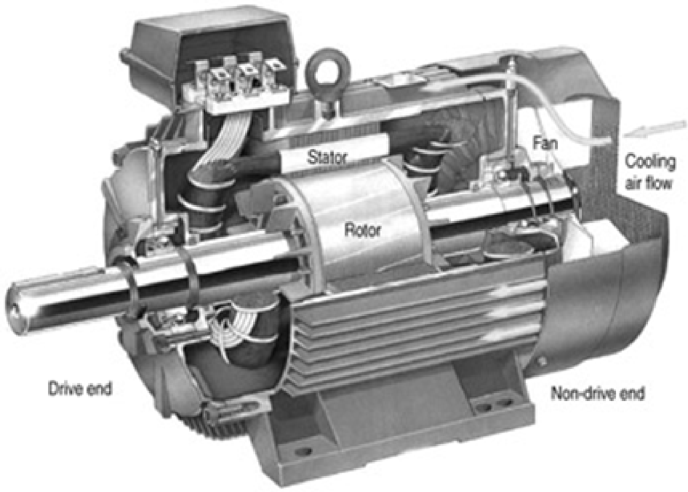
An-Najah National University

Faculty of Engineering

Lab Manual



Electrical Machines Lab

(10641325/10641392)

Instructor: O. Tamimi
Lab Assistant: Saeed Dwaikat

2018-2019

Department Name: Electrical Engineering
Course Name: Electrical Machines Lab Number: (10641325/10641392)
Report Grading Sheet

Instructor Name:	Experiment #:
Academic Year: 2018/2019	Performed on:
Semester:	Submitted on:

Experiment Name:

Students:

1-	2-
3-	4-
5-	6-

Report's Outcomes

ILO __ =( ) %	ILO __ =( ) %	ILO __ =( ) %	ILO __ =( ) %	ILO __ =( ) %

Evaluation Criterion	Grade	Points
Introduction Sufficient, Clear and complete statement of objectives.	1.5	
Theory Presents sufficiently the theoretical basis.	1.5	
Apparatus/ Procedure Apparatus sufficiently described to enable another experimenter to identify the equipment needed to conduct the experiment. Procedure sufficiently described.	1	
Experimental Results and Calculations Results analyzed correctly. Experimental findings adequately and specifically summarized, in graphical, tabular, and/or written form.	1.5	
Discussion Crisp explanation of experimental results. Comparison of theoretical predictions to experimental results, including discussion of accuracy and error analysis in some cases.	2	
Conclusions and Recommendations Conclusions summarize the major findings from the experimental results with adequate specificity. Recommendations appropriate in light of conclusions. Correct grammar.	1.5	
Appendices Appropriate information, organized and annotated. Includes all calculations and raw data Sheet.	0.5	
Appearance Title page is complete, page numbers applied, content is well organized, correct spelling, fonts are consistent, good visual appeal.	0.5	
Total	10	

Table of Contents

Department of Electrical Engineering	
Electrical Machines Lab. (10641325)	
Total Credits	**1**
major compulsory	
Prerequisites	P1 : Electrical Machines 1 (10641323)
Course Contents	

1- Phasor diagram and efficiency test of 1-phase transformer
2- DC separately excited & series generator (characteristics, voltage reg. & efficiency)
3- Open circuit test & short circuit test of 1-phase transformer
4- DC shunt and compound generator (characteristics, voltage reg. & efficiency)
5- DC shunt and compound motor (characteristics, speed reg. & efficiency)
6- 3-phase transformer (balance & unbalanced RLC load, characteristics, phase sequence)
7- 3-phase synchronous generator (wye & delta connections)
8- 3-phase squirrel-cage induction motor (wiring, characteristic, operation, efficiency)
9- 3-phase slip-ring induction motor (characteristics)
10- 3-phase synchronous motor (characteristics, under excited & over excited)
11- 1-phase induction motor capacitor run & capacitor start motor
12- 1-phase generator synchronized with the mains supply (conditions of parallel operation)

	Intended Learning Outcomes (ILO's)	Student Outcomes (SO's)	Contribution
1	Ability to implement, verify and operate AC &DC rotational machines. In addition to gain the necessary understanding of their electrical characteristics	A	20 %
2	Ability to relate the theoretical aspects of various electrical machines with their practical characteristics and behaviors	D	15 %
3	To become Familiar with the measurements of voltage, current, power, torque & speed	B	25 %
4	Ability to implement and test various electrical machine circuits	C	15 %
5	Knowing how to author a good technical report taking into consideration that the following elements. Such as, paragraph, calculation, results and conclusion are all available	C	25 %

Textbook and/ or Refrences

Electrical Machines Lab Manual, Electric Machinarey Fundamentals Fourth Edition Stephen Chapman

Assessment Criteria	Percent (%)
Projects	10 %
Reports	30 %
Laboratory Work	30 %
Final Exam	30 %

Course Plan

Week	Topic
1	Phase relationship and efficiency test of single phase transformer
2	DC Series and Separately Excited Generator
3	Open circuit test & short circuit test of 1-phase transformer
4	DC Shunt and Compound Generators
5	DC Shunt Motor
6	Poly-phase Induction Motor
7	DC Series and Compound Motors
8	3-Phase Synchronous Generator
9	Single Phase Induction Motor
10	3-Phase Synchronous Motor
11	Three Phase Transformer
12	3 Phase slip-ring induction motor
13	MATLAB Project
14	Final Exam

Lab Safety Guidelines

1) Be familiar with the electrical hazards associated with your workplace.

2) You may enter the laboratory only when authorized to do so and only during authorized hours of operation.

3) Be as careful for the safety of others as for yourself. Think before you act, be tidy and systematic.

4) Avoid bulky, loose or trailing clothes. Avoid long loose hair.

5) Food, beverages and other substances are strictly prohibited in the laboratory at all times. Avoid working with wet hands and clothing.

6) Use extension cords only when necessary and only on a temporary basis.

7) Request new outlets if your work requires equipment in an area without an outlet.

8) Discard damaged cords, cords that become hot, or cords with exposed wiring.

9) Before equipment is energized ensure, (1) circuit connections and layout have been checked by a laboratory technician and (2) all colleagues in your group give their assent.

10) Know the correct handling, storage and disposal procedures for batteries, cells, capacitors, inductors and other high energy-storage devices.

11) Experiments left unattended should be isolated from the power supplies. If for a special reason, it must be left on, a barrier and a warning notice are required.

12) Equipment found to be faulty in any way should be reported to the laboratory technician immediately and taken out of service until inspected and declared safe.

13) Never make any changes to circuits or mechanical layout without first isolating the circuit by switching off and removing connections to power supplies.

14) Know what you must do in an emergency, i.e. Emergency Power Off

15) For microwave and antenna trainer:

   a. You should, whenever possible, remove the power from the gun oscillator before placing yourself in front of transmitting antenna.

   b. For your safety, do not look directly into the waveguides or horn antennas while power is being supplied by the gun oscillator. Because, although the microwave is invisible, it can be dangerous at high levels or long exposure times.

16) For fiber optics trainer:

   a. Do not look inside the connector of the Optical Sources when these are operating. Although nothing can be seen, as the emitted wavelength should be out of the visible range, it can be dangerous for your sight.

b. Do not bend the optical cables with too narrow curves, as the fiber inside should cut off or damage. The minimum curving ray is around 2 cm;

c. Sometimes clean the connectors' head with a cotton wad soaked with alcohol;

Electrical Emergency Response

The following instructions provide guidelines for handling two types of electrical emergencies:

1. *Electric Shock*:

When someone suffers serious electrical shock, he or she may be knocked unconscious. If the victim is still in contact with the electrical current, immediately turn off the electrical power source. If you cannot disconnect the power source, depress the Emergency Power Off switch.

IMPORTANT:

Do not touch a victim that is still in contact with a live power source; you could be electrocuted.

Have someone call for emergency medical assistance immediately. Administer first-aid, as appropriate.

2. *Electrical Fire:*

If an electrical fire occurs, try to disconnect the electrical power source, if possible. If the fire is small and you are not in immediate danger; and you have been properly trained in fighting fires, use the correct type of fire extinguisher to extinguish the fire. When in doubt, push in the Emergency Power Off button.

NEVER use water to extinguish an electrical fire.

Lab Report Format

Following the completion of each laboratory exercise, a report must be written and submitted for grading. The purpose of the report is to completely document the activities of the design and demonstration in the laboratory. Reports should be complete in the sense that all information required to reproduce the experiment is contained within. Writing useful reports is a very essential part of becoming an engineer. In both academic and industrial environments, reports are the primary means of communication between engineers.

There is no one best format for all technical reports but there are a few simple rules concerning technical presentations which should be followed. Adapted to this laboratory they may be summarized in the following recommended report format:

- ABET Cover Page
- Title page
- Introduction
- Experimental Procedure
- Experimental Data
- Discussion
- Conclusions

Detailed descriptions of these items are given below.

Title Page:

The title page should contain the following information

- Your name
- ID
- Experiment number and title
- Date submitted
- Instructors Name

Introduction:

It should contain a brief statement in which you state the objectives, or goals of the experiment. It should also help guide the reader through the report by stating, for example, that experiments were done with three different circuits or consisted of two parts etc. Or that additional calculations or data sheets can be found in the appendix, or at the end of the report.

The Procedure

It describes the experimental setup and how the measurements were made. Include here circuit schematics with the values of components. Mention instruments used and describe any special measurement procedure that was used.

Results/Questions:

This section of the report should be used to answer any questions presented in the lab hand-out. Any tables and /or circuit diagrams representing results of the experiment should be referred to and discussed / explained with detail. All questions should be answered very clearly in paragraph form. Any unanswered questions from the lab hand-out will result in loss of points on the report.

The best form of presentation of some of the data is graphical. In engineering presentations a figure is often worth more than a thousand words. Some simple rules concerning graphs and figures which should always be followed. If there is more than one figure in the report, the figures should be numbered. Each figure must have a caption following the number. For example, *"Figure 1.1:DSB-SC "* In addition, it will greatly help you to learn how to use headers and figures in MS Word.

The Discussion

It is a critical part of the report which testifies to the student's understanding of the experiments and its purpose. In this part of the report you should compare the expected outcome of the experiment, such as derived from theory or computer simulation, with the measured value. Before you can make such comparison you may have to do some data analysis or manipulation.

When comparing experimental data with numbers obtained from theory or simulation, make very clear which is which. It does not necessarily mean that your experiment was a failure. The results will be accepted, provided that you can account for the discrepancy. Your ability to read the scales may be one limitation. The value of some circuit components may not be well known and a nominal value given by the manufacturer does not always correspond to reality. Very often, however, the reason for the difference between the expected and measured values lies in the experimental procedure or in not taking into account all factors that enter into analysis.

Conclusion:

A brief conclusion summarizing the work done, theory applied, and the results of the completed work should be included here. Data and analyses are not appropriate for the conclusion.

Notes

Typed Reports are required. Any drawings done by hand must be done with neatness, using a straightedge and drawing guides wherever possible.
Freehand drawings will not be accepted.

Groups vs Experiment

1st and 2nd Semesters

	2nd Week	3rd Week	4th Week	5th Week	6th Week	7th Week	8th Week	9th Week	10th Week	11th Week	12th Week
Group-1	*Exp-1*	*Exp-2*	*Exp-3*	*Exp-4*	*Exp-5*	*Exp-6*	*Exp-7*	*Exp-8*	*Exp-9*	*Exp-10*	*Exp-11*
Group-2	*Exp-1*	*Exp-2*	*Exp-3*	*Exp-4*	*Exp-5*	*Exp-6*	*Exp-7*	*Exp-8*	*Exp-9*	*Exp-10*	*Exp-11*
Group-3	*Exp-1*	*Exp-2*	*Exp-3*	*Exp-4*	*Exp-5*	*Exp-6*	*Exp-7*	*Exp-8*	*Exp-10*	*Exp-11*	*Exp-9*
Group-4	*Exp-2*	*Exp-1*	*Exp-4*	*Exp-3*	*Exp-6*	*Exp-5*	*Exp-8*	*Exp-7*	*Exp-10*	*Exp-11*	*Exp-9*
Group-5	*Exp-2*	*Exp-1*	*Exp-4*	*Exp-3*	*Exp-6*	*Exp-5*	*Exp-8*	*Exp-7*	*Exp-11*	*Exp-9*	*Exp-10*
Group-6	*Exp-2*	*Exp-1*	*Exp-4*	*Exp-3*	*Exp-6*	*Exp-5*	*Exp-8*	*Exp-7*	*Exp-11*	*Exp-9*	*Exp-10*

Summer Semester

	2nd Week		3rd Week		4th Week		5th Week		6th Week		7th Week
	1st Session	2nd Session	1st Session	2nd Session	1st Session	2nd Session	1st Session	2nd Session	1st Session	2nd Session	1st Session
Group-1	*Exp-1*	*Exp-2*	*Exp-3*	*Exp-4*	*Exp-5*	*Exp-6*	*Exp-7*	*Exp-8*	*Exp-9*	*Exp-10*	*Exp-11*
Group-2	*Exp-1*	*Exp-2*	*Exp-3*	*Exp-4*	*Exp-5*	*Exp-6*	*Exp-7*	*Exp-8*	*Exp-9*	*Exp-10*	*Exp-11*
Group-3	*Exp-1*	*Exp-2*	*Exp-3*	*Exp-4*	*Exp-5*	*Exp-6*	*Exp-7*	*Exp-8*	*Exp-10*	*Exp-11*	*Exp-9*
Group-4	*Exp-2*	*Exp-1*	*Exp-4*	*Exp-3*	*Exp-6*	*Exp-5*	*Exp-8*	*Exp-7*	*Exp-10*	*Exp-11*	*Exp-9*
Group-5	*Exp-2*	*Exp-1*	*Exp-4*	*Exp-3*	*Exp-6*	*Exp-5*	*Exp-8*	*Exp-7*	*Exp-11*	*Exp-9*	*Exp-10*
Group-6	*Exp-2*	*Exp-1*	*Exp-4*	*Exp-3*	*Exp-6*	*Exp-5*	*Exp-8*	*Exp-7*	*Exp-11*	*Exp-9*	*Exp-10*

Experiment-1

Phase relationship and efficiency test of single phase transformer

Objectives

To experiment and understand the methods of measuring variable and constant losses that are necessary to obtain and analyze the performance curve of a single phase transformer. In addition, the procedure of voltage regulation test is introduced to comprehend the conceptual idea of voltage regulation.

Apparatus Required

- Power supply unit *PS189*
- 2 X Resistor banks *LU178*
- Transformer trainer *TT179*
- Standalone transformer
- External Wattmeter
- Oscilloscope

Theory

A single phase transformer normally consists of a pair of windings, primary and secondary, linked by a magnetic circuit. When an alternating voltage is applied to one of these windings, an induced magnetic field is generated in the core, which then induces a voltage on the second winding.
The winding at which the source is applied is called the primary winding, while the other winding is called the secondary. The primary and secondary voltages are related by a constant determined by the turns-ration(a). This ratio is known as the number of turns on primary divided by the number of turns on the secondary.

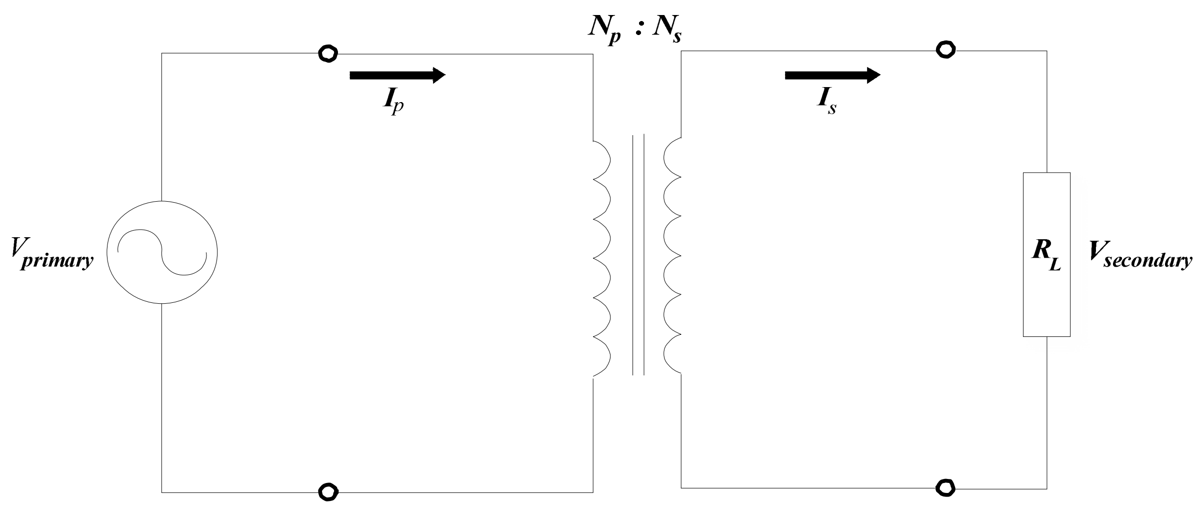


Fig.1 Schematic symbol of a transformer connected with supply & load

In an ideal transformer, the ratio of primary voltage V_P to the secondary voltage V_S is equal to the turns-ratio a. Similarly, the ratio of secondary current I_S to the primary current I_p is equal to the turns-ratio a

$$a = \frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P}$$

A single phase transformer is generally used to step-up or step-down the secondary voltage. This depends on the turn-ratio. For example, if the turn-ratio is 10, then the secondary voltage is less than the primary voltage by 10, and therefore the transformer is called a step-down transformer. The purpose of this experiment is to study the behavior and circuit model of single-phase transformer as reflected by its internal parameters

Running a transformer at no-load, yields a very small voltage drops on the set of primary and secondary components, under this condition the secondary voltage is equal to primary voltage times the turns-ratio. Output-voltage usually drops below its no-load level when a load is connected on the secondary, which causes a net current flow through the secondary and primary components. The measure of how well a transformer maintains constant secondary voltage over a range of load currents is called the transformer's voltage regulation.

$$V_R = \frac{V_{nl} - V_{fl}}{V_{fl}} \times 100\%$$

Procedure

<u>*Turn Ratio Test*</u>

1. Connect the transformer trainer in accordance to the circuit in *Fig.2*
2. After turning on the supply voltage, bring the voltage (primary voltage) (V1.1_1.2 = 50V) AC.
3. Use the secondary voltmeter *V2* to measure the secondary voltage; once across the terminals V3.1_3.2, V2.1_2.2, V2.1_3.2 down the readings in *table-1*

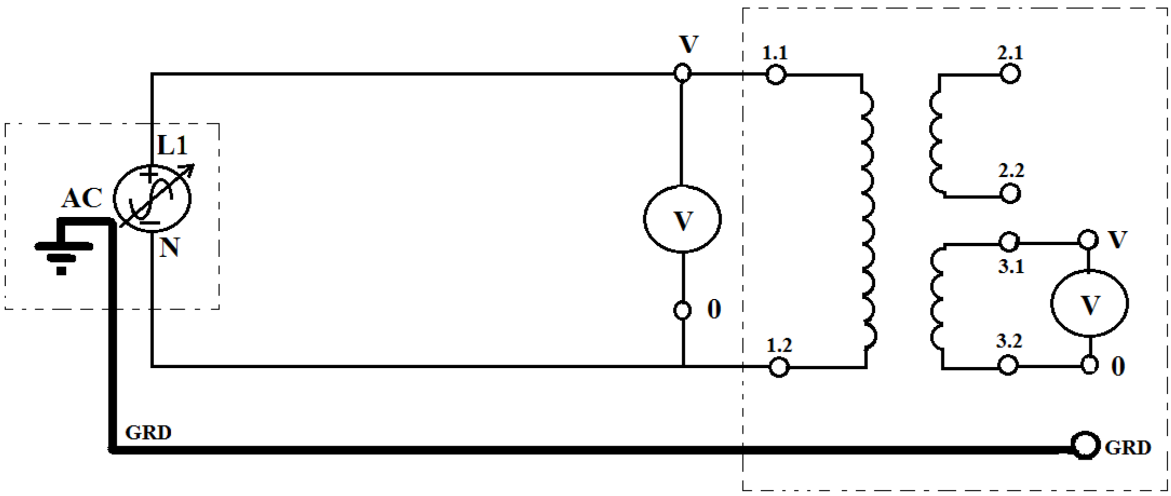


Fig.2 Voltage ratio test

4. This time you may have to repeat the last four steps all over again, after getting the power-supply *PS189* & Voltmeter *V1* connected across the winding *B-C*
5. Note down the readings in *table-1* and then calculate the voltage ratio

Primary voltage (volt)	Secondary voltage(volt)	Turns ratio calculation (V_P/V_S)	Transformer state
$V_{1.1\_1.2}$ = 50V	$V_{3.1\_3.2}$ =		
$V_{1.1\_1.2}$ = 50V	$V_{2.1\_2.2}$ =		
$V_{1.1\_1.2}$ = 50V	$V_{2.1\_3.2}$ =		

Table-1 Experimental data for voltage ratio test

Voltage Regulation Test

1- Make the following connection, make sure that the load R is on the maximum and the power supply minimum, then switch on the power supply and raise the voltage at the primary side **V_1 up to 230 V** then decrease the resistive load to obtain a **load current I_2 equal 1.3 A** then take all results in the following Table-2.

2- Tabulate the results and find the voltage regulation

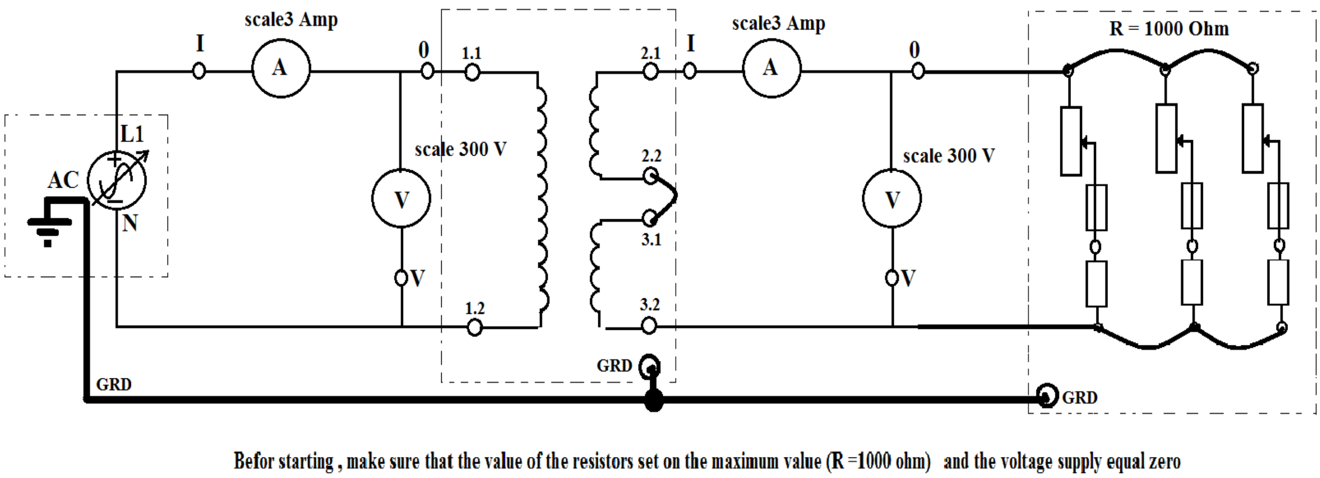


Fig.3 Voltage-regulation test

V1.1_1.2 (volt)	I1 (Amp)	V2.1_3.2 (volt)	I2(Amp)	Load(Ω)
230 V			1.3 Amp	Approximately 180 Ω
230 V				Open circuit (No load)

Table-2 Experimental results of load test

Current & voltage waveform test

1- The oscilloscope comes with two channels *ch-1&ch-2*, get *ch-1* connected across the primary winding *1.1 -1.2* and the second channel across the secondary winding *3.1-3.2*

2- Use the supply unit to bring the primary voltage at *230 V AC*

3- Adjust the controls of oscilloscope in order to display the primary and secondary waveforms in a proper manner

4- Capture or draw the waveforms specifying their amplitudes and phase-shift

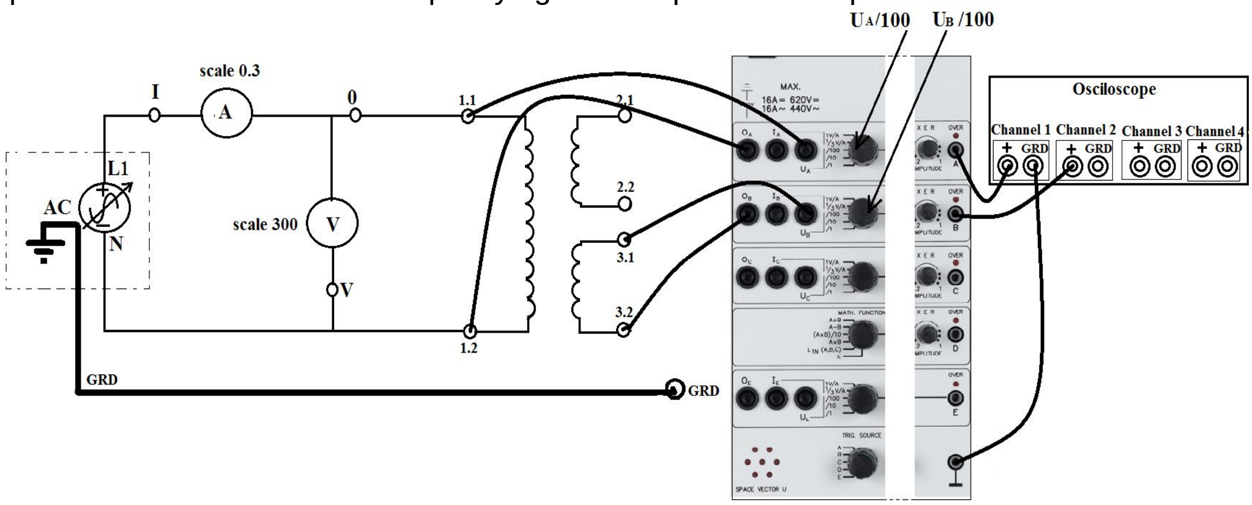


Fig.5 Primary and secondary waveforms test

5- Connect the circuit as in Fig.6 in order to capture the magnetizing current waveform

6- Turn on the power supply again and gradually raise the supply voltage until the primary voltmeter reads *230VAC*

7- Draw the displayed waveforms taking into consideration the amplitudes, phase-shift and divisions (voltage & current)

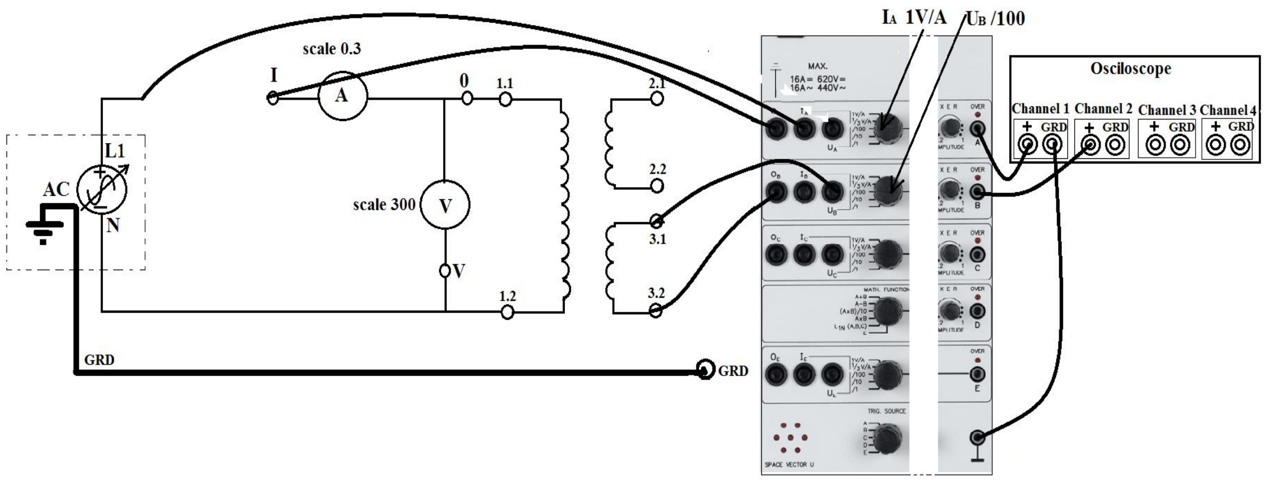


Fig.6 magnetizing current test

Analysis

1- Calculate the voltage regulation

2- Use the peak voltage (found on the primary waveform) to determine the rms value and compare it with the measured primary voltage (displayed by voltmeter)

3- Draw the resulting waveforms on a scaled red sheets and ensure that the signal’s amplitude and the frequency are specified

4- With reference to the magnetizing current curve, explain why it doesn’t look like a pure sinusoidal waveform

Experiment-2
DC Series and Separately Excited Generator

Objectives

In general, the experiment is intended to give a comprehensive knowledge of basic principles of DC generators. This includes; DC series and separately excited generators. In addition, it shows how to determine and analyze the internal and external characteristics and to study the influence of prime mover speed, field current and the load on the generated voltage

Apparatus Required

- Power Supply Unit*AV-1/EV*
- Adjustable Resistive Load *RL-1/EV*
- Series Field Rheostat *RC1a*
- 3X Voltage & Current Meters *AZ-VI*
- Variable Frequency Drive *VSD-1/EV*
- DC Generator (Configured as Shunt or Compound) *M1-2/EV*
- 3-Phase squirrel-cage Induction Motor (Act as Prime-Mover) *M-4/EV*

Theory

DC generators are classified according to the method of producing the main field flux, when the DC field current in such a generator is fed by an independent source, the generator is said to be separately excited. This method of excitation has the obvious disadvantage of the need for external DC source. In self-excited generators the residual magnetism in stator is used to initiate the process of providing field flux. Self-excited generators may be of the series, shunt, or compound type, depending upon the manner of connecting the field winding to the armature.

