INDEX NO. : M-53

RAJAT

TECHNICAL MANUAL FOR

STEADY STATE REACTANCE

Manufactured by :

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STEADY STATE REACTANCES (X_d, X_q)/SLIP TEST

AIM : (a) To measure direct-axis synchronous reactance of synchronous machine.

(b) To measure quadrature-axis synchronous reactance by slip test.

INSTRUMENTS REQUIRED :

S No.	Items	Qty
1.	DIGITAL CLAMP ON METER	1
2.	M.I. VOLTMETER PORT 300/600V	1
3.	DIGITAL MULTIMETER	1
4.	RHEOSTAT 5 AMP 45 OHMS	1
5.	STATIC EXCITATION CONTROLLING ARRANGEMENT	1
7.	M.C. AMMETER PORTABLE 1/2 A,	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.

(i) **Direct-axis synchronous reactance, X_d**

The Direct-axis synchronous reactance of synchronous machine in per unit is equal to the ratio of field current, I_{fsc} at rated armature current from the short circuit test, to the field current, I_{fo} at rated voltage on the air gap line (Fig 'A') i.e.

$$\text{Direct-axis synchronous reactance, } Xd = \frac{I_{fsc}}{I_{fo}} \text{ per unit}$$

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

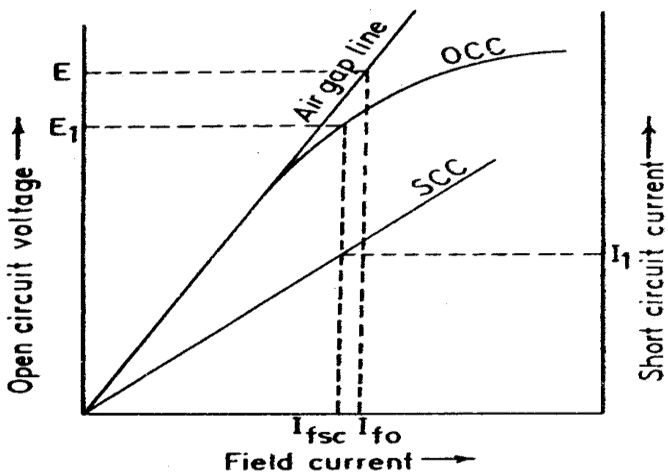


Fig 'A' – Open circuit and Short circuit characteristics of Alternator.

(ii) **Quadrature axis synchronous reactance, X_q 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 will be as shown in Fig 'B'. 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 as shown clearly in Fig 'B'. Thus approximate value of Direct-axis synchronous reactance, X_{ds} is given by,

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

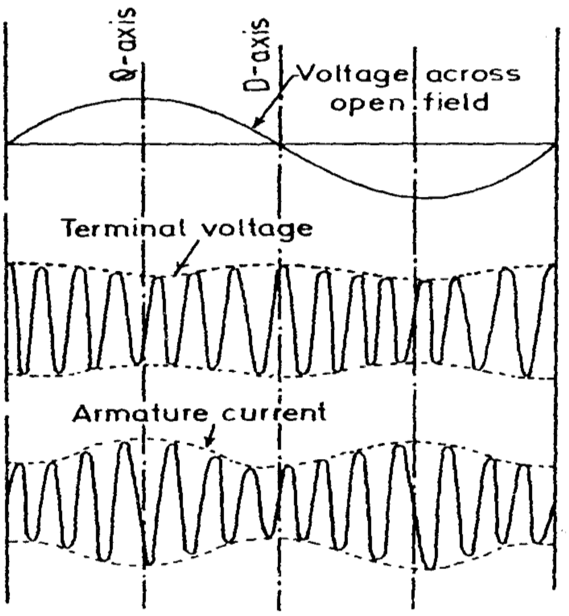


Fig 'B' – Variation of armature current, voltage and field voltage during slip test.

When the crest of stator mmf wave coincides with the quadrature-axis of the rotating field, the induced emf in the open circuit field is maximum, the voltage across the stator terminals will be minimum and the current drawn by the stator winding is maximum as shown in Fig 'B'. Hence, approximate value of Quadrature axis synchronous reactance, X_{qs} is given by,

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

For best result, these values are not taken as final values. The most accurate method for determining the Direct-axis synchronous reactance X_d is the one, that has already been described in (i) above. The most accurate value of Quadrature axis synchronous reactance X_q can now be found out using the above information i.e. X_{ds}, X_{qs} and X_d.

Quadrature axis synchronous reactance, $X_q = \dfrac{X_{qs}}{X_{ds}} X_d$

$$= \left(\frac{E_{max}}{I_{min}}\right) \left(\frac{E_{max}}{I_{min}}\right) X_d \text{ per unit}$$

Hence the accurate value of Xq can be found out by recording minimum and maximum values the above quantities. Accurate result can be obtained, if the osillograms are taken during experimentation for stator current, stator voltage and injected voltage across the field.

