Lab Manual

ELECTRICAL MACHINES LABORATORY – II

B.Tech IV Semester

Subject Code: ELPC 452

Department of Electrical Engineering

J. C. Bose University of Science and Technology

YMCA, Faridabad-121006

DEPARTMENT OF ELECTRICAL ENGINEERING

VISION OF THE DEPARTMENT

Electrical Engineering Department congregates the challenges of new technological advancements to provide comprehensively trained, career-focused, morally strong accomplished graduates, cutting-edge researchers by experimental learning which contribute to ever-changing global society and serve as competent engineers.

MISSION OF THE DEPARTMENT

- To commit excellence in imparting knowledge through incubation and execution of high-quality innovative educational programs.
- To develop the Research-oriented culture to build national capabilities for excellent power management.
- To inculcate and harvest the moral values and ethical behavior in the students through exposure of self -discipline and personal integrity.
- To develop a Centre of Research and Education generating knowledge and technologies which lay ground work in shaping the future in the field of electrical engineering.

PROGRAM OUTCOMES (POs)

Engineering Graduates will be able to:

1. Apply the knowledge of mathematics, science, electrical engineering fundamentals, and an electrical engineering specialization to the solution of complex electrical engineering problems.
2. Identify, formulate, review research literature, and analyze complex electrical engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. Design solutions for complex electrical engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and cultural, societal, and environmental considerations.
4. Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex electrical engineering activities with an understanding of the limitations.
6. Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. Understand the impact of professional electrical engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAM SPECIFIC OUTCOMES (PSOs)

1. To impart State-of-Art knowledge in the field of Electrical Engineering and hand on application-based practical training with regular Academic and Industry interaction.
2. To incorporate research environment and innovation projects towards assimilation of global technology in order to meet needs of automation and articulate a higher education system of ethics and mind set for a realistic education.

PROGRAM EDUCATIONAL OBJECTIVES (PEOs)

1. To produce competent electrical engineering graduates with a strong foundation design, analytics and problem solving skills for successful professional careers in industry, research and public service.
2. To provide a stimulating research environment so as to motivate the students for higher studies and innovation in the specific and allied domains of electrical engineering.
3. To encourage the graduates to practice the profession following ethical codes, social responsibility and accountability.
4. To train students to communicate effectively in multidisciplinary environment.
5. To imbibe an attitude in the graduates for life-long learning process.

COURSE OBJECTIVES & OUTCOMES

Course objectives:

1. **Enhance analytical skills** to assess the performance of induction motors by conducting no-load, blocked rotor, and load tests, while determining equivalent circuit parameters and performance characteristics.
2. **Gain practical expertise** in various starting techniques and speed control methods for three-phase induction motors, such as Direct-On-Line (DOL), Auto-Transformer, Star-Delta, and rotor resistance control.
3. **Develop an in-depth understanding** of synchronous machines by analyzing performance characteristics, including voltage regulation, synchronous reactance, and symmetrical impedances, through various test methods like direct loading, synchronous impedance, and Zero Power Factor (ZPF) tests, slip tests, etc.
4. **Obtain hands-on experience** in the parallel operation of alternators and evaluate the behavior of synchronous motors by analyzing V-curves and inverted V-curves under different field currents and load conditions.

Course outcomes:

CO[1] Students will be able to analyze the equivalent circuit parameters of three-phase and single-phase induction motors through no-load and blocked rotor tests, enabling them to understand motor performance characteristics.

CO[2] Students will gain the ability to conduct load tests on both three-phase and single-phase induction motors, allowing them to evaluate motor efficiency, torque-speed characteristics, and overall performance under different loading conditions.

CO[3] Students will develop proficiency in various starting methods and speed control techniques for three-phase induction motors, including Direct-On-Line (DOL), Autotransformer, Star-Delta, and rotor resistance control, equipping them with practical skills in motor control and operation.

CO[4] Students will be able to determine and analyze the voltage regulation and synchronous reactance of three-phase alternators and synchronous machines using different methods such as direct loading, synchronous impedance (EMF method), and ZPF method, preparing them for tasks related to power generation and alternator synchronization.

||General Instructions||

1. Students should come well-prepared for the experiment they will be conducting.
2. Usage of mobile phones in the laboratory is strictly prohibited.
3. In the lab, wear shoes and avoid loose-fitting clothes.
4. Read and understand the experiment manual thoroughly before starting the experiment. Know the objectives, procedures, and safety precautions.
5. Before starting the experiment, check the condition of the equipment, wiring, and connections. Report any damaged or malfunctioning equipment to the lab instructor immediately.
6. Ensure all connections are made as per the circuit diagram. Double-check all connections before powering the equipment.
7. Do not switch on the power supply until the instructor has approved your setup. Always start with the minimum voltage/current required and gradually increase as needed.
8. Do not overload machines beyond their rated capacity. Overloading can damage the equipment and pose safety risks.
9. Familiarize yourself with the lab's emergency shutdown procedures, including the location of emergency switches and fire extinguishers.
10. Do not bring food or drinks into the lab to avoid accidental spills, which can lead to electrical hazards.
11. Stay attentive during the experiment. Avoid distractions like mobile phones, and do not engage in unnecessary conversation during lab work.
12. Accurately record all measurements and observations during the experiment. Ensure that all data is properly noted in your lab report.
13. If you are unsure about any procedure or face difficulties during the experiment, do not hesitate to ask the lab instructor for guidance.
14. After completing the experiment, switch off the power supply, disconnect the setup, and return all equipment to its proper place. Ensure the workspace is clean and organized.

Syllabus

Electrical Machines Lab-II (ELPC-452)

L-T-P | **Internal Marks-15**
0-0-2 | **ExternalMarks-35**
Total-50

List of Experiments

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2.	To perform a load test on a three-phase induction motor and obtain the performance characteristics.	**8-12**
3.	To study various starting methods of three-phase squirrel cage induction motor. [DOL, Auto-Transformer, Star-Delta]	**13-21**
4.	To perform speed control of the three-phase slip-ring induction motor by rotor resistance control.	**22-24**
5.	To perform a load test on a single-phase induction motor and obtain the performance characteristics.	**25-28**
6.	Determination of equivalent circuit parameters of a single-phase induction motor by no-load and blocked rotor test.	**29-34**
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8.	To find regulation of a three-phase alternator by synchronous impedance method (EMF method)	**38-42**
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11.	To determine the direct axis (X_d) and quadrature axis (X_q) synchronous reactance of a three-phase synchronous machine by slip test.	**51-54**
12.	To study the effect of variation of field current upon the stator current and power factor of a synchronous motor at various loads and draw V-curves and invert V-curves.	**55-57**
13.	To determine the symmetrical impedances of a synchronous machine.	**58-61**
14.	To perform the parallel operation of two alternators.	**62-67**

Experiment No. - 1

Aim: To perform no-load and blocked rotor test on a three-phase induction motor and determine the equivalent circuit parameters.

Apparatus :

Sl No	Apparatus Name	Specification	Quantity
1)	Ammeter		
2)	Voltmeter		
3)	Wattmeter		
4)	Tachometer		
5)	Connecting leads		
6)	Auto Transformer (Variac)		

Electrical Machine Specifications:

Induction Motor: HP: _________ Voltage:____________ Current: ______________

Speed: _______________

Theory :

The equivalent circuit of an induction motor closely resembles that of a transformer, with the key difference being the inclusion of 'slip' as an additional parameter. As a result, the equivalent circuit parameter estimation of the induction machine proceeds on similar lines as that of a transformer. The per-phase equivalent circuit of an induction machine is shown in Fig (1).

Here $R'_r + \frac{R'_r\,(1-s)}{s} + X'_{r1}$ represent the rotor impedance as a function of slip (s).

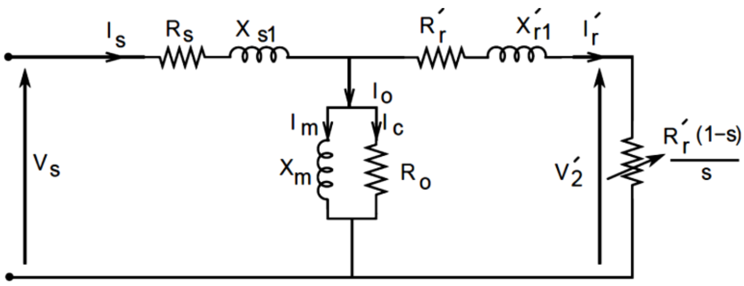


Fig-1- Per phase equivalent circuit of Induction Motor

1. No Load Test :

The no-load test estimates the parameters of the stator circuit (R_s and X_{s1}) and the magnetization branch (X_m) of an induction machine. By applying the rated three-phase voltage to the stator (V_{nl}), the machine is brought to its rated speed, and the corresponding no-load current (I_{nl}) and no-load real power input (P_{nl}) are measured. With no mechanical load, the slip (s) is minimal, making the rotor circuit branch resistance ($R'_r\ (1-s/s)$) significantly large. Consequently, the rotor circuit's impedance is much higher than the magnetization branch's impedance, resulting in their parallel combination being approximately jX_m, assuming core conductance is negligible. This test can be performed on the motor to determine its efficiency.

