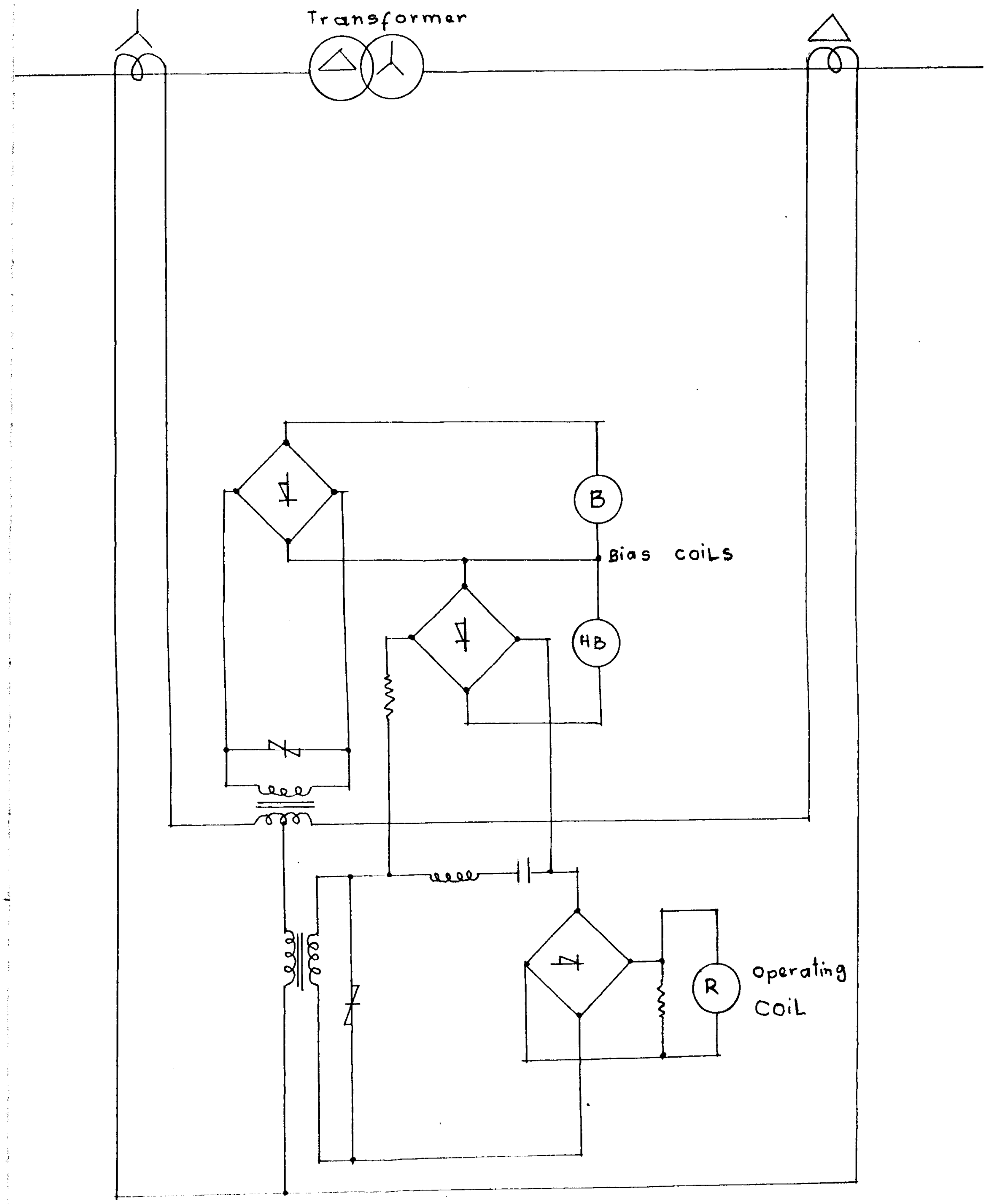


Fig. 19 High-Speed- Biased –Differential-Protection with harmonic bias

A heavy fault would give rise to an explosive generation of gas which displaces the oil and causes a surge to pass along the pipe towards the conservator and in so doing displaces the flap switch which operates an auxiliary relay designated " Buchholz Surge " or " Buchholz Trip".

Under these circumstances, no examination of the windings has been made.

A leakage oil from the transformer tank causes a gradual fall in oil level which will in the first place operate the upper float to give an alarm and if not corrected will cause the lower float to fall and trip the circuit breaker.

CHAPTER FOUR

4.1 TESTING

The importance of testing of protective relays and its associated equipment is to ensure that when operation is required they will function correctly.

Current transformers must be tested to ensure that they are correctly connected and suitable for the protection with which they are associated .Relays have to be checked to make sure they are correctly connected and can operate well, so also the other equipment.