Series field generators have their armature winding, field coils, and external circuit connected in series with each other so that the same current flows through all parts of the circuit $I_f = I_a = I_L$. see Fig.1

If a series generator is operated at no- load, there will be no current through the field coils $I_f = 0$, and the only magnetic flux present in the machine will be that due to the residual magnetism (Ø) which has been retained by the poles from previous operation. Therefore, the no-load voltage (E) of a series generator will be only a few volts produced by cutting the residual flux.

$$E = k\emptyset\omega \quad k: Constant$$

This small emf*(E)* will force a current to flow through the series circuit including the field winding (I_f).

As a result, an additional flux (Ø) will be produced to reinforce the original residual flux.

$$\emptyset = k_f I_f \quad k_f: Constant$$

Because of the increased flux (Ø), the emf *(E)* will accordingly increase, leading to an increase of terminal voltageV_T.This process continues and the generator voltage building up until the flux (Ø) reaches the saturation level. The steady-state operation of a loaded series generator is described by the equations

$$V_T = E - I_a(R_a + R_s)$$

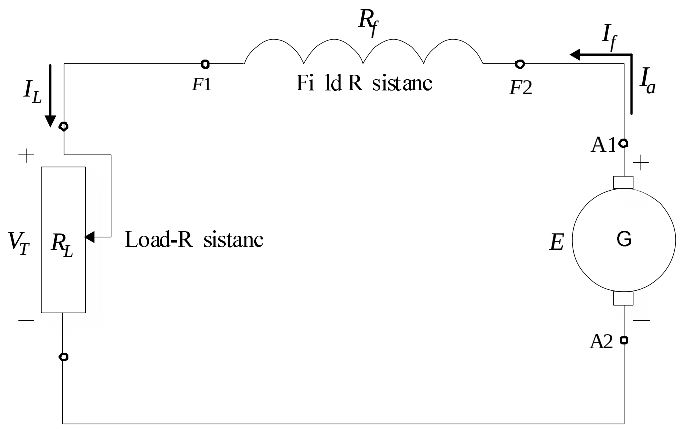


Fig.1 Equivalent circuit model of series generator

The series field coil is made-up of few turns with relatively large diameter in order to reduce the voltage drop across that coil. Based on the flux relation $\emptyset = k_f I_f$, the field current or load current I_L directly affects the flux per pole, which in turn affects the armature voltage. In other words, if the load current is increased, a high magnetic flux will be created by the field current. This leads to an increase of armature voltage E and thus the terminal voltage V_T.

Separately Excited Generator

In a separately excited generator, the field current I_f for the field coils is supplied from a separate DC source like a battery. Thus, achieving an independent flux control is possible for this type of DC generators. The required field (magnetization) current I_f is very small fraction of the rated armature current I_a on the order of 1 to 3 percent in average. Because of this, a small amount of power in the field may control a relatively large amount of power in the armature.

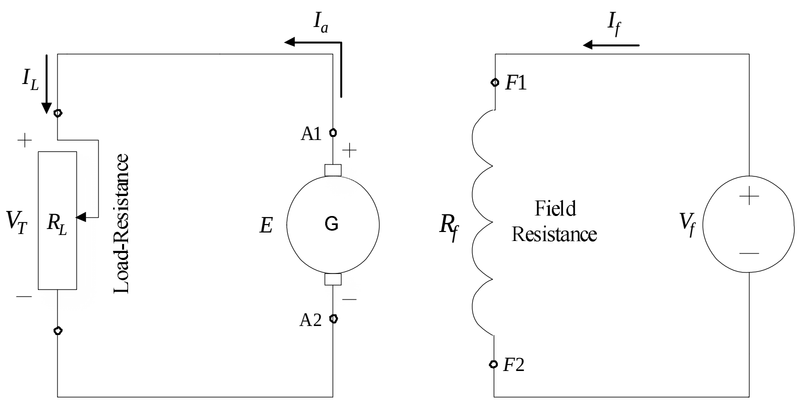


Fig.2 Simplified circuit of DC separately excited generator

The equivalent circuit of such machine is shown in Fig.2, it may be noted that the armature current I_a is equal to the line current I_L, if the machine is driven by a prime-mover at constant speed (ω) and the armature side is left open (load resistance disconnected). In this case a change in the excitation current I_f causes a corresponding change in the induced voltage E. This is indicated in the following relation

$$E = k k_f I_f \omega$$

It is clear that the induced voltage is directly proportional to the field current. However, as the filed current $I_f$increased, the machine core saturates and the voltage tends to increase at a lower rate. See Fig.3

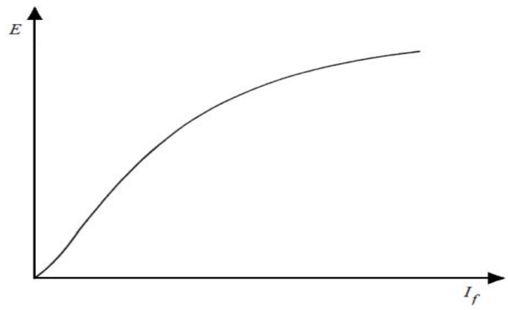


Fig.3 Open circuit characteristic

Running the separately generator under the load-condition, with constant speed and field current, always produces an armature current that is related to terminal voltage according to this equation

$$V_T = E - I_a R_a \qquad E: constant$$

The two parameters are inversely related, which means, a rise in the load current (armature current) often leads to a slight drop in the terminal voltage. This is due to armature resistance and armature reaction. See Fig.4

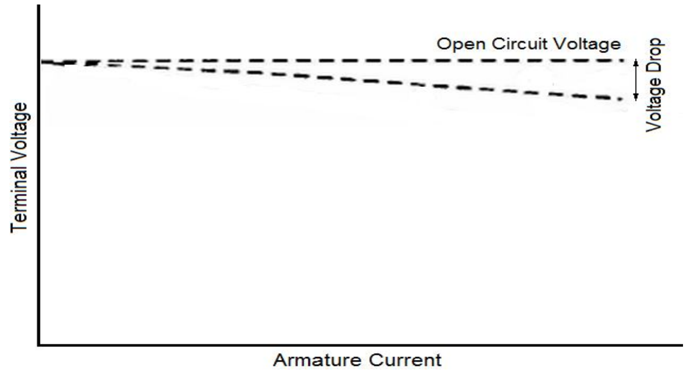


Fig.4 Load characteristic of DC separately generator

Experimental Procedure

Load test on DC series generator

1. Ensure that the resistive load *RL-1/EV*, two meters *AZ-VI*, DC-machine *M1-2/EV*, Induction Motor *M4/EV* and the frequency drive *VSD-1/EV* are all present at you workbench
2. Note down the DC machine name's plate *M1-2/EV* and identify the connection terminals
3. In according to the circuit in Fig.5, carefully connect the DC series generator
4. Use the control knob in*VSD-1/EV* to bring the generator speed at 2500rpm
5. Refer to the list of settings in table-1 and adjust the resistance of *RL-1/EV* accordingly
6. With each step measure the terminal voltage and load-current
7. Note down the measurements in table-1
8. Switch off the *VSD-1/EV* supply and disconnect the circuit
9. Based on the experimental data in *table-1,* draw the output characteristic curve between (V_T versus I_L) and (P_{out} versus I_L)

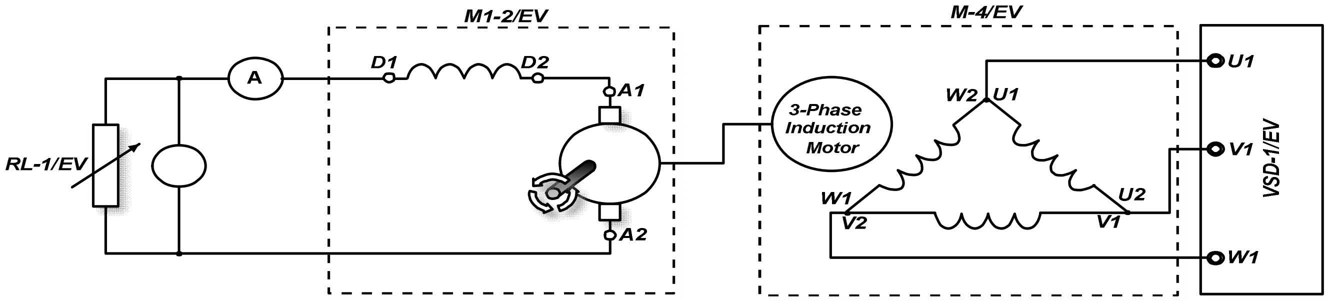


Fig.5 Load test of DC series generator

n (rpm)	RL-1/EV Settings	(Ω)	$I_f = I_a = I_L$ (A)	V_T (V)	P_{out} (w)
2800	*No load*				
2800	*ABC*				
2800	*ABC C*				
2800	*ABC AC*				
2800	*ABC BC*				
2800	*ABC ABC*				
2800	*ABC ABC A*				
2800	*ABC ABC B*				
2800	*ABC ABC AB*				
2800	*ABC ABC C*				

Table-1 Experimental data of DC series generator

Open circuit test of DC separately excited generator

1. In this part of the experiment you will perform an open circuit test by simply connecting the DC separately generator in accordance to *Fig.6*
2. After checking the wiring, turn-on the *VSD-1/EV* drive and bring the speed at low-mode *1800rpm*
3. At this mode use the DC supply *AV-1/EV* to slowly increase the field current in small five steps and observe the rise of voltage across the terminals *(A1 & A2)*
4. In each step measure the induced voltage E and tabulate the results in the top part of *Table-2*
5. Put the prime mover *VSD-1/EV* at high speed mode *3000rpm* and again increase the field current in small five steps to measure the induced voltage E
6. Tabulate the results in the bottom part of *Table-2*
7. Switch off the supply unit *AV-1/EV* and dismantle the whole circuit
8. Draw the internal characteristic curves indicating the (induced voltages E with respect to field currents I_f) and (speed ω with respect to induced voltages E)

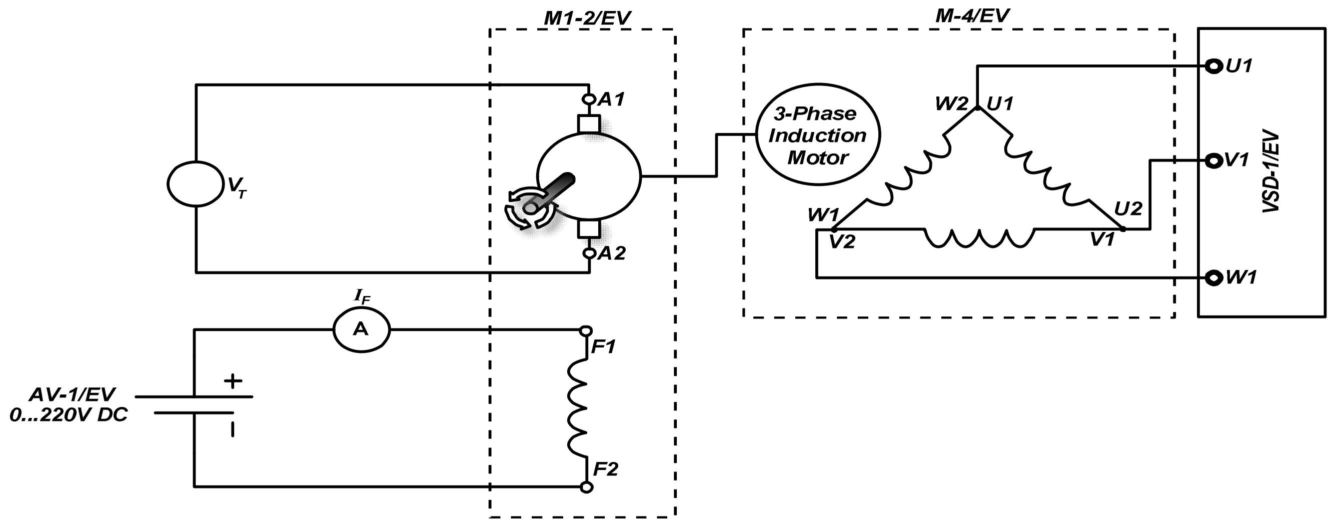


Fig.6 Open circuit test of DC separately excited generator

Speed Mode	n (rpm)	I_f (A)	V_f (V)	$E = V_T$ (V)
Low Speed	1800	0		
		0.02		
		0.04		
		0.06		
		0.07		
		0.09		
		0.10		
High Speed	2800	0		
		0.02		
		0.04		
		0.06		
		0.07		
		0.09		
		0.10		

Table-2 Experimental data for open circuit test

Load test on DC separately excited generator

1. This experiment may have to be carried out using an adjustable resistive load *RL-1/EV* to study the output characteristic curve (current-voltage relationship).
2. Connections are to be made in accordance to the circuit in *Fig.7*
3. Double check the wiring and choose a maximum value for *RL-1/EV* (2200Ω)
4. Bring the speed of prime mover *VSD-1/EV* at *3000rpm* and keep it constant throughout the experiment.
5. Set the field supply at *150V DC* and raise the resistive load *RL-1/EV* in steps (see the list of settings in Table-3), With each step measure the V_T and I_L and tabulate these readings in table-3

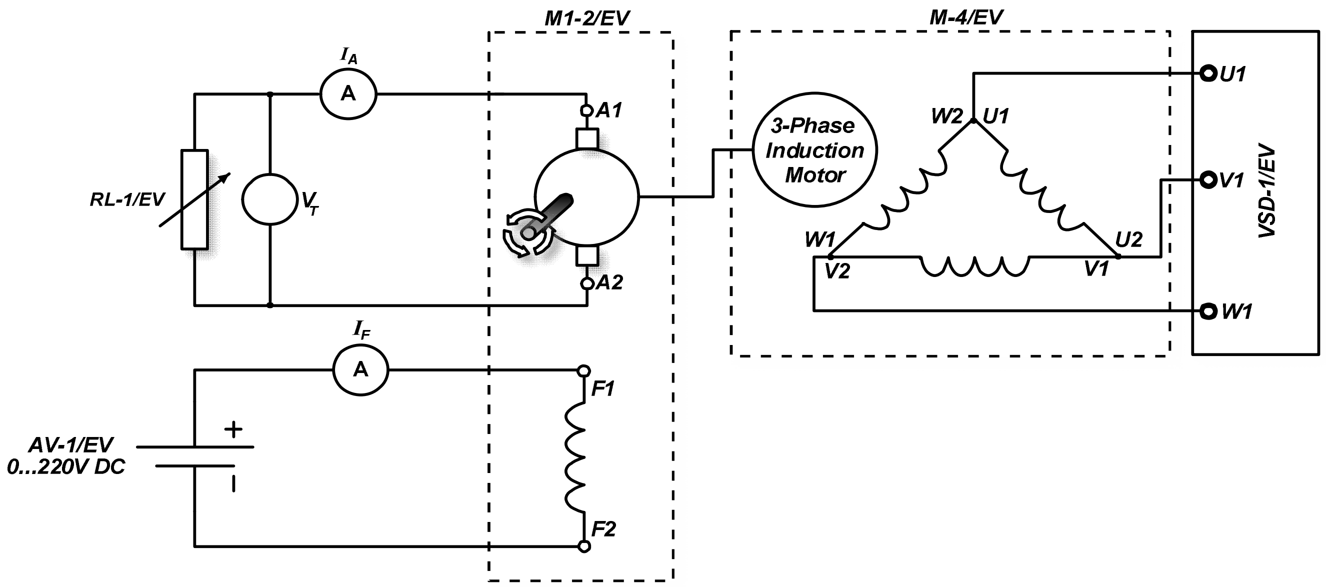


Fig.7 Load test of DC separately generator

n (rpm)	V_f (A)	I_f (A)	RL-1/EV Settings	RL-1/EV (Ω)	$I_a = I_L$ (A)	V_T (V)	P_{out} (w)
2800	150		*No load*				
2800	150		*B*				
2800	150		*C*				
2800	150		*BC*				
2800	150		*ABC A*				
2800	150		*ABC AB*				
2800	150		*ABC AC*				
2800	150		*ABC ABC*				
2800	150		*ABC ABC A*				
2800	150		*ABC ABC B*				

Table-3 Experimental data for separately excited generator

6. Raise the field voltage upto *220V DC* and once again adjust the resistive load *RL-1/EV*
7. Tabulate your readings in *table-4*
8. Switch off *VSD-1/EV* and dismantle the whole circuit

n (rpm)	V_f (A)	I_f (A)	RL-1/EV Settings	RL-1/EV (Ω)	$I_a = I_L$ (A)	V_T (V)	P_{out} (w)
2800	220		*No load*				
2800	220		*B*				
2800	220		*C*				
2800	220		*BC*				
2800	220		*ABC A*				
2800	220		*ABC AB*				
2800	220		*ABC AC*				
2800	220		*ABC ABC*				
2800	220		*ABC ABC A*				
2800	220		*ABC ABC B*				

Table-4 Experimental data for separately excited generator

Analysis

1. With reference to the data in table-3 calculate P_{out} and draw the output characteristic curve showing the relative change of terminal voltage V_T with respect to load current I_L
2. Draw a second curve to show the relationship between P_{out} & V_T
3. Calculate the voltage regulation for both; separately excited generator and series generator
4. From the open circuit test for separately excited generator, Explain the reason why there is a small induced voltage at no-load

Experiment-3
OCT & SCT Test for 1-φ Transformer

Objectives

The experiment demonstrates the concept of open-circuit and short-circuits testing that will be performed on 1-phase transformer. From these tests, it is possible to determine the transformer equivalent circuit and study the excitation and magnetization currents

Apparatus Required

- Power supply unit *PS189*
- 2 X Resistor banks *LU178*
- Transformer trainer *TT179*
- Standalone transformer
- External Wattmeter

Theory

The circuit diagram shows a traditionally accepted model of single phase transform. This model is called an equivalent circuit where all the transformer's parameters including voltage, currents and impedances are referred to the primary side.

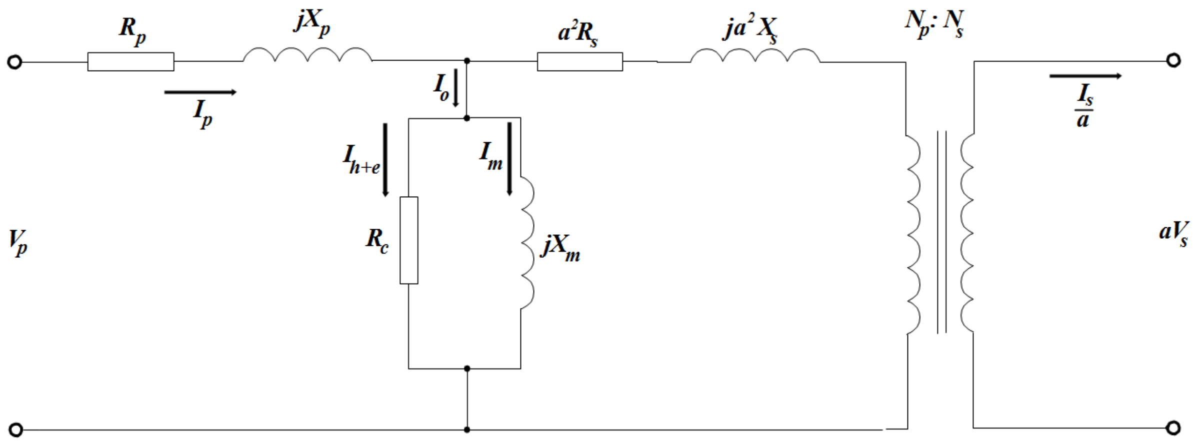


Fig.1 Equivalent circuit of a transformer

In a practical transformer there is always a leakage reactance associated with each winding: these are primary leakage reactance X_p and a secondary leakage reactance X_s. In addition, each winding has some resistance represented by the primary resistance R_p and secondary resistanceR_s. The core of a transformer is subjected to an alternating current causing eddy current losses and hysteresis losses. The sum of these two losses is known as a core-loss and represented by R_c. Core-loss is in parallel with the magnetizing reactance X_m. Thus the no-load current $I_o$drawn from the supply is the sum of core-loss current I_{h+e} and the magnetizing current I_m. It should be noted that the no-load current is about 2-5% of rated current I_1. When running a transformer at no-load, the following phasor diagram can be obtained, I_m lags V_P by 90° and I_{h+e} is in phase with V_P

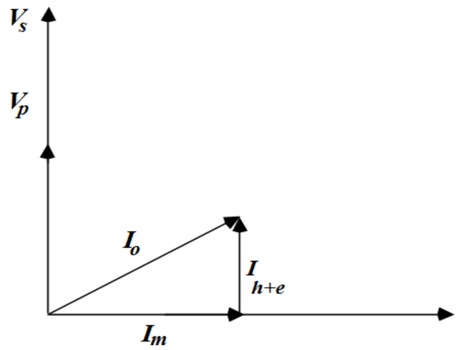


Fig.2 Transformer phasor-diagram at no-load

The excitation current I_o is very small compared to the load current. Because of this a simplified equivalent circuit can be produced that works almost in much the same way as the original model

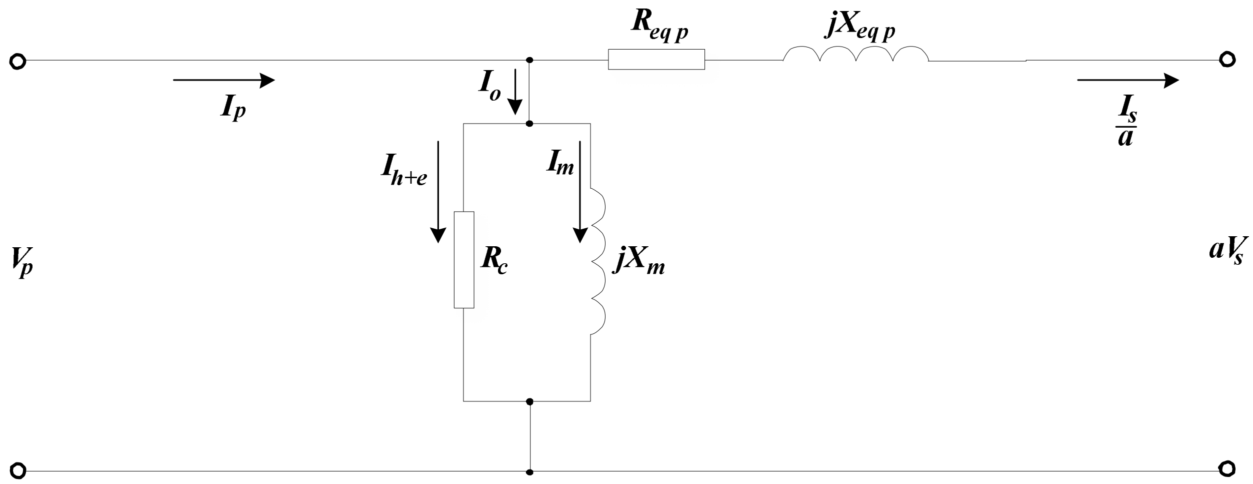


Fig.3 Approximate model of transformer equivalent circuit

The excitation branch is shifted towards the front side and the primary and secondary impedance are left to be added in series with each other.

$$R_{eq\,p} = R_p + a^2 R_s$$
$$X_{eq\,p} = X_p + a^2 X_s$$

<u>Transformer losses and efficiency</u>

Total transformer losses can be divided into two components: no-load losses P_{oc} (core-lossesP_{core}) and load losses P_{sc} (copper losses P_{Cu}). The no-load losses are considered constant and occur at all times regardless of the load conditions. The hysteresis and eddy current losses P_{h+e}contribute over 99% of the no-load losses.

Copper losses $P_{Cu}$is a form of heat dissipation that occurs as a result of current that passes through primary and secondary resistances R_1 and R_2, copper loss is variable and depends on the load current. Short circuit test is the only method that gives an accurate measurement of copper losses.

