POWER SYSTEM LAB

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Syllabus

(A) Hardware Based:

1. To determine direct axis reactance (x_d) and quadrature axis reactance (x_q) of a salient pole alternator.
2. To determine negative and zero sequence reactances of an alternator.
3. To determine sub transient direct axis reactance (x_d) and sub transient quadrature axis reactance (x_q) of an alternator
4. To determine fault current for L-G, L-L, L-L-G and L-L-L faults at the terminals of an alternator at very low excitation
5. To study the IDMT over current relay and determine the time current characteristics
6. To study percentage differential relay
7. To study Impedance, MHO and Reactance type distance relays
8. To determine location of fault in a cable using cable fault locator
9. To study ferranty effect and voltage distribution in H.V. long transmission line using transmission line model.
10. To study operation of oil testing set.

(B) Simulation Based Experiments (using MATLAB or any other software)

11. To determine transmission line performance.
12. To obtain steady state, transient and sub-transient short circuit currents in an alternator
13. To obtain formation of Y-bus and perform load flow analysis
14. To perform symmetrical fault analysis in a power system
15. To perform unsymmetrical fault analysis in a power system

List of Experiments

1. To determine negative and zero sequence reactances of an alternator.
2. To determine direct axis reactance (xd) and quadrature axis reactance (xq) of a salient pole alternator.
3. To study the IDMT over current relay and determine the time current characteristics.
4. To study ferranty effect and voltage distribution in H.V. long transmission line using transmission line model.
5. To determine location of fault in a cable using cable fault locator.
6. To study operation of oil testing set.
7. To study percentage differential relay.
8. To obtain formation of Y-bus and perform load flow analysis
9. To perform symmetrical fault analysis in a power system
10. To perform unsymmetrical fault analysis in a power system

Experiment No. 1

Aim: To determine negative and zero sequence reactances of an alternator.

Apparatus Used:

S.No	Items	Qty.
1.	M.I. Ammeter Portable 0-2.5/5 A	1
2.	M.I. Voltmeter Port 300/600v	1
3.	M.I. Voltmeter Port 75/1 5 0/3 Oov	1
4.	Rheostat 1.4 Amp 230 Ohms	1
5.	Rheostat 1.1 A 1800 Ohms	1
6.	M.C. Voltmeter Port 150/300 V	1
7.	M.C. Ammeter Port 1/2 Amp	1
8.	Upf Wattmeter 2.5/5 Amp, 125/250/500 V	1
9.	Single Phase Variac 4 A	1
10.	M G Set: D C Shunt Motor/3 Phase Alternator	1

THEORY : Direct-axis synchronous reactance and Quadrature axis synchronous reactance are the steady state reactances of the synchronous machine. These reactances can be measured by performing, open circuit, short circuit test and the slip test on a synchronous machine.

Direct-axis synchronous reactance, Xd: The Direct-axis synchronous reactance of synchronous machine in per unit is equal to the ratio of field current, Ifsc at rated armature current from the short circuit test, to the field current, Ifo at rated voltage on the air gap line. Synchronous reactance,

$$Xd = \frac{I_{fsc}}{I_{fo}} \text{ per unit}$$

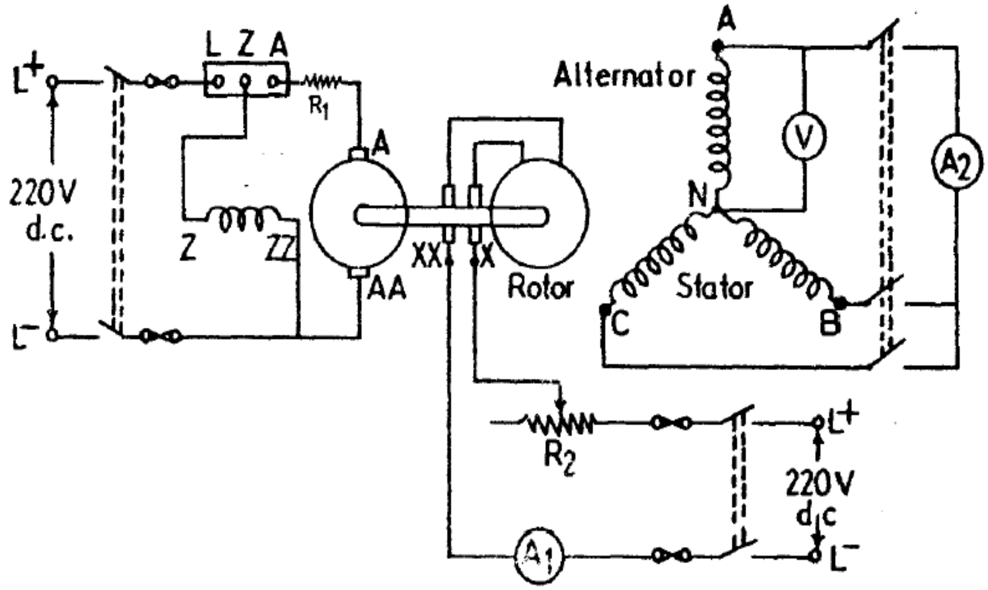
Thus Direct-axis synchronous reactance can be found out by performing open circuit and short circuit test on an alternator.