From no load test, we find the parameters:

$$X_{nl} = X_{s1} + X_m$$

$$Z_{nl} = \frac{V_{nl}}{I_{nl}}$$

$$R_{nl} = \frac{P_{nl}}{I_{nl}^2}$$

$$\cos\varphi_0 = \frac{P_{nl}}{V_{nl}I_{nl}}$$

where Z_{nl} and R_{nl} are the no-load equivalent impedance and resistance respectively. Next, using the above equations, we get,

$$X_{nl} = \sqrt{Z_{nl}^2 - R_{nl}^2}$$

Additionally, since no load current is being drawn, the losses occurring under these conditions would solely represent the rotational losses due to friction and core loss. Hence,

$$P_{loss} = P_{nl} - I_{nl}^2\, R_s$$

2. Blocked Rotor Test :

The blocked rotor test is conducted to determine parameters influencing the machine's performance under load, such as its leakage impedance. This is comparable to the short circuit test performed on a transformer. During a blocked rotor test, the machine's shaft is locked or restrained from rotating by external means, effectively making the slip equal to one ($N_r = 0$). In this condition, E'_2 represents the voltage across the rotor circuit. we have

$$slip\ (s) = \frac{N_s - N_r}{N_s}$$

$$I_r = \frac{E_2'}{\frac{R_r'}{s} + jx_{r1}}$$

It can be observed that, the rotor resistance o_ered in this case is 'e_ectively' lowered by a fraction of $1/s_0$, where s_0 is the slip under rated operation (0.01-0.04). Rated stator currents can thus be established for much lower than rated values of stator terminal voltage.

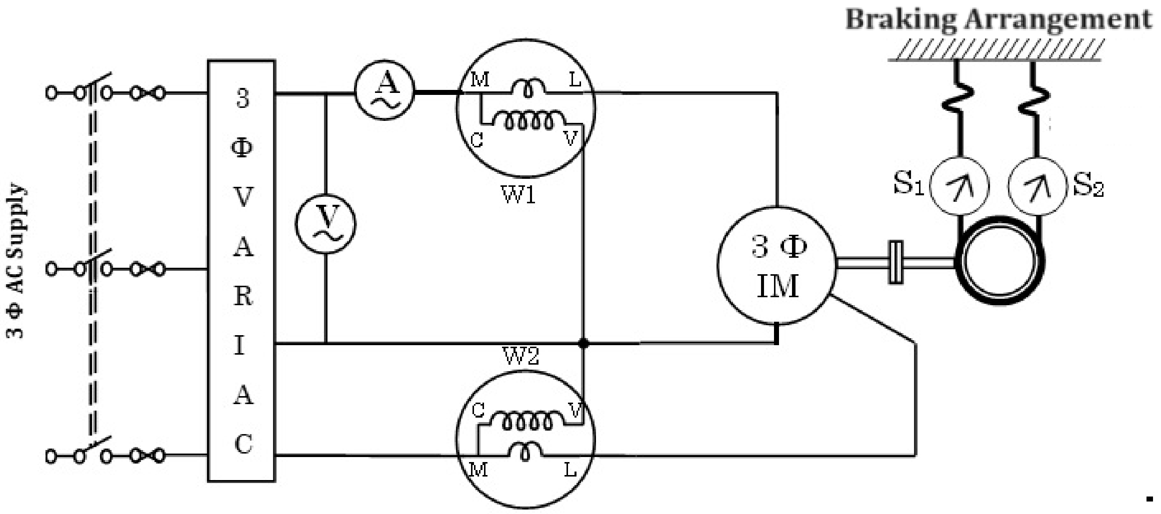
When the rated current (I_{br}) flows through the stator, we observe the stator's applied voltage (V_{br}) and the input power (P_{br}). It is important to recognize that the rotor's position when blocked influences the required stator voltage (V_{br}) to establish I_{br}. Therefore, an average value derived from various rotor positions can be utilized. Assuming we have the stator circuit parameters R_s ready, the other machine parameters can be calculated as indicated below.

$$Z_{br} = \frac{V_{br}}{I_{br}}$$

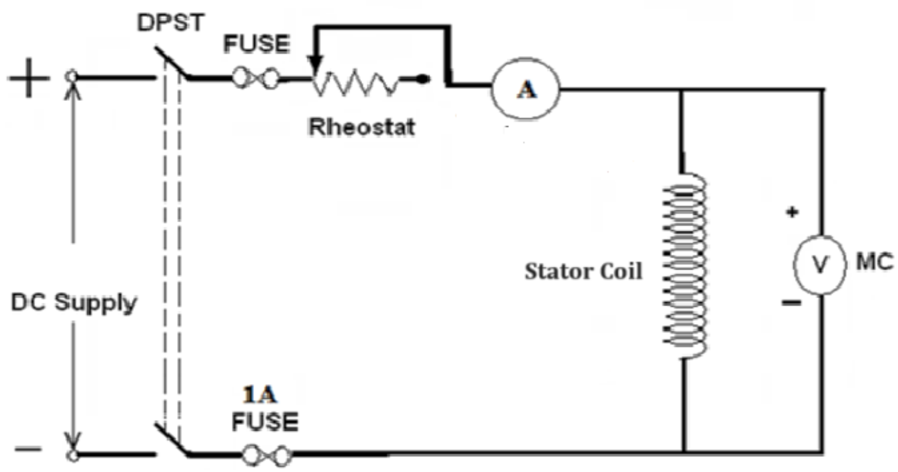
$$R_{br} = \frac{P_{br}}{I_{br}}$$

$$X_{br} = \sqrt{Z_{br}^2 - R_{br}^2}$$

Circuit Diagram :



Measurement of Stator Resistance



No Load Test:

1. Connections are made as per the circuit diagram.
2. Ensure that the 3- ϕ variac is kept at minimum output voltage position and the belt is freely suspended.
3. Switch ON the supply. Increase the variac output voltage gradually until the rated voltage is observed in the voltmeter. Note that the induction motor takes a large current initially, so, keep an eye on the ammeter such that the starting current should not exceed the limiting value.
4. By the time speed gains rated value, note down the readings of the voltmeter, ammeter, and wattmeter.
5. Bring back the variac to zero output voltage position and switch OFF the supply.

Blocked Rotor Test:

1. Connections are as per the circuit diagram.
2. The rotor is blocked by tightening the belt.
3. A small voltage is applied using 3- ϕ variac to the stator so that a rated current flows in the induction motor.
4. Note down the readings of the Voltmeter, Ammeter, and Wattmeter in a tabular column.
5. Bring back the variac to zero output voltage position and switch OFF the supply.

Measurement of Stator Resistance:

1. Connections are made as per the circuit diagram
2. Switch ON the supply. By varying the rheostat, different ammeter and voltmeter readings are taken in a tabular column.
3. From the above readings, the average resistance r_1 of a stator is found.

Observation Table:

No load test:

Sr. No.	Voltmeter reading	Ammeter Reading	Wattmeters Reading		No load Power
	V_{nl}	I_{nl}	W_1	W_2	P_{nl}

Blocked rotor test

Sr. No.	Voltmeter reading	Ammeter Reading	Wattmeters Reading		Power
	V_{br}	I_{br}	W_1	W_2	P_{br}

Measurement of stator resistance

Sr. No.	Voltage (V)	Current (I)	Resistance (R)

Calculations:

For no load test:

Here V_{nl}, I_{nl}, and power P_{nl} are the per-phase values for the No-Load test.

$$Z_{nl} = \frac{V_{nl}}{I_{nl}}$$

$$R_{nl} = \frac{P_{nl}}{I_{nl}^2}$$

$$\cos \varphi_0 = \frac{P_{nl}}{V_{nl} I_{nl}}$$

$$X_{nl} = \sqrt{Z_{nl}^2 - R_{nl}^2}$$

For blocked rotor test:

Here V_{br}, I_{br} and power P_{br} are the per-phase values for the Blocked rotor test.