The efficiency varies with output current

To calculate transformer efficiency in any condition we must first measure P_{core} and P_{sc} using open and short circuit tests. By referring to Fig.4, the efficiency often takes the shape of curve that start from zero and reach the maximum and then drop back to zero again,

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%$$

$$\eta = \frac{P_{out}}{P_{out} + P_{core} + P_{Cu}} \times 100\%$$

$$\eta = \frac{V_s I_s cos\theta}{V_s I_s cos\theta + P_{oc} + P_{sc}} \times 100\%$$

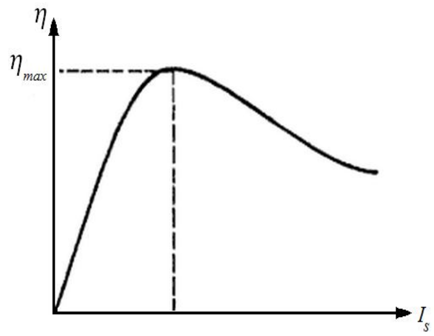


Fig.4 Efficiency curve of a transformer

Open Circuit Test

The open circuit test is performed on a single phase transformer to estimate the core-loss R_c and the magnetizing reactance X_m. In this test, one side of the transformer is left in open circuit condition, while the rated voltage is applied to the other side. Since this test requires application of rated voltage, it is convenient to keep the high-voltage side in open circuit condition as shown in the following figure.

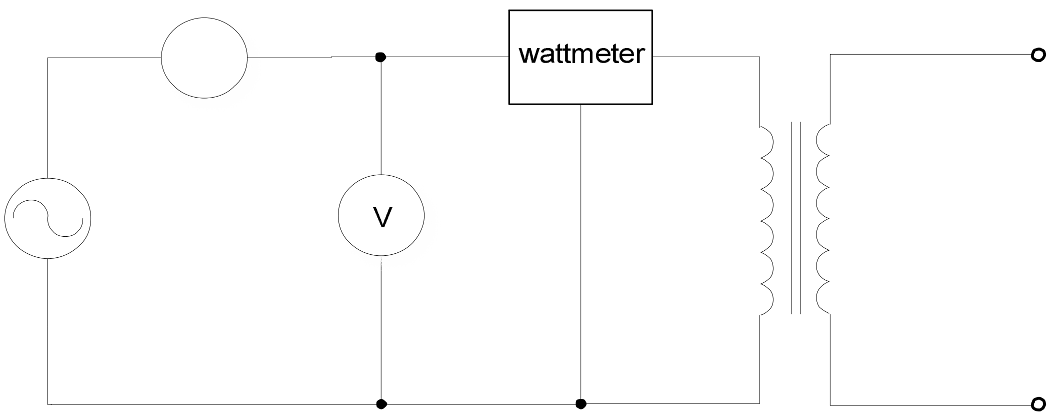


Fig.5 Transformer connection during open-circuit test

With reference to the devices connected on the primary side, the following can be measured: Open-circuit voltageV_{oc} , open-circuit current I_{oc} and the core-lossP_{oc}

$$pf = cos\theta = \frac{P_{oc}}{V_{oc} \times I_{oc}}$$

$$\theta = cos^{-1}\frac{P_{oc}}{V_{oc} \times I_{oc}}$$

$$Y_E = \frac{I_{oc}}{V_{oc}}\angle-\theta^{\circ}$$

$$Y_E = \frac{1}{R_c} - j\frac{1}{X_m} \qquad Y_E: excitation\ admittance$$

Short Circuit Test

The short circuit test is performed on the transformer to estimate the series resistance and reactance of the two windings. In this test, the secondary side of the transformer is short circuited, and the rated current is allowed to flow into the transformer from the primary side.

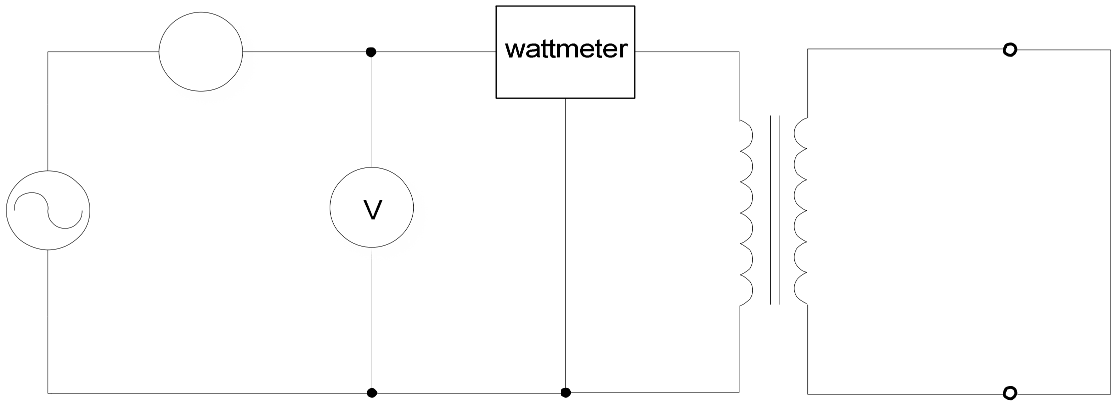


Fig.6Transformer connection during short-circuit test

$$pf = cos\theta = \frac{P_{sc}}{V_{sc} \times I_{sc}}$$

$$\theta = cos^{-1}\frac{P_{sc}}{V_{sc} \times I_{sc}}$$

$$Z_{SE} = \frac{V_{sc}}{I_{sc}}\angle\theta^{\circ}$$

$$Z_{SE} = R_{eq} + jX_{eq} \qquad Z_{SE}: Impedance\ of\ series\ equivalence$$

Experimental Procedure

Open circuit test

1- The circuit in *Fig.7* shows the experimental setup for the single phase transformer under open circuit test.

2- While building the circuit, ensure that the terminals *2.2 & 3.1* are attached together

3- The correct settings of wattmeter have to be always selected to obtain accurate readings

4- Gradually increase the supply voltage until a rated voltage of *220 VAC* is observed on voltmeter V1.

5- Note down the readings of each: primary voltmeter *V1*, primary ammeter *A1*, wattmeter and the secondary voltmeter *V2*

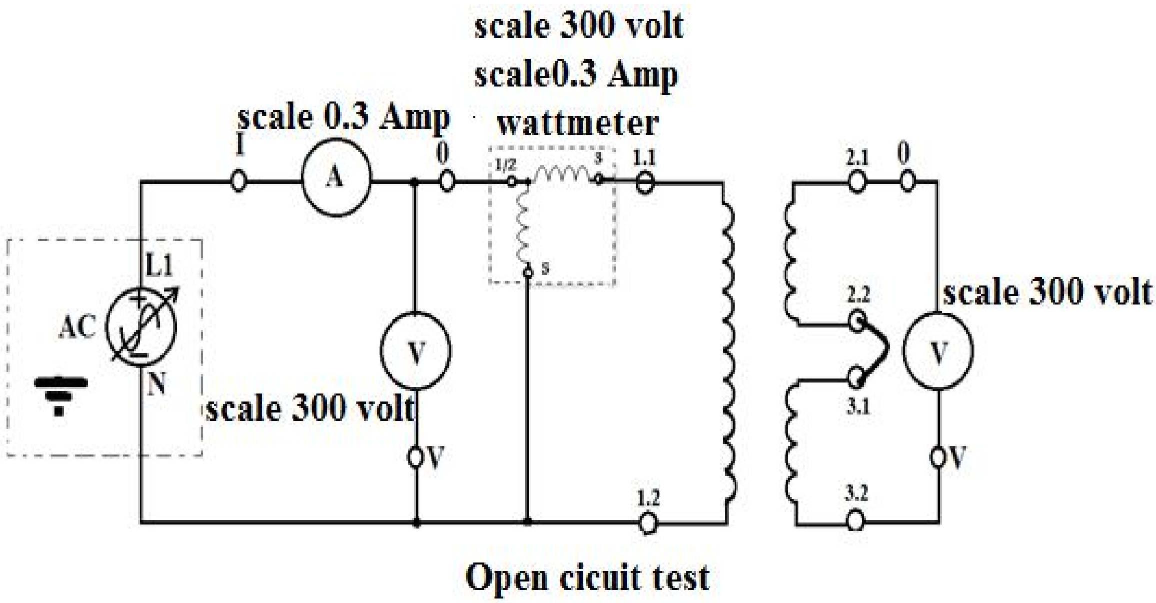


Fig.7 Open circuit test

V1 (Voc) Volt	I1 (Ioc) Amp	P1 (Poc) Watt	V2 Volt
220			

Table-1 Experimental results of open circuit test

Short-circuit test

1. Switch-off the power-supply by turning the control knob completely back to zero
2. Replace the secondary voltmeter with an ammeter
3. Reconfigure the voltage and current ranges according to the circuit diagram *Fig.8*

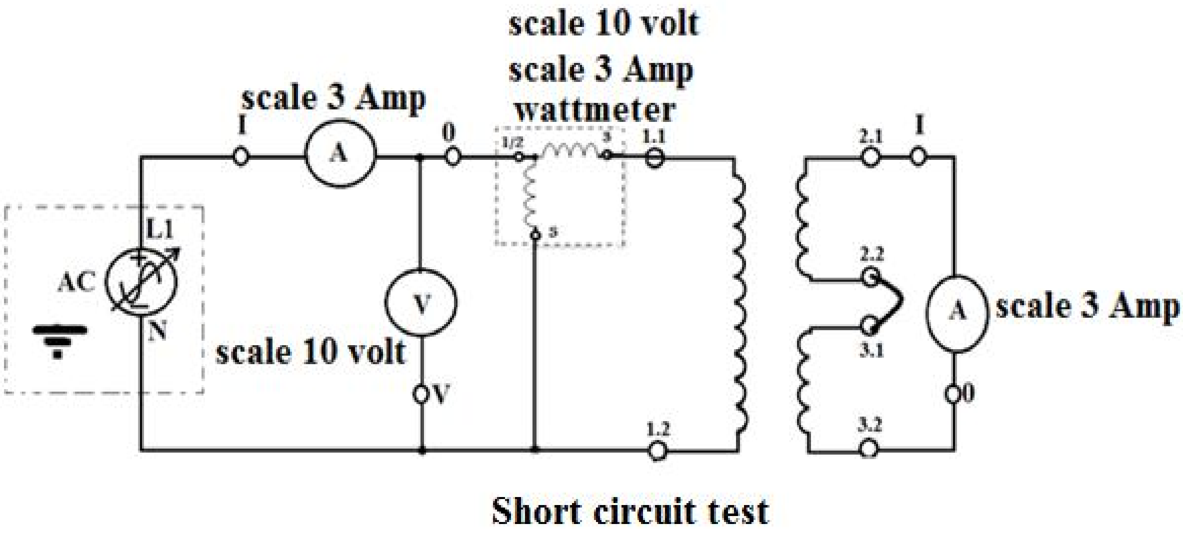


Fig.8 Short circuit test

4. Use the control knob to gradually raise the supply voltage until a short-circuit current (I_{sc} = 1.36A) on the secondary ammeter is attained
5. Record the readings of :primary voltmeter *V1*, primary and secondary ammeters *A1 & A2*, in addition to the wattmeter reading

V1 (Vsc) Volt	I1 (Isc) Amp	P1 (Psc) Watt	I2 Amp
			1.36 Amp

Table-2 Experimental results of short circuit test

Efficiency Test

1. The open and short circuit tests are typically performed to determine the transformer's efficiency. Refer to efficiency formula as indicated in page-22.
2. The core-losses or P_{oc} in a given transformer remains always unchanged (under all operation conditions). Therefore, the P_{oc} column in *Table-3* is to be filled with the same reading being measured in *Table-1*
3. While keeping the last circuit connected on , vary the supply voltage in several steps and observe the ammeter reading A_2 as in Table-3 with each step note down the wattmeter reading in *table-3*

Remark "The rated full load values: V =220 Volt, I = 1.36 Amp"

% of full load	I2 Amp	Wattmeter scales	Pout watt	Pcore (Poc) Watt	Pcopper (Psc) Watt	Poc+ Psc (A)	Pinput Watt (B)	A/B	Efficiecy η% 100 (1- A/B)
25%	0.34	1A , 3V	75						
50%	0.68	1A , 10V	150						
75%	1.02	1A , 10V	225						
100%	1.36	3A , 10V	300						
125%	1.7	3A , 30V	375						

Table-3 Experimental results of transformer test

Analysis

1. Based on the results obtained from the open-circuit test, calculate the core-loss and the magnetizing reactance
2. From the measurement of short-circuit test, calculate the equivalent resistance and the equivalent reactance
3. Draw the complete equivalent circuit showing the calculated parameters
4. Find the magnetizing current, hysteresis & eddy-current and excitation current
5. Draw the complete phasor-diagram showing the above mentioned currents
6. Use the measured values of P_{out}, P_{oc} and $P_{sc}$to calculate and draw the efficiency curve with respect to secondary current
7. On the efficiency drawing, pin-point the maximum efficiency and observe the values of P_{sc} and P_{oc} (are they equal or not)

Experiment-4
DC Shunt and Compound Generators

Objectives
This experiment is intended to state the differences between the shunt and compound DC generator in terms of; external characteristic and voltage regulation
To study and analyze the steady state performance of cumulative compound and differential compound DC generators. Also, to examine how the generated voltage is influenced by varying the electrical load

Apparatus Required
- Power Supply Unit*AV-1/EV*
- Adjustable Resistive Load *RL-1/EV*
- Series Field Rheostat *RC1a*
- 3X Voltage & Current Meters *AZ-VI*
- Variable Frequency Drive *VSD-1/EV*
- DC Machine (Configured as Shunt and Compound Generators) *M1-2/EV*
- 3-Phase squirrel-cage Induction Motor (Act as a Prime-Mover) *M-4/EV*

Theory
<u>DC shunt generator</u>
In this generator, the field winding R_f is connected across the armature. Hence, the terminal voltage V_T is also the field voltage V_f and the armature current is the sum of load and field currents.

$$I_a = I_f + I_L$$

When the rotor of this machine is rotated see Fig.1, the residual flux $Ø_r$ in the field circuit will setup a small induced-voltage E across the armature. This generates a small current through the field winding. And a field flux $Ø_f$ will also be generated.

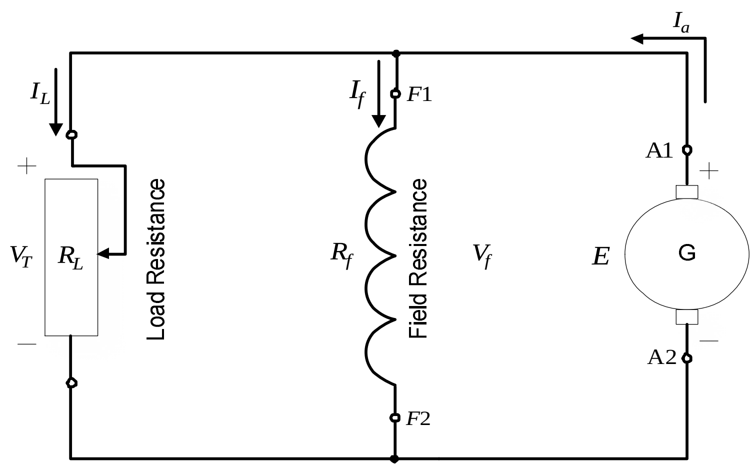


Fig.1 Typical circuit diagram of DC shunt generator

The polarity of the field winding (leads direction) determines the field flux polarity, if the polarity of the field flux $Ø_f$ is in the same direction as the residual flux $Ø_r$. The total air gap flux $Ø_t$ increases leading to a voltage buildup. On the other hand, if the field polarity has been reversed the two fluxes $\emptyset_r$ and $\emptyset_f$ will oppose one another, leading to a failure in building up the voltage

The excitation current I_f in a shunt-wound generator is dependent upon the field resistance. Normally, field excitation is maintained between 0.5 to 5 percent of the armature current. Increasing the load on the shunt generator, results in a significant voltage drop across the output terminals. This is because of the reduction in the field current that weakens the flux which in turn it affects the induced voltage.

<u>DC compound generator</u>

Series-wound and shunt-wound generators have a disadvantage in that changes in load current cause changes in generator output voltage. Many applications by which generators are used require a more stable output voltage than can be supplied by a series-wound or shunt wound generator. One means of supplying a stable output voltage is by using a compound generator. The compound generator has a shunt field R_{sh} in parallel with the generator armature (the same as a shunt-wound), and a field winding in series with the generator armature R_s, see Fig.2

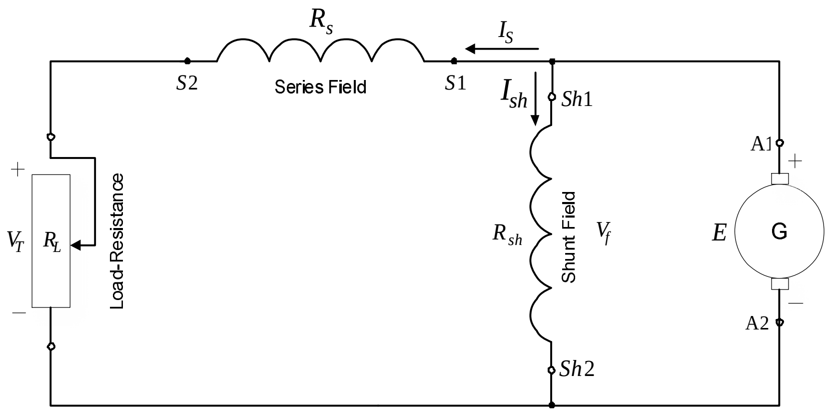


Fig.2 Equivalent circuit model of DC compound generator

The windings of the compounded generator are made such that their magnetic flux will either aid or oppose one another. If the two fields are wound so that their fluxes oppose one another *i.e.* $\emptyset_{sh} - \emptyset_s$, the generator is said to be *differentially-compounded*.

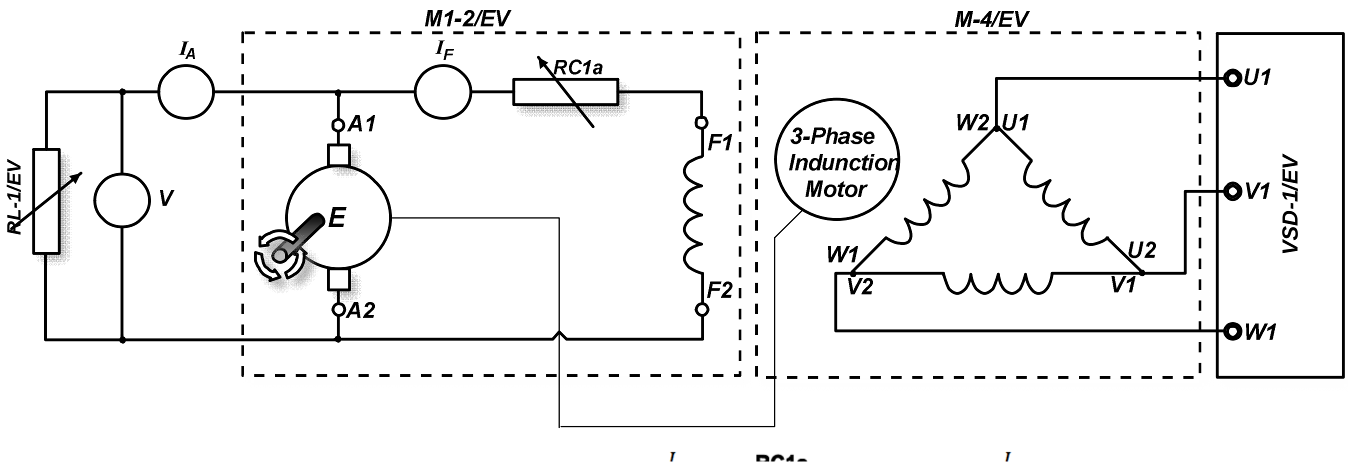
If the two fields are wound so that their magnetic fields aid one another *i.e.* $\emptyset_{sh} + \emptyset_s$, the generator is said to be *cumulatively-compounded*

As the load current increases, the current through the series field winding increases, increasing the overall magnetic field strength and causing an increase in the output voltage of the generator. With proper design, the increase in the magnetic field strength $\emptyset_s$ of the series winding will compensate for the decrease in shunt field strength $\emptyset_{sh}$. Therefore, the overall strength of the combined magnetic fields remains almost unchanged, so the output voltage will remain constant. In reality, the two fields cannot be made so that their magnetic field strengths compensate for each other completely. There will be some change in output voltage from the no-load to full-load conditions.

Experimental Procedure

<u>Output characteristics of DC shunt generator</u>

1. Construct the circuit implementing the DC shunt generator as presented in *Fig.3*
2. Note down the name plate of DC machine *M1-2/EV* and measure the field resistance
3. keep the field resistance *RC1a* and resistive load *RL-1/EV* at mid point
4. Bring the speed of prime mover VSD-1/EV at 2800rpm and leave it fixed throughout the experiment then vary the value of *RC1a* to obtain the rated field current *If =0.11 amp*
5. Measure the no-load voltage
6. Firstly, setup the *RL-1/EV* resistance at 2200Ω and measure the field current I_f, load current I_L& terminal voltage V_T
7. Vary the resistive load *RL-1/EV* in accordance to the list of settings in *table-1* and repeat the last measurements
8. Tabulate the readings in *table-1*



n (rpm)	RL-1/EV Settings	(Ω)	I_f (A)	I_L (A)	V_T (V)	P_{out} (w)
2800	*No Load*					
2800	*B*					
2800	*C*					
2800	*BC*					
2800	*ABC A*					
2800	*ABC AB*					
2800	*ABC BC*					
2800	*ABC ABC AB*					
2800	*ABC ABC AC*					
2800	*ABC ABC ABC*					

Table-1Experimental data of DC shunt generator under load tests

Output characteristics of differential compound generator

1. Construct a DC compound generator implementing the circuit in *Fig.4*
2. Set the field rheostat *RC1a* at half rated resistance by moving the sliding part (wiper) right in the middle
3. Set the load resistance RL-1/EV at full rated value
4. Bring the prime mover speed *M4/EV* at 3000rpm (Using the control knob of *VSD-1/EV*), and keep it constant throughout the experiment.
5. Measure the no-load voltage (across *RL-1/EV*)
6. Adjust the load resistance *RL-1/EV* at 2200Ω and measure the field current I_f, load current I_L, terminal voltage V_T and power output P_{out}
7. Adjust the resistance *RL-1/EV* in accordance to the list of steps in table-2, with each step repeat the previous measurements
8. Tabulate your readings and disconnect the circuit

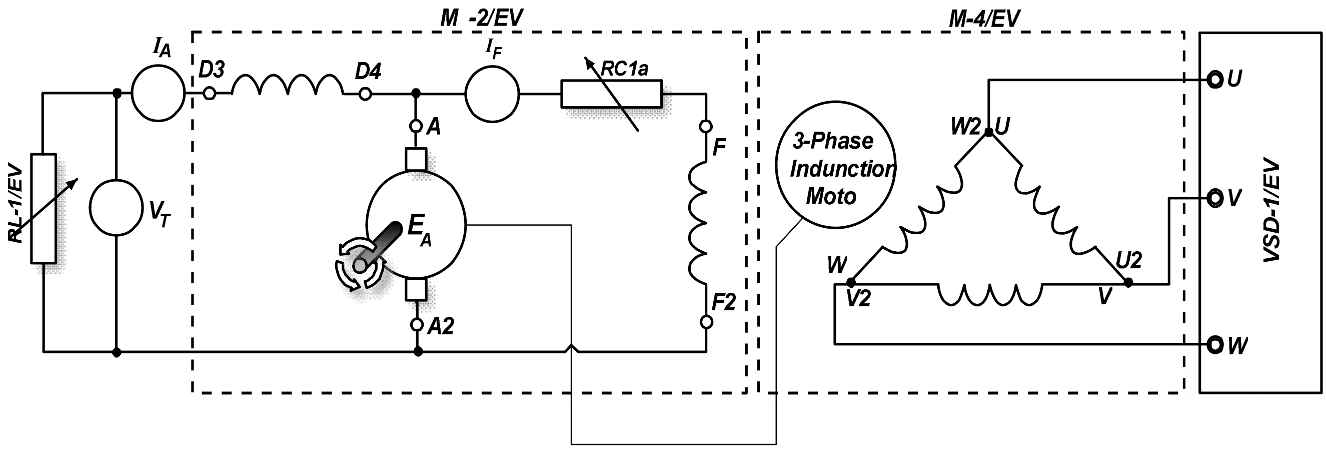


Fig.4 Typical wiring diagram of DC compound generator (Differential-Compound)

n (rpm)	RL-1/EV Settings	(Ω)	I_f (A)	I_L (A)	V_T (V)	P_{out} (w)
2800	*No Load*					
2800	*A*					
2800	*B*					
2800	*AB*					
2800	*C*					
2800	*AC*					
2800	*BC*					
2800	*ABC*					
2800	*ABC A*					
2800	*ABC B*					
2800	*ABC AB*					

Table-2 Experimental data of DC compound generator

Output characteristics of cumulative compound generator

1. Construct a DC compound generator implementing the circuit in *Fig.4*
2. Set the field rheostat *RC1a* at half rated resistance by moving the sliding part (wiper) right in the middle
3. Set the load resistance RL-1/EV at full rated value
4. Bring the prime mover speed *M4/EV* at 3000rpm (Using the control knob of *VSD-1/EV*), and keep it constant throughout the experiment.
5. Measure the no-load voltage (across *RL-1/EV*)
6. Adjust the load resistance *RL-1/EV* at 2200Ω and measure the field current I_f, load current I_L, terminal voltage V_T and power output P_{out}
7. Adjust the resistance *RL-1/EV* in accordance to the list of steps in table-2, with each step repeat the previous measurements
8. Tabulate your readings and disconnect the circuit

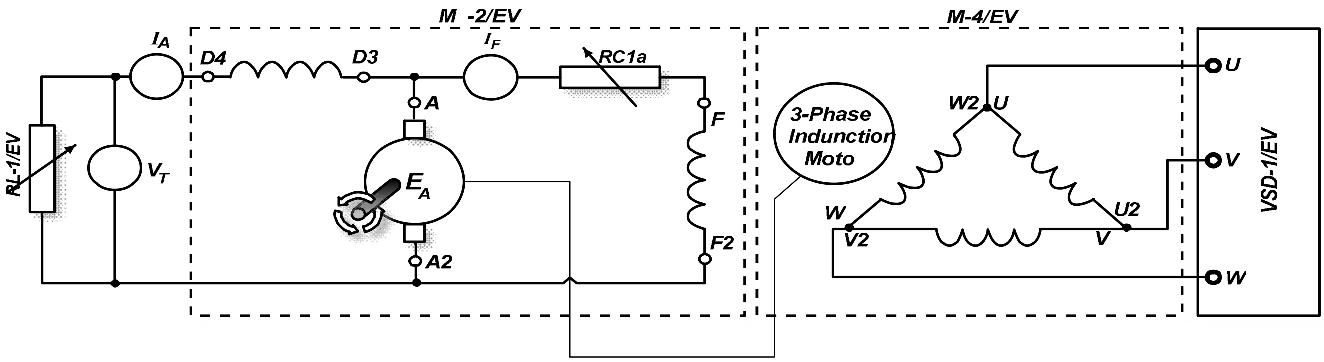


Fig.5 Typical wiring diagram of DC compound generator (Cumulative-Compound)

n (rpm)	RL-1/EV Settings	(Ω)	I_f (A)	I_L (A)	V_T (V)	P_{out} (w)
2800	*No Load*					
2800	*A*					
2800	*B*					
2800	*AB*					
2800	*C*					
2800	*AC*					
2800	*BC*					
2800	*ABC*					
2800	*ABC A*					
2800	*ABC B*					
2800	*ABC AB*					

Table-3Experimental data of DC compound generator

Analysis

1. Draw the relevant characteristic curves for the above mentioned generators, illustrating the relationship between (V_T verses I_L) & (P_{out} verses V_T)
2. Assuming that the full load voltage occurs at *RL-1/EV* = 200Ω. Calculate the voltage regulation for both: DC shunt generator and the compound generator
3. Determine which generator is considered good in terms of speed regulation
4. Explain how the voltage buildup occurs in self-excited generator

Experiment-5

DC Shunt Motor

Objectives

To gain a hands on experience with the wiring and operation of DC shunt motor and to analyze its characteristics under various load conditions. To examine the impacts of applying the techniques of speed control on the DC shunt motor

Apparatus Required

- Power Supply Unit*AV-1/EV*
- Adjustable Resistive Load *RL-1/EV*
- Series Field Rheostat *RC1a*
- Armature Rheostats *RC3-9T*
- 3X Ammeters &2X Voltmeters *AZ-VI*
- Speed-Torque Meter*UM-G1/EV*
- DC Machine (to be configured as Shunt &compound motors) *M1-2/EV*
- Load Unit (DC Generator)*M12/EV*

Theory

DC motors are the obvious choice in applications where DC sources are all that is available; one capability that DC motors possess than the induction and synchronous machines do not, is a precise speed and torque control. One significant advantage of a DC motor is the variety of performance characteristics that can be achieved by interconnecting the field and armature windings in various ways. A shunt wound DC motor results when the field winding is connected in parallel with the armature. If a combination of series and parallel field connections are made. The machine is classified as a compound DC motor

DC shunt wound motor

The field winding in shunt motor is made of a large number of turns of fine wire and connected in parallel with the armature. The armature and field are fed from the same source, and the input current is equal to the sum of armature and field currents.