Quadrature axis synchronous reactance, Xq by slip test

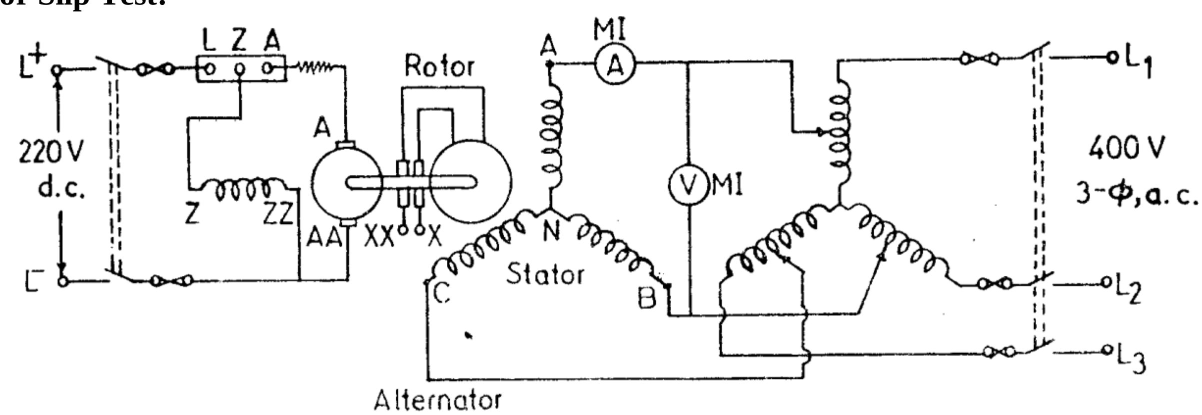
For the slip test the alternator should be driven at a speed, slightly less than the synchronous speed with its field circuit open. 3 phase balanced reduced voltage of same frequency is applied to armature (stator) terminals of the synchronous machine. Applied voltage is to be adjusted, so that the current drawn by the stator winding is full load rated current. Under these conditions of operation, the variation of the current drawn by the stator winding, voltage across the stator winding and the voltage across the field winding. The wave shapes of stator current and stator voltage clearly indicated that these are changing between minimum and maximum value. When the crest of the stator mmf wave coincides with the direct axis of the rotating field the inducted emf in the open field is zero, the voltage across the stator terminals will be maximum and the current drawn by the stator winding is minimum. Thus approximate value of Direct-axis synchronous reactance, Xds is given by,

$$X_{ds} = \frac{E_{max}}{I_{min}}$$

Circuit Diagram:



For Slip Test:



PROCEDURE :

(a) Open Circuit Test

1. Connect the circuit as per circuit Diagram.
2. Ensure that the external resistance in the field circuit of DC motor acting as a prime mover for alternator is minimum and the external resistance in the field circuit of alternator is maximum.
3. Switch on DC supply to DC motor and the field of alternator.
4. Start the DC motor with the help of stator. The starter arm should be moved slowly, till the speed of the motor builds up and finally all the resistance steps are cut out and the starter arm is held in on position by the magnet of no volt release.
5. Adjust the speed of the DC motor to rated speed of the alternator by varying the external resistance in the field circuit of the motor.
6. Record the field current of the alternator and its open circuit voltage per phase.
7. Increase the field current of alternator in steps by decreasing the resistance and record the field current and open circuit voltage of alternator for various values of field current.
8. Field current of alternator is increase till the open circuit voltage of the alternator is 25 to 30 percent higher than the rated voltage of the alternator.

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9. Decrease the field current of alternator to minimum by inserting the rheostat fully in the field circuit.

(b) Short Circuit Test

10. With the DC motor running at rated speed and with minimum field current of alternator close the switch, thus short-circuiting the stator winding of alternator.
11. Record the field current of alternator and the short circuit current.
12. Increases the field current of alternator in steps till the rated full load short circuit current. Record the reading of armature in both the circuit at every step. 4 to 5 observations are sufficient as short circuit characteristics is a straight line.
13. Decrease the field current of alternator to minimum and also decrease the speed of DC motor by field rheostat of the motor.
14. Switch off the DC supply motor as well as to alternator field.

