# Sem II, 2024-25

# ELP203 Lab Manual

# Cycle I

**List of Experiments:**

1. Steady- state performance of a 1-phase transformer
2. Parallel Operation of single-phase transformers
3. Steady-state performance of 3-phase transformer
4. Study of the steady state performance of a separately excited DC generator
5. Steady- state performance of a DC motor

# CYCLE-1: Experiment 1

## Steady- state performance of a 1-phase transformer.

**Objectives:**

a) Obtain equivalent circuit parameters by conducting open-circuit, short-circuit and resistance measurement tests.
b) Obtain voltage regulation and efficiency at different resistive loads.

**Motivation**

Insulation considerations limit the voltage of generation to a few kilovolts ($\approx$10kV). But in order to reduce the transmission losses, the electric power is transmitted over long distances at highest possible voltage (220kV, 400kV, ...). Again due to considerations of safety, the power has to be distributed to the consumers at much lower voltages. Thus, the considerations of economy and safety dictate that in large power system, generation, transmission and distribution should be done at different voltages. In fact, the electric power is transformed several times from one voltage to another, with the help of power transformers, before it is made available to the consumer's terminals.

To find the performance of large power transformers by direct load test, a huge amount of energy has to be wasted. Also, it is difficult to obtain a suitable load large enough for direct loading. Thus for large power transformers, the performance characteristics (efficiency, regulation etc.) are computed from the knowledge of losses and equivalent circuit parameters, which in turn are determined by conducting simple tests like open-circuit and short-circuit tests.

**Theory**

It is well known that the equivalent circuit of a single phase transformer can be approximately represented as shown in Fig.1.1. The parameters $R_0$ and $X_0$, which take into account the two components of no load current, can be determined by conducting O.C. test. The parameter $R_1$ and $X_1$ are determined by S.C. test. These parameters depend to a certain extent on the actual load conditions of the transformer. Besides, the measurement of temperature-rise attained by a transformer under actual load conditions is also important. However, OC test is conducted under rated voltage which actually makes the transformer operate under rated flux. Similarly, SC test is conducted under rated current and hence it is made to operate with rated copper losses. So, these are like phantom loading tests. Thus, using these tests, with minimum wastage of power, the losses, the equivalent circuit parameters, efficiency, regulation, expected temperature-rise etc. can easily be determined for actual load conditions.

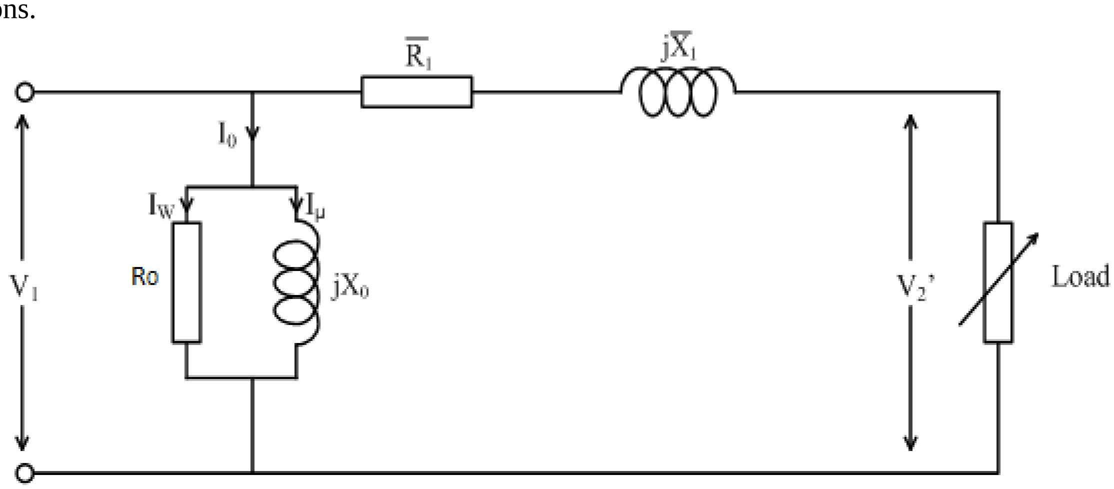



Fig.1.1 Approximate equivalent circuit

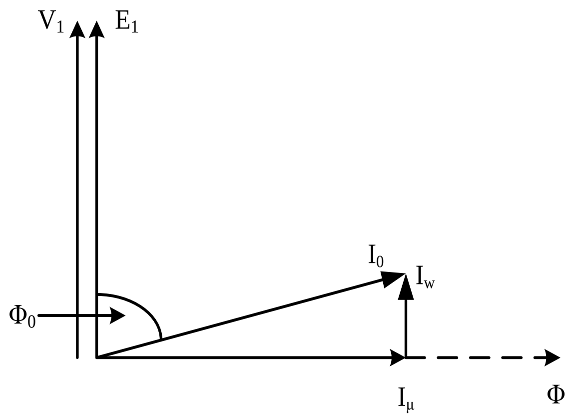



Fig.1.2 No load phasor diagram

**Equipment and Components Required:**

(a) One 1-ϕ transformer (under test).
(b) One 1-ϕ auto-transformers.
(c) One low PF and one UPF Wattmeters.
(d) Two AC ammeters.
(e) Two AC voltmeters or Multimeter.

**Procedure, Connection Diagrams, Experimentation and Precautions**

Note down the name plate details of the transformer and identify terminals. Observe the windings and constructional features.

***O.C. Test***

The open circuit test is usually done on the LV side, keeping the HV side open. Make connections as shown in Fig. 1.3. Apply rated voltage $V_0$ and note the corresponding power input ($W_0$) and current drawn ($I_0$). Repeat the above for different input voltages (below $V_{rated}$) and tabulate the readings as shown in Table.1.1.

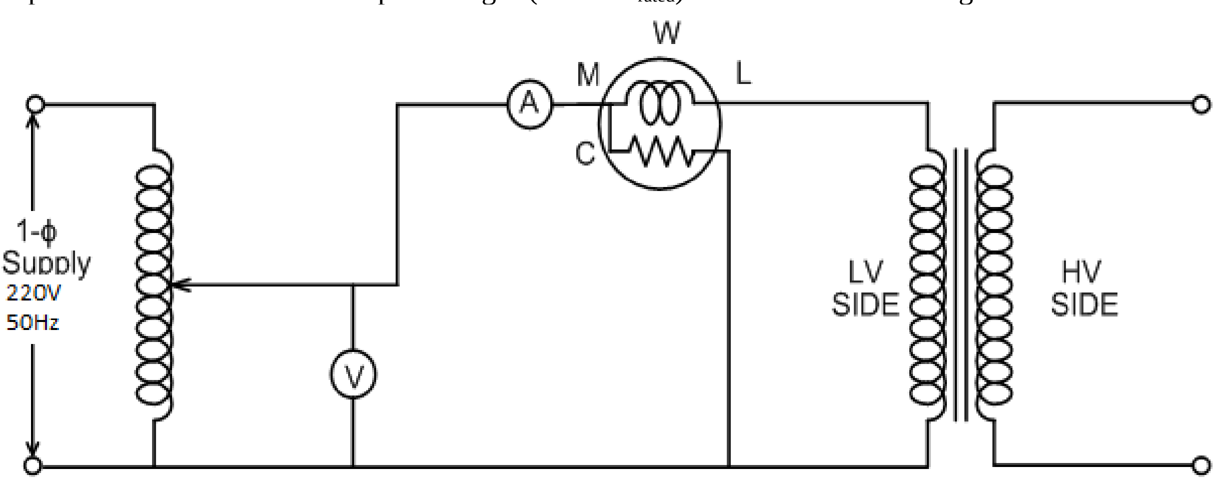



Fig.1.3 Connection diagram for O.C. test

Table. 1.1 O.C. test readings

| Voltage applied<br>$V_0$ (volts) | Current drawn<br>$I_0$ (amps) | Power input<br>$W_0$ (watts) |
|---|---|---|
| | | |

***S.C.Test***

The short circuit test is conducted by applying the supply on the HV side, keeping the LV side short circuited. Make connections as shown in Fig.1.4. Apply the required voltage ($V_{SC}$) so that the current drawn ($I_{SC}$) is equal to the rated current. Note the corresponding power input ($W_{SC}$). Repeat the above for different values of short circuit currents (below the rated current) and tabulate the readings as in Table.1.2.