A shunt wound motor will run at a relatively constant speed regardless of the load. Consider a DC shunt motor running at no-load. If a mechanical load is applied to the shaft, the small no-load current does not produce enough torque to carry the load and the motor begins to slow down. This causes the E_a to diminish, resulting in a higher armature current $I_a$and corresponding higher torque$T$. Therefore, shunt wound motors have a good speed regulation where the difference in speeds from no-load to full-load is ranges between 10-15%

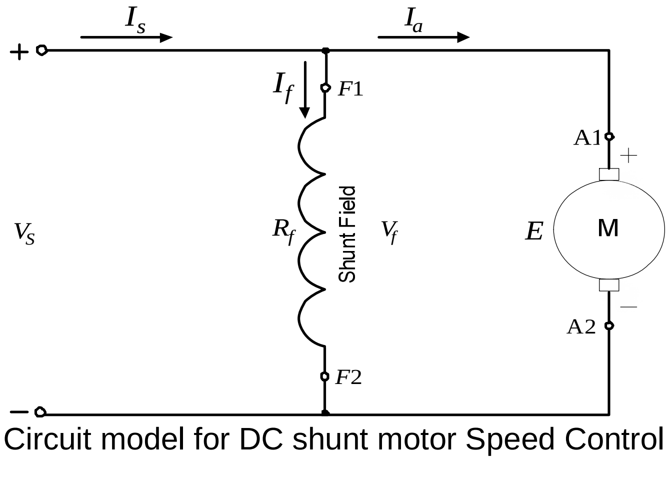


Fig.1 Circuit model for DC shunt motor Speed Control

DC motors including the shunt wound type have an advantage over AC motors in, terms of variable speed characteristics. This means, they can be driven over a wide range of speed. Speed control techniques including

1) Armature voltage control
2) Armature resistance control
3) Field flux control

These techniques can be implemented to obtain speeds over or under the rated speed. If for example, we desire a speed greater than the rated speed; the field flux control shall be used. On the other hand, the other two techniques are used to provide a speed control below the rated speed .

It possible to drive a motor at rated speed by applying a full rated voltage on the field and armature circuits.

The speed of a DC shunt motor can be expressed according to this relationship

$$\omega = \frac{V_T - I_a R_a}{k\emptyset}$$

V_a: Supply voltage
I_a: Armature current
$\emptyset$: Field flux

In certain applications involving the shunt wound motor its desirable to control the speed below the rated value. The technique of armature voltage control is no longer recommended. However, armature resistance control is a very useful where a variable resistance is typically inserted in series with the armature, see Fig.2. Increasing the series resistance result in a significant drop in armature voltage E_a, leading to a decrease in the motor speedω.

Armature resistance control provides a constant field flux $\emptyset$ thereby the developed torque remains constant. However, the technique is considered wasteful because the series resistance must have a sufficient power rating to dissipate the heat produced by armature current

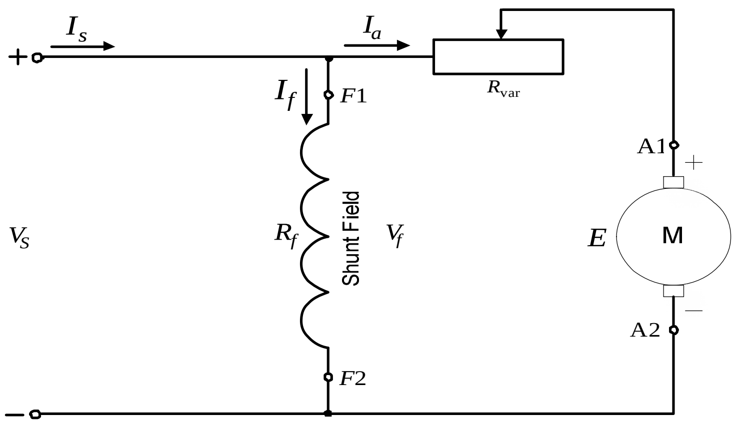


Fig.2 Armature voltage control for DC shunt motor

The technique of field flux control is based on the principle of weakening the field current. This can be achieved by inserted a variable resistor (rheostat) in series with the field winding.
By applying a rated supply voltage to the armature and increasing the resistance of rheostat. The field flux will be reduced and since the speed is inversely proportional with the field flux, the motor will speed-up. However, the torque is directly proportional with the field flux so that the rise of speed will be accompanied by a reduction in torque

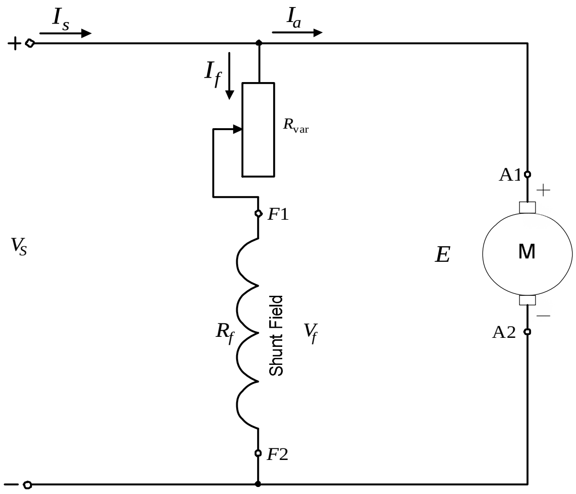


Fig.3 Field Flux control for DC shunt motor

Speed Regulation
Is a term often used in conjunction with electrical motors to describe their capability to maintain a certain speed under varying load conditions; from no-load to full-load

$$speed\ regulation = \frac{No\ Load\ Speed - Full\ Load\ Speed}{Full\ Load\ Speed} \times 100\%$$

Experimental Procedure

Output characteristics of DC shunt motor

1. Note down the name plate of DC machine *M1-2/EV*
2. The experimental setup consists of a DC machine *M1-2/EV*, load unit *M12/EV*, supply unit *AV-1/EV*, Resistive Load *RL-1/EV* and measuring instruments *AZ-VI*.
3. Connect the whole setup in accordance to the circuit in Fig.4
4. Adjust the resistance of field rheostat *RC1a* to about half rated resistance (wiper located in the middle)
5. Adjust the resistance of armature rheostat *RC3-9T* to about half rated resistance
6. Simultaneously, turn the power on for the load-unit *M12/EV* and dc motor *M1-2/EV*
7. Adjust the DC supply *AV-1/EV* to about 220VDC (rated voltage)
8. Initially, set the load resistance *RL-1/EV* at 2200Ω and measure the armature current I_a, field current I_f, terminal voltage V_T, armature voltage E_a, Torque T & speed n
9. Note down the readings in table-2
10. Vary the *RL-1/EV* in accordance to the list of steps in *table-2*, with each step repeat the previous measurements in step-3
11. Switch off the DC power after tabulating the readings

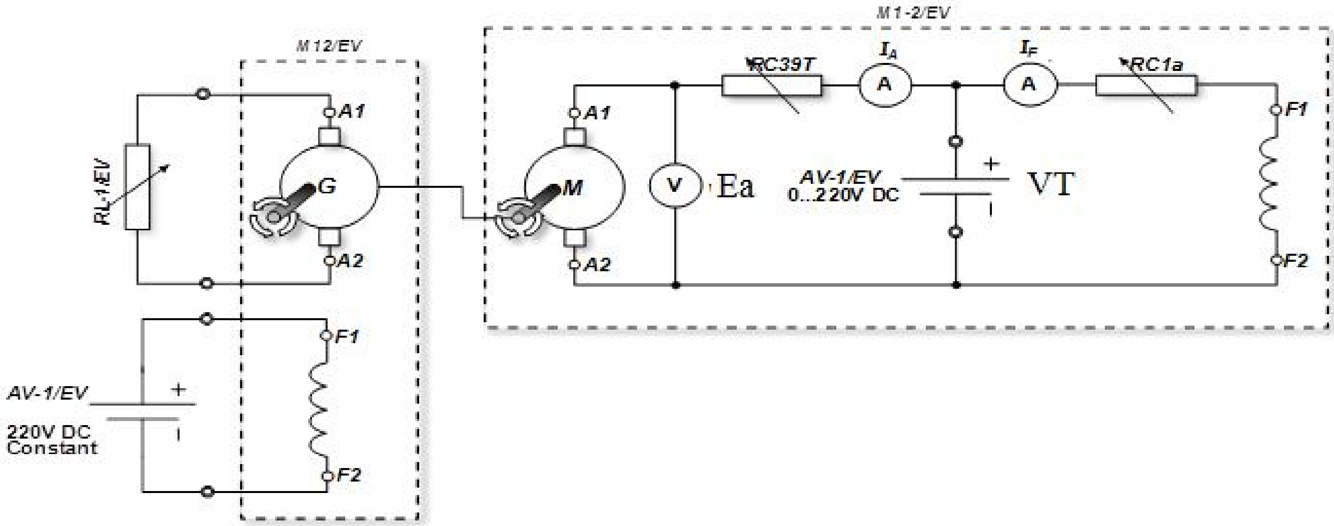


Fig.4 Typical wiring diagram of DC shunt motor

RL-1/EV$(Load)$ Settings	(Ω)	T (N.m)	n (rpm)	V_T (V)	E_a (V)	I_f (A)	I_a (A)	P_{in} (watt)	P_{out} (watt)	η
No Load										
B										
C										
AC										
BC										
ABC										
ABC A										
ABC B										
ABC AC										
ABC BC										

Table-1 Experimental results of load characteristic test

Armature resistance control

1. While the power is turned-off for the circuit in *Fig.1*, set the wiper of *RC3-9T* rheostat right at the maximum (full rated resistance)
2. Turn the power back on at *220VDC* for both DC motor *M1-2/EV* and load unit *M12/EV*
3. Initially, set the load resistance *RL-1/EV* at 2200Ω and measure the armature current I_a, field current I_f, terminal voltage V_T, armature voltage E_a, Torque T & speed n
4. Note down the readings in table-2
5. Vary the *RL-1/EV* in accordance to the list of steps in *table-2*, with each step repeat the previous measurements in step-3
6. Switch off the DC power after tabulating the readings

RL-1/EV$_{(Load)}$		T	n	V_T	E_a	I_f	I_a	P_{in}	P_{out}	
Settings	(Ω)	(N.m)	(rpm)	(V)	(V)	(A)	(A)	(watt)	(watt)	η
No Load										
B										
C										
AC										
BC										
ABC										
ABC A										
ABC B										
ABC AC										
ABC BC										

Table-2 Experimental results of armature resistance control

Field Flux Control

1. Check that the armature rheostat *RC3-9T* is set at half rated value (wiper moved back to the middle)
2. Put the power back on for both field and armature circuitries
3. Field flux control is performed with help of field rheostat *RC1a,* just gradually increase the resistance in small steps (see table-3) and observe the rise of speed
4. Note down the readings of field current I_f , armature current I_a, and speed n in table-3
5. Switch the power off and disconnect the circuit

V_T (V)	I_a (A)	*RC1a* Resistance (Ω)	I_f (A)	n (rpm)
220		0		
220				
220				
220				
220				
220				
220		max		

Table-3 Experimental results of field flux control

Analysis

1. Based on the results of table-1, calculate the P_{in}, P_{out} & η.
2. Draw the relative speed-torque relationship taking into consideration that the torque is presented on the x-axis.
3. Determine and compare the speed regulation of DC shunt motor under output characteristics test and armature resistance control test
4. Draw the relevant characteristic curves for armature resistance control and field flux control illustrating the relationship between (I_a verses n) & (I_f verses n)

Experiment-6
Poly-phase Induction Motor

Objectives

Perform a no-load test and a blocked-rotor test to evaluate the physical parameters of the motor's circuit and subsequently develop the equivalent circuit of the motor. Also, we will study the output characteristics by observing the motor behavior at different loads.

Apparatus Required

- DC Power Supply*AV-1/EV*
- Power analyzer meter *AZ-VIP*
- Speed-Torque meter *UM-G1/EV*
- Measurement Devices *TSI/EV & AZ-VI/EV*
- DC Sep Excited Gen. *M1-2/EV*
- 3-phase squirrel-cage *M-4/EV*
- Starting rheostat *RC3-9T*

Theory

The poly-phase induction motor is the most commonly used industrial motor, finding applications in industrial machineries where speed regulation is not essential. It is simple and relatively inexpensive, and the absence of sliding contacts with the rotor reduces maintenance to minimum. There are two general types of poly-phase induction motors: the squirrel-cage type and the wound-rotor machine. Both motors have a stator structure similar to that of the synchronous generator, consisting of three individual windings which overlap one another and offset by an electrical angle of 120°.The phase displacement between the voltages applied to the stator windings produces a travelling MMF or rotating magnetic field in the uniform air gap. This field links the short-circuited rotor bars, and the relative motion induces short-circuit currents in them, which move about the rotor in exact synchronism with the rotating magnetic field. It is well known that any induced current will react in opposition to the flux linkages producing it, resulting herein a torque on the rotor in the direction of the rotating field. This torque causes the rotor to revolve. If the rotor were to revolve at exactly synchronous speed, there would be no changing flux linkages about the rotor coils and no torque would be produced. However, the practical motor has friction losses requiring some electromagnetic torque, even at no-load, and the system will stabilize with the rotor revolving at slightly less than synchronous speed.

If the stator coils are connected to AC supply, the coils become magnetized and generate a rotating magnetic field that rotates at a speed known as synchronous speed (n_s):

The following equation clarifies the relationship between the synchronous speed and mains frequency.

$$n_s = \frac{120.f_s}{p}$$

The difference in speed between rotor and rotating magnetic field is termed "slip" which is numerically equal to:

$$s = \frac{syncronous\ speed - rotor\ speed}{syncronous\ speed} = \frac{n_s - n_r}{n_s}$$

At no-load the slip is relatively zero, whereas at full loads it become close to 1. The slip normally affects the frequency of the induced emf in the rotor bars. If the slip is increased due to mechanical load, the f_r will accordingly increase according to the following relationships.

$$f_r \;\; = s.f_s$$

When the rotor is at standstill (s=1), the rotor frequency will be the same as the stator frequency (f_r = f_s). Hence the rotor current I_2 increases; in the same way the stator current I_1 will also be increased, resulting in coils overheating. Therefore, blocking the rotor for longer period of times should be avoided to prevent overheating and damaging the stator coils.

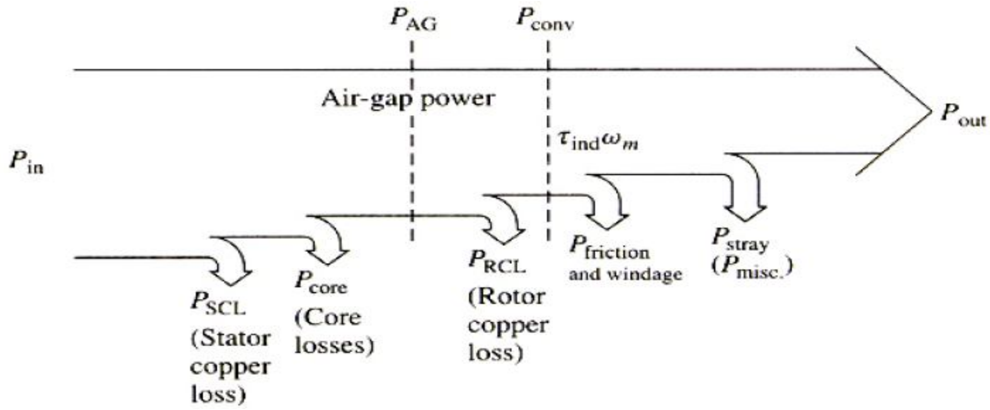


Fig.1 Power flow diagram

The 3-phase power input $p_{in}$to an induction motor is

$$p_{in} \; = 3V_1 I_1 cos\theta_1$$

The applied input power p_{in} encounters two types of losses; stator copper-loss P_{SCL} = $3I_1^2 R$ and Stator core-loss P_{core} which is dissipated in the form of hysteresis and eddy current losses

The remainder power (air gap power P_g) is transferred from the stator to the rotor via the air-gab. This power

$$P_g = P_{in} - P_{SCL} - P_{cu}$$

Generates an induced emf in the rotor bars, but part of it will be dissipated as a heat due to rotor copper loss

$$P_{cu\,(rotor)} \; = 3I_2^2 R_r$$

The rest of air-gap power will be converted from the electrical power into mechanical power P_m.

$$P_m \; = 3I_2^2 R_2 (\frac{1 - s}{s})$$

In this case the motor shaft will rotate, but it will be subjected to two new different types of mechanical power: friction loss and stray loss. The remaining and the last power is the output mechanical power

$$P_{out} \; = \tau_{load} \omega_m$$

Since there is no enough data to calculate the core, stray and friction losses, we only focus our attention on the copper loss and consider the remaining losses negligible.

Equivalent circuit model

An induction motor is essentially a transformer. In the transformer model the secondary side is electrical where in case of induction motor the load is a mechanical, which can be replaced by an equivalent electrical load given by

$$R_L = \frac{k^2 r_2 (1-s)}{s} \qquad k\text{: Ratio of stator turns to rotor turns per phase}$$

The value of R_L ranges from zero to infinity depends on the mechanical load. For instance, at no-load$R_L = 0$. Whereas at full-load $R_L = \infty$ (open-circuit)

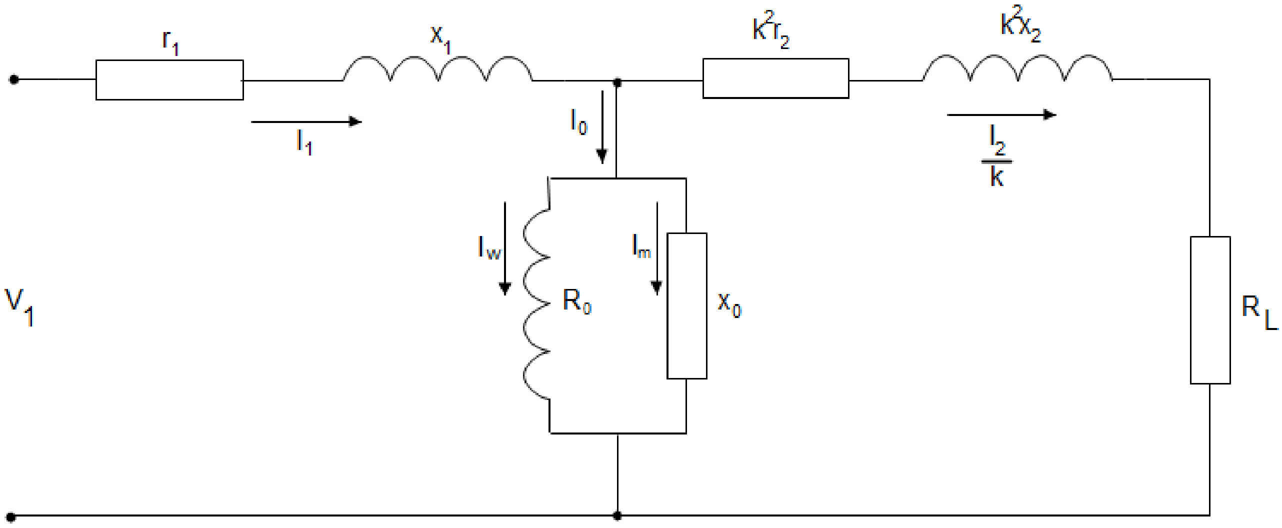


Fig.2 Equivalent circuit model for induction motor

When a voltage V_1 is applied to stator terminals, a flux $\emptyset_m$ is set up. This flux induces emf E_1 in the stator winding. The flow of current I_1 causes voltage drops $I_1 r_1$ and $I_1 x_1$ in the stator winding E_1The $I_1 r_1$, $I_1 x_1$,$E_1$and V_1 are related according to ohms law

$$V_1 = E_1 + I_1(r_1 + jx_1)$$

The mutual flux $\emptyset_m$ induces emfs in stator and rotor. These emfs under running conditions are E_1 and sE_2 respectively. The secondary emf (sE_2) act in much the same way as a secondary supply, which produces a secondary current. The phasor sum of $\frac{I_2}{k}$ and I_0 gives stator currentI_1

The torque developed T is defined as the torque generated due to mechanical power developed by the power conversion process in the motor.

$$T = \frac{P_m}{\omega_m} = \frac{P_m}{2\pi n} = \frac{3I_2^2 r_2}{2\pi n}\left[\frac{1-s}{s}\right] = \frac{P_g}{2\pi n_s}$$

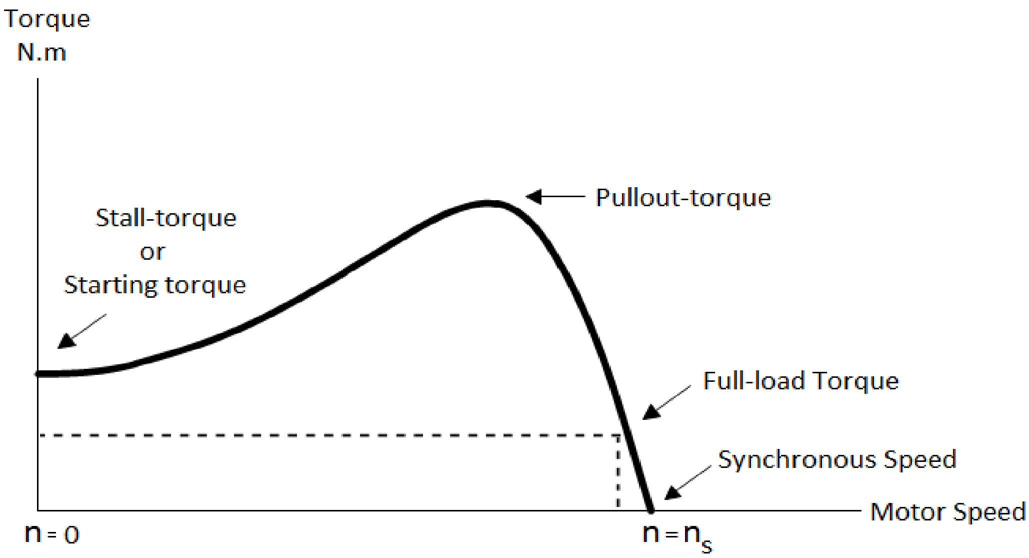


Fig.3 Characteristic Curve of Induction motor

The curve shows the characteristic curve of squirrel cage induction motor, the curve shows several important pieces of information about the motor's operation. For example, the torque is zero at synchronous speed, there is a maximum torque called pull-out torque which is two to three times the rated full-load torque. The starting torque is slightly larger than its full-load torque, so the motor is able to start carrying any load

Experimental Procedure

1. Note down the induction motor name-plate *M-4/EV* and identify the connection terminals
2. Assemble the 3-phase induction motor circuit as indicated in Fig.4
3. Then verify your connections and choose a maximum value of resistive load *RL-1/EV* (say 2200Ω)
4. Using the controls on the supply unit *AV-1/EV* ,Turn-on the supply for the load unit *M-12/EV* and then the 3-phase supply *M-4/EV*
5. raise theV_{ph} of 3-phase supply at 300V and keep it constant throughout the experiment
6. Since the resistive load *RL-1/EV* is set to maximum, the motor *M-4/EV* supposed to be running at synchronous speed (3000-rpm)
7. With reference to the *RL-1/EV* settings in table-1. The load torque shall be increased in progressive steps accordingly.
8. For each step take the necessary measurements of speed, torque, voltage and current and tabulate them in table-1

$V_{L L}$ (V)	RL-1/EV$(Load)$ Settings	(Ω)	I_{line} (A)	n (rpm)	s (100%)	ω (rad/s)	T (N.m)	P_{in} (watt)	P_{out} (watt)	P_f	η (100%)
230	*No Load*										
230	*A*										
230	*B*										
230	*AB*										
230	*C*										
230	*AC*										
230	*BC*										
230	*ABC*										
230	*ABC A*										
230	*ABC B*										
230	*ABC AB*										

Table-1 Experimental data for 3-phase induction motor (wye connected motor)

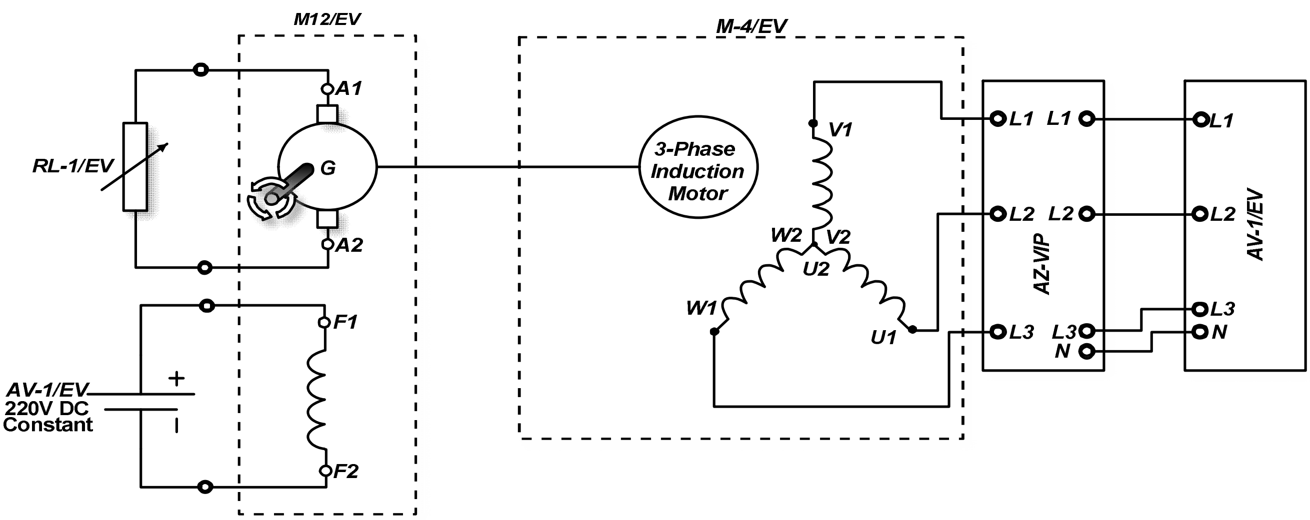


Fig.4 Circuit diagram of 3-phase squirrel cage induction motor

9. Delta connection gives a higher current at lower voltage, compared to wye connection. Thus, motor terminals of *M-4/EV* are to be connected in delta mode (see Fig.5)
10. Notice that the delta connected circuit is identical to Fig.4 apart from the motor connection
11. Start the motor and repeat the steps *6,7 & 8*
12. Once you are done, switch of the supply unit *AV-1/EV* and dismantle the circuit