Since $X_m >> X_2$

$X_{br} = X_1 + X_2$

For squirrel cage induction motor, total leakage reactance $X_{br} = (X_1 + X_2)$ can be distributed between stator and rotor as per the following table:

Sl no	Class of motor	Fraction of X_{br}	
		X_1	X_2
1	Class A	0.5	0.5
2	Class B	0.4	0.6
3	Class C	0.3	0.7
4	Class D	0.5	0.5

$$Z_{br} = \frac{V_{br}}{I_{br}}$$

$$R_{br} = \frac{P_{br}}{I_{br}}$$

$$X_{br} = \sqrt{Z_{br}^2 - R_{br}^2}$$

$$\cos\varphi_{sc} = \frac{P_{br}}{V_{br}I_{br}}$$

$$X_m = X_{nl} - X_1$$

$$R_2 = (R_{br} - R_1)\left(\frac{X_2}{X_m}\right)^2$$

$$I_{sc} = I_{br}\left(\frac{V_s}{B_{br}}\right)$$

Stator and rotor ohmic losses at standstill are assumed equal.

Precautions:

1. Ensure all electrical connections are correct and secure before starting the experiment to avoid incorrect readings or damage to the motor.
2. Verify that the supply voltage is stable and within the rated range of the motor to ensure accurate results.
3. Use properly rated and calibrated measuring instruments (voltmeters, ammeters, and wattmeters) to obtain precise measurements and avoid damage to the instruments.
4. During the no-load test, make sure the motor shaft is free of any mechanical load to ensure the accuracy of the readings.
5. Do not run the motor under no-load conditions for extended periods to prevent unnecessary heating and potential damage to the motor.
6. During the blocked rotor test, securely lock the rotor to prevent any movement that could lead to incorrect results or damage to the motor.
7. Apply a reduced voltage (typically 20-30% of the rated voltage) during the blocked rotor test to avoid excessive current, which can cause overheating and damage to the windings.
8. Limit the duration of the blocked rotor test to only a few seconds to prevent the motor from overheating due to the high current.
9. Continuously observe the motor for any abnormal conditions, such as excessive heating, unusual sounds, or smoke, and stop the test immediately if any issues are detected.

Result:

Thus various parameters of an equivalent circuit for a three-phase induction motor are determined.

Viva Questions:

1. What is the purpose of performing a no-load test on a three-phase induction motor?
2. Explain the setup for a no-load test on a three-phase induction motor.
3. What parameters are measured during the no-load test?
4. How do you calculate the no-load current and power factor from the no-load test data?
5. What is the significance of no-load power in an induction motor?
6. How is the core loss determined from the no-load test?
7. Why is it necessary to perform the no-load test at rated voltage and frequency?

8. What are the typical values of no-load current as a percentage of rated current for a three-phase induction motor?
9. How do you distinguish between friction, windage losses, and core losses in a no-load test?
10. What is the role of the slip in the no-load test of an induction motor?
11. What is the purpose of performing a blocked rotor test on a three-phase induction motor?
12. Describe the setup for a blocked rotor test on a three-phase induction motor.
13. What parameters are measured during the blocked rotor test?
14. How do you calculate the short-circuit impedance and reactance from the blocked rotor test data?
15. What safety precautions should be taken while performing the blocked rotor test?
16. Why is the blocked rotor test performed at reduced voltage?
17. How can you determine the starting torque of the motor from the blocked rotor test?
18. What is the significance of the blocked rotor current in relation to the rated current?
19. Explain the impact of temperature on the results of the blocked rotor test.
20. How do you use the blocked rotor test to determine the rotor resistance and reactance?

Experiment No. - 2

Aim: To perform the load test on a 3-φ induction motor and obtain the performance characteristics.

Apparatus:

Sl No	Apparatus Name	Specification	Quantity
1)	Ammeter		
2)	Voltmeter		
3)	Wattmeter		
4)	Auto Transformer		
5)	Tachometer		
6)			

Specifications of Machine:

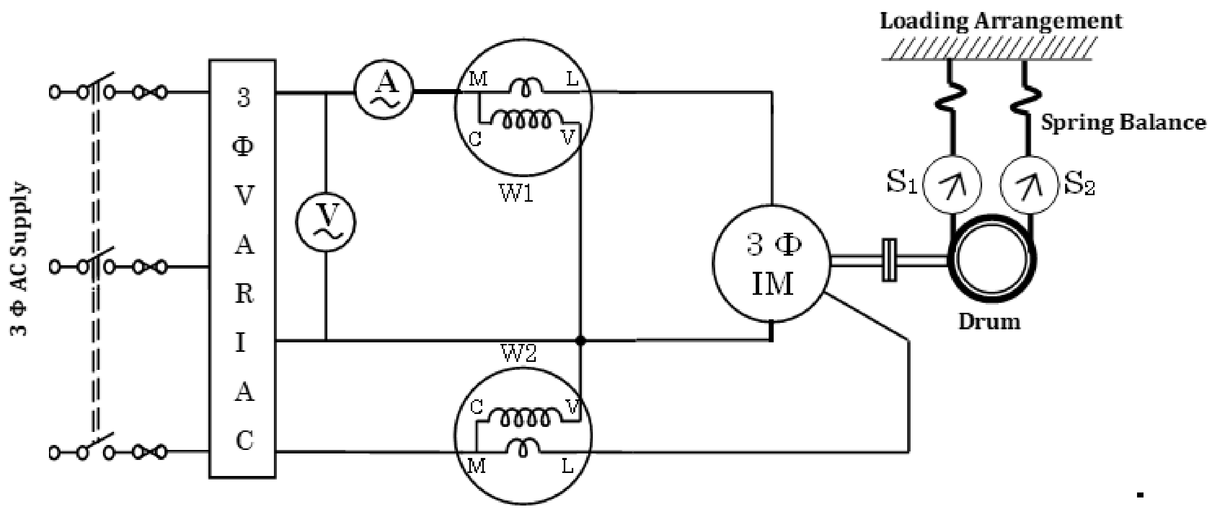
Induction Motor: HP: ________ Voltage:__________ Current: ____________

Speed: _____________

Theory :

Conducting a load test on an induction motor allows for a comprehensive evaluation of its performance by determining various parameters such as torque, slip, efficiency, power factor, and more under different load conditions. During the test, the motor is supplied with voltage and subjected to a variable mechanical load applied to its shaft, often using a brake and pulley setup. By measuring the input current, input voltage, input power, and motor speed, we can calculate and assess the motor's performance characteristics.

Circuit Diagram:



Procedure :

1. Assemble the circuit as illustrated in the diagram.
2. Adjust the three-phase variac to its minimum voltage setting and ensure the brake pulley arrangement is configured for no load.
3. Turn on the power supply to start the induction motor.
4. Slowly increase the voltage by carefully adjusting the variac until the rated voltage is reached.
5. Incrementally add mechanical load to the motor, recording the readings at each step.
6. Turn off the power supply and disconnect the motor.

Observations:

SL NO	Input Voltage V (volt)	Input Current I (amp)	Input Power		Force (Kgf)			Speed N_r (rpm)
			W_1 (watt)	W_2 (watt)	S_1	S_2	$W = S_1 - S_2$	
1								
2								
3								
4								
5								

Diameter of pulley, d =_____ m.

Calculations:

S. No.	Input Power Pin (watt)	Total Force W (Kgf)	Output Torque T (N-m)	Output Power P_o (watt)	Slip (%)	Power Factor cosΦ	Efficiency (%)
1							
2							
3							
4							
5							

Slip:

So the slip of the motor is given by the following equation.

$$s = \frac{N_s - N_r}{N_s} X\ 100$$

Where, N_r is the actual speed of the rotor and N_S is the synchronous speed.

Torque:

Net force exerted on the drum, $W = (S_1 - S_2)K_g f$

$$T = \left(\frac{d}{2}\right) * W * 9.8\ Nm$$

Output Power:

The output power of the induction motor can be calculated as

$$P = \frac{2\,\pi\, N_r T}{60}$$

Input Power:

The input power can be calculated from the readings of two wattmeters connected in the circuit W_1 and W_2

$$P_i = W_1 + W_2$$

Power Factor:

The power factor can be calculated from the two-wattmeter reading using the following relation

$$\tan \varphi = \sqrt{3}\ \frac{W_1 - W_2}{W_1 + W_2}$$

Once the angle Φ is known, the power factor, cosΦ can be easily known.

Efficiency:

Efficiency can be calculated using

$$\eta = \frac{output\ power}{input\ power}\ X\ 100$$

Precautions:

1. Ensure that all electrical connections are secure and correct before starting the test to avoid short circuits and inaccurate readings.
2. Use properly rated and calibrated measuring instruments for voltage, current, and power to ensure accurate results and prevent damage to the instruments.
3. Gradually apply load to the motor, increasing it in small increments to avoid sudden stress on the motor and the mechanical system.
4. Special attention should be given to cooling the break pully, otherwise the wearing out of the belt may be very rapid.
5. Avoid overloading the motor beyond its rated capacity to prevent damage to the windings and insulation.
6. Special care should be taken about the sign of the reading s of wattmeters.
7. Keep the supply voltage stable throughout the test to ensure consistent results and avoid voltage fluctuations that can affect motor performance.
8. Regularly check for abnormal noises, vibrations, or smells during the test, and stop the experiment immediately if any issues are detected.