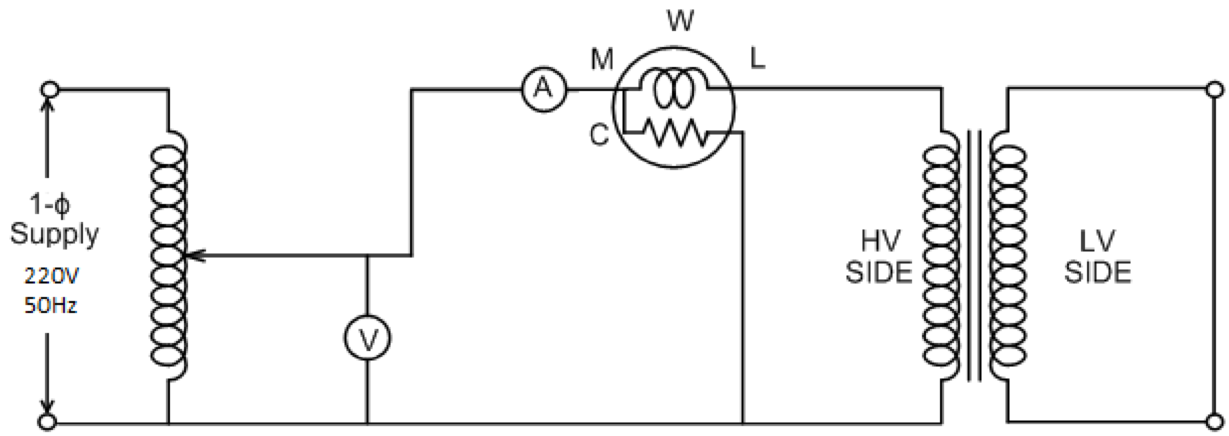



Fig.1.4 Connection diagram for S.C. test

Table. 1.2 S.C. test readings

| Voltage applied<br>$V_{SC}$ (volts) | Current drawn<br>$I_{SC}$ (amps) | Power input<br>$W_{SC}$ (watts) |
|---|---|---|
| | | |

**Data Sheet**

1-ϕ transformer: kVA rating: Primary voltage: Secondary voltage: Frequency: 50Hz

## Data Processing and Analysis

***Losses***

Iron loss (for rated voltage) = …………Watts

Full load copper loss = …………Watts

Plot the following graphs:

(a) $I_0$ vs. $V_0$ (b) $W_0$ vs. $V_0$ (c) $I_{SC}$ vs. $V_{SC}$ (d) $W_{SC}$ vs. $V_{SC}$

Comment on the shapes of the above graphs.

*Equivalent Circuit Parameters*

The four parameters of the equivalent circuit are $R_0$, $X_0$, $R_1$ and $X_1$ (see Fig.1.1).$R_0$ and $X_0$ are obtained from O.C. test and $R_1$ and $X_1$ are obtained from the S.C. test as follows:

From O.C. test,

No load PF ($\cos\phi_0$) = ($W_0/V_0I_0$) = ……….

$\therefore$ $\sin\phi_0$ = ……….

$I_W = I_0\cos\phi_0$ = ……….A

$I\mu = I_0 \sin\phi_0$ = ……….A

$R_0 = V_0/I_W$ = ……..Ω

$X_0 = V_0/I\mu$ = ……..Ω

From S.C. test,

Total impedance referred to HV side (sec. side),

$\overline{Z}_2 = V_{SC}/I_{SC}$ = ……..Ω

Total resistance referred to HV side

$\overline{R}_2 = W_{SC}/I_{SC}^2$ = ……..Ω

$\therefore \overline{X}2 = \sqrt{\overline{Z}_2^{\,2} - \overline{R}_2^{\,2}}$ = ……..Ω

$\therefore$ Total resistance referred to LV side (primary),

$\overline{R}_1 = \overline{R}_2(N_1/N_2)^2$ = ……..Ω

Similarly $\overline{X}_1 = \overline{X}_2(N_1/N_2)^2$ = ……..Ω

***Efficiency at any load ('x' times full load) at a given PF***

Let the given value of PF be $\cos\phi$

Output at 'x' times full load = x (rated kVA.1000)$\cdot\cos\phi$ = ……..W

Iron loss ($W_i$) = constant $= W_0$ = ……..W.

Copper loss at 'x' times full load, $W_{CU} = x^2$ (full load copper loss)

$= x^2 \cdot W_{SC}$ = ……..W

Therefore percentage efficiency = $\dfrac{Output}{Output + Losses} = \dfrac{\mathbf{Output}}{\mathbf{Output} + \mathbf{W_i} + \mathbf{W_{CU}}}$

***Regulation at full load at a given PF***

The percentage regulation can be approximately put down for the general case as.

Percentage regulation = $r\cdot\cos\phi \pm x\cdot\sin\phi$

(the + sign is for lagging PF and – sign for leading PF)

where r = Percentage resistance = $(I_1R_1/E_1).100 = (I_2R_2/E_2).100$

and x = Percentage reactance = $(I_1X_1/E_1).100 = (I_2X_2/E_2).100$

**Suggestions For Further Study**

(a) Compute the all-day efficiency of the given transformer for different daily load schedules.

(b) Measure self and mutual inductance in the transformer by suddenly applying a low dc voltage to the windings and recording the current build up using a storage oscilloscope. Mutual inductance could be measured by monitoring the secondary voltage rise with respect to primary current. Using these inductances derive the standard equivalent circuit. Highlight the differences.

## Sample Curves

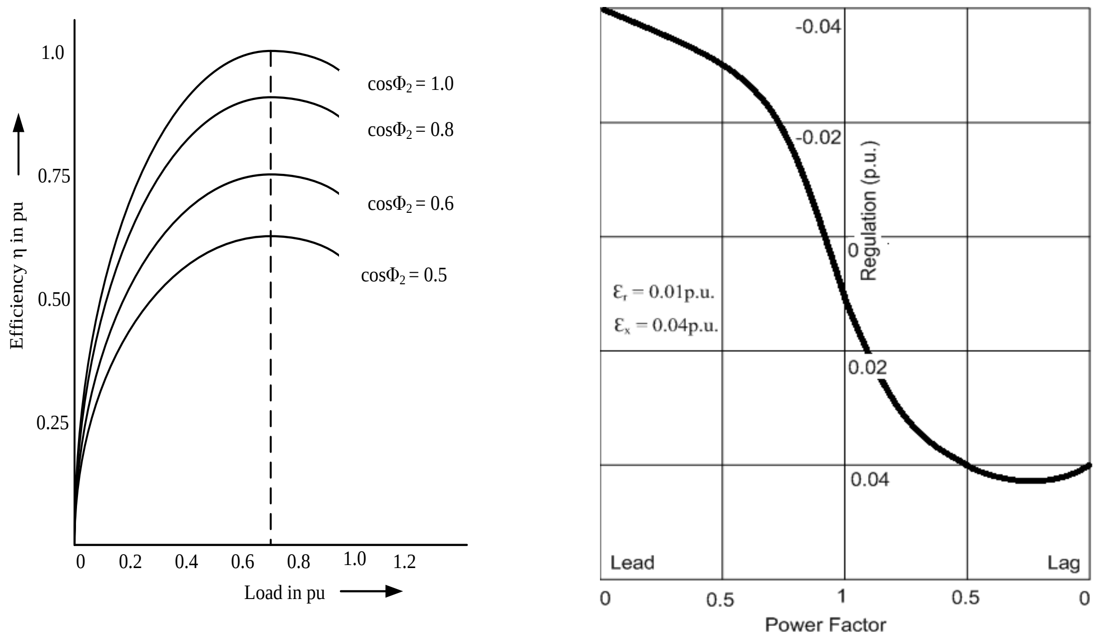



Fig.1.5.(a) Efficiency Curve, (b) Regulation Curve

## Post-Experimental Quiz

(a) For a power transformer, O.C. test is usually performed on the LV side, keeping the HV side open and S.C. test is carried out on HV side, keeping the LV side shorted. Explain why.
(b) How will you justify taking Wattmeter reading on OC, as only iron losses?
(c) How will you justify taking the Wattmeter reading on SC, as only copper losses?
(d) Can the regulation of a transformer be negative? If so, when?
(e) What are the factors affecting regulation in a transformer?
(f) Compute the efficiency of the given transformer for 0.8 PF with
(i) full load, (ii) ¾ full load, (iii) ½ full load, (iv) ¼ full load
Plot the graph of percentage efficiency vs. output.
(g) For a load of 0.8PF, predetermine the maximum efficiency of the given transformer and also the load at which it occurs.
(h) At what PF the regulation will be minimum for rated kVA condition?
(i) Compute the percentage regulation at full load for different power factors (both lagging and leading) and plot the graph of percentage regulation (at full load) vs. PF.
(j) Predetermine the maximum full load regulation of the given transformer.