(c) Slip Test

1. Connect the circuit of alternator as shown in Fig 'D' keeping the connections of the DC motor same.
2. Ensure that the resistance in the field circuit of DC motor is maximum.
3. Switch on the DC supply to the motor.
4. Repeat steps 4 described is (a).
5. Adjust the speed of the DC motor slightly less than the synchronous speed of the alternator by varying the resistance in the field circuit of the motor. Slip should be extremely low, preferably less that 4 percent.
6. Ensure that the setting of 3 phase Variac is at zero position.
7. Switch on 3 phase AC supply to the stator winding of alternator.
8. Ensure that the direction of rotation of alternator, when run by the DC motor and when run as a 3 phase induction motor at reduced voltage (alternator provided with damper winding can be run as 3 phase induction motor) is the same.
9. Adjust the voltage applied to the stator winding till the current in the stator winding is approximately full load rated value.
10. Under these conditions the current in the stator winding the applied voltage to the stator winding and the induced voltage in the open field circuit will fluctuate from minimum values to maximum values which may be recorded by the meters included in the circuit. For better results, oscillogram may be take of stator current applied voltage and induced voltage in the field circuit.
11. Reduce the applied voltage to the stator winding of alternator and switch off 3 phase AC supply.
12. Decrease the speed of DC motor and switch off DC supply.

Observation Table:

S. No.	Open Circuit Test		Short Circuit Test		Slip Test			
	I_f	V_o	I_a	I_f	V_{min}	V_{max}	I_{min}	I_{max}

Result: We have performed the experiment and determine negative and zero sequence reactances of an alternator

Experiment No. 2

Aim: To determine direct axis reactance (xd) and quadrature axis reactance (xq) of a salient pole alternator.

Apparatus Used:

S No.	Name	Type	Range	Quantity
1	Ammeter	MI	0-5 A	1
2	Voltmeter	MI	0-300 V	1
3	Single phase variac	-	230/0-270 V, 06 A	1

Theory: The direct-axis subtransient reactance and quadrature-axis subtransient reactance of 3 phase synchronous machine can be measured by applying a reduced single phase voltage to the two stator phase connected in series, with the field winding short circuited and the machine being stationary. The rotor is moved by hand, so that the current in the short circuited field winding is maximum. Under this condition. The reactance offered by the armature is direct-axis subtransient reactance i.e.

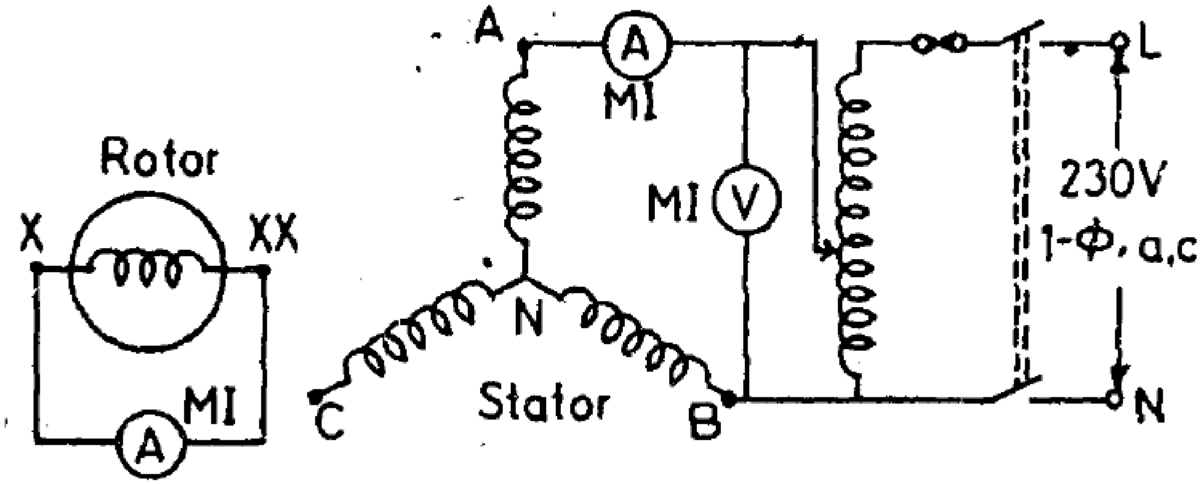
$$X_d'' = \frac{V}{2I''}$$

Next the rotor is turned through half a pole pitch, so that q axis coincides with the crest of the armature mmf and the current in the field winding is minimum. The reactance offered by the armature under this condition will be quadrature-axis subtransient reactance. This method necessitates an exact alignment of the rotor with the armature mmf wave, which is not possible. As such a more convenient method discussed below can be adopted for the measurement of subtrasient reactances.

Direct-axis subtransient reactance, Xd"

Direct-axis subtransient reactance can be determined by applied voltage method (most convenient method) in which single phase voltage of reduced magnitude and of rated frequency is applied across the two terminals of the stator winding the third being left isolated as shown in Fig 'A'. The test is repeated for another two combinations of connections of stator terminals i.e. first voltage applied between terminals A,B, second between B,C and third between terminals C,A. During this test rotor is stationary and the field winding on the rotor is short circuited through an armature. The test should be conducted at full load current flowing in the stator winding as such applied voltage should be adjusted accordingly. Direct-axis subtransient reactance can now be found out as discussed below.