9. Ensure that all safety equipment, such as fuses and circuit breakers, is in place and functioning correctly to protect against electrical hazards.
10. Use appropriate safety gear, such as insulated gloves and safety goggles, to protect yourself from potential electrical and mechanical hazards during the test.

Results: Draw the following curve of the three-phase induction motor

a) Efficiency vs. output power.
b) Torque vs. output power.
c) Line current vs. output power.
d) Power factor vs. output power.
e) Slip vs. output power
f) Torque vs. slip.

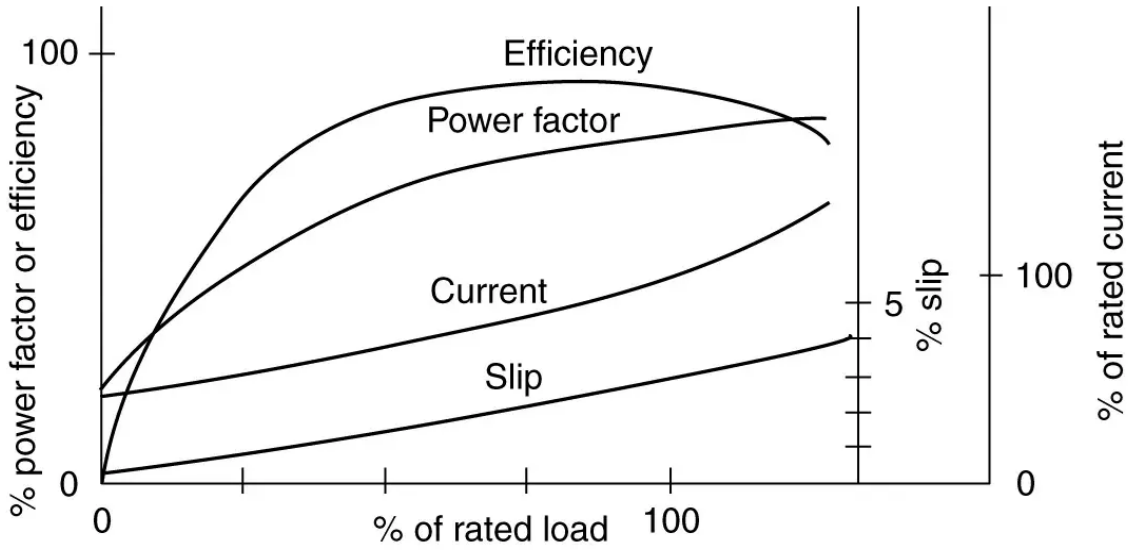


Fig: Performance Curve

Viva questions:

1) What is the purpose of conducting a load test on a three-phase squirrel cage induction motor?
2) How do you define the efficiency of an induction motor during a load test?
3) Define slip in the context of an induction motor.
4) Why do three-phase induction motors always run at less than synchronous speed?
5) What are the key parameters measured during a load test of an induction motor?
6) Why is it important to measure the input power during a load test?
7) How can you measure the input power of an induction motor during a load test?
8) How is the output power of a three-phase squirrel cage induction motor calculated?
9) Explain the significance of maximum torque in an induction motor.

10) What instruments are typically used to measure input power, voltage, and current during a load test?
11) How do you determine the power factor of the induction motor during the load test?
12) What are the losses considered when calculating the efficiency of an induction motor?
13) What factors influence the starting torque of a three-phase squirrel cage induction motor?
14) What is the significance of measuring the slip of the induction motor?
15) How is the slip of a three-phase squirrel cage induction motor calculated during a load test?
16) Why is it necessary to perform the load test at different load conditions?
17) How does the efficiency of an induction motor vary with load?
18) What is the typical shape of the efficiency vs. load curve for an induction motor?
19) What precautions should be taken while performing a load test on an induction motor?
20) How does the load test help in identifying any abnormalities in motor performance?
21) Why is it important to compare the test results with the manufacturer's data?
22) What could be the reasons for discrepancies between the test results and the manufacturer's specifications?
23) How does the load test help in determining the mechanical power output of the motor?
24) What are the common sources of error in a load test, and how can they be minimized?
25) How does rotor resistance affect the torque characteristics of an induction motor?

Experiment No. - 3

Aim: To study the connections of different starters for starting the three-phase squirrel cage induction motor. [DOL, Auto-Transformer, Star-Delta].

Apparatus :

Sl No	Apparatus Name	Specification	Quantity
1)	Ammeter		
2)	Voltmeter		
3)	DOL Starter		
4)	Auto Transformer		
5)	Star-Delta Starter		
6)	Tachometer		

Electrical Machine Specifications:

Induction Motor: HP:__________ Voltage:____________ Current: ______________

Speed: ______________

Theory :

1. DIRECT ONLINE (D.O.L.) STARTER :

A Direct-On-Line (DOL) starter is one of the simplest and most commonly used methods to start a three-phase induction motor. It directly connects the motor terminals to the power supply, allowing the motor to draw full line voltage from the moment it starts. This method is highly effective for small to medium-sized motors that can withstand the high inrush current generated during startup.

Working Principle:

When the motor is started using a DOL starter, a high starting current is drawn from the power supply. Typically, the starting current can be 6 to 8 times higher than the full-load current. This high current creates a strong magnetic field in the stator windings, which induces a rotating magnetic field. This rotating magnetic field interacts with the rotor to generate torque, causing the rotor to accelerate to its rated speed.

Construction and Components:

A DOL starter typically consists of the following components:

1. **Contactor**: This is an electromechanical switch that connects or disconnects the motor from the power supply. It is controlled by a start/stop push-button or a relay.
2. **Overload Relay**: The overload relay protects the motor from drawing excessive current during operation. If the motor exceeds its rated current, the relay trips, cutting off the power supply.
3. **Push Buttons**: Start and stop buttons are used to control the contactor. Pressing the start button energizes the contactor, connecting the motor to the power supply. The stop button de-energizes

the contactor, disconnecting the motor.

4. **Fuses/Circuit Breaker**: These components provide short-circuit protection, ensuring that the motor is disconnected in case of a fault.

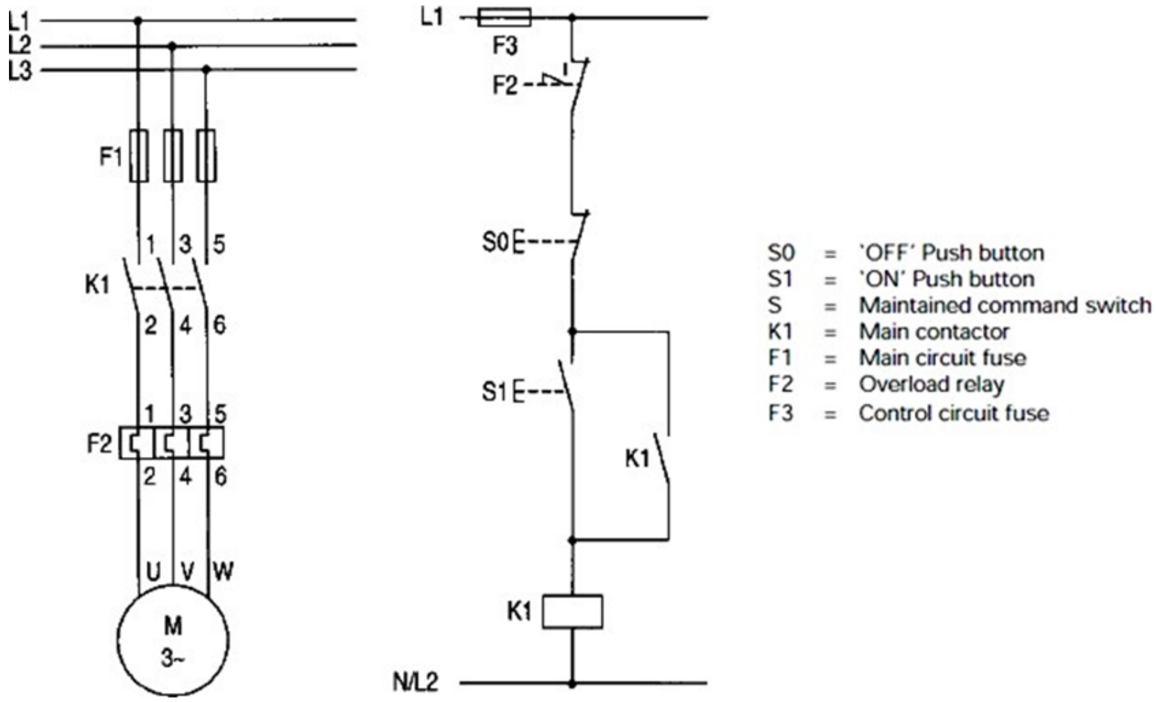


Fig: Direct Online Starter

Advantages:

- **Simplicity**: The DOL starter is easy to install, operate, and maintain.
- **Cost-Effective**: Since it requires fewer components, the cost of a DOL starter is relatively low compared to other starting methods.
- **Full Torque at Start**: The motor receives full voltage from the start, providing maximum torque, which is beneficial for applications requiring high starting torque.