4.2 CARE OF PROTECTION RELAYS

Relays are generally of robust construction and not easily damaged after they have been installed. There is, however, some danger of damage before and during installation and during this time they should be treated like the measuring instruments that they are and should not be subjected to mechanical shock nor stored in unsuitable conditions. They should be handled with care and the cover should not be removed unless absolutely necessary. The removal of he cover during installation not only allows the ingress of dust, which is usually abundant during installation, but if drilling or filing is taking place nearby, there is a danger that steel particles enter the relay which sooner or later will be pulled into the air - gaps of electromagnet or permanent magnet and impair relay operation. Before any work on the relay is started the trip circuit should be inspected and only cleaned if there is discoloration to such an extent that may impair good contact.

4.3 TRANSFORMER MAINTENANCE

4.3.1 **TRANSFORMER INSPECTION**

The transformer is an electrical apparatus reliable in service and convenient to maintain. Regular inspection and trouble-shooting are vital to the efficient operation and maintenance of transformers. Main and house transformers should be inspected daily without disconnecting them from line, and all other transformers in attended installations, once a week. In unattended installations, the transformer should be inspected at least once a month. To prevent accidents, attending personnel should inspect a power transformer while on the threshold of the transformer cell or bay outside the guard barrier. The inspector may go beyond the guard only if the lower flanges of the bushings on the transformer tank cover are at least 2m above floor level and the unguarded live parts above the passageway are at least 2.75m above floor level for an operating voltage of 35 KV, and 3.5 m for a voltage of 110 KV.

Off-schedule transformer inspections are made when the ambient temperature has changed sharply, each time a transformer has been disconnected by its protective gear, or a warning signal has come from the Buchholz relay. The points to be watched during an inspection of power transformers are:

The approaches and passages to the substation should not be obstructed; the fences, guards doors, window and ventilating openings, and the structure as a whole should be intact; the transformer tanks should be intact, no oil should leak at the tank cover joints, flanges, and drain cakes, the oil level in the conservator should be sufficient for the prevailing temperature, and the oil-filled bushings should be full of oil; the transformer oil temperature should be accurately monitored by the (indicating Bourdon-tube) thermometers. The earning system and the fire fighting equipment should be in good order.

Any troubles discovered during an inspection should be remedied at earliest possible occasion; should an emergency or accident occur, the unit must be immediately disconnected from the line.

4.3.2 **DRY-TYPE TRANSFORMER MAINTENANCE**

For maintenance of dry-type transformers, they must be kept dust-free and protected against pollution. They should be cleaned with bellows or vacuum cleaners at regular intervals. Terminals or bolted joints should also be checked regularly.

The insulation resistance between windings and windings -to earth provides good indication of insulation especially when a transformer has been out of service over a long period and may have absorbed moisture, subsequent drying out may be necessary.

At room temperature the insulation, resistance should not be less than the following:

Resistance	operating voltage
15 Mohm	up to 1kv
40 Mohm	Above 5kv.

The insulation resistance is normally measured with either a 1kv or 2 KV instrument or a meggar.

The windings can be dried out as follows:

a. By heating in a drying oven at a temperature approximately 80^o c or with heaters such as incandescent lamps, resistor elements or radiators. The surface of the windings must not exceed 100^oC when using direct heating.

b. Heating under short-circuit conditions with maximum rated current. The output side of the transformer is short-circuited and the input connected to a voltage which is adjusted such that the maximum rated current is not exceeded. During the drying /heating process the value of the insulation resistance should be measured repeatedly.

CHAPTER FIVE

5.1 RECOMMENDATIONS

Protection is very important for the progress of a power system. It reduces the service interruption as well as loss of equipment and personnel injury. In the case of transformers it increases their service life thus:

- Protective equipment should be checked periodically to ensure that its operation and coordination have not been impaired by exposure to dusty, smoky, oil, or corrosive atmosphere, by mechanical vibration or shock, by excessive temperature, by tampering, or in any other manner. The consequences of neglecting proper testing may at first seem slight; but they are cumulative and such neglect can lead to an increasing loss of protection.
- All tests should be carried out by skill persons to avoid damage of equipment caused by inexperience;
- For maintenance and security, the transformer should be close in a wall and should not be accessible to unauthorized persons.
- When the Buchholz relay disconnects the transformer from the line due to internal fault, the windings and core assembly should be inspected and tested before switching back the transformer.
- Routine repairs to power transformers should be carried out at least once a year.

5.2 CONCLUSION

Protection is very important in power system. It is a means of reducing personnel injury as well as damage of equipment. It also provides a reduction of service interruption .The capital investment is also reduced by the reduction of equipment reserves. The high-speed-Biased differential protection is a good scheme for protection of transformers.

Due to its high speed of operations, internal fault is cleared quickly within a short time (60 ms).

Under this scheme, the earth fault relay is of secondary importance. The relay does not operate under magnetizing inrush current which is not the case in biased differential protection. Therefore, the High -Speed-Biased-Differential protection is more valuable than biased –Differential-protection.

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