Circuit Diagram:



1. Let the applied voltage across the terminals A,B of the stator winding with terminal C kept isolated be E volts and the current flowing through the winding in currentbe I amperes. The ration of voltage across each phase to current is a reactance which can be represented by a quantity A' i.e.

$$A' = \frac{E/2}{I} = \frac{E}{2I} \qquad .....(i)$$

2. Similarly the ratio of applied voltage E'/2 across each phase with voltage E' across the terminals B,C and the resultant current flowing, I' can be represented by a quantity B' i.e.

$$B' = \frac{E'}{2I'} \qquad .....(ii)$$

3. In a similar way the ratio of applied voltage, E"/2across each phase with voltage E" across the terminals C.A and current flowing I" is represented by a quantity C' i.e.

$$C' = \frac{E''}{2I''} \qquad .....(iii)$$

4. From the value od A', B', and C' determined from the experimental data, calculate the values of K and M from the equations given below.

$$K = \frac{A' + B' + C'}{3}$$

$$\text{and } M = \sqrt{(B' - K)^2 + \frac{(C' - A')^2}{3}}$$

5. Then direct-axis subtransient reactance Xd" = K – M (smaller possible stationary rotor reactance).

Procedure:

1. Connect the circuit as per the circuit diagram.
2. Ensure that the moving knob of single phase variac is at zero position.
3. Switch on the AC supply.
4. Apply a reduced voltage to the circuit consisting of stator terminals A and B in series, so that the current flowing in the stator winding is of full load value. Record the voltage applied and the current flowing in the circuit.
5. Repeat step 4 with stator terminals B and C connected in series.
6. Repeat step 4 with stator terminals C and A connected in series.
7. Repeat step 4, 5 and 6 for a new position of the rotor to confirm that the value of K and M are same for the both the position of rotor.
8. Switch off the supply.

Observation Table:

S. No.	E	I	E'	I'	E"	I"	A'	B'	C'	K	M

Result: We have performed the test and direct-axis subtransient reactance of synchronous machine.

Experiment No. 3

Aim: To study the IDMT over current relay and determine the time current characteristics.

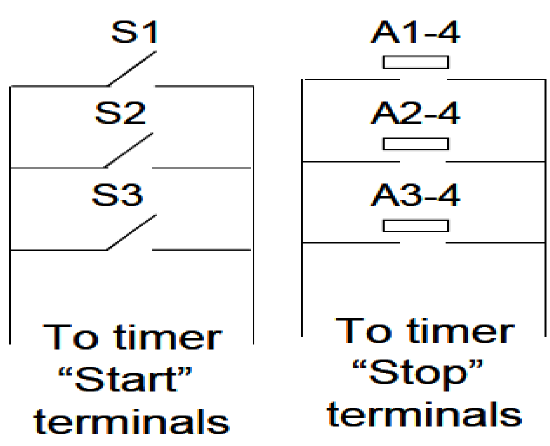
Apparatus Used:

1. Voltmeter (0-300 V) Digital
2. Ammeter (0-10 A) Digital
3. Loading C.T.
4. Auto Transformer 0-270V
5. Indicating Light
6. I.D.M.T. Relay Type CDG
7. Timer with Start & Stop facility
8. Push Button for Timer START & STOP
9. Rotary Switch
10. DP Switch
11. Insulating terminals

Theory: There are several over current protection such as fuse, thermal relay & IDMT Relay. IDMT (Inverse Definite Minimum Time) Relay is a high accuracy over current relay. If we does not want to flow the current in lines more than 1 Amp, we will set the tripping current in our relay 1 Amp. As the current will become 1.10 or 1.20, the relay disc will start forward and trip the breaker after certain time. It is widely used to prevent over current on transmission lines, power transformers etc, because the error & tripping time of the relay is tolerable by the lines and transformer.

As the requirement of system is that the faulted line should be open instantaneously. If the faulted line breaker fails to open the faulted line, the next supply breaker have to be open to for making dead the faulty line. The next breaker may be at higher voltage line or the same voltage. The next breaker should open only after the first breaker failure. So we will allow approx 0.4 sec time to operate first breaker. If first breaker does not become open within 0.4 sec than it will be assume failure and the next breaker will become functional. These time and current distinguish is made by IDMT relay.

Circuit Diagram:



Procedure:

Study the operating current & de-operating current of disc.
(i) Keep the current source at minimum.
(ii) The amp adj / relay test rotary switch is kept at AMP ADJ.
(iii) Switch ON the test set.
(iv) Increase the current source slowly and pay attention at disc of relay.
(v) At certain current, it just moves in forward direction, this current is **operating current** and note the current.
(vi) Now decrease the current through current source and pay hard attention at disc.
(vii) The disc will stop at certain current and moves in reverse direction just after reducing the current. This current is **de-operating current** and note its value.

Observation Table:

S NO.	PLUG SETTING	OPERATING CURRENT	DE-OPERATING CURRENT
1.	1 A	1.06 A	0.90 A
2.			
3.			
4.			
5.			
6.			
7.			