It may be noted clearly that for synchronous machine X_d is greater than X_q i.e. $X_d > X_q$.

Important caution for conducting slip test

1. Slip should be extremely low during experimentation. In case of high slip (more than about 5%), following effects may be observed.

    (a) Currents induced in the damper winding of alternator will produce an appreciable error.

    (b) Induced voltage in the open circuit field may reach dangerous values.

2. It should be assured that the induced voltage in the field circuit is less than the rating of the voltmeter connected in this circuit.

CIRCUIT DIAGRAM :

Fig ‘C’ and Fig ‘D’ show the circuit diagrams to perform the open circuit, short circuit and slip test respectively on synchronous machines, which are self explanatory.

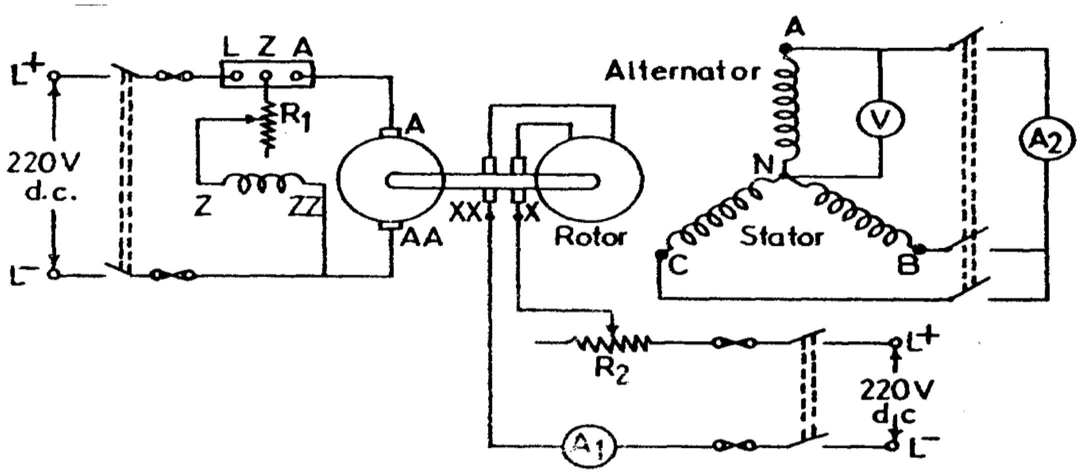


Fig ‘C’ – Open circuit and Short circuit tests on Alternator.

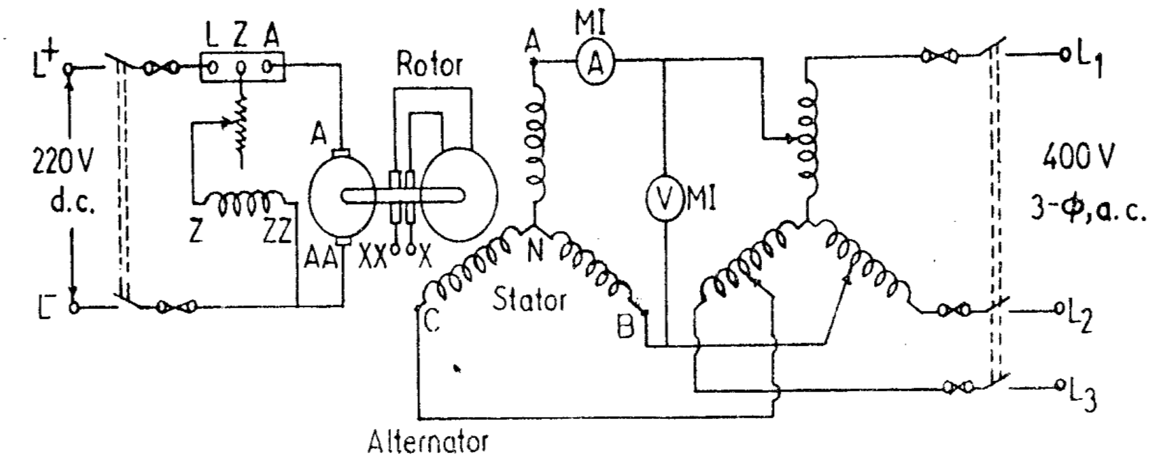


Fig 'D' – Circuit diagram for slip tests on Alternator.

PROCEDURE :

(a) Open Circuit Test

1. Connect the circuit as per fig 'C'.

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.

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.

OBSERVATIONS : May be tabulated as follows.