Disadvantages:

- **High Starting Current**: The inrush current can cause a voltage dip in the power supply, potentially affecting other connected equipment.
- **Mechanical Stress**: The high torque generated during startup can cause mechanical stress on the motor and connected load, leading to wear and tear over time.
- **Limited Application**: DOL starters are typically suitable for small to medium-sized motors. For larger motors, other starting methods, such as star-delta or autotransformer starters, are preferred due to the high inrush current.

Applications:

DOL starters are commonly used in applications where the starting current and mechanical stress are not critical concerns. These include Small pumps, Fans, Compressors, Conveyors, Air conditioning systems etc.

2. AUTOTRANSFORMER STARTER:

An autotransformer starter is a type of motor starter used to reduce the inrush current and starting torque of a three-phase induction motor. It is particularly useful for starting large motors where the high starting current of a Direct-On-Line (DOL) starter could cause excessive voltage drops or mechanical stress. The autotransformer starter provides a gradual increase in voltage to the motor, allowing for a smoother startup.

Working Principle:

The autotransformer starter operates by initially supplying a reduced voltage to the motor through an autotransformer. This reduced voltage results in a lower starting current and torque, which helps to mitigate the impact on the electrical network and reduce mechanical stress on the motor and its load. When the motor has picked up the speed up to 85 % of its normal speed auto-transformer is taken out from the motor circuit as shown in Fig.

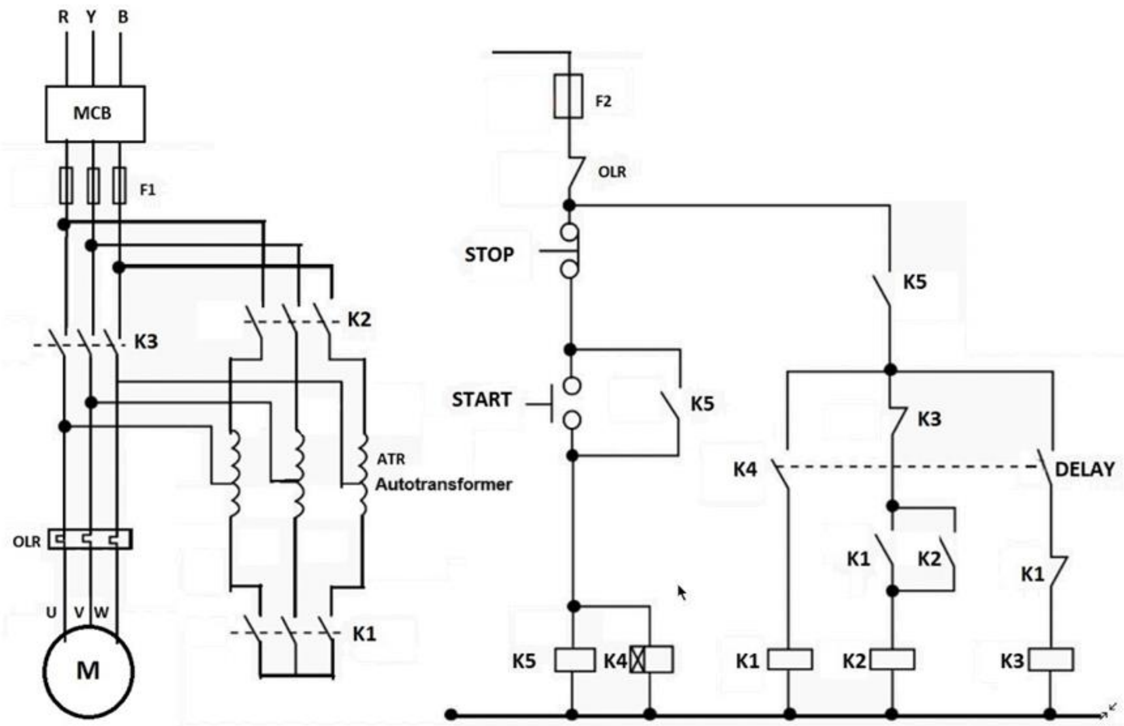


Fig: Autotransformer Starter

Construction and Components:

An autotransformer starter typically includes the following components:

1. **Autotransformer**: This is the key component that reduces the voltage applied to the motor during startup. It has multiple taps (usually 50%, 65%, or 80% of the line voltage) that allow for different levels of voltage reduction.

2. **Contactor**: Multiple contactors are used to control the switching between the autotransformer and the direct line connection. One contactor connects the motor to the autotransformer during startup, and another bypasses the autotransformer to connect the motor directly to the line voltage after the startup phase.
3. **Timer or Relay**: A timer or relay controls the transition from reduced voltage (through the autotransformer) to full voltage. The timer ensures that the motor reaches a sufficient speed before the bypass contactor is engaged.
4. **Overload Relay**: This protects against overcurrent conditions by disconnecting the motor if the current exceeds the safe operating limit.

Advantages:

- **Reduced Starting Current**: The autotransformer starter significantly lowers the inrush current, typically reducing it to 25-60% of the current required for a DOL starter.
- **Reduced Mechanical Stress**: By lowering the starting torque, the autotransformer starter reduces mechanical stress on the motor and connected load, extending the lifespan of the equipment.
- **Adjustable Voltage Reduction**: The taps on the autotransformer allow for adjustable voltage reduction, providing flexibility in the starting process based on the specific motor and load requirements.

Disadvantages:

- **Higher Cost**: Compared to simpler starters like the DOL starter, the autotransformer starter is more expensive due to the additional components and complexity.
- **Larger Size**: The autotransformer and additional contactors make the starter bulkier and require more space for installation.
- **Complexity**: The operation and maintenance of an autotransformer starter are more complex than simpler starters, requiring careful calibration and monitoring.

Applications:

Autotransformer starters are commonly used in applications where reducing the starting current is critical to prevent excessive voltage dips or mechanical stress, such as, Large pumps. Compressors, Fans, Crushers, Conveyors, Large air conditioning systems

The autotransformer starter is an effective solution for starting large three-phase induction motors while minimizing the impact on the electrical network and reducing mechanical stress. Its ability to provide a smooth and controlled startup makes it suitable for applications where the high starting current and torque of a DOL starter would be problematic. However, the higher cost, size, and complexity of the autotransformer starter must be considered when selecting this starting method.

3. STAR-DELTA STARTER:

A Star-Delta starter is one of the most commonly used methods for reducing the starting current of three-phase induction motors. It achieves this by initially connecting the motor windings in a star (Y) configuration during startup and then switching to a delta (Δ) configuration once the motor reaches a certain speed. This method is particularly effective for medium to large motors where the high inrush current of a Direct-On-Line (DOL) starter could cause electrical and mechanical stress.

Working Principle:

The Star-Delta starter operates in two stages:

1. **Star Connection (Y):** During startup, the motor windings are connected in a star configuration. In this configuration, each winding receives a phase voltage that is $1/\sqrt{3}$ (or approximately 58%) of the line voltage. This reduced voltage results in a lower starting current, typically around 1/3 of the current drawn in a DOL starter. Consequently, the torque is also reduced to approximately 1/3 of the full-load torque, minimizing mechanical stress on the motor and the driven equipment.
2. **Delta Connection (Δ):** After the motor accelerates and reaches about 80-90% of its rated speed, the starter switches the motor windings from the star to the delta configuration. In the delta configuration, each winding receives the full line voltage, allowing the motor to operate at full power and deliver full torque.

Construction and Components:

A Star-Delta starter typically consists of the following components:

1. **Contactor Set:** The system uses three contactors—one for the star connection, one for the delta connection, and one for the main power connection. These contactors control the switching between the star and delta configurations.
2. **Timer:** A timer is used to determine the duration for which the motor remains in the star configuration before switching to the delta configuration. The timing is adjusted based on the motor's characteristics and the load it drives.
3. **Overload Relay:** The overload relay protects the motor from excessive current during normal operation. If the motor exceeds its rated current, the relay will trip, disconnecting the motor from the power supply.
4. **Push Buttons:** Start and stop push buttons are used to control the starter. The start button initiates the star configuration, and the timer eventually triggers the switch to delta configuration. The stop button deactivates the motor.