Result: We have draw the characteristics of IDMT relay after performing the test.

Experiment No. 4

Aim: To study ferranty effect and voltage distribution in H.V. long transmission line using transmission line model.

Apparatus Used: Transmission line model is consisting of four actions of transmission on line operatable at 220V with current rating at 2A connected in pi network. A continues variable power supply with two Digital voltmeter and two digital ammeter mounted on front panel with Resistive, Inductive, Capacitive load fitted in m.s. sheet complete with patch chords for interconnection. Additionally one LPF Wattmeter is required if A.B.C.D. parameter with phase angle is to be calculated, for which the calculation are given in our manual.

Theory: Transmission line model consists of four sections and each section represents 50 km long 400 KV transmission line. Parameters of 50 km long 400 KV Transmission line are taken as :-

Series Inductance = 80 mH
Series Resistance = 2 ohm
(In addition to resistance of inductance coil)
Shunt Capacitance = 0.47 microF
Leakage resistance or Shunt Conductance = 470 kohm

For actual 400 KV transmission lines range of parameter is :-

l = Series Inductance = 1.0 to 2.0 mH/Km
r = Series Resistance = 0.5 to 1.5 ohm /Km
c = Shunt Capacitance = 0.008 to 0.010 microF/Km
g = Leakage resistance (Shunt Conductance) = 3×10^{-8} to 5×10^{-8} mho/Km

A long transmission line draws a substantial quantity of charging current. If such a line is open circuited for a very lightly loaded at the receiving end, the voltage at the receiving end may become higher then the voltage at the sending end. This is known as 'FERRANTI EFFECT' and is due to the voltage drop across the line inductance (due to the charging current) being in phase the sending end voltage. The both capacitance and inductance are necessary to produce this phenomenon. The capacitance and charging current is negligible in short line but significant in medium length lines and appreciable in long lines. Therefore, phenomenon occures in medium and long lines.

In the phaser diagram, Ferranti effect is illustrated. The line may be represented by a nominal pi circuit so that half of the total line capacitance is assumed to be concentrated at the receiving end. OM represents the receiving end voltage. OC represents the current drawn by the capacitance assumed to be consetrated at the receiving end. MN is the resistance drop and NP is inductive reactance drop. OP is the sending end voltage under no load condition and is less than receiving end voltage.

Circuit Diagram: Figure 1

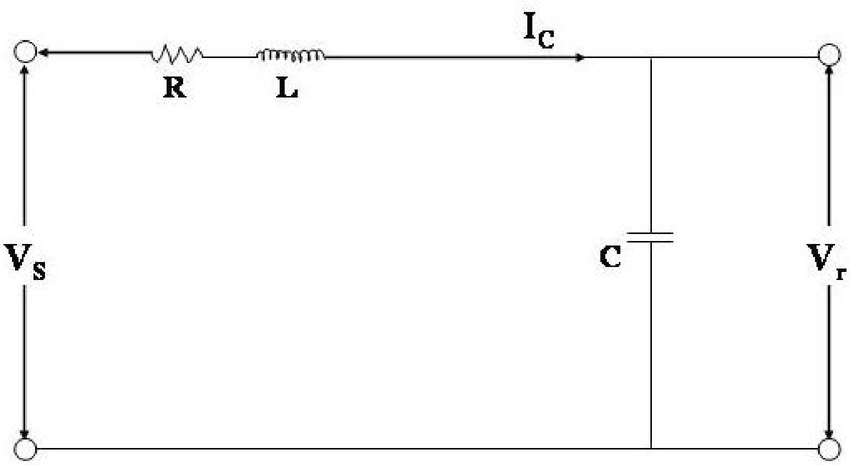
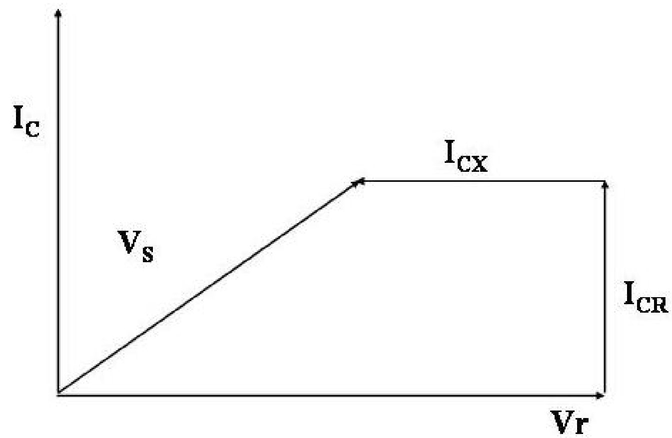


Figure 2



Procedure:

(i) Apply the voltage (200 V max.) to the sending end and connect power factor meter. Also connect 1 ammeter and voltmeter to each end (receiving and sending).

(ii) Connect the load comprising of R, L and C at the receiving end and note down the value of receiving end voltage.