V_{LL} (V)	RL-1/EV($Load$) Settings	(Ω)	I_{line} (A)	n (rpm)	s (100%)	ω (rad/s)	T (N.m)	P_{in} (watt)	P_{out} (watt)	P_f	η (100%)
230	*No Load*										
230	*A*										
230	*B*										
230	*AB*										
230	*C*										
230	*AC*										
230	*BC*										
230	*ABC*										
230	*ABC A*										
230	*ABC B*										
230	*ABC AB*										
230											
230											
230											

Table-2 Experimental data of 3-phase induction motor (delta connected motor)

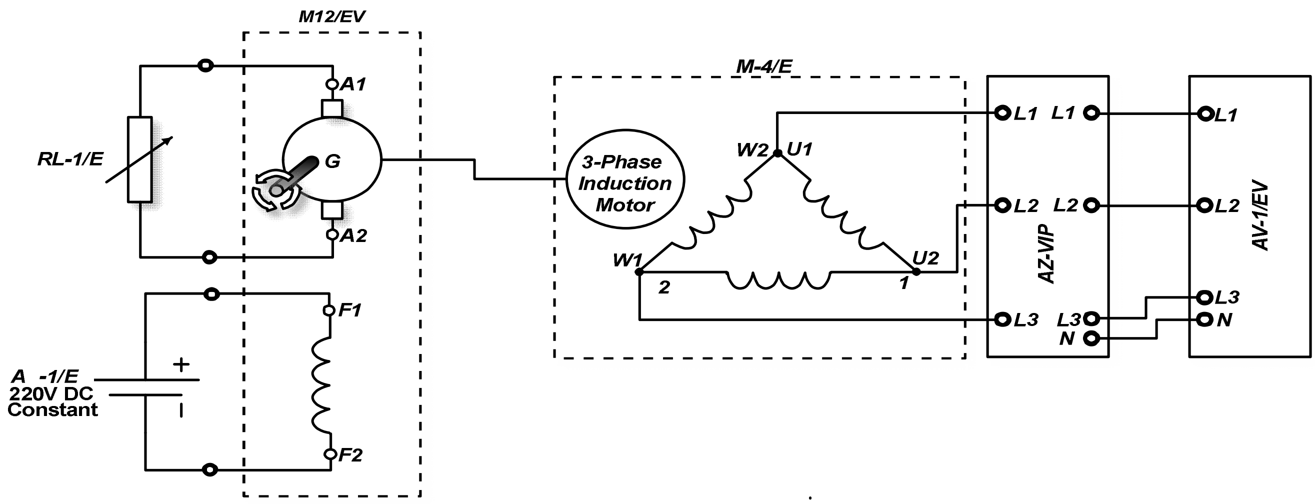


Fig.5 Circuit diagram of 3-phase squirrel cage induction motor

Analysis

1. Perform the necessary calculation to find ω, s, P_{in} ,P_{out} , P_f and η
2. Evaluate the speed-torque results and draw a characteristic curve to analyze the relationship between them
3. From the data obtained in table-1,draw two curves; the first to represent the efficiency η relative to input power $P_{in}$and the second to represent the efficiency ηrelative to power factor P_f
4. Discuss the observations that can be made on the speed-torque curve and briefly explain how to relate it with the characteristic curve in Fig.3

Experiment-7
DC Series and Compound Motors

Objectives

To gain a hands on experience with the wiring and assembly of DC series and compound motors then obtain and analyze their performance under various load conditions. In addition, examine the impact of varying the field or armature currents on the speed, and finally determine their speed regulation

Apparatus Required

- Power Supply Unit*AV-1/EV*
- Adjustable Resistive Load *RL-1/EV*
- Series Field Rheostat *RC1a*
- Armature Rheostats *RC3-9T*
- 3X Ammeters &2X Voltmeters *AZ-VI*
- Speed-Torque Meter*UM-G1/EV*
- DC Machine (to be configured as Shunt &compound motors) *M1-2/EV*
- Load Unit (DC Generator)*M12/EV*

Theory

<u>DC series motors</u>

DC series motors have the ability to develop a large amount of starting torque with a corresponding large current during the starting condition. This property allows them to be used indriving crane hoists, bridge, trolley drives and vehicles, such as locomotives and electric cars. In series motor, the armature winding is connected in series with the field whose winding consists of few turns of a heavy gauge that is large enough to carry the full rated armature current. Initially at the motor start up, with the voltage source connected to the motor, it draws a huge amount of current because both the winding and the armature of the motor, both made up of large conductors, offer minimum resistance to the current path. The large current through the winding yields a strong magnetic field. This strong magnetic field provides high torque to the armature shaft, thus invoking the spinning action of the armature. Thus the motor starts rotating at its maximum speed in the beginning. Unlike the compound motor, the series motor cannot be used in applications with constant speed under varying loads. Additionally, the speed of a series motor during the no-load can accelerate to the point where the motor can become damaged. Therefore, some load must always be present on the shaft

The characteristic of developing high torque in the motor is attributed to the fact that the flux is directly proportional to the armature current

$$\text{Ø} = kI_a$$

The induced torque in the machine may be expressed according to this formula

$$T = k_1 {I_a}^2$$

This indicates that the torque is proportional to the square of armature current, taking the speed-torque equation of the machine

$$\omega = \frac{V_T}{\sqrt{K_m}} \frac{1}{\sqrt{T}} - \frac{R_a + R_f}{K_m}$$

The second term on the right hand side is very small; so the speed equation can therefore be approximately expressed as

$$\omega = \frac{V_T}{\sqrt{K_m}}\frac{1}{\sqrt{T}}$$

Based on this formula it can be concluded that the relationship between the speed and torque is inverse hyperbola

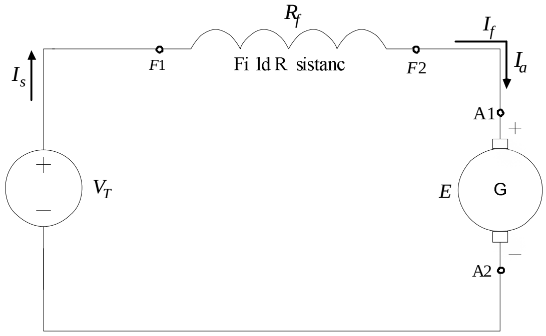


Fig.1 Circuit model for DC series motor

<u>DC compound motor</u>

The series motor has greater torque capabilities while the shunt motor has a constant and controllable speed over various loads. These two desirable characteristics can be found in the DC compound motor. The motor is widely used in mixed load applications where it provides a good response against heavy load changes than a shunt motor. This thing occurs because; an increase in series current will be followed by strength in the field coil, providing an added torque and speed. DC compound motors are usually designed with two different sets of windings; series winding and shunt winding. The fluxes produced by the series and shunt windings are denoted by $\emptyset_s$, $\emptyset_{sh}$ receptively. There are two common types of DC compound motor; cumulative compound motor and differential compound motor. The difference between the two types is based on the total flux that is produced from $\emptyset_s$ and $\emptyset_{sh}$. For example, if the series flux $\emptyset_s$ aids the shunt flux $\emptyset_{sh}$ the motor is therefore called a cumulative compound and will have a different characteristic from the other type (differential compound motor), in which the series and shunt fluxes are opposing one another.

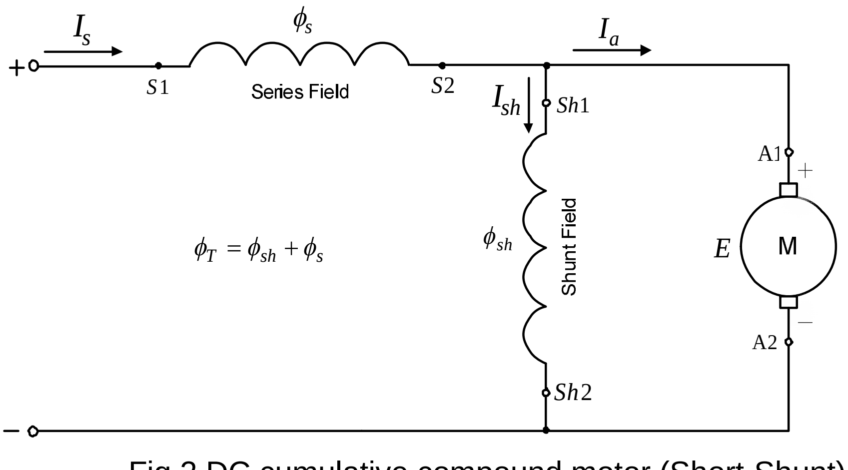


Fig.2 DC cumulative compound motor (Short-Shunt)

Under no-load or full-load conditions, the flux of shunt winding $\emptyset_{sh}$ will be relatively constant, while the series flux $\emptyset_s$ is directly proportional with the armature currentI_a.

Increasing the load on cumulative compound motor will consequently increase the armature current $I_a$and hence the series flux $\emptyset_s$.this flux may therefore increase the total flux $\emptyset_T$ as well as the motor's toque. See the relation below

$$T = k\emptyset_T I_a$$

It is now clear that the total flux for cumulative motor is directly related with the armature current. Thus, the torque will always be greater than that in DC shunt motor. In addition, because the flux and speed are inversely related, the rate at which the drop of speed in cumulative motor is greater than that for DC shunt motor

$$\omega = \frac{E}{k\emptyset}$$

The differential compound motor tends to decrease the field flux as a result of an increase in load torque. From the previous relation, because the speed is inversely proportional to the field flux, it is seen that a decrease in field flux provides an additional speed to the differential motor. If both factors vary in the same proportion, the differential motor speed will remain relatively constant.

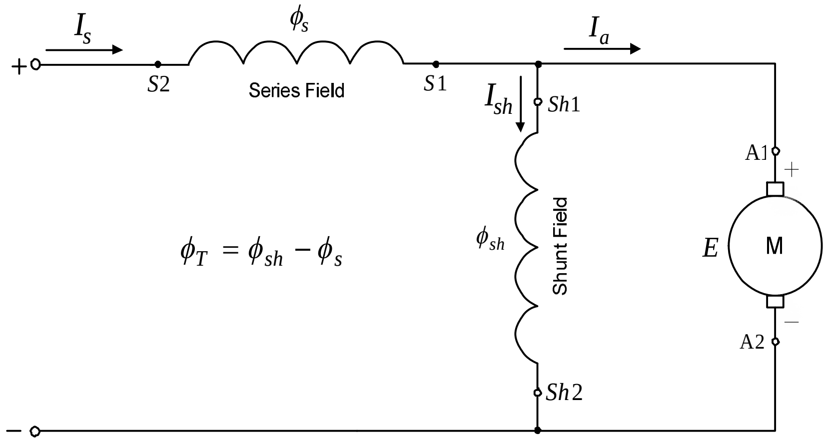


Fig.3 DC differential compound motor (Short-Shunt)

Speed Regulation

Is a term often used in conjunction with electrical motors to describe their capability to maintain a certain speed under varying load conditions; from no-load to full-load

$$speed\ regulation = \frac{No\ Load\ Speed - Full\ Load\ Speed}{Full\ Load\ Speed} \times 100\%$$

Experimental Procedure

External characteristic of DC series motor

1. Construct a DC series motor circuit as per the following figure
2. First of all ensure that the load-cell *M12/EV* is turned on (the resistive load *RL-1/EV* is set to 2200Ω and the field-excitation is also turned-on)
3. Accelerate the motor by gradually increasing the applied voltage through the supply *AV-1/EV* and carefully watch the ammeter and voltmeter
4. Measure the input current, voltage, torque and speed while increasing the load using the RL-1/EV (Refer to the list of load settings in table-1)
5. Tabulate your results in the table and calculate the input and output power in addition to the efficiency
6. Shutdown the main supply *AV-1/EV* and disconnect the wires you have been using

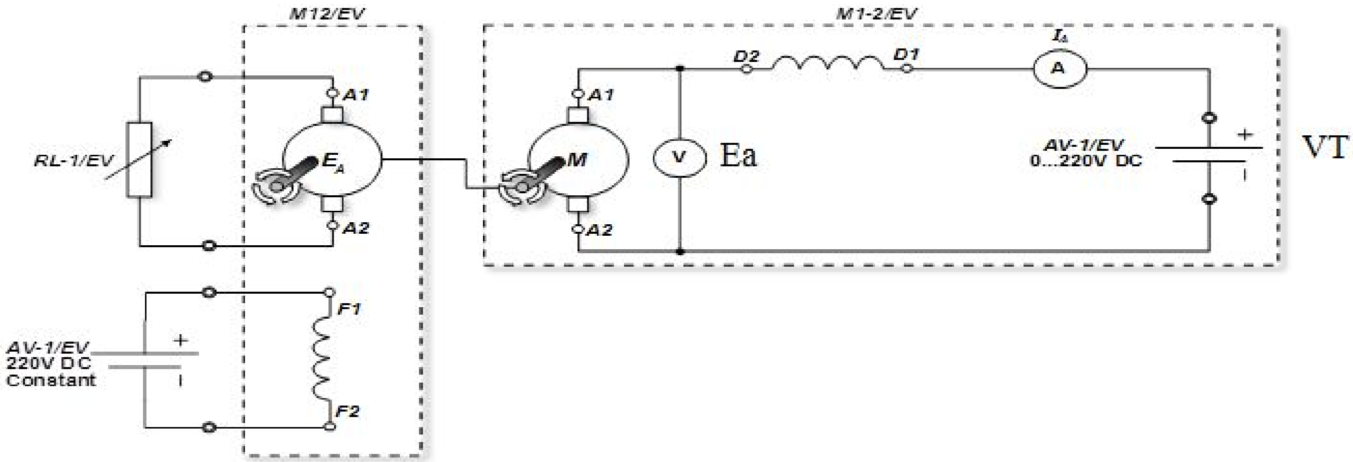


Fig.4 wiring diagram of DC series motor and load-cell

V_T (V)	RL-1/EV Settings	(Ω)	$I_f = I_a$ (A)	T (N.m)	n (rpm)	ω (rad/s)	P_{in} (w)	P_{out} (w)	η (%)
	A								
	AB								
	AC								
	ABC								
	ABC B								
	ABC AC								
	ABC ABC								
	ABC ABC B								
	ABC ABC C								
	ABC ABC AC								

Table-1 Experimental results of DC series motor

External characteristic of DC compound motor

1. The circuit diagram in Fig.7 relates to a DC compound motor *M1-2/EV* coupled to a DC generator (Load-cell) *M12/EV*, connect the whole circuit and carefully verify the connections
2. At the start of the experiment its necessary to adjust the resistive load *RL-1/EV* at 2200 Ω
3. Turn-on the supply for the generator field winding M12/EV
4. Raise the supply voltage (Use the control knob on the supply unit *AV-1/EV*) to bring the motor speed at 2000rpm.
5. According to the list of settings in table-2, decrease the resistive load *RL-1/EV* in progressive steps to slowly increase the torque. For each step record the readings of speed, voltage, current and torque
6. Once you finish taking the measurements, switch off the supply unit *AV-1/EV* and disconnect the circuit

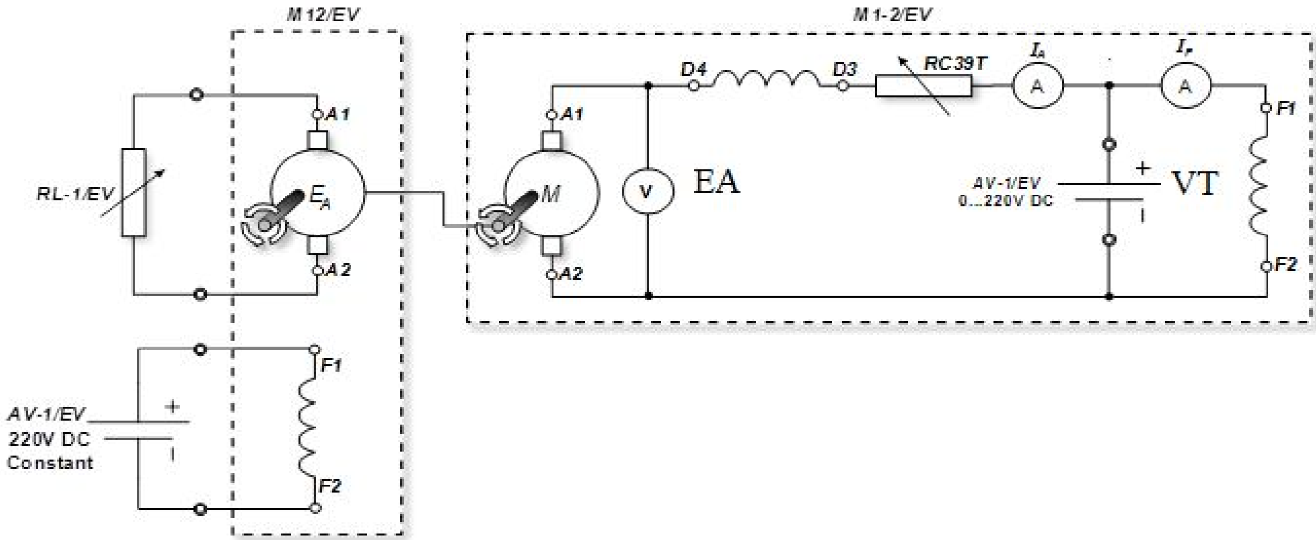


Fig.5 Wiring diagram of DC compound motor (Long-Shunt)

V_T (V)	RL-1/EV$(Load)$ Settings	RL-1/EV$(Load)$ (Ω)	I_f (A)	I_s (A)	T (N.m)	n (rpm)	ω (rad/s)	P_{in} (watt)	P_{out} (watt)	η (%)
	NO LOAD									
	A									
	AB									
	C									
	BC									
	ABC									
	ABC A									
	ABC C									
	ABC AC									
	ABC ABC									

Table-2 Experimental results of DC compound motor (Long-Shunt)

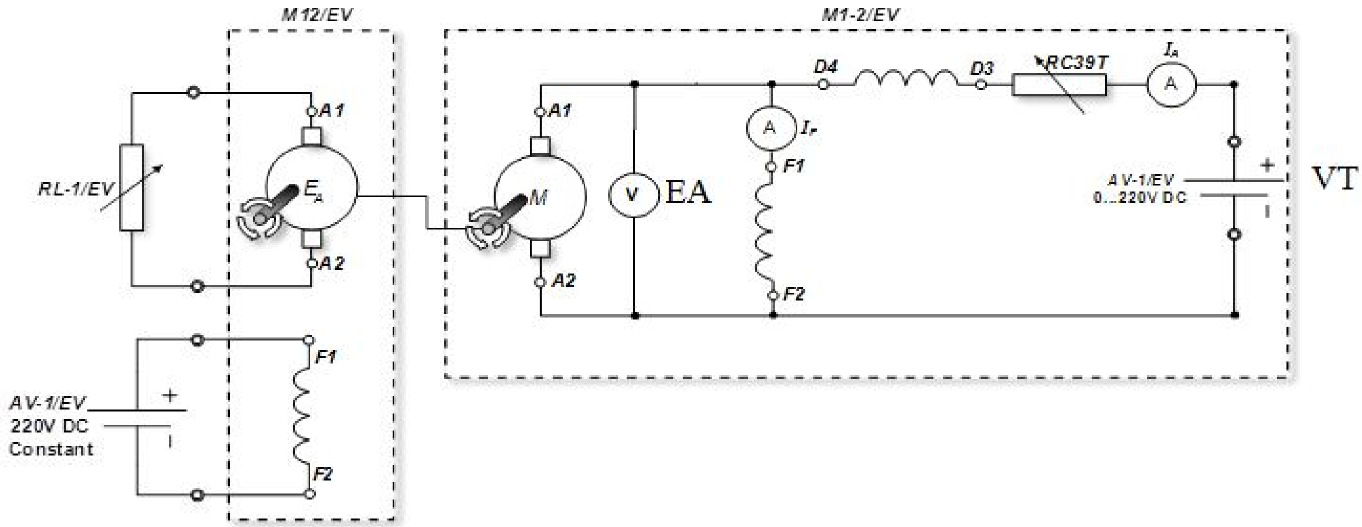


Fig.6 Wiring diagram of DC compound motor (Short-Shunt)

7. The previous part is carried out to obtain the performance of a long-shunt compound motor against various loads. The same test is required on the short-shunt.
8. To configure the motor as a differential compound, just swap the connections of *D3-D4* windings.
9. Repeat the steps *5 & 6* and then tabulate the results in table-3

V_T (V)	RL-1/EV$_{(Load)}$ Settings	(Ω)	I_f (A)	I_s (A)	T (N.m)	n (rpm)	ω (rad/s)	P_{in} (watt)	P_{out} (watt)	η (%)
	NO LOAD									
	A									
	AB									
	C									
	BC									
	ABC									
	ABC A									
	ABC C									
	ABC AC									
	ABC ABC									

Table-3 Experimental results of DC compound motor (Short-Shunt)

Analysis
5. Explain the reason why the series motor is never started at no-load
6. Based on the results of table-1, calculate the P_{in}, P_{out} & η.additionallydraw the relative speed-torque relationship taking into consideration that the torque lies on the x-axis.
7. Draw the relevant characteristic curves for the Long-shunt and short-shunt motors illustrating the relationship between (η verses I_a) & (η verses P_{out})
8. Refer to the experimental results of long-shunt and short-shunt and compare their output characteristics.
9. Calculate the speed regulation for each motor and specify which motor has the best speed regulation (Note: full load is attained at 200Ω)

Exp.8
3-Phase Synchronous Generator

Objectives

Understanding the behavior of synchronous generator and determining its equivalent network and performance characteristics are of prime importance in this experiment. Specific tests are run to determine the equivalent circuit parameters, torque, and power factor control. This lab shows that system design considerations must include frequency, speed, power factor, and voltage.

Apparatus Required

- Variable Frequency Drive *VSD-1/EV*
- 3-Phase squirrel-cage Induction Motor (Configured as Prime-Mover) *M-4/EV*
- 3-Phase synchronous machine (Configured as a generator) *M-3/EV*
- Power analyzer unit *AZ-VIP*
- Power supply unit*AV-1/EV*
- Adjustable Resistive Load *RL-1/EV*
- Adjustable Inductive Load *IL-1/EV*
- Adjustable Capacitive Load *CL-1/EV*

Theory

The generation of electrical power is mostly achieved by a synchronous generator. This machine is robust, simple to control and almost maintenance free, It generates electrical power with a frequency proportional to the speed of the rotor, so the electrical frequency and mechanical speed are synchronous, which explains the machine's name.
The frequency of an AC generator is exclusively given by the rotational speed of the generator shaft. This means that the mechanical drive has to be equipped with a speed controller to keep the speed within close limits independent of torque fluctuation, initiated by electrical load variations.
Synchronous machines usually consist of two mechanical parts: rotor and stator and two electrical parts called; field winding and armature winding.
The stator is made up of sheet steel lamination fitted with three separate windings that are displaced by 120 degree. The three windings can be connected in wye or delta configuration.
There are two basic rotor structures used, depending on speed. For low speed machines, such as hydraulic turbines, a relatively large number of poles are required to produce rated frequency, hence a rotor with salient poles is well suited to this application. For high speed machines, such as steam and gas turbines, a relatively small number of poles (2 to 4) are required to produce rated frequency, hence a cylindrical rotor is well suited to this application.

If the motor is excited by a DC current and run using a prime-mover, a mutual flux will be developed across the air gap between the rotor and stator. This causes the interaction necessary to produce an EMF. As the magnetic flux developed by the DC field poles crosses the air gap of the stator windings, a sinusoidal voltage is developed at the generator output terminals.

The magnitude of the AC voltage generated is controlled by the amount of DC exciting current supplied to the field. If “FIXED” excitation were applied, the voltage magnitude would be controlled by the speed of the rotor

$$E = k\emptyset\omega$$

however, this would necessitate a changing frequency since the frequency component of the power system is to be held constant, solid state voltage regulators or static exciters are commonly used to control the field current and thereby accurately control generator terminal voltage. The frequency of
The voltage developed by the generator depends on the speed of the rotor and the number of field poles. For a 60 Hz system,

$$f = \frac{n \times p}{120}$$

According to the arrangement of the field and armature windings, synchronous machines may be classified as a rotating armature type or rotating field type. For instance, the rotating armature type has the armature windings located on the stator and the field system on the rotor. The generated power is brought out of the rotor via slip rings. Comparing this type with the rotating field type, the later one is considered better and its universally employed because it does not limit the amount of power being generated from the armature, unlike the rotating armature type.

In steady state, one phase can be modeled as an AC voltage source E feeding the current I_a against the terminal voltage V_T through the synchronous impedance Z

$$E = V_T + I_a(R_a + \mathrm{j}X_s)$$

A voltage phasor diagram of synchronous generator supplying a unity power factor load is indicated in the following diagram. Due to the synchronous impedance drop= $R_a + jX_s$, the terminal voltage V_T is less than the open circuit voltage E

Fig.1 Phasor diagram at unity power factor

To describe the behavior of such a synchronous generator, a simplified equivalent circuit model can be used. The model represents a single phase that has a internal generated voltage connected in parallel with a load via the synchronous impedance.

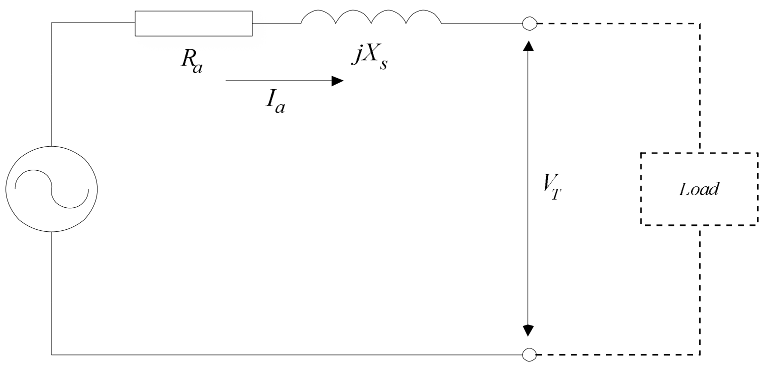


Fig.2 Simplified equivalent circuit model for synchronous generator

Two simple techniques are normally performed to determine the parameters of a given synchronous generator: these are the open circuit test and short circuit test
During the open circuit test, the generator is driven at rated speed and the armature terminals are left opened, (I_a= 0A) so $V_T = E$. The field current is then increased in small steps and the open circuit voltage is measured to obtain the open circuit characteristic curve

The short circuit test is performed by shorting the alternator through a set of ammeters, to record the rated current. The alternator field current is adjusted to get the rated current when the alternator is running at rated speed. Since Z_p is almost constant for a given machine, the short circuit current varies directly with the field current

$$\frac{V_{oc}}{I_{sc}} = |Z_s| = \sqrt{(R_a)^2 + (X_s)^2}$$

Since $X_s \gg R_a$, the equation can be reduced to

$$\frac{V_{oc}}{I_{sc}} = X_s$$

The armature windings are assumed to be connected in Wye. The dc resistance per phase is calculated by using a dc source and the voltmeter-ammeter method. The ac resistance is obtained by multiplying the dc resistance by a factor of 1.2

Voltage regulation

When an alternator is subjected to a varying load, the voltage at the armature terminals varies to a certain extent, and the amount of this variation determines the regulation of the machine. The numerical value of the regulation is defined as the percentage rise in voltage when full load at the specified power-factor is switched off with speed and field current remaining unchanged

$$voltage\ regulation = \frac{E - V}{V} \times 100\%$$

Here E is voltage across open terminals of stator (at no load) and V is voltage across terminals at full load. $E$is also called internal voltage.