Advantages:

- **Reduced Starting Current:** The star connection during startup significantly reduces the inrush current, making it suitable for larger motors that would otherwise cause excessive electrical stress.
- **Lower Mechanical Stress:** The reduced torque during startup minimizes mechanical stress on the motor and the driven load, increasing the lifespan of both the motor and the machinery it drives.

- **Cost-Effective:** Compared to more complex starting methods like autotransformer starters, the Star-Delta starter is relatively inexpensive and easy to implement.

Disadvantages:

- **Torque Reduction:** The torque in the star configuration is reduced to one-third of the full-load torque, which may not be sufficient for high-torque applications during startup.
- **Sudden Transition:** The transition from star to delta configuration can cause a sudden change in current and torque, which may lead to mechanical or electrical disturbances if not properly timed.
- **Limited Application:** The Star-Delta starter is best suited for applications where the motor is lightly loaded during startup. It is not ideal for heavy load conditions that require high starting torque.

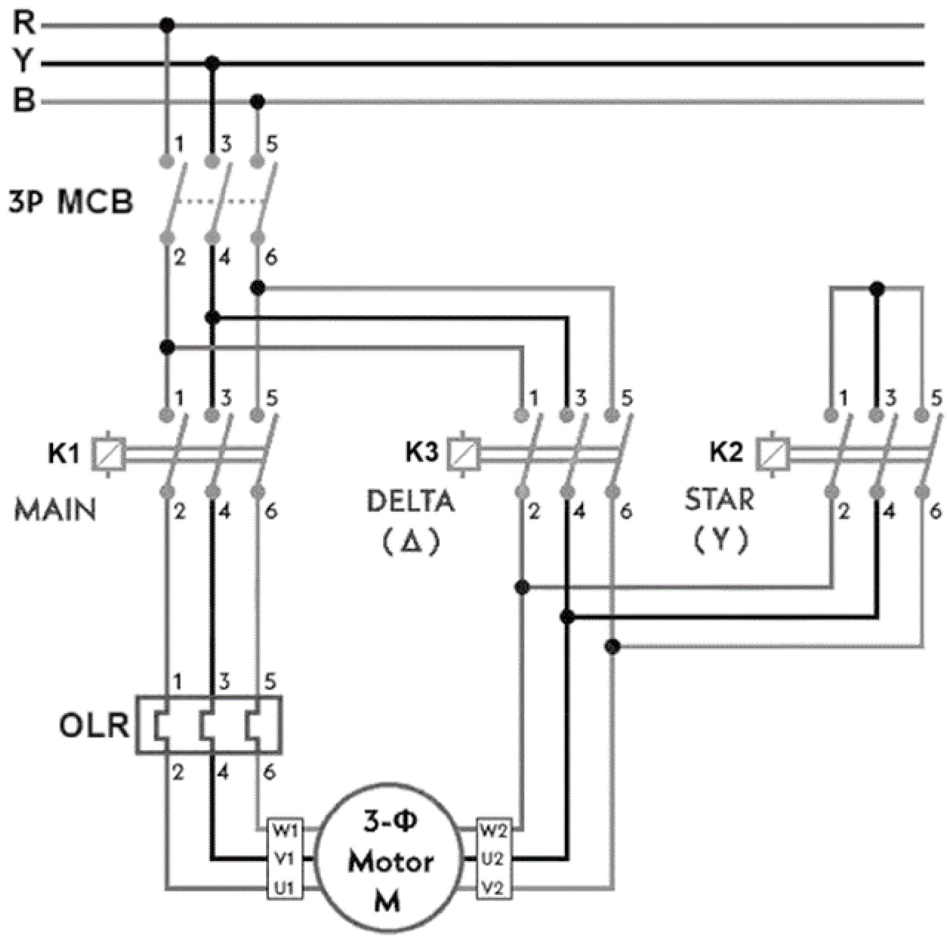


Fig: Star-Delta Starter Power Circuit

- Main contactor rating = 58%X Full Load Line Current
- Delta contactor rating = 58%X Full Load Line Current
- Star contactor rating = 33%X Full Load Line Current

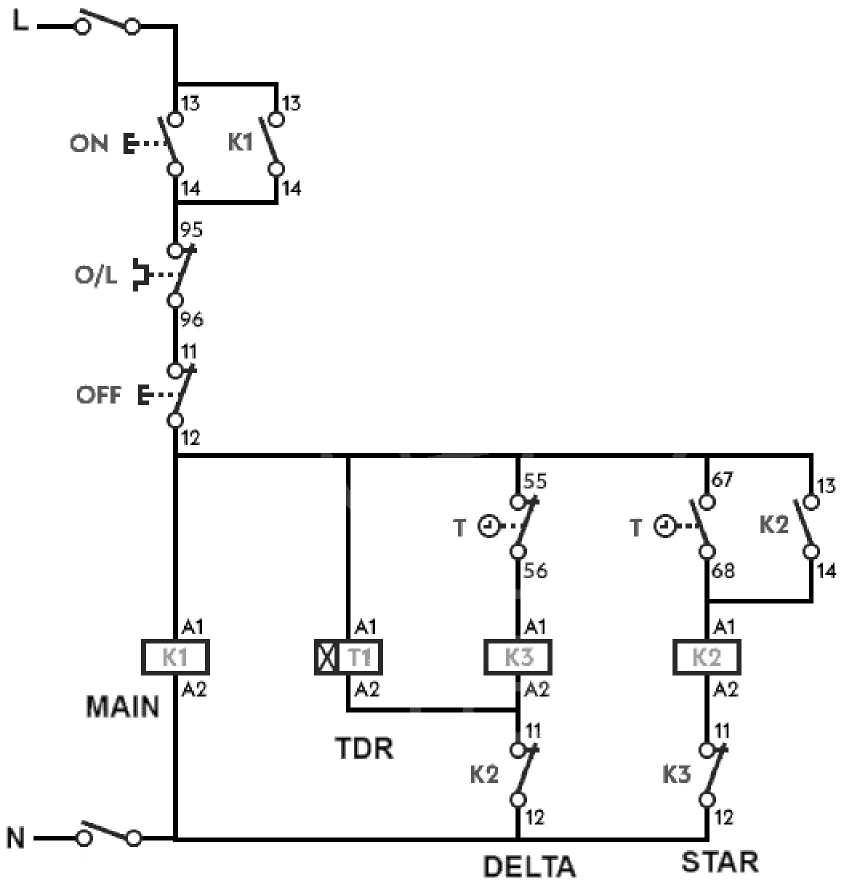


Fig: Automatic Star-Delta Starter Control Circuit

Applications:

Star-Delta starters are commonly used in applications where a reduced starting current is essential, and the load conditions allow for a lower starting torque. These applications include Large fans, Pumps, Compressors, Conveyors, Blowers, etc.

The Star-Delta starter is an effective and widely used method for starting medium to large three-phase induction motors. It offers the advantage of reducing the starting current and mechanical stress on the motor, making it suitable for applications where these factors are critical. However, its limitations in providing full starting torque and potential issues during the transition from star to delta should be considered when selecting this method for specific applications.

Procedure :

Direct On Line Starting.

a) Make the connection as per the circuit diagram.

b) Connect the motor in Delta switch ON the DOL starter and instantly note down theinitial current.

c) When the motor attains the rated speed note down the voltage, current, and speed of the motor.

d) Switch OFF the power supply and disconnect the motor.

Auto-transformer starting.

a) Make the connection as per the circuit diagram.

b) Connect the motor in Delta and switch ON the power supply.

c) Put the knob of the starter on the 25 % tap position and instantly note down the initial current.

d) When the motor attains the rated speed note down the voltage, current, and speed of the motor.

e) Follow the same procedure for 50 % tap and 100 % tap.

f) Switch OFF the power supply and disconnect the motor.

Star-Delta starting.

a) Make the connection as per the circuit diagram.

b) Switch ON the power supply.

c) Put the handle of the starter on the start position and instantly note down the initial current.

d) When the motor attains a speed about 85 % of its normal speed put the handle of starter on the run position and note down the voltage, current, and speed of the motor. (In case of manual star-delta starter) **OR** in case of automatic star-delta starter TDR turn ON the Delta Relay and turns OFF the Star Relay.

e) Switch OFF the power supply and disconnect the motor.

Viva Questions

1. What is the purpose of a starter in a three-phase induction motor?
2. Why is it necessary to reduce the starting current of a three-phase squirrel cage induction motor?
3. What is the difference between full-load current and starting current in induction motors?
4. What are the common methods used to start a three-phase squirrel cage induction motor?
5. Explain the working principle of a Direct-On-Line (DOL) starter.
6. Why is a DOL starter suitable for small motors?
7. What are the advantages and disadvantages of using a DOL starter?
8. What is the typical starting current in a DOL starter relative to full-load current?
9. How does a DOL starter protect the motor from overload?
10. Describe the working principle of a Star-Delta starter.
11. Why is the star connection used during the starting phase in a Star-Delta starter?
12. How does the transition from star to delta configuration occur in a Star-Delta starter?
13. What are the benefits of using a Star-Delta starter compared to a DOL starter?
14. What is the typical reduction in starting current achieved with a Star-Delta starter?
15. What are the limitations of a Star-Delta starter?
16. In what type of applications is a Star-Delta starter most effective?
17. Explain how an Auto-Transformer starter reduces the starting current of a three-phase induction motor.