(iii) Now remove the load from the receiving end and note down the voltage on receiving end. This voltage at the receiving end is quite large as compared to sending end voltage.

Observation Table:

LOAD	V_S (V)	I_S (A)	V_R (V)	I_R (A)
For Inductive	208			
For Capacitive	208			
For Resistive	208			
At No Load	208			

Result: We have performed ferranty effect and voltage distribution in H.V. long transmission line using transmission line model.

Experiment No. 5

Aim: To determine location of fault in a cable using cable fault locator.

Apparatus Used:

1. Rheostat 1.1 A, 800 Ohms – 2 Nos.

2. Galvanometer – 1 No.

3. Measuring Tape (5M) – 1 No.

4. 3 Core Cable (25M) – 1 No.

5. DC Power Source – 1 No.

6. Digital Multimeter

Theory: Most of the distribution and part transmission of electrical power is now-a-days carried out through underground cables because of several advantages over the over head system. Many a times locating a fault becomes a difficult task because cable is buried under the ground and is not accessible. The faults which are most likely to occur are :-

(a) Ground Fault :- A break down of the insulation of the cable which allows current to flow from core to earth or to cable sheath.

(b) Short Circuit :- A cross or short circuit between two cables or between two cores of a multicore cable.

Amongst various methods used for localizing cable faults. Murray Loop Test is very common and is described here.

This test is carried out for locating a ground or a short circuit fault, provided that a cable runs along with the grounded cable or with two cables (or with two cores of a multi-core cable) which are short circuited. The advantage of loop test is that the resistance of the fault does not affect the results obtained. Provided this resistance is not very high. Otherwise it may adversely affect the sensitivity.

Circuit Diagram:

Figure 1

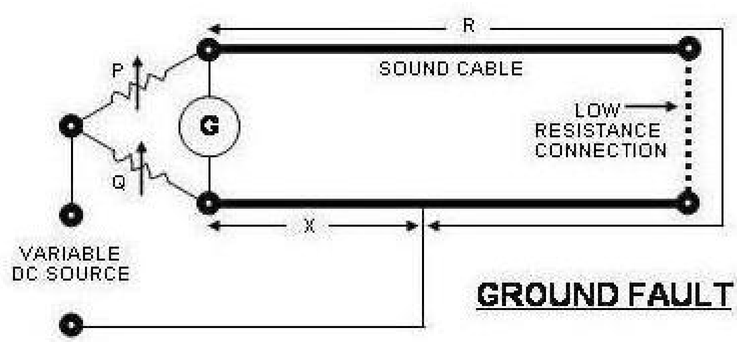


Figure 2

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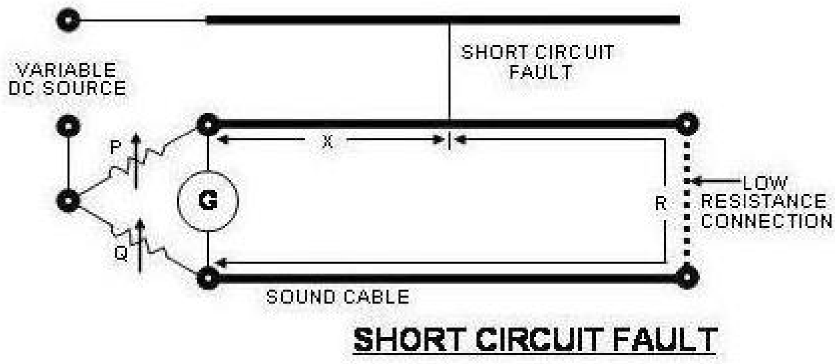


Then $$\frac{P}{Q} = \frac{R}{X}$$

Or $$\frac{P+Q}{Q} = \frac{R+X}{X}$$

Or $$\frac{Q}{P+Q} = \frac{X}{R+X} = \frac{x\ (r)}{21\ (r)}$$

$$x = 21 \left(\frac{Q}{P+Q} \right)$$

Procedure:

1. Take a multicore cable (say 3 core) of known length (say 25M). Measure the resistance of each core. Make connections as shown in Figure 1. Short circuit the two cores of the cable at the other end. Adjust P and Q such that balance is obtained. Note P, Q and calculate distance of fault x. Take three-four observations and take the mean of calculated value of length of the fault from each set of readings. This length should be equal to the distance of fault from the lower end of resistance Q.
2. Note down the actual distance of fault by measuring the actual distance of fault and calculate the % error.
3. Make connections as shown in Figure 2. Short circuit any two cores of cable to create short circuit fault. Adjust P and Q such that balance is obtained. Note P and Q in the observation table. Calculate x with. Take three-four observations and find average of x. calculate the distance of short circuit fault from the measuring end of the cable.