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}

CALCULATION OF Z_{BASE}

Rating of AC Generator
KVA = 2 Volts = 415V
Amp = 2.8 Star-Conection

$$\text{P.U. (Per Unit)} = \frac{\text{Actual}}{\text{Base}}$$

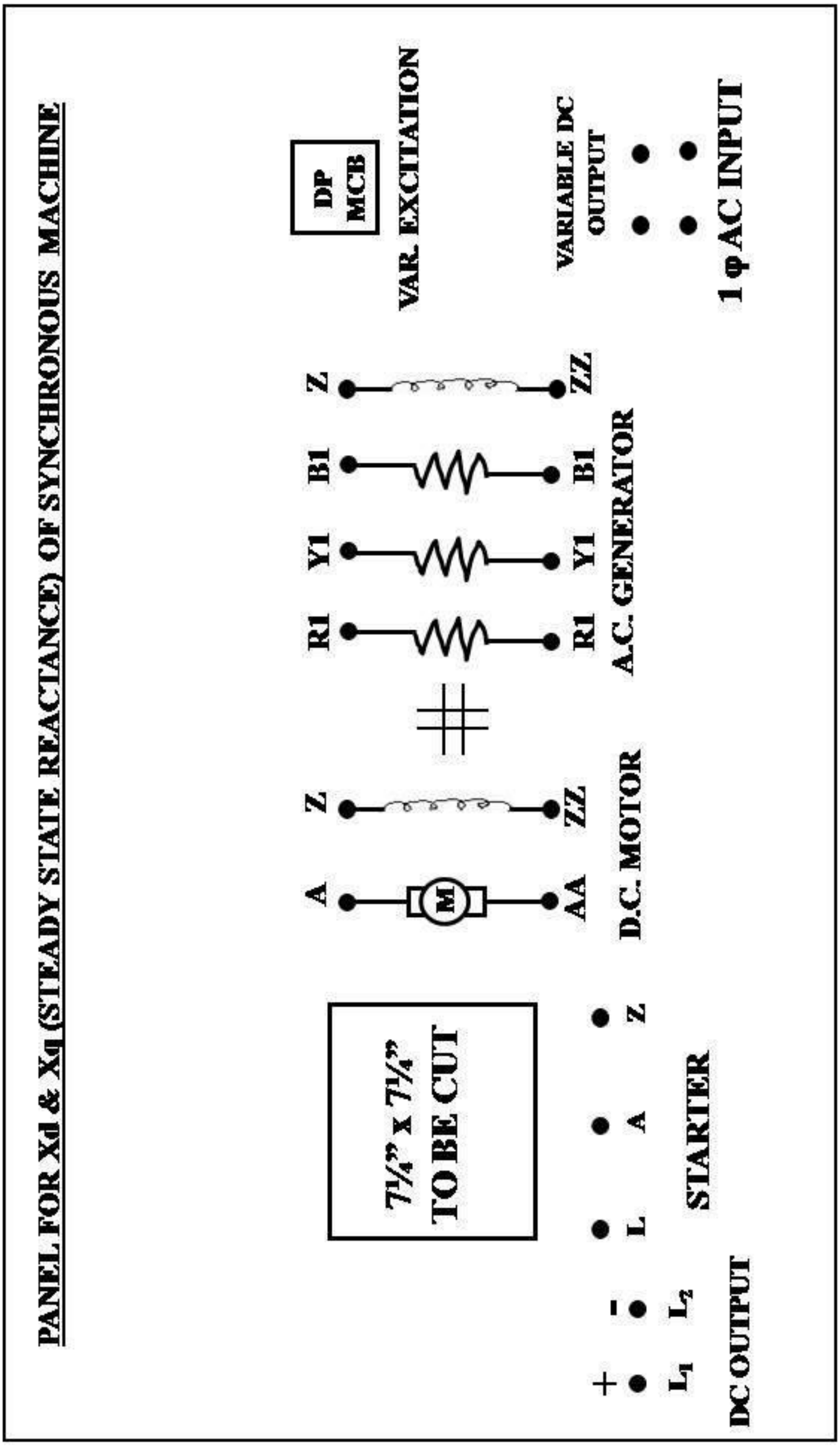
$$I_{Base} = \frac{KVA_{Base}}{KV_{Base}} = \frac{2}{0.14}$$

$$= 4.819$$

$$\text{Impedance } (Z_{Base}) = \frac{(\text{Base KV})^2}{\text{Base KVA}} \times 1000$$

$$(Z_{Base}) = \frac{(0.145)^2}{2} \times 1000$$

$$Z_{Base} = 86.11$$


PANEL FOR Xd & Xq (STEADY STATE REACTANCE) OF SYNCHRONOUS MACHINE
VAR. EXCITATION
DP
MCB
VARIABLE DC
OUTPUT
1 φ AC INPUT
Z
ZZ
B1
B1
Y1
Y1
R1
R1
A.C. GENERATOR
Z
ZZ
A
M
AA
D.C. MOTOR
7¼" x 7¼"
TO BE CUT
Z
A
L
STARTER
+
-
L1
L2
DC OUTPUT