## References

(a) A.S. Langsdorf, Theory of *Alternating-Current Machinery*, McGraw-Hill, II ed., (1955).
(b) M.G. Say, *Performance of AC Machines*, ELBS (1961).
(c) P.C.Sen, Principles of Electrical machines and Power Electronics, John Wiley. 2nd edition.
(d) A.E. Fitzgerald and C. Kingsley, *Electric Machinery*, McGraw-Hill, Second ed., (1961).

## Cycle 1: Experiment No. 2

Parallel Operation of single-phase transformers

**Objective:**

The aim of this experiment is to operate two single phase transformers in parallel and estimate the way in which they would share the load between them and verify the same experimentally.

**Motivation:**

When a power system is expanding, we may be using a transformer of a particular capacity. As the demand increases, it is essential to increase the capacity of the transformer as well. This could be done by completely replacing the old transformer with anew one of larger capacity or adding one more transformer in parallel. The advantages of using multiple transformers in parallel are: (i) even if one of them fails, at least, partial loads can be energized. (ii) the additional transformers we store in the inventory (as a back-up) could be of lower capacity.

To operate two transformers in parallel, they should have same voltage ratings on the primary and secondary sides, they should have same phase sequence and same connections: Y-Y or Y-Δ (in three-phase case), their impedances should be comparable . Before connecting them in parallel, we have to make sure that the polarities of the secondary winding are tested and then they are connected in parallel properly.

**Theory:**

Two transformers can be connected in parallel to supply a common load. If a given transformer is insufficient in capacity to deliver a particular load, it may either be taken out of the circuit and replaced with a larger unit or an additional unit may be added to the circuit by connecting its primary side to the same source and its secondary side to the same load. The second unit is then said to be operating in parallel with the first unit.

Parallel operation of transformers is used for load sharing; these transformers are connected in parallel on both primary and secondary side. The two transformers connected in parallel meet the need of common load.

Satisfactory performance for parallel operation of two or more transformers require that they have :

1. the same voltage ratio;
2. the same polarities;
3. the same per unit (or percentage) impedances;
4. the same phase sequence (in 3-phase case) and zero relative phase – displacement.

The currents carried by two transformers are proportional to their ratings if their numerical or ohmic impedances are inversely proportional to those ratings OR their per unit impedances are equal. A difference in quality of per unit impedance (i.e., ratio of resistance to reactance) results in divergence of phase angle of the two currents. So, one transformer will be working with a higher and other with a lower power factor than that of the combined output.

With OC secondary voltages of both transformers being the same, $\mathbf{I_1 Z_1 = I_2 Z_2}$

$$\mathbf{I = I_1 + I_2}$$

$$\mathbf{I_1} = \frac{Z1}{Z1+Z2}\,\mathbf{I} \quad \textbf{and} \quad \mathbf{I_1} = \frac{Z2}{Z1+Z2}\,\mathbf{I}$$

$$\mathbf{Cos\ \text{Ø}_1} = \frac{W1}{V1I1} \quad \textbf{and} \quad \mathbf{Cos\text{Ø}_2} = \frac{W2}{V2I2} \qquad \mathbf{V1=V2=V=Load\ Voltage}$$

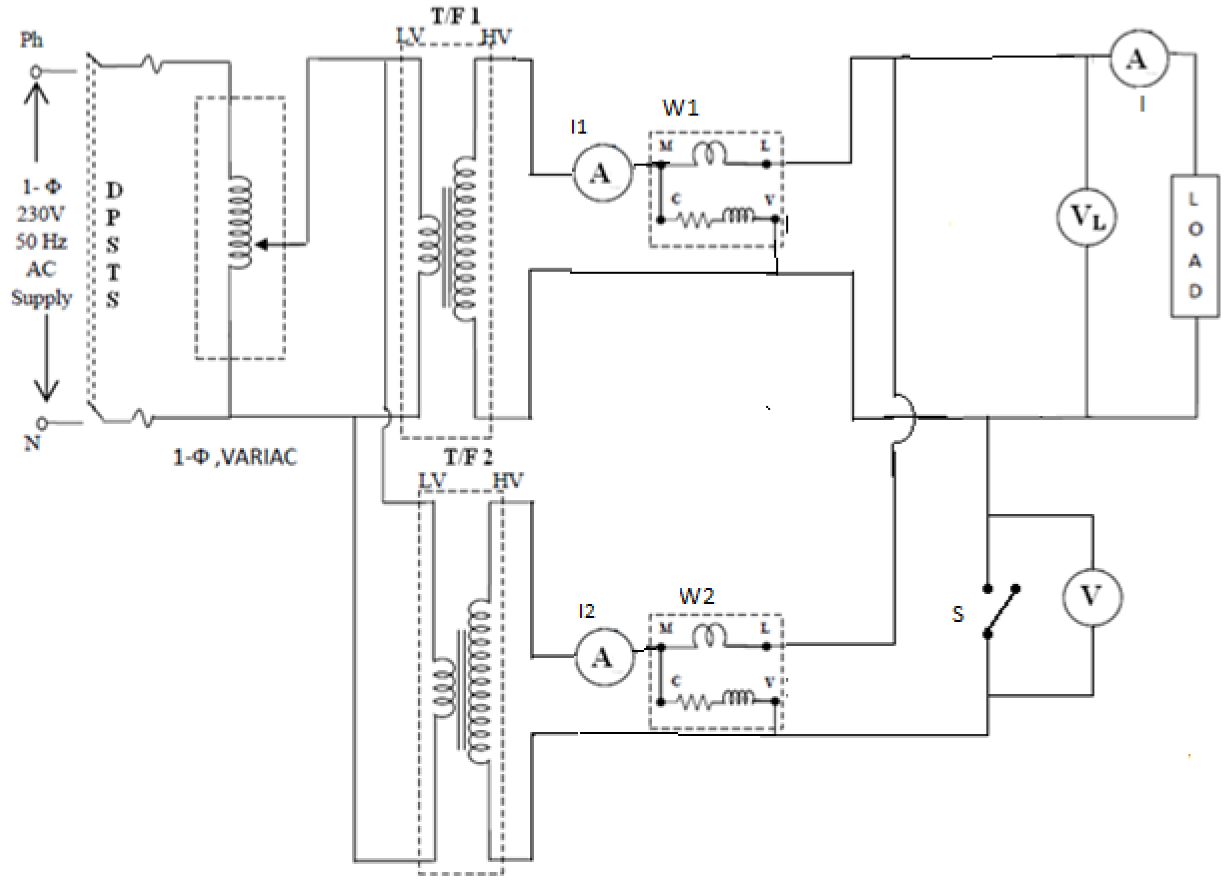



Fig.2.1 Parallel Operation of Two Single-Phase Transformers

**Procedure:**

1. Connections are made as shown in Figure 2.1.
2. In fact, before connecting the secondaries in parallel, polarity has to be checked; for this, connect the primaries to the same single phase supply; connect the two secondary windings in series (Let S1,S2 be the secondary terminals of Tr1 and S11,S21 be the secondary terminals of Tr2. Connect S2 to S11). Measure the voltage across S1 and S21, after exciting the primaries with rated voltage. If the voltage is double the expected voltage of the secondary, then S1 and S11 are of the same polarity and S2 and S21 are of the same polarity. If the voltage is zero, then S1 and S21 are of the same polarity and S2 and S11 are of the same polarity. For connecting two secondaries in parallel, terminals of the same polarities should be tired together.
3. The single phase variac should be in minimum output position. Switch on the 1- Φ supply.
4. Slowly increase the variac to get the rated voltage. The voltmeter across the switch should read zero, then close the switch S.
5. If the voltmeter does not read zero interchange the terminals of secondary of any one transformer and repeat the step-3.
6. Load the transformers in steps, note down the values of current, Voltage, Power from the primary sides of the two transformers. Also, note down $V_{L,}$ and I from the meters connected to load. The load is applied until full rated current is carried by the variac.
7. Note all the values in the observation table.