Circuit Diagram:

Localization of Earth Fault

S No.	P (Ohm)	Q (Ohm)	x = 2l [Q/(P+Q)]	Distance of fault from measuring end = $\overline{x}$ (m) (Average of x1, x2, x3…)	Actual location of fault	% Error
1.	699	172.7	9.91	9.82	10.00	1.8
2.	609	148.3	9.79			
3.	799	194	9.77			

Localization of Short Circuit Fault

S No.	P (Ohm)	Q (Ohm)	X = 2l [P/(P+Q)]	Distance of fault from measuring end = $\overline{x}$ (m) (Average of x1, x2, x3…)	Actual location of fault	% Error
1.	161	670	10.32	9.96	10.00	0.4
2.	185	761	9.78			
3.	165	678	9.77			

Result: We have performed the location of fault in a cable using cable fault locator.

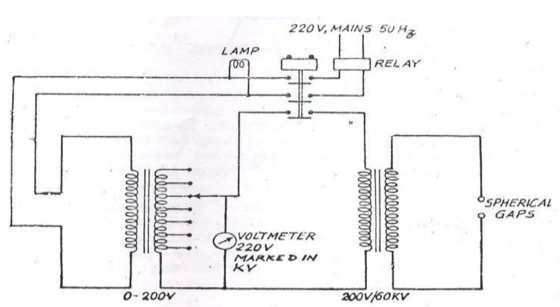
Experiment No. 6

Aim: To study operation of oil testing set.
Apparatus Used: Oil Testing Set

Theory: When a sample of oil is subjected to dielectric stress in a gap between two spheres the materials of higher conductivity and higher spheres capacity are drawn into the intense field between the spheres and causes a distortion of the field resulting in local high density and disruption begins at these points.
When testing transformer oil it is found often that one or more discharge occur across the gap at comparatively low voltages due to the presence of water particles but that the voltage can be raised to a very much higher value before complete rupture occurs.
If particles of higher dielectric constant than the oil are drawn into the intense field, they will cause excessive local stress which may result in dissociation or ionization of oil and the gases of ionization may bridge the gap and causes complete rupture.
In standard specifications for 'Insulating Oil' the method of applying the testing voltage (which must be alternating or approximately sine waveform of frequency between 25 and 100 Hz and with a peak factor of □ 2 +5% has been laid down. The test has to be carried out under standard conditions. The minimum dimensions of the test cell, diameter of the electrode and the distance between them are specified.

Procedure: When testing oils the set is operated according to a particular method (in compliance with the regulations) i.e. with a fixed spark gap and variable testing voltage. The voltage should be increased gradually under continues observation of the measuring until the breakdown occurs. To test oils of high quality the distance between electrodes should be adjusted to 2 mm. The equipment permit 310 KV/cm to be measured. For testing oils of medium quality or inferior quality the spark gap should be adjusted to 4 mm by means of a distance gauge. The insulating material oil testing cup is equipped normally with two calotte-shaped electrodes of 36 mm dia, radius of each sphere is 25 mm. The oil testing cup is kept as small as possible to do with minimum quantity of oil. Suitable safety contacts are provided to put the set out of operation as soon as the top lid is opened in order to insert or remove the test cup, thus eliminating HT danger. The set is disconnected automatically as soon as the puncture occurs. No oil tests are possible as long as the lid of the rear of the cabinet is open.

Circuit Diagram:



Result: Distance between electrodes = ____
Breakdown voltage = _____

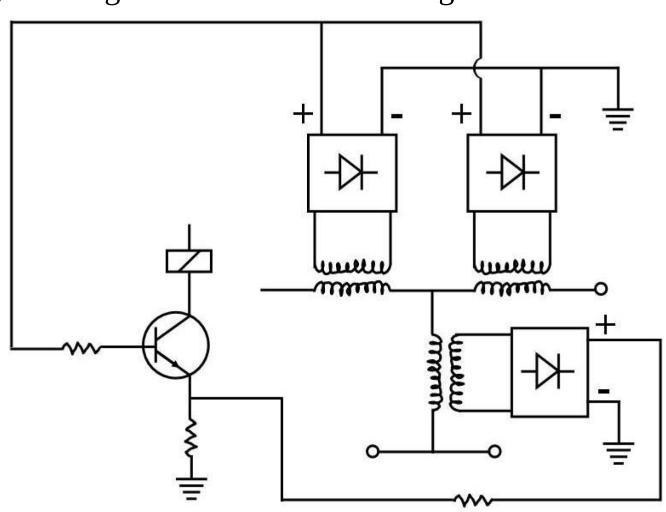
Experiment No. 7

Aim: To study percentage differential relay.