Procedure

Open-circuit test

1. From the circuit seen in Fig.1. the power analyzer *AZ-VIP* is connected across the terminals of synchronous generator *M-3/EV* to measure the open circuit voltage
2. A prime mover *M-4/EV* is attached to the synchronous generator *M-3/EV* via the shaft
3. Accelerate the prime mover *M-3/EV* speed to 3000 rpm using the *VSD-1/EV* drive
4. Raise the field current $I_f$in small steps (observe the list of currents in table-1)
5. With each step measure the field voltage V_f and the armature voltage V_T
6. Once you finish the test, gradually bring the speed of prime-mover *M-4/EV* down to zero
7. Switch of the power supply unit *AV-1/EV* and clear away all the wires you have been using

n (rpm)	I_f (A)	V_f (V)	$V_T = E$ (V)
3000	0.05		
3000	0.10		
3000	0.15		
3000	0.20		
3000	0.25		
3000	0.30		
3000	0.35		

Table-1 Experimental results of open circuit test

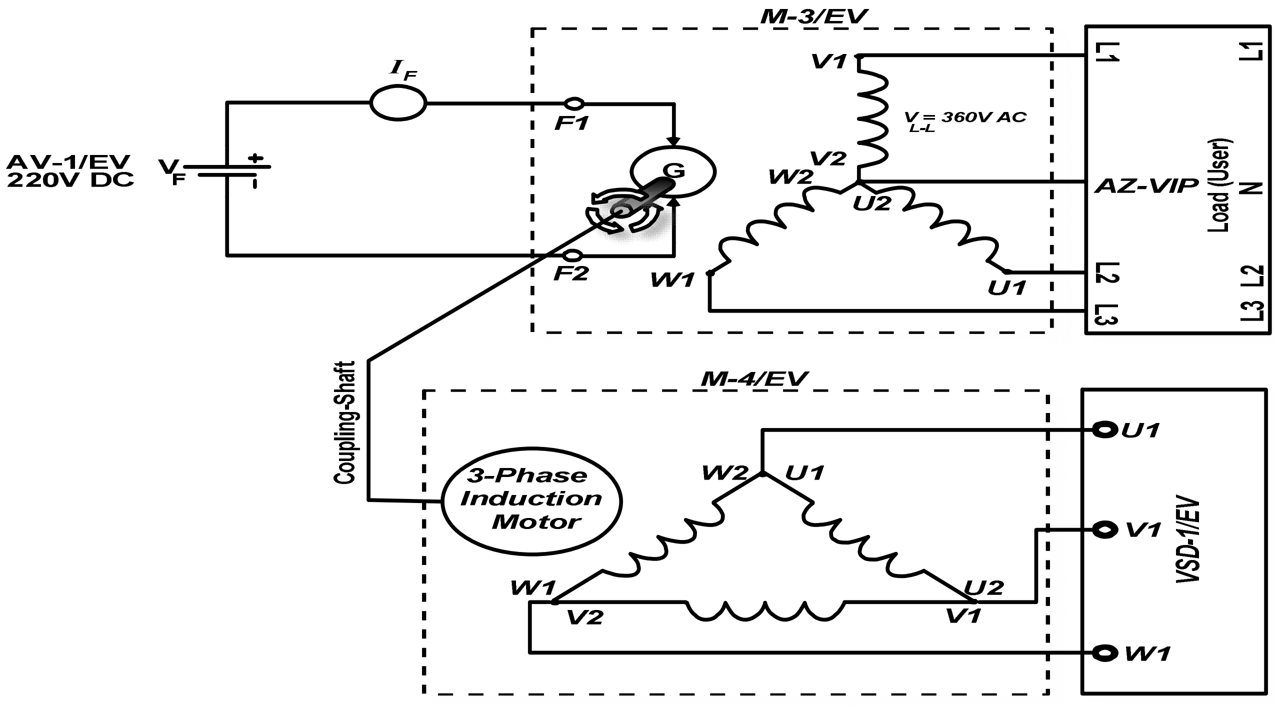


Fig.3no-load test on synchronous generator

Short-circuit test

1. From the circuit seen in Fig.2. the outputs of the power analyzer *AZ-VIP* are short circuited using the cam-switch *AZ-50*
2. Check that the control knob of power supply *AV-1/EV* is set to zero
3. Accelerate the speed of prime-mover *M-4/EV* to 3000 rpm
4. Carefully raise the field current in small steps (the same steps in the OCT), and measure the armature current
5. Tabulate the results in table-2, and use the *VSD-1/EV* drive to bring down the prime-mover speed at zero
6. Switch of the supply unit *AV-1/EV* and clear away all the wires you have been using

n (rpm)	I_f (A)	I_a (A)	$Z_s(\Omega)$
3000	0.05		
3000	0.10		
3000	0.15		
3000	0.20		
3000	0.25		
3000	0.30		
3000	0.35		

Table-2 Experimental results of short circuit test

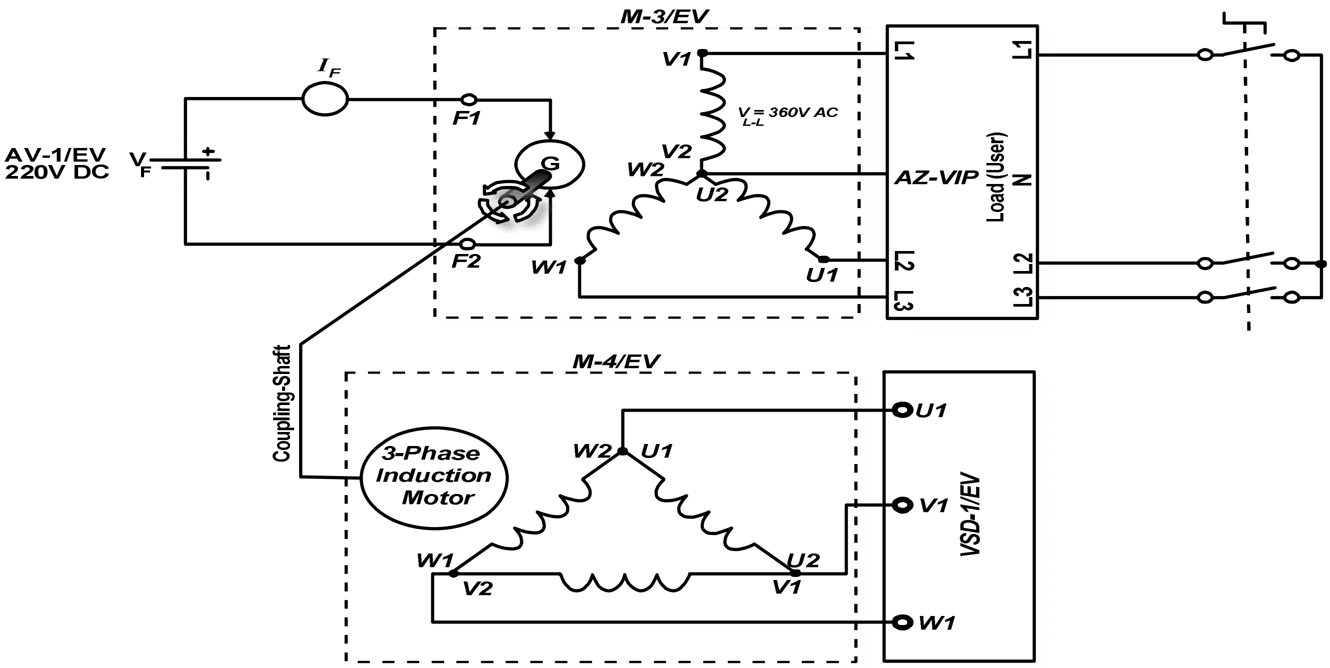


Fig.4 Short circuit test

Synchronous generator with RLC load

1. Construct the circuit in Fig.5 implanting the synchronous generator
2. Refer to Fig.6 & Fig.7 to wire up the *RLC load*
3. Use the *VSD-1/EV* drive to accelerate the speed of the prime mover *M-4/EV* at 3000 rpm
4. Firstly ensure that the *RLC* load is switched off
5. Switch on the supply unit *AV-1/EV* and raise the field current until the armature attains a rated voltage ($V_T = 400v$)
6. Adjust the resistive load in accordance with the list of settings in table-3. (start with setting A)
7. With each step use the power analyzer *AZ-VIP* to measure the I_a, V_T&P_{out}
8. Tabulate these measurements in table-3

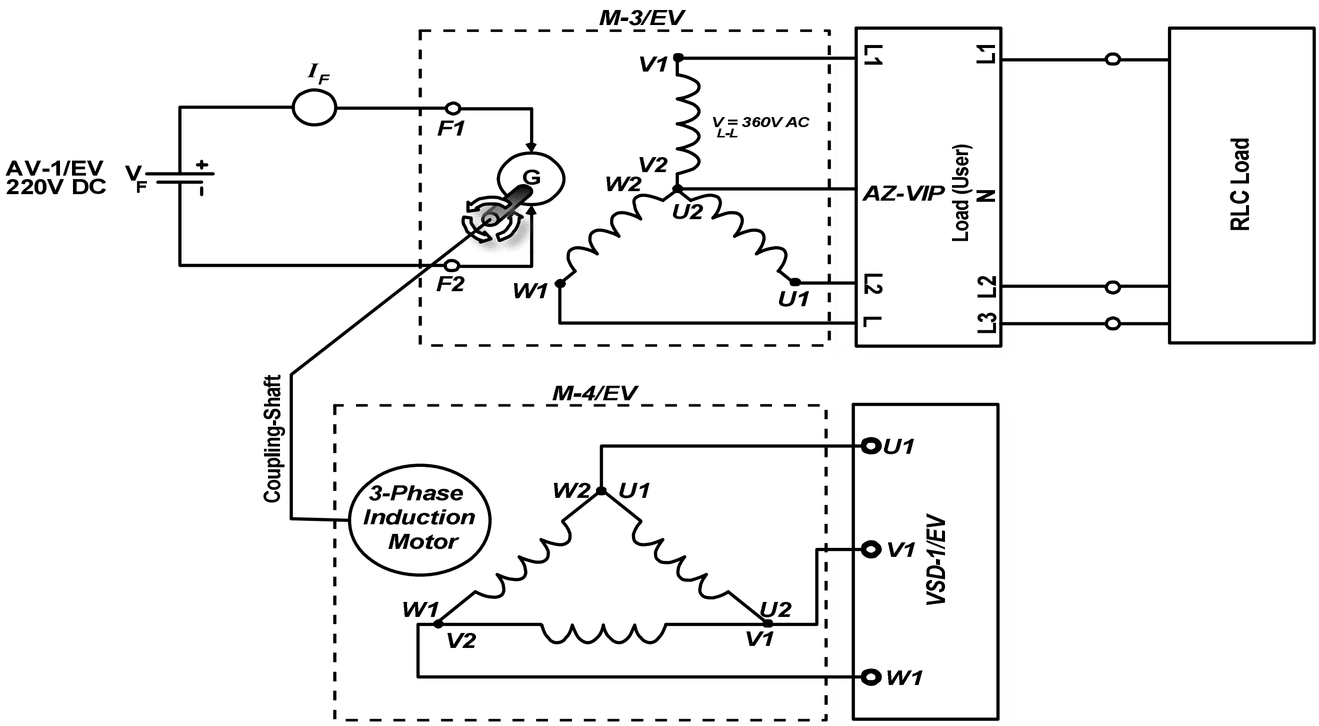


Fig.5 Load test on synchronous generator

$Load$	n (rpm)	RL-1/EV Settings	I_f (A)	I_a (A)	V_T (V)	P_{out}(w)	pf
R	3000	*No Load*					
	3000	*A*					
	3000	*B*					
	3000	*AB*					
	3000	*C*					
	3000	*AC*					
	3000	*BC*					
	3000	*ABC*					

Table-3 Experimental results for resistive load

9. Start over the test again by incorporating the inductive load this time
10. Ensure that the armature voltage is maintained at 300V during the no-load
11. Adjust both the resistive and inductive load in accordance with the settings in table-4
12. Use the same power analyzer *AZ-VIP* to measure I_a, V_T&P_{out}
13. Tabulate your readings

$Load$	n (rpm)	RL-1/EV	IL-1/EV	I_f (A)	I_a (A)	V_T (V)	P_{out}(w)	pf
		Settings	Settings					
$R + L$	3000	*No Load*	*No Load*					
	3000	*A*	*A*					
	3000	*A*	*B*					
	3000	*A*	*AB*					
	3000	*A*	*C*					
	3000	*A*	*AC*					
	3000	*A*	*BC*					
	3000	*A*	*ABC*					

Table-4 Experimental results for resistive & inductive load

14. Switch off the RLC load to check whether the field current is maintained
15. Fix the resistance at 2200 and adjust the capacitive loads over its entire range as seen in table5
16. Measure the terminal voltage

$Load$	n (rpm)	RL-1/EV	CL-1/EV	I_f (A)	I_a (A)	V_T (V)	P_{out}(w)	pf
		Settings	Settings					
$R + C$	3000	*No Load*	*No Load*					
	3000	*A*	*A*					
	3000	*A*	*B*					
	3000	*A*	*AB*					
	3000	*A*	*C*					

Table-5 Experimental results for resistive & capacitive load

Regulation Test

1. Initially, turn-on the VSD drive *VSD-1/EV* and accelerate the speed of prime mover at 3000 rpm
2. Refer to the list of settings in the table to raise the load at each step
3. Using the excitation current, ensure that the armature voltage is maintained at 300 VAC while increasing the load
4. Take the necessary measurements and tabulate them in the table

$Load$	n (rpm)	RL-1/EV	IL-1/EV	CL-1/EV	V_f (V)	I_f (A)	I_a(A)	P_{out}(w)	pf
		Settings	Settings	Settings					
R	3000	*No Load*	*No Load*	*No Load*					
	3000	*A*	–	–					
	3000	*B*	–	–					
	3000	*AB*	–	–					
	3000	*C*	–	–					
	3000	*AC*	–	–					
	3000	*BC*	–	–					
	3000	*ABC*	–	–					
$R + L$	3000	*A*	*A*	–					
	3000	*A*	*B*	–					
	3000	*A*	*AB*	–					
	3000	*A*	*C*	–					
	3000	*A*	*AC*	–					
	3000	*A*	*BC*	–					
	3000	*A*	*ABC*						
$R + C$	3000	*A*	–	*A*					
	3000	*A*	–	*B*					
	3000	*A*	–	*AB*					
	3000	*A*	–	*C*					
	3000	*A*	–	*AC*					
	3000	*A*	–	*BC*					

Table-6 Experimental results for regulation test

Analysis

1. Draw the open circuit characteristic curve showing the relative change of E with respect to I_f
2. Draw the short circuit characteristic curve showing the relative change of I_a with respect to I_f
3. Calculate the synchronous impedance Z_s
4. Plot the synchronous impedance curve which represents the open circuit voltage V_T(in table-1) against the short circuit current I_a (in table-2)

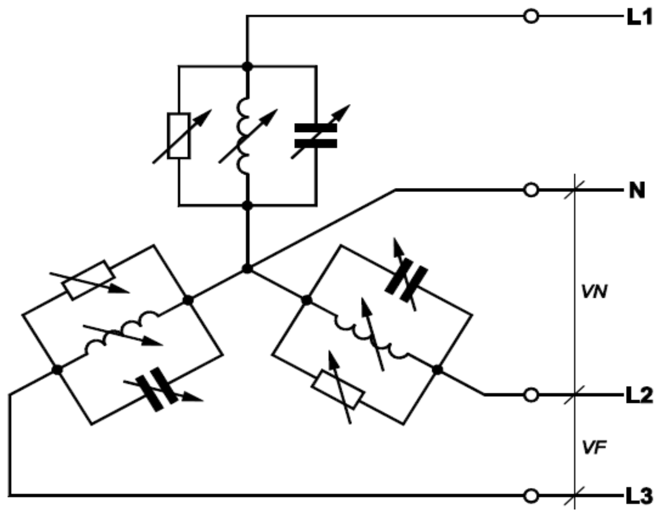


Fig.6 wye-connected balanced RLC load

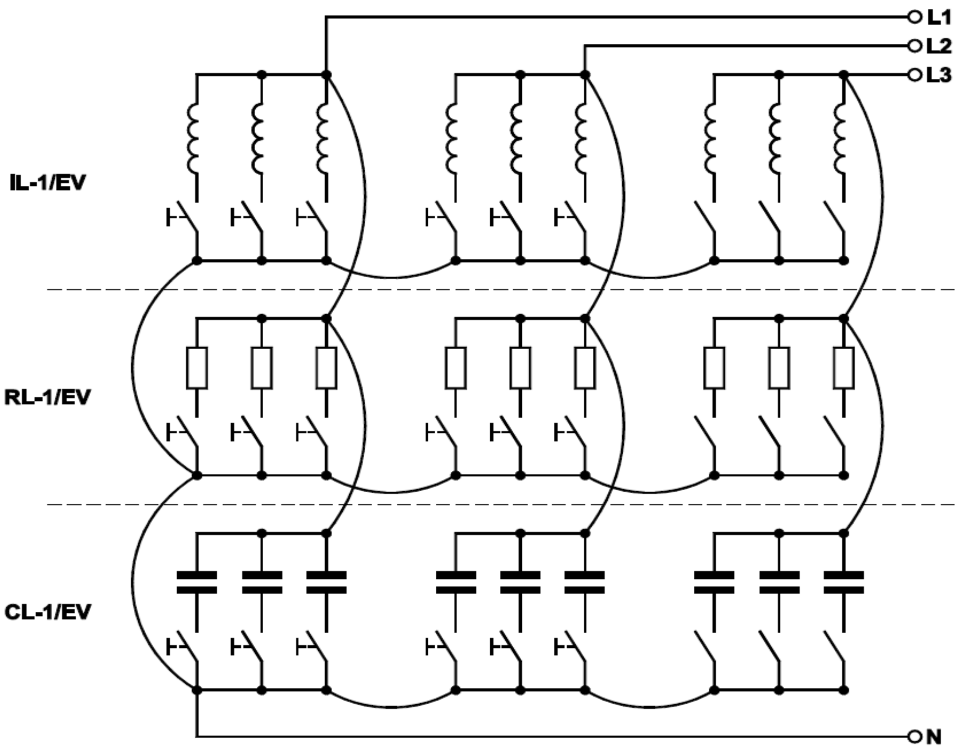


Fig.7 Detailed wiring diagram of RLC load

Exp-9

Single Phase Induction Motor

Objectives

The experiment aims at identifying the main operating characteristics of both the 1-phase capacitor start and 1-phase capacitor run motors

Apparatus Required

- Single-phase induction motor *M-9/EV*
- Load cell (Configured as Separately excited generator)*M-12/EV*
- Power analyzer unit *AZ-VIP*
- Power supply unit*AV-1/EV*
- Adjustable Resistive Load *RL-1/EV*
- Adjustable Capacitive Load *CL-1/EV*
- Speed-Torque Meter*UM-G1/EV*

Theory

In single phase induction motors, a single phase supply voltage is 'split' into two phase currents to create a rotating magnetic field in order to start the rotation of the rotor. The principle of operation for these motors is the same as the 3 phase induction motor in that, they consist of a stator winding inducing currents in a 'caged rotor'. The only difference is that the 1-phase has no inherent starting torque and some special arrangements have to be made for making it self-starting. It follows that during starting the induction motor will be turned to some form of two phase motor in order to produce a rotating magnetic field

The classification of 1-phase induction motor is based on the method of starting which in fact is known by the same name descriptive of the method. Appropriate selection of these motors depend upon the starting and running torque requirements of the load, duty cycle, starting and running current draws from the supply

Split-phase induction motor

The stator of a split phase induction motor has two windings, the main winding and the auxiliary winding. These two windings are displaced in space by 90 electrical degrees.

The auxiliary winding is made up of thin copper wires of a greater turns compared to the main winding which has a thick copper wire. A higher reactance/resistance ratio will therefore be developed in the auxiliary winding. This is important to provide a rotating magnetic field

Because the two windings are connected across one supply, the current I_m in the main winding and I_a in the auxiliary winding always lag behind the supply voltage V

Because of the two fields a starting torque is developed and the motor becomes a self-starting motor. After the motor starts, the auxiliary winding is disconnected usually by means of centrifugal switch that operates at about 1900 rpm. After starting period the motor runs at its rated speed due to the action of main winding. It should be pointed out that there is concurrent humming noise associated with this particular type of motor

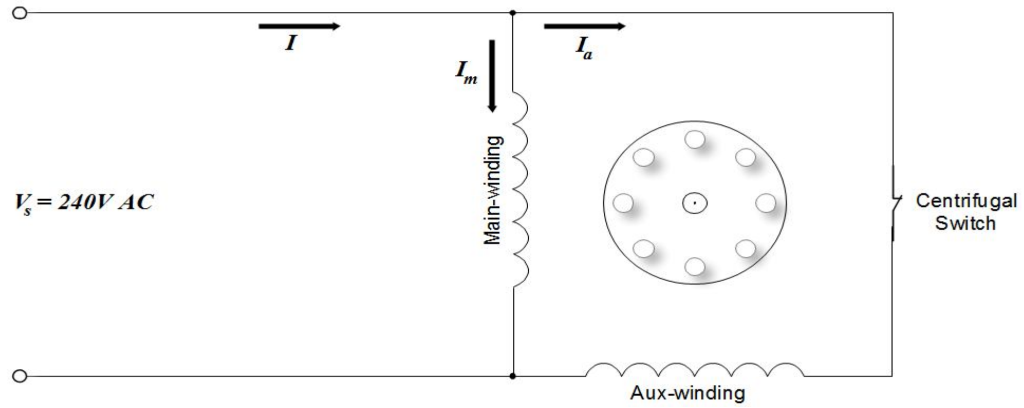


Fig.1 Typical circuit diagram of split phase induction motor

Capacitor start induction motor

Capacitors are used to improve the starting and running performance of the single phase induction motor. The capacitor start induction motor is also a split phase motor. A capacitor of suitable value is connected in series with the auxiliary coil through a switch such that the current in the auxiliary coil I_a leads the main current I_m by90° so the torque will be maximized. Then the auxiliary winding and capacitor are disconnected by means of the centrifugal switch once the motor has picked up 70% of the synchronous speed

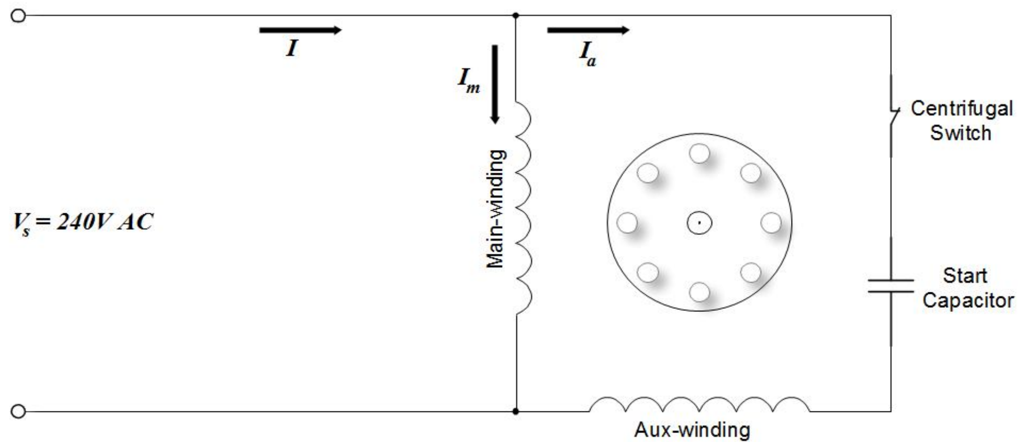


Fig.2Typical circuit diagram of capacitor start motor

Capacitor run induction motor

In this motor the auxiliary winding and capacitor are not disconnected from the motor after starting, thus the construction is simplified by the omission of the centrifugal switch

Here the auxiliary winding and capacitor could be so designed that the motor works as a perfect 2-phase motor with improved power factor and efficiency

Capacitor-start capacitor-run induction motor

At the instant of starting the motor, the two capacitors are in parallel. Once the motor picks 70% of the synchronous speed, the centrifugal switch disconnects the larger capacity capacitor. The motor then operates with the smaller capacitor only connected in series with the starting winding.