8. Reduce the load on transformer, bring back to variac in minimum output position and switch off the 1- Φ supply.
9. Connections are made for the SC test for each of the transformers separately.
10. Conduct short-circuit test (by increasing the current to rated value with the help of variac) on each of the single-phase transformers separately to determine their $R_{eq}$,, $X_{eq}$and $Z_{eq}$ (series parameters of the equivalent circuit) values.

**OBSERVATIONS:**

**1. Measured voltage, current and power**

Applied Voltage =                                Frequency =

| S.No. | Transformer 1 | | Transformer 2 | | Output | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $I_1$ | $W_1$ | $I_2$ | $W_2$ | $V_L$ | $I_L$ | $W_L$ | $I_1 + I_2$ | $W_1 + W_2$ |
| | | | | | | | | | |
| | | | | | | | | | |

**2. Short Circuit Test of two transformers to determine their equivalent impedances**

| S.No. | $V_{SC1}$(V) | $I_{SC1}$ (A) | $W_{SC1}$=WxM.F(W) | $V_{SC2}$(V) | $I_{SC2}$ (A) | $W_{SC2}$=WxM.F (W) |
|---|---|---|---|---|---|---|
| | | | | | | |

**3. Measured and estimated KVA loads and power factors of transformers**
**Applied voltage = Z1= Z2 =**

| S. No. | KVA output | Transformer 1 | | | | Transformer 2 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | KVA load | | Power factor | | KVA load | | Power factor | |
| | S = $V_L I_L$ | Measured | Estimated | Measured | Estimated | Measured | Estimated | Measured | Estimated |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |
| | | | | | | | | | |

**CALCULATIONs:**

Calculation of $R_{eq}$,$X_{eq}$ and $Z_{eq}$for both transformers as it was done in the previous experiment
Calculation of power factor for both transformers under different load conditions .
Verifying if theoretically calculated values are matching with the experimental values.

**RESULTs:**
Compare load distribution of both transformers (current ,active power and reactive power ) with respect to series parameters of transformers
Compare power factors of both transformers

## POST-EXPERIMENTAL QUIZ QUESTIONS

1) What is the significance of the polarity of the transformer windings?
2) What is the effect of difference in voltage ratings of the secondaries?
3) What are the essential and desirable conditions for parallel operation of transformers?
4) If the two secondary open circuit voltages are slightly different, then what would be the effect?

## References


(a) Chapman "Electric Machinery Fundamentals" PHI.

(b) M.G.Say "*Alternating Current Machines*", Fourth Edition, Pitman (1983).

(c) Fitzgerald and Kingsley "Electric Machinery" McGraw Hill.

# CYCLE-1: Experiment 3

## Steady-state performance of 3-phase transformer

(a) To verify the voltage and current transformation ratios of different 3-phase transformers (Star-Star; Star-Delta; Delta-Star; Delta-Delta).
(b) Voltage relationship verified on Open circuit and current relationship verified on certain load.

**Motivation**

The importance of three-phase system in generation, transmission and distribution of power is well known. To transform the three-phase electric power from one voltage to another, three-phase transformers are required both at generating and distribution ends of a power system. It is therefore essential to learn about the performance of three-phase transformers connected in different possible manners.

In order to keep down the third harmonic voltages in Y-Y bank of transformers, tertiary winding connected in Δ is provided. This provides a path for zero sequence current during ground fault condition. Such a winding may also help to stabilize the neutral of the fundamental frequency voltages and prevent third harmonic currents in the lines and ground. Hence, it is interesting to study such multi-winding transformers. In some cases tertiary windings are designed for voltages which may be useful to supply local circuits in a power station.

**Theory**

***Delta-Delta Connection***

The ratio of primary to secondary line voltages remain equal to the ratio of transformation ‘a’. The main advantage of this connection lies in the fact that the system can still operate on 58% of its rated capacity. Even in case of failure of one of the transformers. The remaining two transformers work in open Δ or V. This connection is favored for voltages below 50kV.

***Delta-Star Connection***

This gives a higher secondary voltage for transmission purposes than the connections with Δ secondaries without increasing the strain on the insulation on the transformers. It is the connection commonly used at the generating end of transmission lines. The Y neutral is generally grounded.

***Star-Star Connection***

This permits grounding the neutral points of both primary and secondary three-phase circuits. When the primary neutral is not connected to the source neutral, it is necessary to use Δ connected tertiary windings in order to avoid imbalance in the system.

***Star-Delta Connection***

This connection is commonly used at the receiving end of high voltage transmission lines.

***Star-Delta-Star Connection***

(Y-Y connected transformers with Δ connected tertiary windings).

The tertiary delta is an additional auxiliary winding used under certain conditions with three-phase transformers or transformer groups, and is separate and distinct from both primary and secondary main windings, though wound upon the same core, or cores. The auxiliary connection consists of a single winding per phase, the three being connected to form an ordinary closed delta circuit which may be isolated entirely from external circuit, or from which a load may be taken. If the primary neutral of a Y-Y connected group of transformers is isolated, but the transformers are provided with tertiary windings connected in delta, the tertiary winding can carry zero sequence currents under unbalanced loading necessary to balance the ampere-turns due to corresponding component currents in the secondary windings.

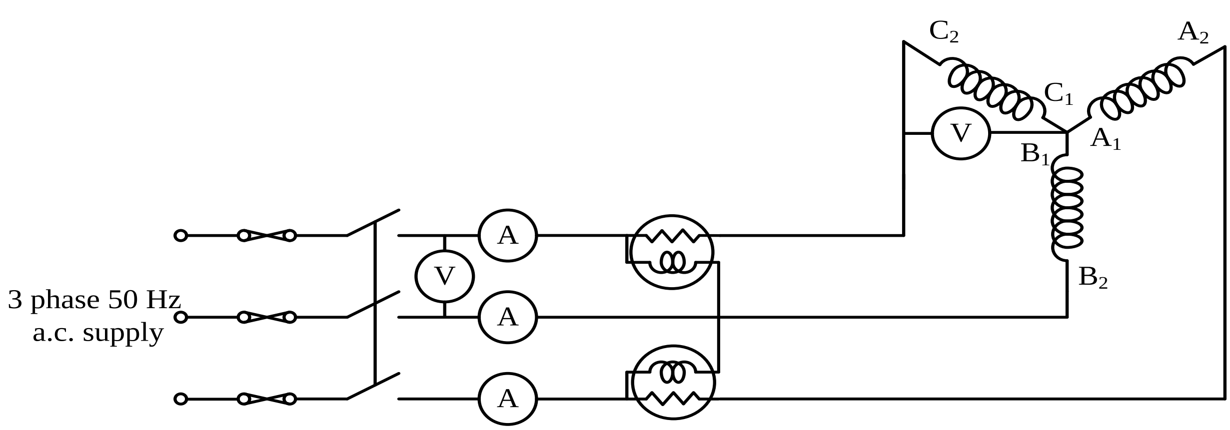
**Equipment and Components**

(a) Three identical single phase transformers of suitable ratings OR a single 3-phase transformer
(b) Voltmeters and ammeters of suitable ratings.
(c) Three-phase loading devices.