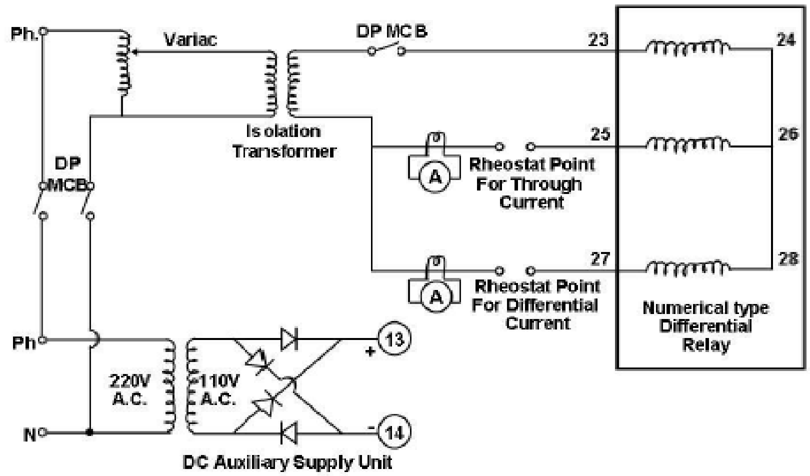
Apparatus Used:

1. Relay Single Pole Version 1 A (Numerical Type) ‘AREVA’ make MBCH-12
2. Timer
3. Auto Transformer 0-270V, 10 A
4. Ammeter (10 A, AC) - 2 Nos.
5. Neon lamp 1A, AC, 230 V
6. Rheostat 5 A, 45 Ohms - 1 Nos.
7. Rheostat 10 A, 20 Ohms - 1 Nos.
8. Isolation Transformer
9. Auxiliary DC Supply Unit with Transformer

Theory: It is a very important protection of the transformer. It is based on the ratio of H.T. current and L.T. current should be constant. Consider the Fig No ‘1’, here we considering the single pole of 132/33 KV Transformer. It’s H.T. current and L.T. current ratio will be 1:4. If the CT of H.T. side is considered 100/1 Amp, so the CT of L.T. side will be 400/1 Amp. The secondary current of L.T. side CT and H.T. side CT will always equal in normal condition. Both the secondary of CTs will enter in Numerical type % Differential Relay. The secondary of CT connection is make in such a way that the CT current will flow only through coil circuit and no extra current is to flow from Differential coil. As soon as the fault occurs in transformer, the H.T. current will high. The ratio of H.T. current and L.T. current will change. The secondary of H.T. side CT current will become high with respect to secondary of L.T. side CT current. So the difference of current will flow through differential winding. The secondary of differential winding transformer will go to an electronic circuit that will operate a tripping relay to trip the breaker of main transformer. The through windings are used to restraining the differential relay. It will more clearly by drawing the curve between through current and differential current.



Circuit Diagram:



Observation Table:

S No.	Restraining Current (A) (Through Current)	Operating Current (Differential Current)
1	0.50 Amp	
2	0.60 Amp	
3	0.70 Amp	
4	0.80 Amp	
5	0.90 Amp	
6	1.00 Amp	
7	1.10 Amp	
8	1.20 Amp	
9	1.30 Amp	
10	1.40 Amp	
11	1.50 Amp	

Result: we have perform the test on percentage differential relay.

Experiment No. 8

Aim: To obtain formation of Y-bus and perform load flow analysis

```
%    From  To   R    X
z = [ 0    1    0   1.0
      0    2    0   0.8
      1    2    0   0.4
      1    3    0   0.2
      2    3    0   0.2
      3    4    0   0.08];
 Y = ybus(z)                     % bus admittance matrix
Ibus = [-j*1.1; -j*1.25; 0; 0]; % vector of injected bus currents
Zbus = inv(Y)                    % bus impedance matrix
Vbus = Zbus*Ibus
```

Experiment No. 9

Aim: To perform symmetrical fault analysis in a power system

```
write a matlab program for the fault analysis
z12 = j*.8; z13 = j*.4; z23 = j*.4;
Ybus = j*[-8.75    1.25   2.5
          1.25   -6.25   2.5
          2.5     2.50  -5.0];
Zbus = inv(Ybus)
Zf = j*.16;
V0=[1; 1; 1];
I3F = V0(1)/(Zbus(3,3)+Zf)
VF = V0-I3F*Zbus(:,3)
I12 = (VF(1) - VF(2))/z12
I13 = (VF(1) - VF(3))/z13
I23 = (VF(2) - VF(3))/z23
```

Experiment No. 10

Aim: To perform unsymmetrical fault analysis in a power system

```
Z133 = j*0.093; Z033 = j*0.18; Z233 = j*0.0997; Zf = j*0;
disp('(a) Balanced three-phase fault at bus 2')
Ia2F = 1.0/(Z133+Zf)
disp('(b) Single line-to-ground fault at bus 2')
I03 = 1.0/(Z033 + 3*Zf + Z133 + Z233);
I012=[I03; I03; I03]
%sctm;
Iabc3 = sctm*I012
Va0=-I03*Z033
Va1=1-Z133*I03
Va2=-I03*Z233
Va=Va0+Va1+Va2
Vb=Va0+(-0.5-0.866*j)*Va1+(-0.5+0.866*j)*Va2
Vc=Va0+(-0.5+0.866*j)*Va1+(-0.5-0.866*j)*Va2
```