This type of motor has a very good starting torque, good speed regulation, in addition to a higher power factor of nearly 100 percent at rated load. Application of this type of motor includes furnace stokers, refrigerator units and compressors

Procedure

Capacitor- start motor

1. Examine the motor's name plate *M-9/EV* and identify the main and auxiliary windings
2. Refer to circuit diagram in Fig.3 while connecting the capacitor start motor
3. Before turning on the power supply *AV-1/EV,* ensure that the control knob is on its utmost counter-clock wise position
4. Accelerate the motor speed by gradually increasing the AC supply *AV-1/EV*up until 220 VAC
5. Initially perform the no-load test while the supply voltage is maintained at 220 VAC
6. Switch on the field supply for the load cell *M-12/EV*
7. Adjust the resistance of *RL-1/EV* at 2200Ω and measure the necessary input and output parameters (Refer to table-1)
8. Tabulate the results being measured and adjust the resistive load *RL-1/EV* so that the torque is increased, then measure the current, speed and power factor
9. Once the test has been finished, switch off the supply *AV-1/EV*

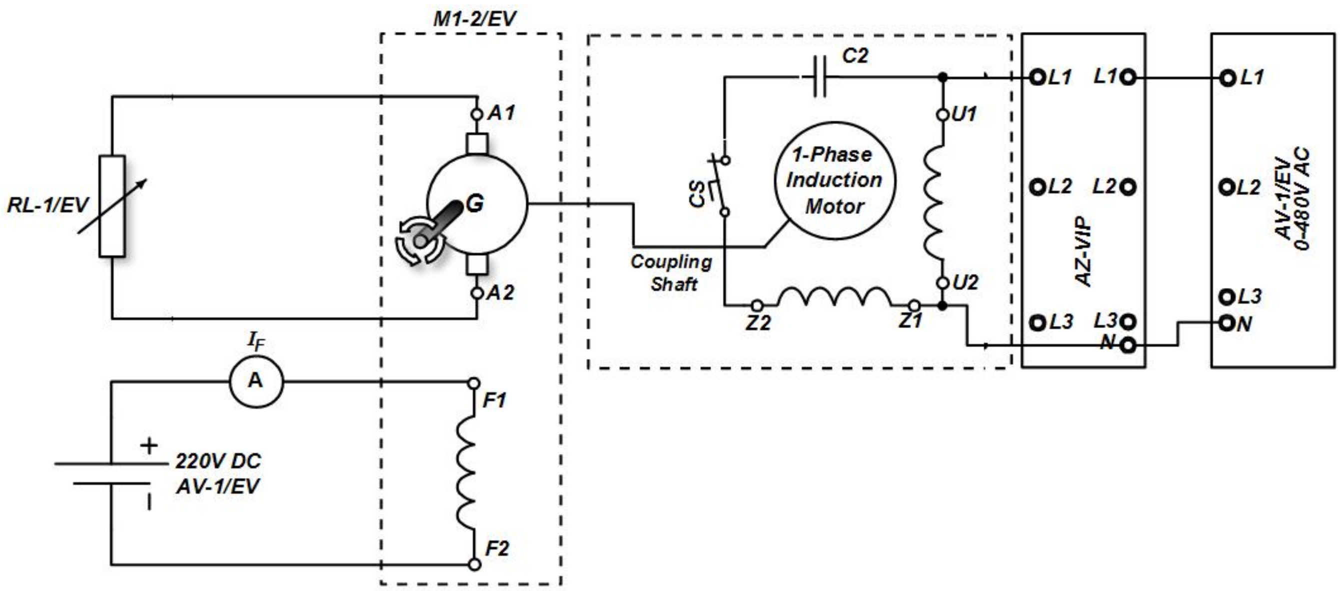


Fig.3 Capacitor start motor

V_s (V)	Capacitor Start *C2*	RL-1/EV($Load$) Settings	(Ω)	I_s (A)	n (rpm)	ω (rad/s)	T (N.m)	P_{in} (watt)	P_{out} (watt)	$p.f.$	η (100%)
150	60μF	No Load									
150	60μF	*A*									
150	60μF	*B*									
150	60μF	*AB*									
150	60μF	*C*									
150	60μF	*AC*									
150	60μF	*BC*									
150	60μF	ABC									

Table-1 Experimental results of capacitor start motor

Capacitor-run motor

1. Construct the capacitor-run motor circuit as shown in Fig.3
2. Switch on the field supply for *M-12/EV*
3. Measure the relevant motor's parameters at no-load and tabulate them in table-2
4. Adjust the resistance of *RL-1/EV* in steps, with each step measure the input current, speed, power input, power output and efficiency
5. Tabulate the results in table-2 and finish off the test and shut down the supply *AV-1/EV*, then disconnect the circuit

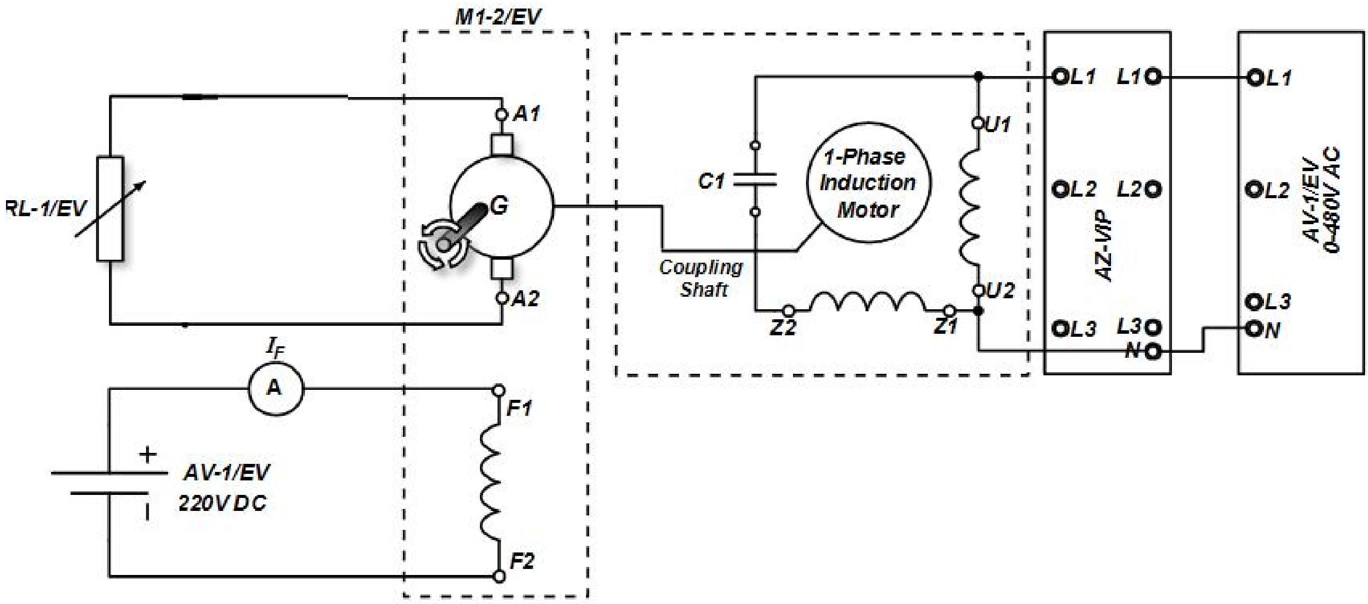


Fig.4 Capacitor run-motor

V_s (V)	Capacitor Run*C1*	RL-1/EV($Load$) Settings	(Ω)	I_s (A)	n (rpm)	ω (rad/s)	T (N.m)	P_{in} (watt)	P_{out} (watt)	$p.f.$	η (100%)
150	25µF	No Load									
150	25µF	*A*									
150	25µF	*B*									
150	25µF	*AB*									
150	25µF	*C*									
150	25µF	*AC*									
150	25µF	*BC*									
150	25µF	ABC									
150	25µF	ABC A									
150	25µF	*ABC B*									
150	25µF	*ABC AB*									
150	25µF	*ABC C*									
150	25µF	*ABC AC*									
150	25µF	*ABC BC*									

Table-2 Experimental results of capacitor-run motor

Power factor correction of Capacitor-start induction motor

1. Carefully connect the motor in accordance to the circuit diagram in Fig.4
2. Switch on the field supply for *M-12/EV* and adjust the supply voltage to 150V .
3. Add *10μF* to the motor terminals by switching on *ABC* from the capacitor banks *CL-1/EV*
4. Measure the relevant motor's parameters at no-load and tabulate them in table-2
5. Adjust the resistance of *RL-1/EV* in steps, with each step measure the input current, speed, power input, power output and efficiency
6. Add another *10μF* to the motor terminal to be equal *20μF by* switching on another *ABC* from the capacitor banks *CL-1/EV*
7. Tabulate the results in table-3
8. Once you finish the test bring the motor's speed down to zero using the supply *AV-1/EV* and clear away all cables and leads you have been using

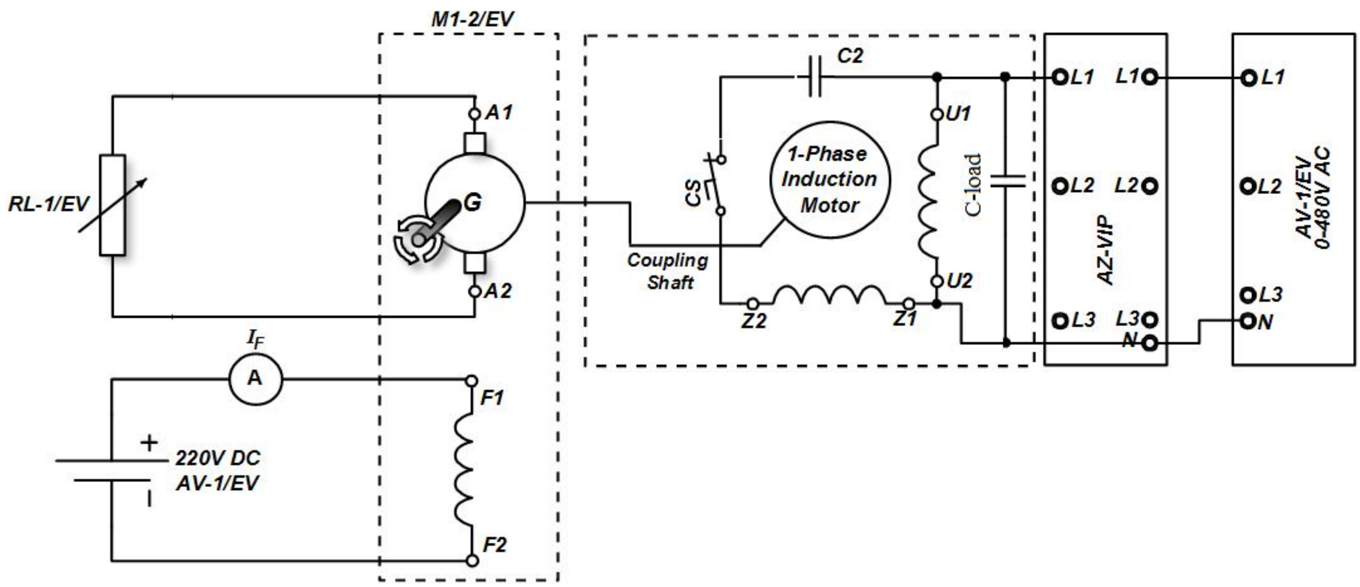


Fig.5 Capacitor-start with power factor correction

V_s (V)	Capacitor Start *C2*	Capacitor Banks CL-/EV (ABC)	RL-1/EV$(Load)$		I_s (A)	n (rpm)	ω (rad/s)	T (N.m)	P_{in} (watt)	P_{out} (watt)	$p.f.$	η (100%)
			Settings	(Ω)								
150	60μF	10μF	No Load									
150	60μF	10μF	*A*									
150	60μF	10μF	*B*									
150	60μF	10μF	*AB*									
150	60μF	10μF	*C*									
150	60μF	10μF	*AC*									
150	60μF	10μF	*BC*									
150	60μF	10μF	ABC									
150	60μF	10μF	ABC A									

V_s (V)	Capacitor Start $C2$	Capacitor Banks CL-/EV (ABC ABC)	RL-1/EV($Load$)		I_s (A)	n (rpm)	ω (rad/s)	T (N.m)	P_{in} (watt)	P_{out} (watt)	$p.f.$	η (100%)
			Settings	(Ω)								
150	60μF	20μF	No Load									
150	60μF	20μF	*A*									
150	60μF	20μF	*B*									
150	60μF	20μF	*AB*									
150	60μF	20μF	*C*									
150	60μF	20μF	*AC*									
150	60μF	20μF	*BC*									
150	60μF	20μF	ABC									
150	60μF	20μF	ABC A									
150	60μF	20μF	*ABC B*									

Table-3 Experimental results of capacitor-start capacitor-run motor

Analysis

5. Calculate the power factor and observe its variation against the load and capacitance

6. Draw the output characteristic curve for the two motors showing the relative change of ω with respect to T

7. Explain the effect of capacitor start on the overall motor performance (refer to experimental data)

8. Compare between both motors in terms of P_{in}, P_{out}&η and specify which one has the best performance

Appendix

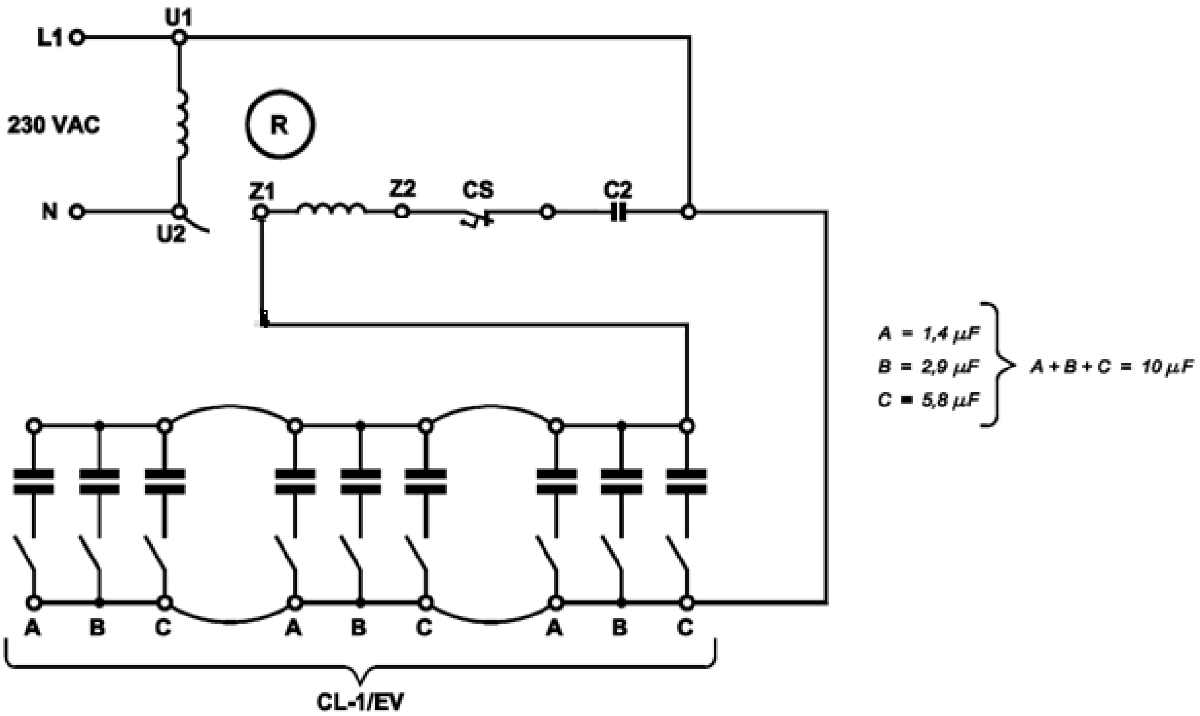


Fig.6 Detailed circuit diagram of capacitor-start capacitor-run motor

Exp-10

3-Phase Synchronous Motor

Objectives

To investigate the operation and characteristics of a 3-phase synchronous motor. Then study the effect of the varying field current on the overall motor's performance. And finally, demonstrate the variation of load torque on each; speed and the efficiency

Apparatus Required

- 3-Phase synchronous generator *M-3/EV*
- Load cell (Configured as Separately excited generator) *M-12/EV*
- Power analyzer unit *AZ-VIP*
- Power supply unit*AV-1/EV*
- Adjustable Resistive Load *RL-1/EV*
- Rheostat *RC1a*
- Two-Pole Switch *AZ-50*
- Speed-Torque Meter*UM-G1/EV*

Theory

Synchronous motor has a special property in maintaining a constant running speed under all conditions of no-load to full load. This constant running speed can be maintained even under variable line voltage conditions. It is, therefore, a useful motor in applications where the running speed must be accurately known and unvarying. It should be noted that, if a synchronous motor is severely overloaded, its operation will be pulled out of synchronism and suddenly lose its synchronous properties and the motor will come to a halt

Synchronous motors in their simplest form are not self-starting motor. The rotor is heavy and it's not possible to bring it in magnetic lock with the rotating magnetic field. For this reason, all synchronous motors are equipped with some kind of starting device that brings the rotor speed to 90% of its synchronous speed. The most commonly starting method is to have the rotor core fitted with squirrel cage rotor. This achieves a strong magnetic field that provides a good interaction with the stator's rotating field. Starting the motor from the standstill is now possible by firstly energizing the armature windings and waits till the rotor picks up a good speed (that is equal to synchronous speed). Thin switch the motor from asynchronous mode to synchronous by exciting the field windings

Synchronous motor has an additional interesting property which is the ability of acting like a variable 3-phase inductor/capacitor during no-load. The value of reactance is determined according to the amount of field excitation

When running the motor at zero excitation current a considerable amount of positive reactive power will be drawn from the supply to create the necessary magnetism in the stator windings. The reactive power has the disadvantage of low power factor. The motor in this case act in much the same way as any other type of motors (a combination of inductive-resistive load)

Once the rotor is excited, some of the magnetism in the motor will be produced by which the stator draws less reactive power, when field excitation is brought further up, a point can be reached where all the magnetism produced by rotor is used to compensate for the stator magnetism. As a result the power supply will only produce a real-power and the power factor becomes unity

Tending to create more magnetism is likely achievable by over exciting the field winding. The power supply in this case produces a negative reactive power in an attempt to keep the total flux constant.
And the synchronous motor acts like a capacitive load

Procedure

Load-test

1. Assemble the experimental circuit of 3-phase synchronous motor
2. Verify that all electrical wires are connected tightly that there is no lose connection
3. While keeping the excitation of *M-12/EV* and *M-3/EV* off, accelerate the motor speed by gradually increasing the 3-phase voltage of *AV-1/EV*
4. The motor *M-3/EV* is fitted with squirrel-cage bars in order to start from standstill
5. The DC excitation of *M-3/EV* is applied by closing the switch *AZ-50* and raising the supply voltage using *AV-1/EV*
6. Turn on the load cell*M-12/EV*while maintaining the armature and field supply for *M-3/EV* at rated value
7. During no-load(RL-1/EV opened) measure the necessary motor's parameters as indicated in table-1
8. Increase the load of *RL-1/EV* in steps as per the list of settings in table-1, with each step measure the armature current, input-power, speed, torque and power-output
9. Tabulate the readings in table-1 and observe the minimal variation of motor's speed
10. For a time being, switch-off the supply unit *AV-1/EV* and leave the circuit connected for the second test

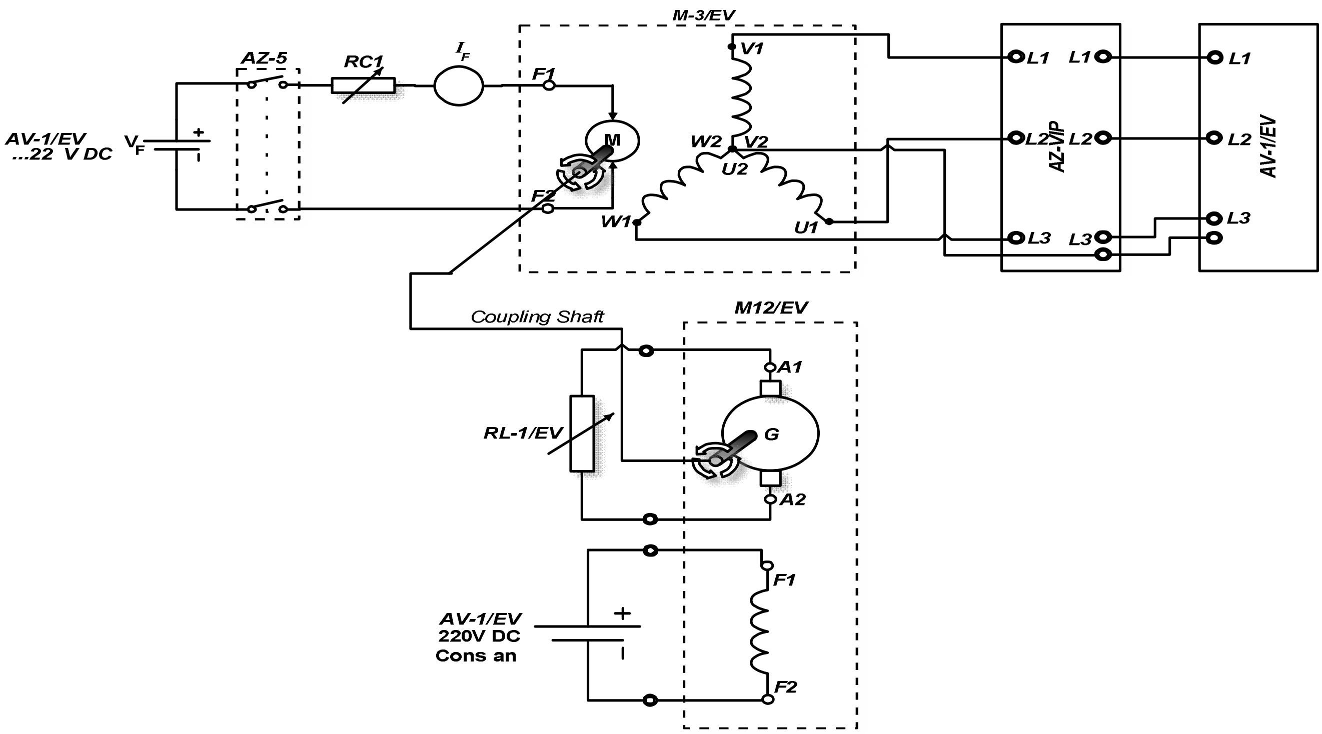


Fig.1 Typical circuit diagram of synchronous motor circuit

V_{L-L} (V)	RL-1/EV $(Load)$	I_a (A)	P_a (W)	P_{in} (W)	V_f (V)	I_f (A)	n_s (rpm)	ω_s (rad/s)	T (N.m)	P_{out} (W)	PF	η 100%
400	No-Load											
400	*A*											
400	*B*											
400	*AB*											
400	*C*											
400	*AC*											
400	*BC*											
400	*ABC*											
400	*ABC A*											
400	*ABC B*											
400	*ABC AB*											

Table.1 Experimental results of synchronous motor

<u>V-Curve Test</u>

1. This test is performed to examine the modes of field excitation on the armature current
2. With the load-cell *M-12/EV* turned-off, use the supply unit *AV-1/EV* to bring the speed of motor *M-3/EV* at 2990 rpm
3. Initially adjust the field supply at 50V and measure the armature current in addition to the relevant parameters of table-2
4. Bring the excitation from under-excited to over-excited mode by increasing the field voltage in steps (refer to list of setting in table-2)
5. Take the necessary measurements and tabulate them in table-2
6. Once the test has been finished, prepare for the last test which requires the load-cell *M-12/EV*

V_{L-L} (V)	I_a (A)	V_f (V)	I_f (A)	n_s (rpm)	ω_s (rad/s)	T (N.m)	P_a (W)	P_{in} (W)	PF
400		100				—			
400		110				—			
400		120				—			
400		130				—			
400		140				—			
400		160				—			
400		180				—			
400		200				—			
400		220				—			

Table.2 V-curve test at no-load

7. While the speed of motor is maintained at 2990 rpm, turn-on the field excitation of *M-12/EV*
8. Adjust the resistive load *RL-1/EV* so that the equivalent resistance is 733Ω
9. Star-up the excitation of *M-3/EV* at 100v and measure the armature current in addition to some other parameters as per table-3
10. Increase the field excitation in steps while measuring the parameters
11. Once the test has been done, shut-down the *AV-1/EV* supply and disconnect the circuit

V_{L-L} (V)	RL-1/EV($Load$)	I_a (A)	V_f (V)	I_f (A)	n_s (rpm)	ω_s (rad/s)	T (N.m)	P_a (W)	P_{in} (W)	PF
400	*Settings*		100							
400	AB		120							
400	*AB*		130							
400	*AB*		140							
400	AB		150							
400	AB		160							
400	AB		180							
400	AB		200							
400	AB		220							

Table.3 V-curve test under-load

Analysis

1. With reference to the results in table-1, calculate the angular speed, input power & efficiency
2. Draw the output characteristic curve showing the relative change of ω with respect to T
3. Get the input power calculated for table-2 & table-3
4. Calculate the power factor
5. From the results of table-2 and table-3 draw on a single scale the two V-curves showing the relationship between armature current and field current

Useful formulas

$$pf = \frac{P_a}{3.I_a.\frac{V_{L-L}}{\sqrt{3}}}$$

$$P_{in} = P_a + V_f.I_f$$

Exp. 11

Three Phase Transformer

Objectives

This experiment is intended to give a demonstration to the wiring, operation and the characteristics of three phase transformer circuit. It is also intended to giving a comprehensive illustration to the connection of 3-phase RLC load added with measuring devices.

The experiment also demonstrates how to configure both the transformer and the RLC-load in wye and delta connection. At the end of the experiment, the students should be able to note-down the transformer's measurements including line currents, voltages, power and the power-factor.

Apparatus Required

1. 3Φ Power supply unit
2. Adjustable 3Φ RLC loads
3. Analogue Meters Unit

Theory

A basic 3-phase transformer consists of three sets of primary windings (one for each phase), and three sets of secondary windings wound on the same iron-core. The primary and secondary windings are electrically isolated and operate on the principles of Faraday's principle of mutual induction. In which an EMF is induced in the transformer secondary by the magnetic flux generated by the primary windings. The iron core is made of laminated metal sheets to reduce eddy-current and power losses. The primary is connected to 3-phase source which has to be sinusoidal in nature while the load is connected to the secondary.

Separate single-phase transformers can be used and externally interconnected to yield the same results as a 3-phase unit. The set of primary and secondary windings can be connected in four different combinations; these are

- Star-Star (Y-Y)
- Star-Delta (Y-Δ)
- Delta-Star (Δ-Y)
- Delta-Delta (Δ-Δ)

Choosing one of these combinations depends on; Voltage levels, the need for neutral terminal and the connection reliability. For example, if it is required to obtain a neutral terminal (on the secondary) with two voltage levels (line-line and phase voltage) then its recommended to use either(Y-Y) or (Δ-Y) connections. On the other hand, the delta connection (on the secondary)enjoys a higher reliability because if one winding fails open, the other two can still maintain full line voltages to the load.

The voltage induced into the secondary windings is mainly determined by the amount of primary voltage and the value of turn-ratio. The 3-phase transformers are typically used to either step-up or step-down the secondary voltage. This entirely depends on the turn-ration. For example, If the number of turns on the primary with respect to secondary is high (a: is greater than one), then the transformer called a step-up (voltage induced into the secondary greater than the primary). While if the number of primary turns compared to the secondary is high (a: less than one), the transformer is called a step-down transformer.