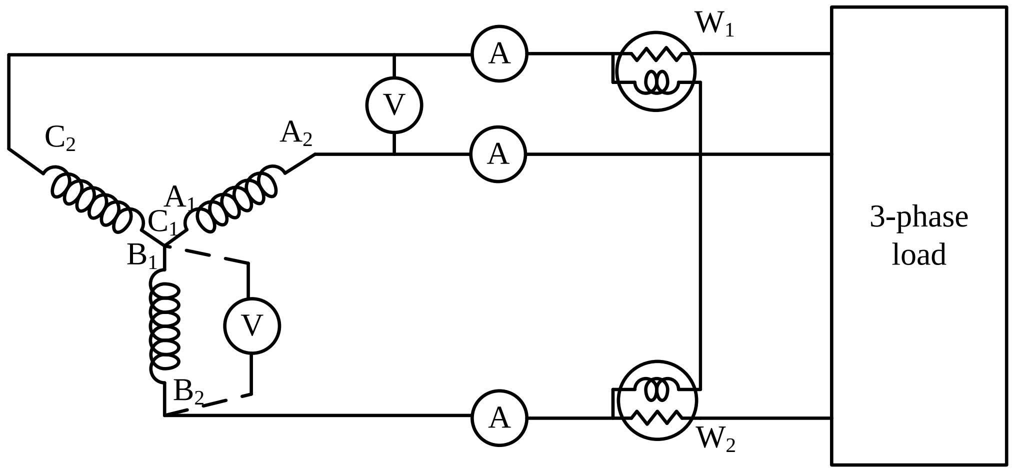
**Procedure, Connection Diagrams, Experimentation and Precautions**

Fig.3.1 shows the connection diagram for Y-Y connected three-phase transformer.

(a) Carry out the polarity test for all three single-phase transformers.
(b) Connect the primaries and secondaries as shown in Fig.3.1. (Wattmeters are not needed)
(c) In each case connect the primary to the appropriate three-phase supply (as per specified ratings). Make measurements of open circuit primary and secondary voltages (both line and phase voltage).
(d) In each case connect the loads across the secondary windings according to their ratings. Measure the relevant current and powers.

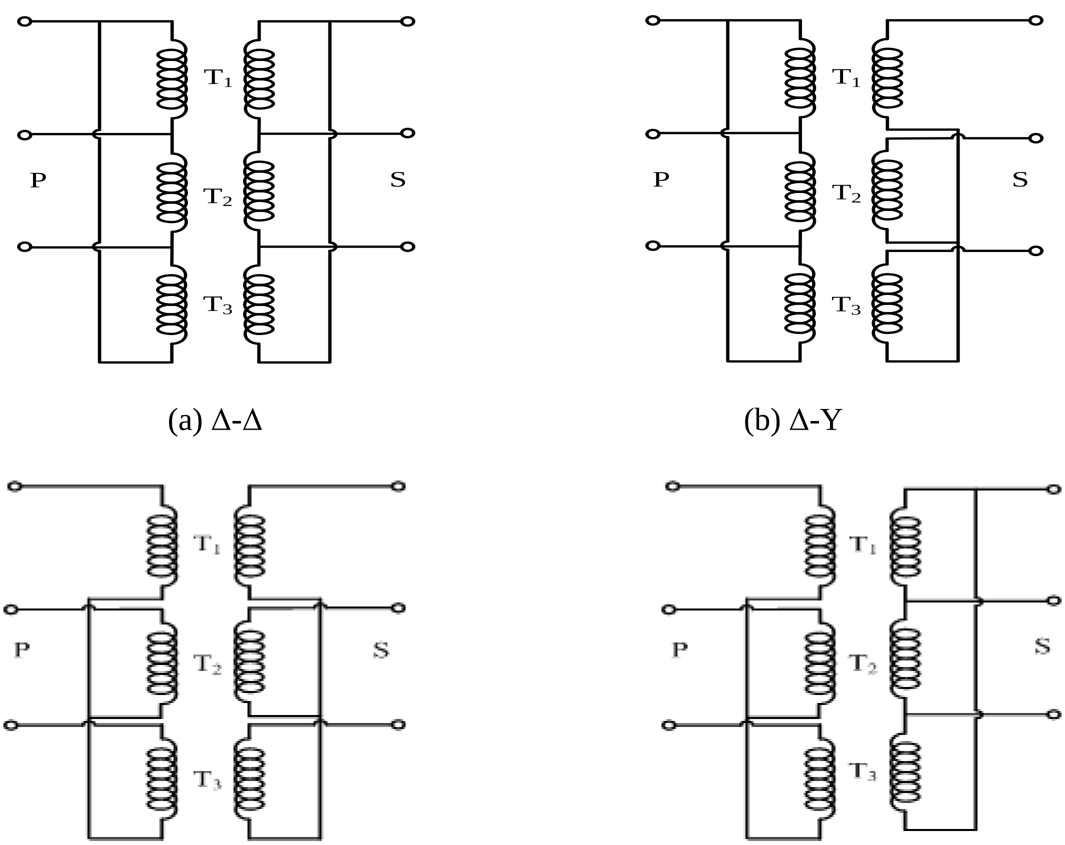



(a)




(b)

Fig.3.1.Connection diagram for load test on a Y-Y connected transformer.




(a) Δ-Δ

(b) Δ-Y

(c) Y-Y

(d) Y-Δ

Fig.3.2. Transformer Connections

**Data Sheet**

***(a) Name plate ratings***

Name of the manufacturer:

Rated output:

Rated voltages:

Supply frequency:

Number of phases:

Rated current:

***(b) Observations***

Table.2.1 No load test

| Type of connection | Primary | | | | Secondary | |
|---|---|---|---|---|---|---|
| | Line voltage | Phase voltage | Line current | Phase current | Line voltage | Phase voltage |
| | | | | | | |

Table.2.2 Load test

| Type of connection | Primary | | | | | Secondary | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $N_p$ | Line voltage | Phase voltage | Line current | Phase current | $N_s$ | Line voltage | Phase voltage | Line current | Phase current |
| | | | | | | | | | | |

**Data Processing and Analysis**

(a) Compare the results of observations with the theoretical values obtained from the transformer ratings.

(b) Analyze the phase and line currents and phase and line voltages obtained (in primary and secondary) for various cases.

**Experimental Quiz**

(a) Discuss the advantages and disadvantages of using single three-phase transformers instead of three single-phase transformers in three-phase system.

(b) Can a tertiary winding of Y-Δ-Y transformer be loaded?

(c) What are the advantages and disadvantages of using tertiary winding?

(d) Mention the constructional features of three-phase transformers.

(e) What sort of cooling system is used in power transformers?

(f) How is a three-phase transformer specified?

(g) How is a three-phase four-wire connection better than three-phase three-wire connection with Y-Y transformers?
(h) If a single phase load is applied between line and neutral of a bank of Y-Y connected single phase transformers without neutral connection, explain why a smaller load current can be obtained even if the impedance of load is reduced to zero.

**Suggestions For Further Study**

(a) Study the parallel operation of three-phase transformers and their load sharing.
(b) Study the phenomenon of magnetizing in-rush current in three-phase transformers.

**References**

(d) P.C.Sen Principles of Electrical machines and Power Electronics" John Wiley.
(e) M.G.Say "*Alternating Current Machines*", Fourth Edition, Pitman (1983).
(f) Fitzgerald and Kingsley "Electric Machinery" McGraw Hill.

# Cycle 1 Experiment No. 4
# Study of the steady state performance of a separately excited DC generator

**Objectives:**

The aim of this experiment is to get open circuit characteristics and external characteristics of the given separately excited DC generator.

**Motivation**:

Despite the advantages of ac systems, the dc machines continue to find use in a wide range of industrial applications because of their flexibility and versatility. The special features which determine the choice of a dc machine for a particular application are the torque speed characteristics of motors and the voltage-Ia characteristics of generators. The knowledge of the limits within which these characteristics can be varied, and of the way, in which such variations could be obtained are also important. Study of these features for a dc machine is accordingly the motivation for this experiment. In the present experiment, we are exploring generators and in the next one, we will be exploring motors.

**Theory:**

When the armature circuit is open in a separately excited generator, the relationship between the induced emf in the armature and excitation current in the field (while the rotor is being driven at rated speed) is known as open circuit characteristics or magnetization characteristics. When a load is connected across the armature with the excitation and speed being a constant, how the terminal voltage changes with the current drawn from the armature, is known as the external characteristics.