18. What are the advantages of using an Auto-Transformer starter over a DOL or Star-Delta starter?
19. How does the starting current in an Auto-Transformer starter compare with that in a Star-Delta starter?
20. What are the different taps available in an Auto-Transformer starter, and how do they affect starting performance?
21. How does a rotor resistance starter work in starting a three-phase squirrel cage induction motor?
22. Why is rotor resistance control more commonly used in wound rotor induction motors rather than squirrel cage motors?
23. What are the key advantages of using a rotor resistance starter for starting induction motors?
24. How would you choose the appropriate starting method for a specific application?
25. Compare the starting torque provided by different starting methods like DOL, Star-Delta, and Auto-Transformer starters.

Experiment No. - 4

Aim: Speed control of three-phase Slip Ring Induction Motor by rotor resistance control.

Apparatus:

Sl No	Apparatus Name	Specification	Quantity
1)	Ammeter		
2)	Voltmeter		
3)	Auto Transformer (Variac)		
4)	Connecting Leads		

Electrical Machine Specifications:

Induction Motor: HP: _________ Voltage:___________ Current: ______________

Speed: ______________

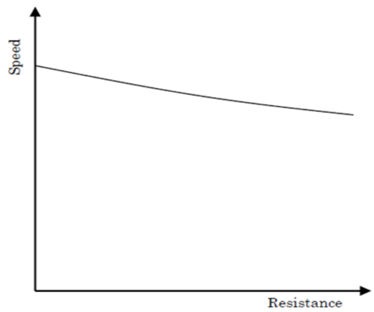
Theory :

Slip-ring induction motors are typically started by inserting resistances into the secondary circuit, which are gradually shorted out as the motor accelerates. When the resistance values are appropriately selected and the resistors are designed for continuous operation, they can fulfill a dual function: starting the motor and controlling its speed. This method of speed control exhibits characteristics similar to DC motor speed control achieved by placing a resistor in series with the armature.

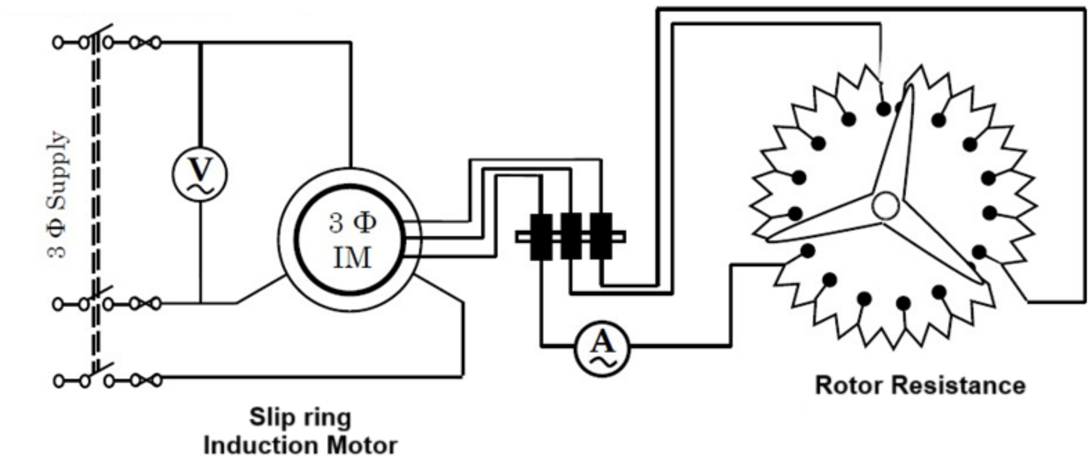
Torque developed by an induction motor is given by

$$T = \frac{ksR_2E_2^2}{R_2^2 + s^2X_2^2}$$

When the speed is very near to synchronous speed Ns i.e. when sip is very low the value of the term $s^2X_2^2$ is very small and can be neglected as compared to R_2^2 and torque developed become proportional to s/R_2. So, it is obvious that for a given torque, slip s can be increased or speeds can be reduced by increasing the rotor resistance. In this method, speed can be controlled only below the rated speed. If step of external resistance is larger speed control is smoother. In this method, efficiency is largely reduced at low speed. The curve of speed vs. resistance is shown in Fig below.



Circuit Diagram:



Procedure:

1) Connect the circuit as shown in Fig.
2) Switch ON the power supply.
3) With the help of external rotor resistance starts the induction motor.
4) Vary the rotor resistance and note down the various speed.
5) Switch OFF the power supply and disconnect the motor.
6) Measure the external rotor resistance in each step by multimeter.
7) Draw the speed vs. rotor resistance curve.

Observation Table:

S. No.	Voltage (volts)	Rotor Current (amp)	Rotor Resistance (Ω)	Speed (rpm)

Precautions:

1. Ensure that all electrical connections are secure and correct before starting the test to avoid short circuits and inaccurate readings
2. Apply the rotor resistance in steps and observe the motor's behavior at each step to prevent sudden changes that could cause mechanical stress or electrical faults.
3. Avoid running the motor at extremely low speeds for prolonged periods, as it can lead to overheating and reduced efficiency.
4. Use appropriate safety gear, such as insulated gloves and goggles, to protect against electrical shocks while handling live circuits.

5. Regularly monitor the motor temperature, current, and voltage during the experiment to prevent overheating and potential damage.
6. Make sure the load on the motor is within the rated capacity to avoid overloading, which could lead to motor damage or tripping of protective devices.

Result: Draw the speed vs. rotor resistance curve of slip ring induction motor.

Viva Questions:

1. Why is external resistance added to the rotor circuit when a slip ring induction motor is started?
2. How does inserting resistance in the rotor circuit affect the starting torque of a slip-ring induction motor?
3. What happens to the external resistances as the motor reaches its operating speed?
4. How does the starting method of a slip ring induction motor differ from that of a squirrel cage induction motor?
5. Explain how the external resistors used in the rotor circuit can also be utilized for speed control.
6. What are the advantages of slip-ring induction motors for applications requiring variable speed?
7. Compare the speed control characteristics of a slip-ring induction motor with those of a DC motor.
8. What are the limitations of using external resistors for speed control in slip-ring induction motors?
9. In what type of applications is slip ring induction motor speed control particularly beneficial?
10. How does the efficiency of a slip ring induction motor change when operating with external resistances in the rotor circuit?

Experiment No. - 5

Aim: To perform a load test on a single-phase induction motor and obtain the performance characteristics.

Apparatus :

Sl No	Apparatus Name	Specification	Quantity
1)	Ammeter		
2)	Voltmeter		
3)	Wattmeter		
4)	Auto Transformer		
5)	Tachometer		

Electrical Machine Specifications:

Induction Motor: HP: ________ Voltage:__________ Current: ____________

Speed: _____________

Theory :

The load test on induction motor helps us to compute the complete performance of induction motor means to calculate the various quantities i.e. torque, slip, efficiency, power factor etc at different loading. In this test supply voltage is applied to motor and variable mechanical load is applied to the shaft of motor. Mechanical load can be provided by brake and pulley arrangement. The input current, input voltage, input power and speed of motor are observed from the experiment and various performance quantities are calculated as explain below.

Slip :

Due to the single-phase ac supply given to stator of an induction motor, a rotating magnetic field of constant magnitude is set up in the stator of the motor. The speed with which this rotating magnetic field rotates is known as synchronous speed and is given by

$$N_s = \frac{120\,f}{P}$$

Where f =supply frequency.

P =no of poles on the stator of the rotor.

The actual speed of the rotor N_r is always less than the synchronous speed. So the slip of the motor is given by following equation. This value of slip at full load lies between 2 to 5%.

$$s = \frac{N_s - N_r}{N_s} X\ 100$$

Torque :

Mechanical loading is applied on induction motor by means of brake and pulley arrangement. The belt can be tightened or loosened by means of threaded rods with handles fixed on frame. Two spring balances are provided at the end of belt. The net force exerted at the brake drum can be obtained from the readings of the two spring balance i.e. S_1 and S_2

Net force exerted on drum,

$$W = (S_1 - S_2)K_g f$$

$$T = \left(\frac{d}{2}\right) * W * 9.8\ Nw - m$$

Where d = effective diameter of brake drum in meter.