Despite the fact that transformers are used to step-up or step-down the voltage, it should be clear that the frequency and power are maintained constant. In other words, the frequency and power on the secondary is the same as the primary. All transformers are rated in volt-amperes (VA) or in KVA

Voltage Regulation

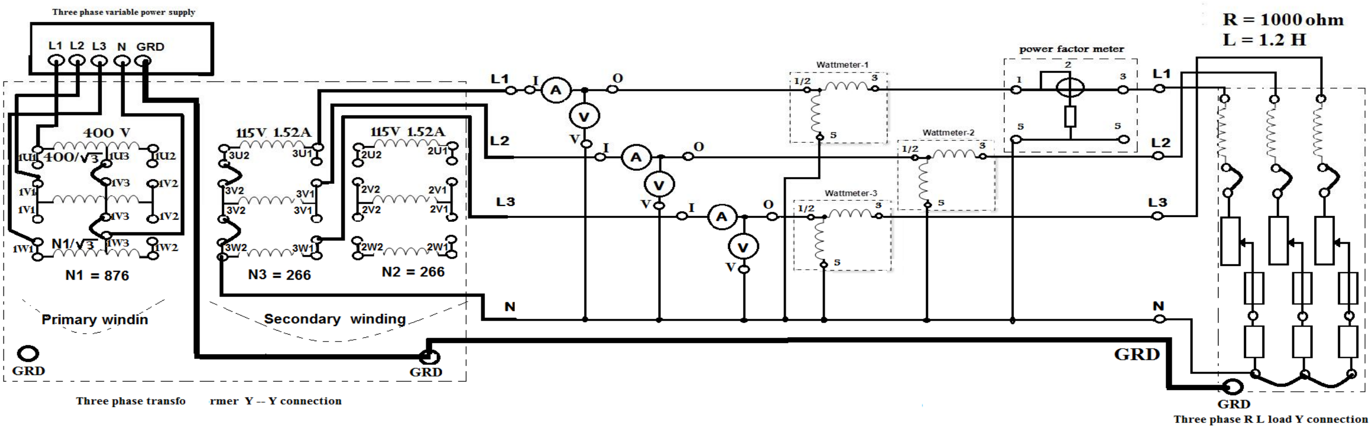
The output voltage of a transformer drops due to load rise, even if the supply voltage remains constant. To determine the transformer ability in handling such a load, it is necessary to incorporate the voltage regulation. This compares between transformer under no-load and full-load. High efficiency transformer maintains a considerably low voltage regulation and reaches zero in the ideal one

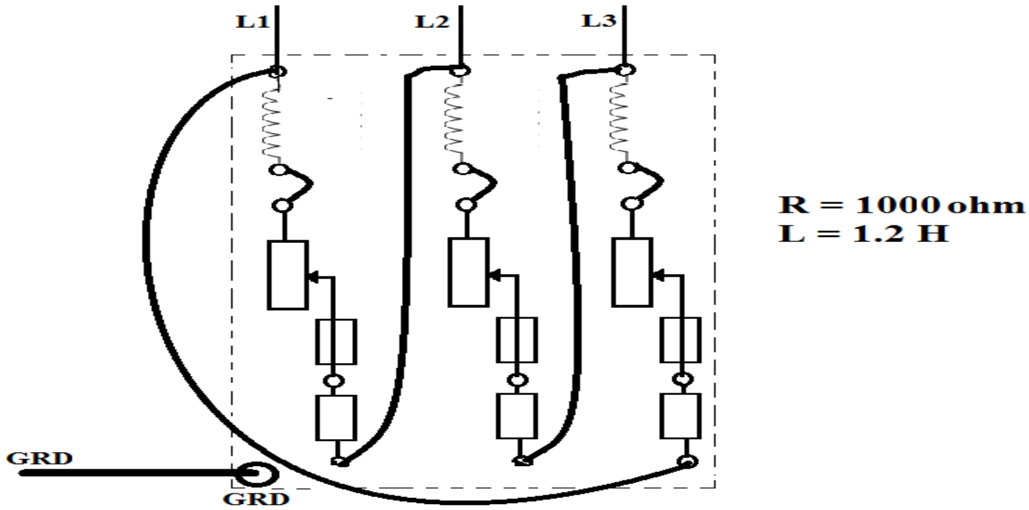
$$V_R(\%) = \frac{V_{nl(ph)} - V_{fl(ph)}}{V_{fl(ph)}} \times 100\%$$

$$V_R(\%) = \frac{V_{nl(line)} - V_{fl(line)}}{V_{fl(line)}} \times 100\%$$

Procedure

1. **Take** few steps to get the whole transformer circuit connected, firstly use the 3Φ Power supply unit to construct the left-hand side of circuit in Fig. 1.1
2. Make the connection of the three phase transformer circuit as shown in the following **:**





Three phase R L load Δ connection

1. Before starting, make sure that three phase power supply is at minimum (VLL = 0) and the three phase resistive load is on the maximum (R = 1000 Ω)
2. Now start the three phase power supply and vary it to obtain line to line voltage at the primary side of the three phase transformer equal to 400 V
3. Decrease the three phase resistive load to obtain 400 Ω.
4. The three phase system measurement

3 Φ R – L load	VAN volt	VBN volt	VCN volt	IA Amp	IB Amp	IC Amp	PA watt	PB watt	PC watt	P.F measured	P.F calculation
Y											
Δ											

5. **Calculate the value of the capacitor required to improve the power factor of the three phase system <u>to 0.92</u>**
6. **Connect that capacitor parallel to the load and notice the effect of that on your three phase measurement**

Results after power factor improvment

3 Φ R – L load	**VAN volt**	**VBN volt**	**VCN volt**	**IA Amp**	**IB Amp**	**IC Amp**	**PA watt**	**PB watt**	**PC watt**	**P.F measured**	**P.F calculation**
Y											
Δ											

Exp-12

LOAD TEST ON 3-PHASE SLIP RING INDUCTION MOTOR

Objectives

To understand how to characterize and control the slip-ring induction motor. In addition, to examine and analyze its performance and compare it with the squirrel cage motor. This is accomplished by determining the variation of (speed, torque, current, efficiency and power-factor) against the torque at different loads

Apparatus Required

- Power Supply Unit *AV-1/EV*
- Power Analyzer Meter *AZ-VIP*
- Speed-Torque Meter *UM-G1/EV*
- Measurement Devices *TSI/EV & AZ-VI/EV*
- DC Sep Excited Generator*M-12/EV*
- 3-phase slip-ring induction motor *M-5/EV*
- Starting rheostat *RC3-9T*
- Adjustable Resistive Load Unit *RL-1/EV*

Theory

The slip ring or wound rotor motor is an induction machine where the rotor comprises a set of coils that are terminated in slip-rings to which external resistors can be connected, see Fig.1. The stator construction is the same as used with a standard squirrel cage motor.

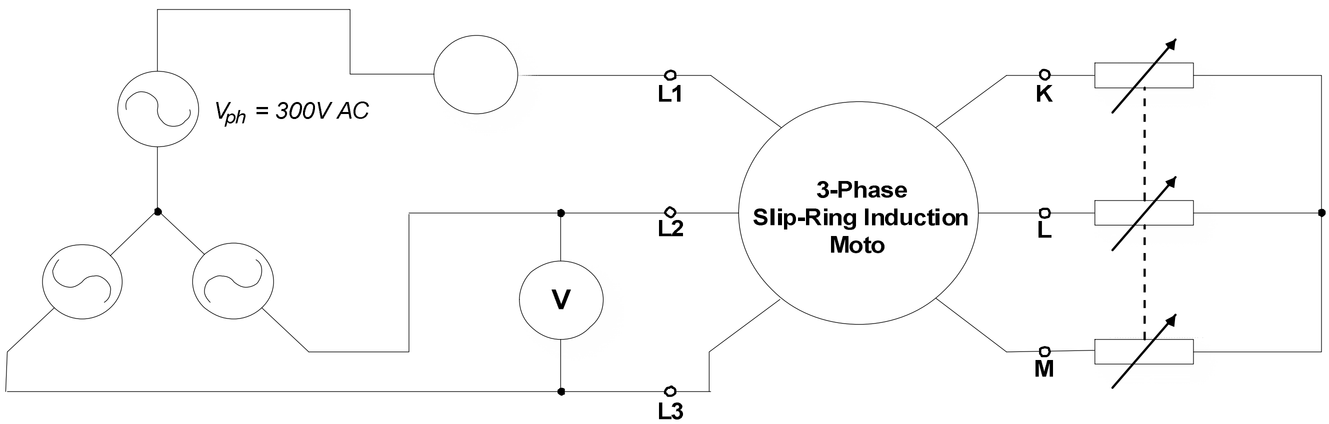


Fig.1 simplified circuit diagram of wound rotor induction motor

The figure below shows the torque-speed curve for a slip-ring motor at different values of motor resistance. Since the rotor terminals are brought out to slip-rings, additional resistance can be inserted in the rotor circuit. The higher the resistance the lower the speed gets, but the maximum torque remains relatively constant at all values of resistance. This characteristic can be utilized to control speed/current and speed/torque curves.

The slip ring motor is used primarily to start a high inertia load or a load that requires a very high starting torque across the full speed range. By correctly selecting the resistors used in the secondary resistance or slip ring starter, the motor is able to produce maximum torque at a relatively low current from zero speed to full speed. A secondary use of the slip ring motor is to provide a means of speed control. Because the torque curve of the motor is effectively modified by the resistance connected to the rotor circuit, the speed of the motor can be altered. Increasing the value of resistance on the rotor circuit will move the speed of maximum torque down. If the resistance connected to the rotor is increased beyond the point where the maximum torque occurs at zero speed, the torque will be further reduced.

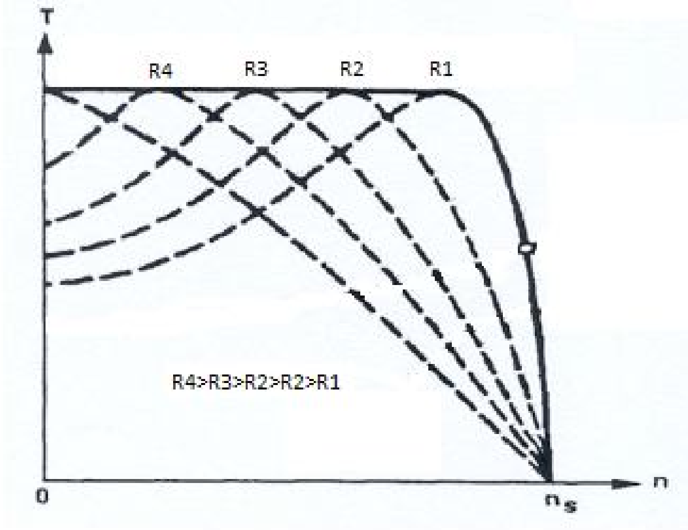


Fig.2 Characteristic Curve of Wound rotor induction motor

When used with a load that has a torque curve that increases with speed, the motor will operate at the speed where the torque developed by the motor is equal to the load torque. Reducing the lad will cause the motor to speed up, and increasing the load will cause the motor to slow down until the load and motor torque are equal. Operated in this manner, the slip losses are dissipated in the secondary resistors and can be very significant. The speed regulation is also very poor.

Experimental Procedure

1- Observe the ratings on the nameplate of *M-5/EV*. And identify the connection terminals (U1-U2, V1-V2, W1-W2) and the rotor terminals (K, L, M).

2- The power analyzer meter is utilized to provide various AC measurements, like input voltage, current and power. According to the circuit diagram. This meter is connected between the power supply *AV-1/EV* terminals via (L1, L2 & L3)and the induction motor *M-5/EV* via terminals (U1,V1& W1).

3- The motor has a three separate connections for rotor terminals (K, L , M), connect these to the rheostat *RC-9T.*

4- The speed-torque meter is necessary to give specific torque and speed measurements, the device has two separate connections one for load cell and the second for optical tachometer.

5- Connect the motor in wye configuration mode; join the terminals (W2, V2 & U2) together, and the terminals (W1, V1& U1)to go to the supply unit *AV-1/EV*.

6- Once you are done with the wiring, adjust the phase input voltage at 300 VAC and keep it constant throughout the test

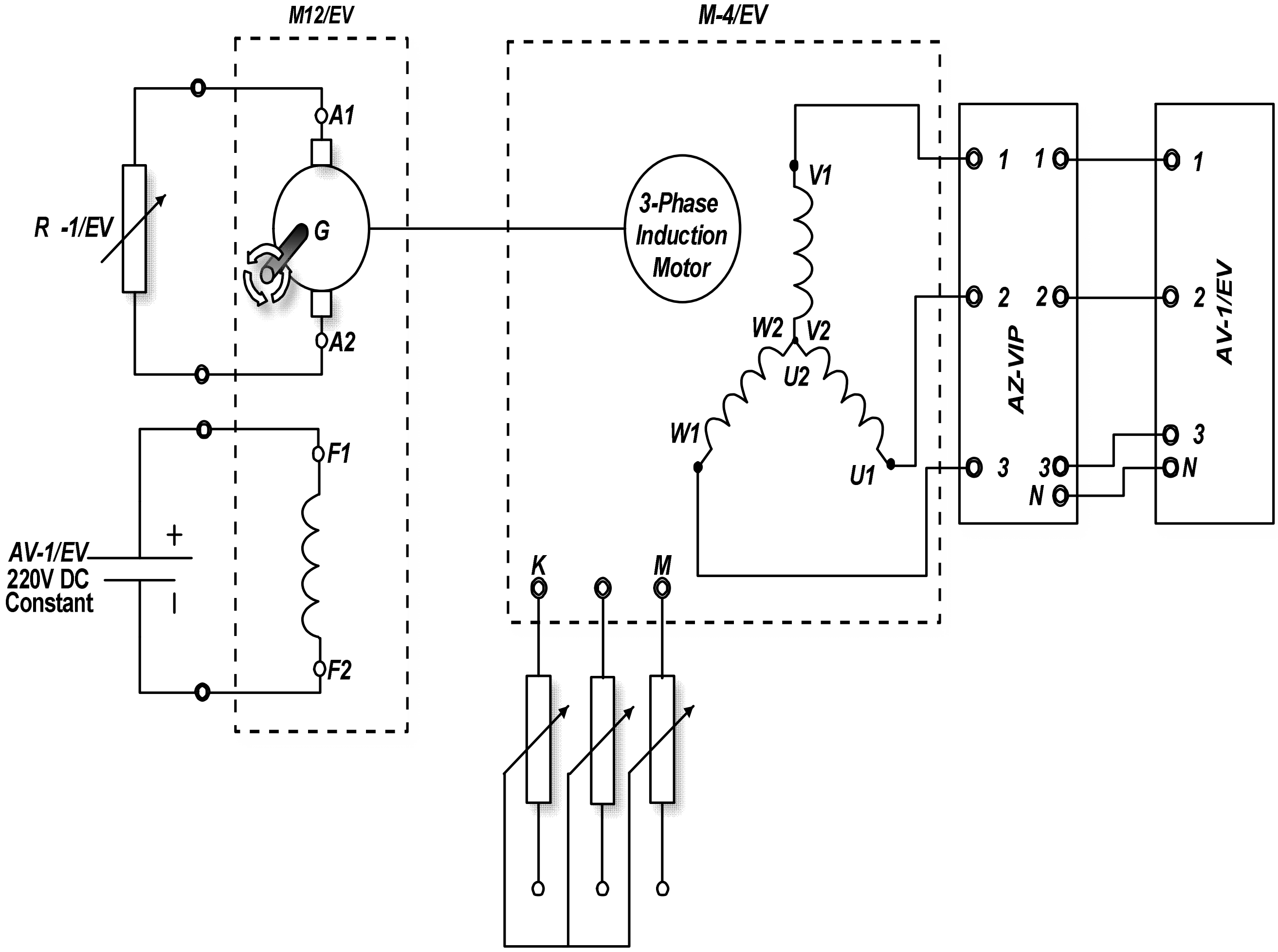
7- Run the motor at no-load (keep the DC generator switched off) and read the no-load speed, the reading shall be close to 3000 rpm

8- Adjust the starting rheostat *RC3-9T* to 0Ω and gradually increase the resistive load *RL-1/EV*in progressive steps (refer to the list of *RL-1/EV* settings in table-1)

9- With each step use the power analyzer *AZ/VIP* to measure the input current and power and take the speed and torque readings from the *UM-G1/EV*

10-Tabulate the measurements in table-1

11-Switch of the supply unit and dismantle the circuit


M12/EV
M-4/EV
R -1/EV
A1
G
A2
F1
F2
AV-1/EV
220V DC
Constant
+
3-Phase
Induction
Motor
V1
W2
V2
U2
W1
U1
K
M
1
2
3
N
AZ-VIP
AV-1/EV

KLM Resistance	0 Ω										10 Ω									
	RL-1/EV($Load$)		V_{ph} (V)	n (rpm)	T (N.m)	I_{line} (A)	P_{in} (watt)	P_{out} (watt)	η 100%	s 100%	RL-1/EV ($Load$)		V_{ph} (V)	n (rpm)	T (N.m)	I_{line} (A)	P_{in} (watt)	P_{out} (watt)	η 100%	s 100%
	Settings	Ω									Settings	Ω								
Min. Load	*A*	2200	300								*A*	2200	300							
	B	1100	300								*B*	1100	300							
	AB	733	300								*AB*	733	300							
	C	550	300								*C*	550	300							
	AC	440	300								*AC*	440	300							
	BC	367	300								*BC*	367	300							
	ABC	314	300								*ABC*	314	300							
	ABC A	275	300								*ABC A*	275	300							
	ABC B	244	300								*ABC B*	244	300							
Max. Load	*ABC AB*	200	300								*ABC AB*	200	300							

Table-1 Experimental data for slip-ring induction motor under various load conditions R_{KLM} = 0Ω & 10Ω

KLM Resistance	20 Ω										30 Ω									
	RL-1/EV($Load$)		V_{ph} (V)	n (rpm)	T (N.m)	I_{line} (A)	P_{in} (watt)	P_{out} (watt)	η 100%	s 100%	RL-1/EV ($Load$)		V_{ph} (V)	n (rpm)	T (N.m)	I_{line} (A)	P_{in} (watt)	P_{out} (watt)	η 100%	s 100%
	Settings	Ω									Settings	Ω								
Min. Load	*A*	2200	300								*A*	2200	300							
	B	1100	300								*B*	1100	300							
	AB	733	300								*AB*	733	300							
	C	550	300								*C*	550	300							
	AC	440	300								*AC*	440	300							
	BC	367	300								*BC*	367	300							
	ABC	314	300								*ABC*	314	300							
	ABC A	275	300								*ABC A*	275	300							
	ABC B	244	300								*ABC B*	244	300							
Max. Load	*ABC AB*	200	300								*ABC AB*	200	300							

Table-2 Experimental data for slip-ring induction motor under various load conditions R_{KLM} = 20Ω & 30Ω

Analysis

- Refer to table-1 and calculate the following; angular speedω, input power P_{in},output power P_{out}, slip $s$and efficiency η.
- Evaluate the results being obtained in table-1 & 2 and draw the variation of speed (n) with respect to torque (T)
- Briefly explain how does the speed change as the torque increases
- Draw a curve representing the efficiency (η) relative to input power (P_{in})
- With reference to the results in talbe-1, comment on the relationship between the motor current, motor speed and the starting resistance.
- From the result in table-2, draw a curve representing the speed (ω)relative to the current (I_L)

Exp-13

Three phase induction motor power factor correction

Experimental Procedure

13. Note down the induction motor name-plate *M-4/EV* and identify the connection terminals

14. Assemble the 3-phase induction motor circuit as indicated in Fig.4

15. Then verify your connections and choose a maximum value of resistive load *RL-1/EV* (say 2200Ω)

16. Using the controls on the supply unit *AV-1/EV* ,Turn-on the supply for the load unit *M-12/EV* and then the 3-phase supply *M-4/EV*

17. raise the V_{ph} of 3-phase supply at 300V and keep it constant throughout the experiment

18. Since the resistive load *RL-1/EV* is set to maximum, the motor *M-4/EV* supposed to be running at synchronous speed (3000-rpm)

19. With reference to the *RL-1/EV* settings in table-1. The load torque shall be increased in progressive steps accordingly.

20. For each step take the necessary measurements of speed, torque, voltage and current and tabulate them in table-1

$V_{L\,L}$ (V)	RL-1/EV($Load$) Settings	(Ω)	I_{line} (A)	n (rpm)	s (100%)	ω (rad/s)	T (N.m)	P_{in} (watt)	P_{out} (watt)	P_f	η (100%)
230	*No Load*										
230	*A*										
230	*B*										
230	*AB*										
230	*C*										
230	*AC*										
230	*BC*										
230	*ABC*										
230	*ABC A*										
230	*ABC B*										
230	*ABC AB*										

Table-1 Experimental data for 3-phase induction motor (wye connected motor)

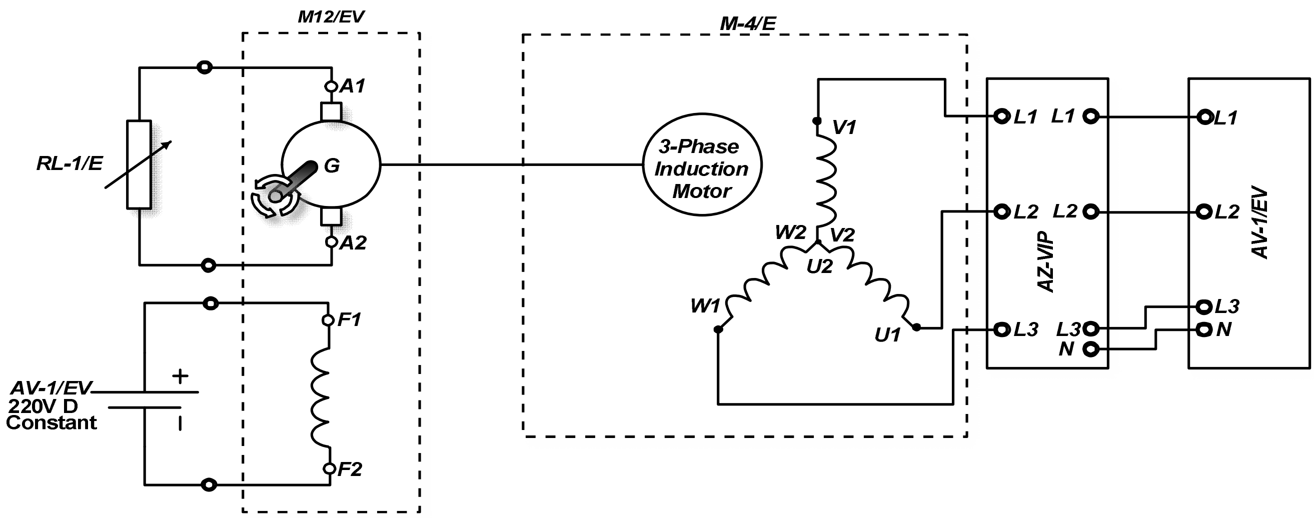


Fig.4 Circuit diagram of 3-phase squirrel cage induction motor

21. Delta connection gives a higher current at lower voltage, compared to wye connection. Thus, motor terminals of *M-4/EV* are to be connected in delta mode (see Fig.5)

22. Notice that the delta connected circuit is identical to Fig.4 apart from the motor connection

23. Start the motor and repeat the steps *6,7 & 8*

24. Once you are done, switch of the supply unit *AV-1/EV* and dismantle the circuit

V_{LL}	RL-1/EV$(Load)$		I_{line}	n	s	ω	T	P_{in}	P_{out}	P_f	η
(V)	Settings	(Ω)	(A)	(rpm)	(100%)	(rad/s)	(N.m)	(watt)	(watt)		(100%)
230	*No Load*										
230	*A*										
230	*B*										
230	*AB*										
230	*C*										
230	*AC*										
230	*BC*										
230	*ABC*										
230	*ABC A*										
230	*ABC B*										
230	*ABC AB*										
230											
230											
230											

Table-2 Experimental data of 3-phase induction motor (delta connected motor)

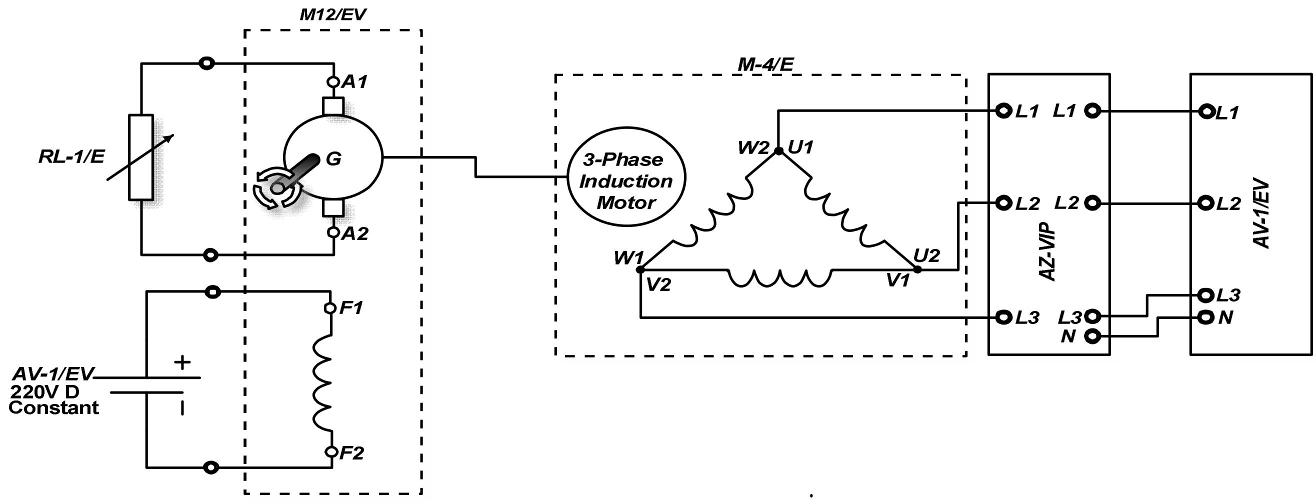


Fig.5 Circuit diagram of 3-phase squirrel cage induction motor

Analysis

5. Perform the necessary calculation to find ω, s, P_{in} ,P_{out} , P_f and η

6. Evaluate the speed-torque results and draw a characteristic curve to analyze the relationship between them

7. From the data obtained in table-1,draw two curves; the first to represent the efficiency η relative to input power $P_{in}$and the second to represent the efficiency ηrelative to power factor P_f

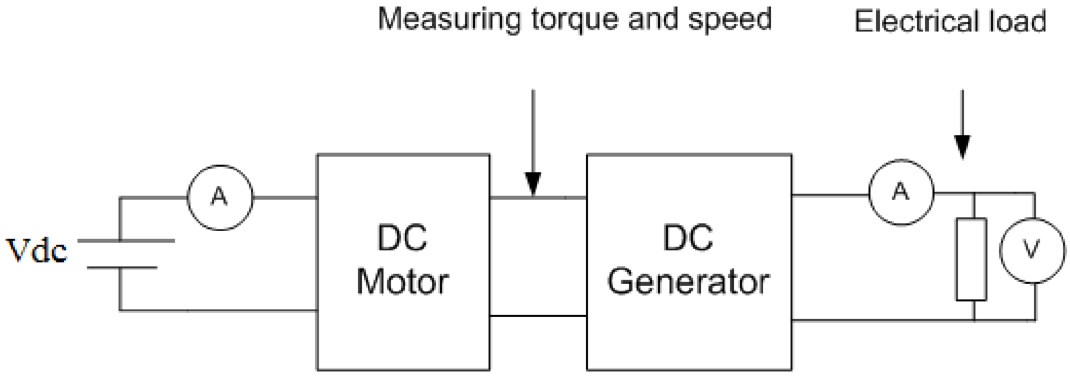
8. Discuss the observations that can be made on the speed-torque curve and briefly explain how to relate it with the characteristic curve in Fig.3

9. At rated condition add capacitors to measure the line currents before and after adding capacitors In three steps (1.8 micro-farad, 3.6 micro-farad, 4.6 micro-farad). With each step you must use two power analyzers in order to be able measuring the change in line current.

Exp-14

Matalb simulink for DC machine: a DC motor used as prime mover for a DC generator

The main objective of the experiment is drawing the characteristic curves of DC generator and DC motor, The DC motor is shunt motor and the DC generator = separately excited DC generator.



The Experiment will be discussed in computer lab

Exp-15

Matalb simulation of three phase induction motor

The main objective of this experiment to model, and perform simulation and analysis of three phase AC induction motor with reactive power compensation. Three phase capacitor can be used with star connected and delta connected. Measurements of line currents at different capacitor values and performing power calculations.

The Experiment will be discussed in computer lab