***(i) Open Circuit Characteristics***

An important relation essential in the determination of dc generator performance is the relation between field current or field ampere turns and armature emf. The resulting curve at the desired speed is the magnetization characteristic or the open-circuit characteristics (OCC). The magnetization characteristics at several different speeds can be obtained from any one characteristic by recognizing that the voltage is directly proportional to speed for a fixed flux or field current.

***(ii) Load Characteristics***

The load characteristic of a dc generator at a particular speed is the relationship between armature voltage of the generator and its load current at that speed. It is called the external characteristic if the plot is between the terminal voltage vs load current; the internal characteristic is the plot is between the generated emf vs armature current.

In a separately excited dc generator, the field current is independent of armature conditions. At constant field current and constant speed, the terminal voltage in this case drops gradually as the load current increases, because of the increased armature resistance drop and reduction in flux due to armature reaction.

***(iii) Process of self-excitation and critical resistance.***

As long as some residual flux remains in the field poles and the field winding mmf produces a flux that aids the residual flux and also the field winding resistance is less than the critical resistance, the shunt generator is capable of building up the terminal voltage. When the generator is rotating at its rated speed, the residual flux in the field poles, however small it may be, induces an emf in the armature winding. Because the field winding is connected across the armature, the induced emf sends a small current through the field winding depending upon field circuit resistance ($R_f$). This small current sets up a flux that aids the residual flux. The total flux per pole increases the induced emf which in turn increases the field current. The action is therefore cumulative till the machine reaches the no-load voltage where saturation seals the fate of the no-load voltage (depending upon $R_f$).

The value of no-load voltage at the armature terminals depends upon the field-circuit resistance. A decrease in the field-circuit resistance causes the shunt generator to build faster to a higher voltage as shown in Fig.4.1. The value of the field circuit resistance that makes the field resistance line tangent to the magnetization curve is called the critical resistance. The speed at which field resistance becomes the critical resistance is called the critical speed.

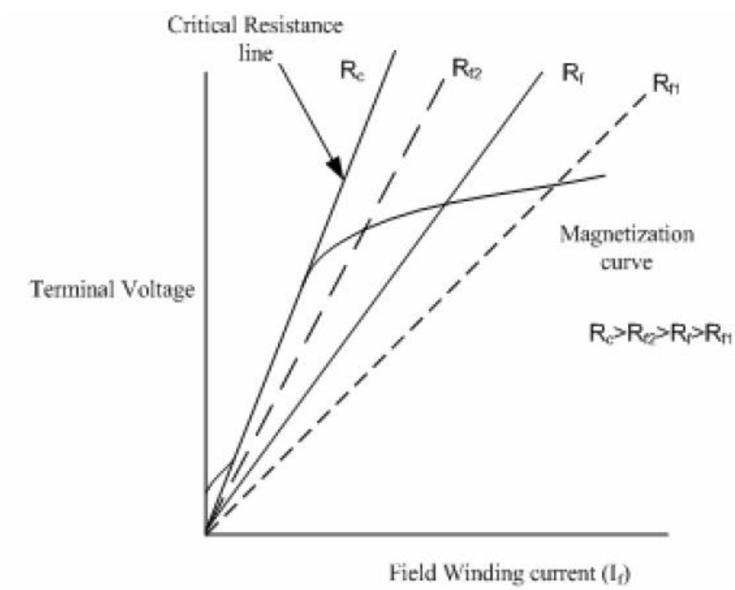



Fig.4.1 Open circuit characteristic

**Equipment and Components**

(a) Separately excited dc motor-generator set
(b) Two Rheostats of suitable range for field control of motor and generator
(c) Two dc Ammeters
(d) Two dc Voltmeters

**Procedure, Connection Diagrams, Experimentation and Precautions**

Note down the name plate details of the dc shunt motors and separately excited dc generator and identify the terminals. Observe the constructional features.

**1. Magnetization Characteristics of a Separately Excited DC Generator**

Connect as in Fig. 4.2 with the generator separately excited. Start the dc shunt motor using the starter and bring it to rated speed by adjusting its external field circuit resistance. Generator's armature terminals should be open. Set the field current of the generator, $I_f$ to zero. Increase the field current in steps to the rated value at which the open circuit terminal voltage Vt of the generator is its rated value. Note the terminal voltage $V_t$ of the generator and its field current. Now, decrease the field current in steps up to zero value and note the corresponding terminal voltage. Take care not to go back and forth while varying the field current. Tabulate the data in Table 4.1. This completes OCC portion of the separately excited generator.

***Precautions:***

- Make sure that field connections of DC shunt motor are proper and three-point starter return to its zero position before every fresh start.
- Use proper range of DC instruments only.

**2. Load Characteristics of Separately Excited DC Generator**

Now, set $I_f$ (field current of the generator) at its rated value, maintain the speed at rated value and note the terminal voltage of the generator. Keeping $I_f$ and speed constant throughout, note the value of terminal voltage of the generator for different values of load current (0 to $I_{rated}$). Tabulate the data in Table 4.2.

Measure the armature and field winding resistances of the generator by using precision multimeter.

***Precautions:*** Check the rating of generator and driving motor and apply the electrical load accordingly.

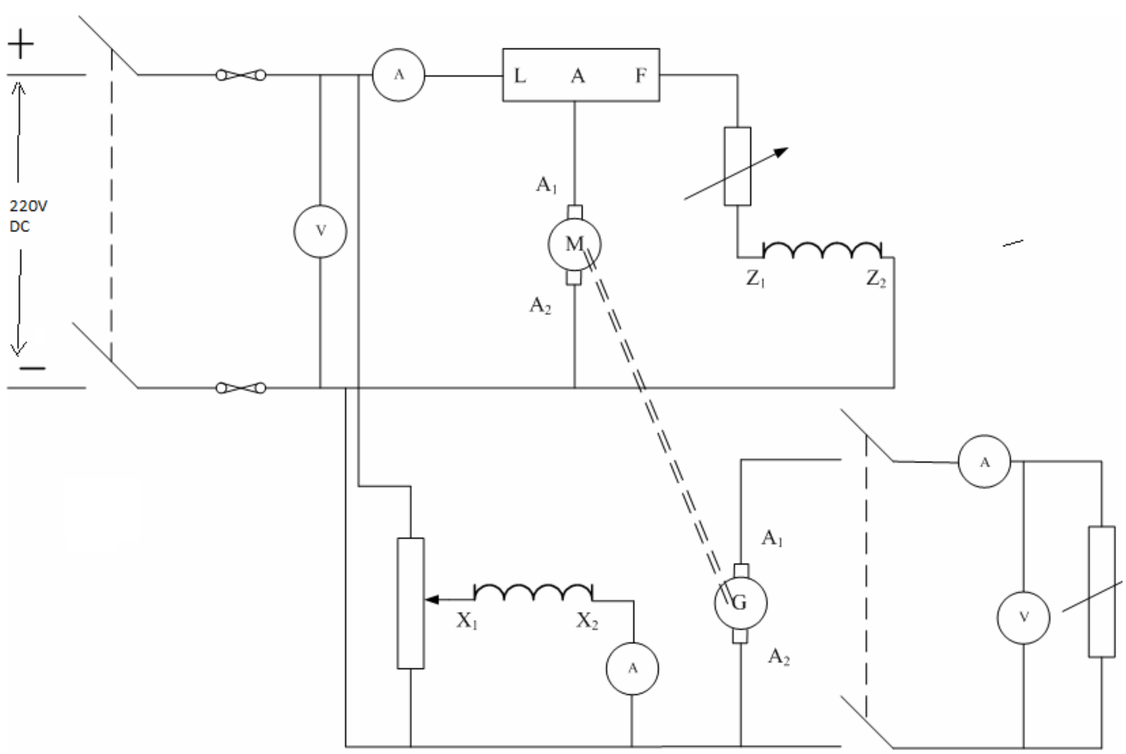



Fig. 4.2 Circuit diagram for DC generator characteristics

Table 4.1 Magnetization Characteristics

| Terminal voltage Eg Volts | $I_f$ increasing Amp | $I_f$ decreasing Amp |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

Table 4.2 External Characteristics

| Load current Amp | Terminal Voltage V | Motor Voltage V | Motor Current A |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |

**Data Sheet**

Name plate details of the shunt motor and separately excited DC generator set:
Name of Manufacturer:
Machine No. Class of Insulation:
kW: RPM:
Voltage: Amperes: Rating: Connections:

**Data Processing and Analysis**

Plots the following graphs
(a) Magnetizing curve and Back emf constant vs. $I_f$ curve
(b) Terminal voltage vs load current starting both scales at origin
(c) From external characteristics draw the internal characteristics
Comment on the shape of the above graphs.

**Post-Experimental Quiz**

a) Why does the open circuit characteristic differ for increasing and decreasing values of field current?
b) Determine the critical resistance of field circuit for normal speed and the critical speed corresponding to the normal field resistance of the machine.
c) How will you determine the load characteristic of a given machine using its OCC?
d) Why does the total flux in a dc machine decrease with load even through the field current is constant?
e) Is the armature reaction mmf in dc machine stationary in space?

**References**

1. A.E.Fitzgerald, Charles Kingsley, Stephen D. Umans "*Electrical machinery*" McGraw-Hill India, 2009.
2. M.G. Say and E.O. Taylor, "*Direct Current Machines*," ELBS Pitman, IInd Edition, London, 1985.
3. A.E. Clayton and N.N. Hancock, "*The Performance and Design of Direct Current Machines*," CBS Publishers and Distributors, Third Edition, Delhi, 2001.
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# CYCLE-1: Experiment 5

## Steady- state performance of a DC motor.

By conducting suitable tests (field circuit resistance control, armature terminal voltage control), obtain the speed control characteristics of a given DC motor.

### Motivation

DC motors are, in general, more controllable than AC motors because AC motor speed control requires a variation in the frequency of the stator supply. Indeed this susceptibility of DC motors to adjustment of their operating speed over wide ranges and by a variety of methods, is one of the important reasons for a strong competitive position of DC motors in adjustable speed industrial drives. It is thus necessary to gather an idea about various speed-control methods along with their associated characteristics.

### Theory

The torque (T) developed and speed (n) of a DC motor are given respectively by equations (i) and (ii) as below:

$$T = K_1\phi\, I_a \qquad \text{(i)}$$

$$n = \frac{V_t - I_a R_a}{K_2\phi} \qquad \text{(ii)}$$

Here $K_1$, $K_2$ are constants decided by design.

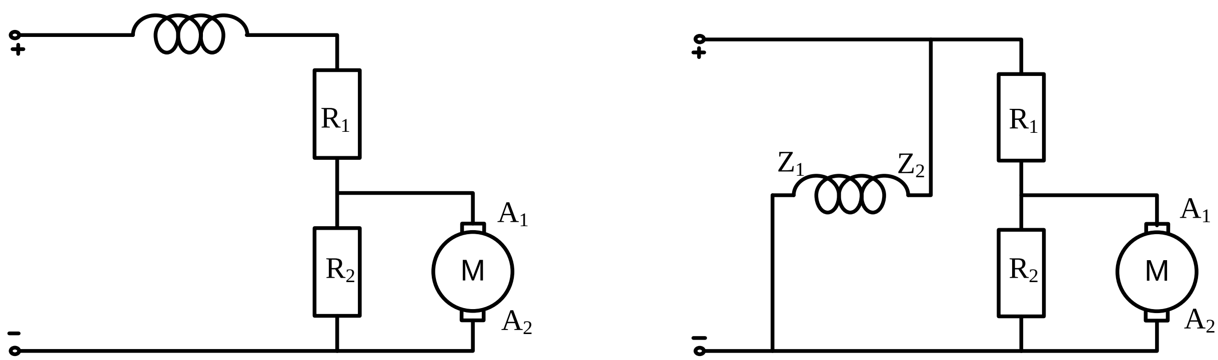
Equations (i) and (ii) can explain the concepts for different methods of speed control.

***a) Varying field excitation ($\phi$)***

In shunt and compound motors speed control can be achieved by varying the shunt field circuit resistance. The lowest speed corresponds to zero resistance in field rheostat (maximum flux). Speed can be increased by increasing the field rheostat resistance (field weakening). The higher speed is limited by armature reaction under weak field conditions, causing motor instability or poor commutation. The DC motors with filed weakening control is generally referred to as a constant horse-power drive, since back emf ($=K_1\varphi\omega$) remains practically constant, as long as motor terminal voltage is maintained constant. The torque on the other hand varies directly with flux and therefore, has its highest allowable value at the lowest (or rated) speed during filed weakening control. Field rheostat control is thus best suited for achieving speeds above base speed while the load requires close to rated torque at lower speeds.

***b) Varying the resistance of armature circuit***

Armature circuit resistance control results in obtaining reduced speeds by the insertion of external series resistance in the armature circuit. It may be used with series, shunt and compound motors. For the last two types, the series resistor must be connected in series with the armature only. It is a common method of speed control of series motors. For fixed value of series armature resistance, the speed will vary widely with load. This is because the speed depends on the voltage drop in the resistance and hence on the armature current demanded by load. The power loss in the external resistor is large, especially when the speed is greatly reduced. Further, the power output to the load decreases with speed and thus in an overall situation, the operating costs are comparatively high for long time running on reduced speeds. This method offers a constant torque drive because both flux and to a first approximation, allowable armature current remain constant as speed changes. A variation of this control scheme is given by the shunted armature method which may be applied to series motor (Fig.5.1a) or shunt motor (Fig.5.1b). In effect the resistors $R_1$ and $R_2$ act as a voltage divider applying a reduced voltage to the armature. Greater flexibility is possible because two resistors may now be adjusted to provide the desired performance. For series motors, the no load speed may be adjusted to finite, reasonable value, and the scheme is therefore, applicable to the production of low speeds at light loads.




(a) Series Motor

(b) Shunt Motor

Fig.5.1 Shunted armature method of speed control

**c) *Varying Armature Terminal Voltage***

A change of the armature terminal voltage results in a change in speed with constant excitation. Usually the power available is constant voltage AC, so that auxiliary equipment in the form of rectifier or motor-generator set is required to provide the controlled armature voltage to the motor. The development of solid state controlled rectifiers capable of handling several kWs has opened up a whole new field of application where precise control of motor speed is required. In conventional scheme, the Ward-Leonard system is used to control the speed of the motor not only over a wide range, but also to control the speed in the reverse direction.

**Equipments and Components**

a) Test DC motor.
b) Rheostats for field and armature control.
c) Voltmeters and Ammeters.
d) Loading device - DC generator
e) Tachometer.

**Procedure, Connection Diagram, Experimentation and Precautions**

The two methods of speed control namely, filed flux control and armature voltage control will be implemented on the DC shunt/separately excited motor (especially under no-load condition).

## a) *Shunt Field Rheostat Control*

Decide the values and ranges of rheostats, ammeters and voltmeters from the specifications of the test motor and then make the connections as shown in Fig.5.2. Apply rated voltage ($V_t$) and start the motor using the starter. Keep the field current at its maximum value.

Gradually increase the field resistance and observe the variation of speed with the field current, for no load condition.

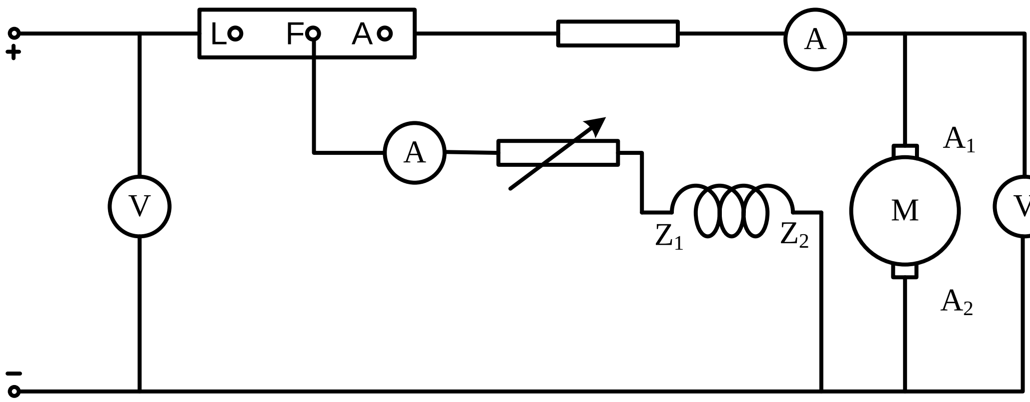



Fig. 5.2 Field flux control method

Repeat the procedure for various constant loads. Here, the motor could be generally loaded using a coupled DC generator which could be electrically loaded using loading rheostats. Speed control at different constant loads could be taken as studying the variation of speed with field current, at different constant armature currents. Tests may be done at 0.5 and 1.0 p.u. of armature current. The DC load generator can be a separately excited machine. With separate excitation its field current can be kept constant at rated value and the armature load current gives the measure of torque.

## b) *Armature Voltage Control*

Bring the motor to its rated speed at no load by applying rated armature voltage. Keeping the field resistance fixed, gradually vary the armature voltage (by a variable AC voltage fed to a diode rectifier through a variac) and observe the variation of speed with respect to the armature terminal voltage. Repeat the procedure for various constant loads as explained in (a) above.

### Data Sheet

Machine(s) specifications

Table. 5.1 Field Rheostat Control

Load = (Record different armature current of the motor)

| S. No. | Field current, (amps) | Motor speed (rpm) |
|---|---|---|
| | | |

Table. 5.2 Armature Voltage Control

Load = (Record different armature current of the motor)

| S. No. | Armature Voltage (Volts) | Test motor speed (rpm) | Armature current (amp) | Voltage across generator |
|---|---|---|---|---|
| | | | | |

**Data Processing And Analysis**

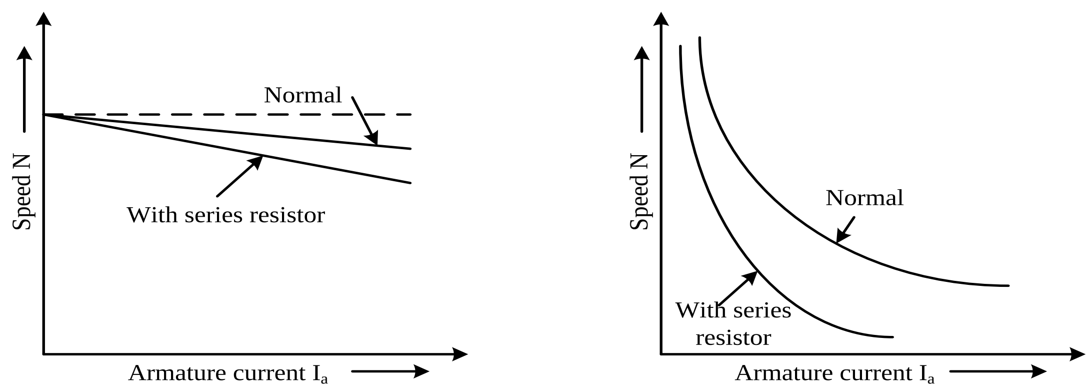
a) Draw graphs of speed vs. field current by field control method for no load and few loading conditions.

b) For the armature resistance control:

   i) Plot graph between armature voltage and speed for no load and few loading conditions.

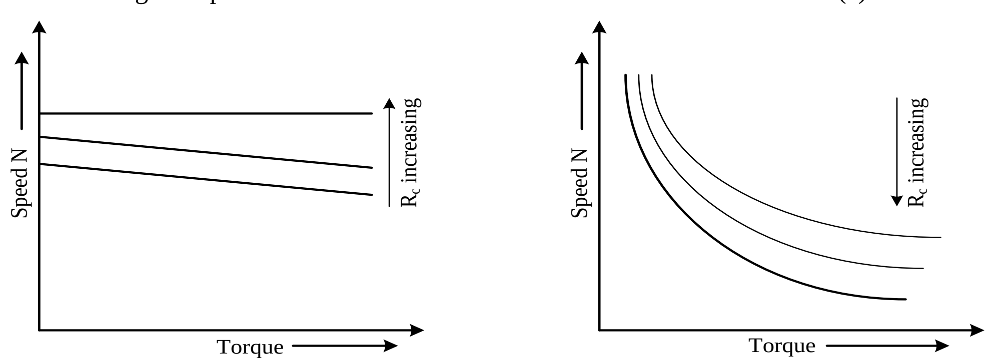
   ii) Plot graph between power loss in the resistance vs. speed for no load and few loading conditions.

**Sample Curves**




(a) (b)

Fig.5.3 Speed/Current characteristic for armature resistance control (a) Shunt motor (b) Series motor




(a) (b)

Fig. 5.4 Typical Speed/Torque curves for field flux control (a) Shunt motor (b) Series motor

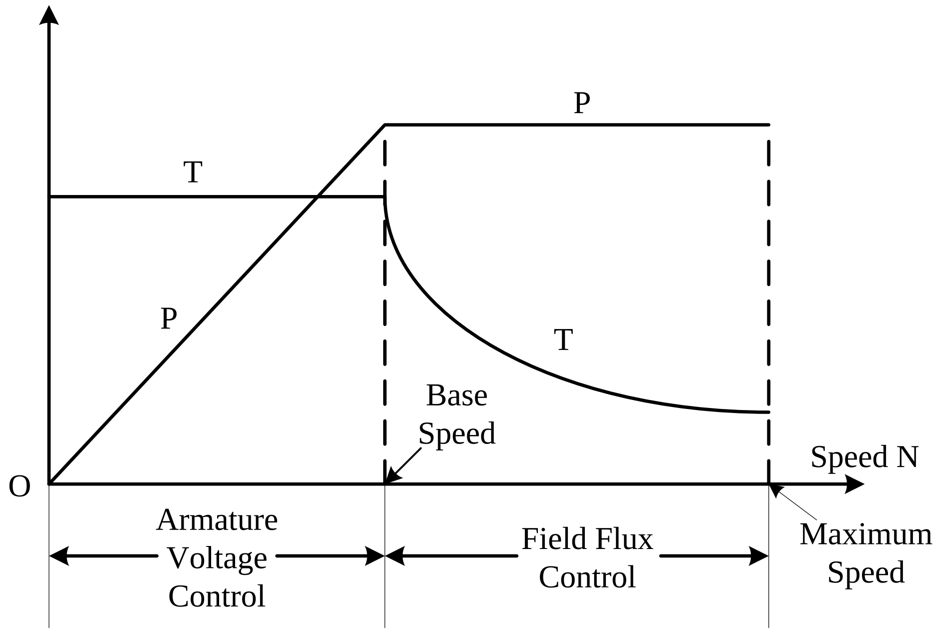



Fig. 5.5 Torque and Power characteristic for combined armature voltage and field control

**Experimental Quiz**

a) In the armature voltage control method, are the two graphs for armature voltage vs. speed, output power vs. speed, linear?
b) Discuss the graphs between speed and load current in the armature voltage control method for series, shunt and compound motors.
c) Comment on the nature of graph speed vs. field current obtained in field control method.
d) In the armature resistance control method for a shunt motor, what would be the nature of graphs for armature resistance vs. speed at various loadings?
e) Can Ward-Leonard system of speed control provide regenerative braking (study about this method)?
f) Can a DC motor starter be used for speed control?
g) It is preferable to interchange the armature terminals instead of field terminals for reversing the direction of rotation in a DC shunt motor. Why?
h) What are the limitations of shunt field control?
i) Between armature resistance control and field control method, which method is more economical?
j) What is the difference between speed control and speed regulation of a motor?
k) Explain why the speed changes with load in a DC shunt/ separately excited motor.
l) Which method of speed control provides constant horse power drive?
m) Which method of speed control provides constant torque drive?
n) Can the field control method be applied to series motor?
o) How is the direction of rotation of a DC series motor changed?

**Suggestions For Further Study**

a) Study in detail ward-Leonard Method of speed control

b) Perform speed control on DC series motor by using simulations.

**References**


a) A.E. Fitzgerald and C. Kingsley, *Electric Machinery*, McGraw-Hill, Second ed., (1971).
b) A.E. Clayton and N.N. Hancock, *Performance and Design of d.c. Machines*, ELBS Pitman (1971).
c) P.C.Sen "Principles of Electrical Machines and Power Electronics" John Wiley.