Output Power :

The output power of induction motor can be calculated as

$$P = \frac{2\,\pi\, N_r T}{60}$$

Where N_r is speed of motor in rpm.

Input Power :

The input power can be determined from the readings of wattmeter connected in the circuit.

$$P_i = W$$

Power Factor :

The power factor can be calculated from the two wattmeter reading using following relation

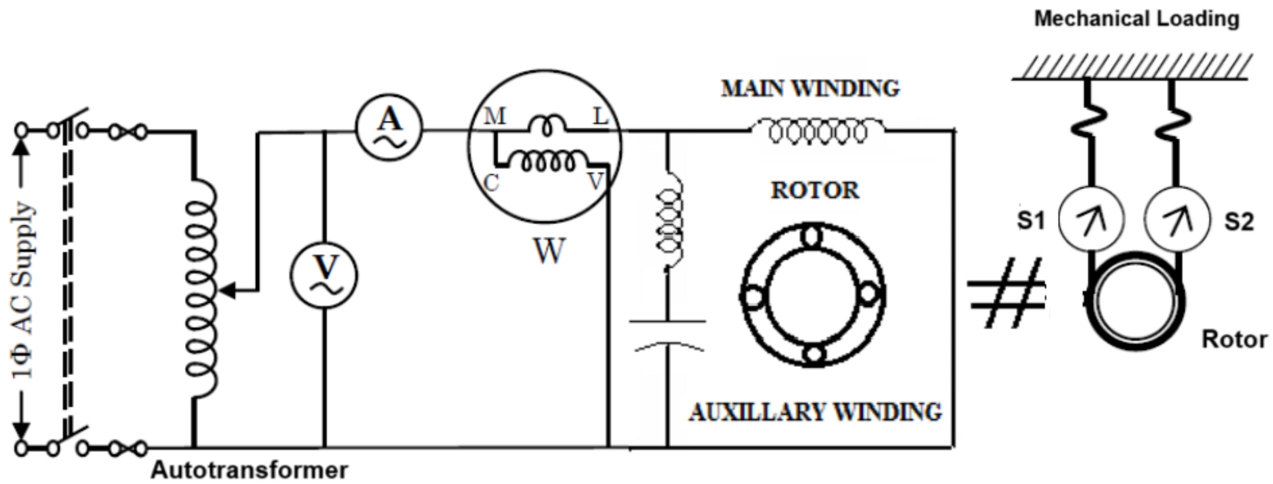
$$\cos\varphi = \frac{P_{in}}{VI}$$

Efficiency :

Efficiency can be calculated using

$$\eta = \frac{output\ power}{input\ power}\ X\ 100$$

Circuit Diagram :



Procedure :

1. Connect the circuit as shown in Fig.
2. Set variac for minimum voltage and brake pulley arrangement is set for no load.
3. Switch ON the power supply and start the induction motor.
4. Now gradually increase the applied voltage by varying the variac very slowly up to the rated voltage.
5. Increase the mechanical load on the motor step by step and note down the reading at each step.
6. Switch OFF the supply and disconnect the motor.
7. Calculate the various quantities and draw the various curves as stated above.

Observation Table :

SL NO	Input Voltage V (volt)	Input Current I (amp)	Input Power	Force (Kgf)			Speed
			W (watt)	S_1	S_2	$F = S_1 - S_2$	N_r (rpm)
1							
2							
3							
4							
5							

Diameter of pulley, d =_____ m.

Calculation :

SL NO	Input Power Pin (watt)	Total Force F (Kgf)	Output Torque T (Nw-m)	Output Power P_o (watt)	Slip (%)	Power Factor cosΦ	Efficiency (%)
1							
2							
3							
4							
5							

Precautions:

1. All connections should be neat and tight.
2. Special attention should be given to cooling the break pully, otherwise the wearing out of the belt may be very rapid.
3. The current ratings should be given special care while selecting wattmeter.
4. Gradually increase the load on the motor to avoid sudden mechanical stress, which could damage the motor or the load.
5. Monitor the motor temperature during the test to prevent overheating, especially at higher loads, and allow cooling if necessary.

6. Maintain a stable supply voltage throughout the test to ensure accurate performance measurements.
7. Use appropriate measuring instruments (e.g., voltmeters, ammeters, wattmeters) that are correctly calibrated and rated for the motor's capacity.
8. Observe the motor for any unusual noise, vibrations, or excessive current draw during the test, and stop the test immediately if any abnormalities occur.

Result: Draw the performance curve of the single-phase induction motor.

Viva Questions:

1. What is the purpose of performing a load test on a single-phase induction motor?
2. Explain the difference between no-load and full-load conditions in a single-phase induction motor.
3. What are the typical parameters measured during a load test on a single-phase induction motor?
4. How does load affect the speed of a single-phase induction motor?
5. Describe the procedure for conducting a load test on a single-phase induction motor.
6. What instruments are required to perform a load test on a single-phase induction motor?
7. How do you apply load to a single-phase induction motor during the test?
8. How is the efficiency of a single-phase induction motor determined during a load test?
9. What is the relationship between load and power factor in a single-phase induction motor?
10. How does the motor’s slip change with an increase in load?
11. Why does the current drawn by a single-phase induction motor increase as the load increases?
12. Explain how torque varies with load in a single-phase induction motor.
13. What is the significance of measuring temperature rise during a load test?
14. What are the common types of loads used in load testing of single-phase induction motors?
15. How do you ensure that the motor operates within safe limits during a load test?
16. What precautions should be taken when performing a load test on a single-phase induction motor?
17. How does load testing help in identifying potential faults in a single-phase induction motor?
18. How does the load test on a single-phase induction motor differ from that on a three-phase induction motor?

Experiment No. - 6

Aim: Determination of equivalent circuit parameters of a single-phase induction motor by no-load and blocked rotor test.

Apparatus :

Sl No	Apparatus Name	Specification	Quantity
1)	Ammeter		
2)	Voltmeter		
3)	Wattmeter		
4)	Tachometer		
5)	Connecting leads		
6)	Auto Transformer (Variac)		

Electrical Machine Specifications:

Induction Motor: HP: ________ Voltage:__________ Current: ____________

Speed: ____________

Theory :

The equivalent circuit of a single-phase induction motor is similar to that of a three-phase induction motor but with additional complexities due to the presence of two stator windings: the main winding and the auxiliary (or starting) winding. The motor can be represented by a combination of resistances and reactances corresponding to the stator and rotor, as well as a magnetizing branch representing the core losses and magnetizing inductance.

The equivalent circuit parameters of single phase induction motor is determined by the no-load and block rotor test. The equivalent circuit of the single-phase induction motor is shown in Fig. 1.

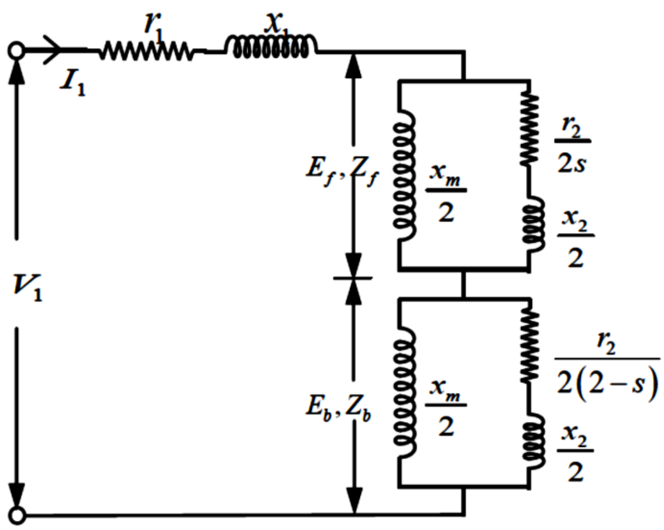


Fig-1- Single phase Induction Motor

1. No Load Test :

This test is similar to an open circuit test on a transformer. The motor runs at no load and the power input is measured by the wattmeter. With the motor running at no load, the slip is very close to zero. It may be therefore assumed that s ≅ 0. Under these conditions $r_2/2s$ becomes infinity and $r_2/2(2\text{-}s) = r_2/4$ becomes several times smaller than $x_m/2$. Given this approximation, ($r_2/2s$ + $jx_2/2$) and $x_m/2$ (across $r_2/4$ +j $x_2/4$) may be neglected, and that gives the equivalent circuit as shown in Fig-2.

Let consider

V_O = No-load applied voltage.

I_O = Exciting current or No-load current

W_O = Core loss and Mechanical loss.

Therefore no-load power factor $\cos\varphi_o = W_o / V_o I_o$

So, the impedance is $Z_o = V_o/I_o$ and

The reactance $X_o = Z_o \sin\varphi_o$

From the circuit $R_o = r_1 + r_2/4$ and $X_o = x_1 + (x_2 + x_m)/2$

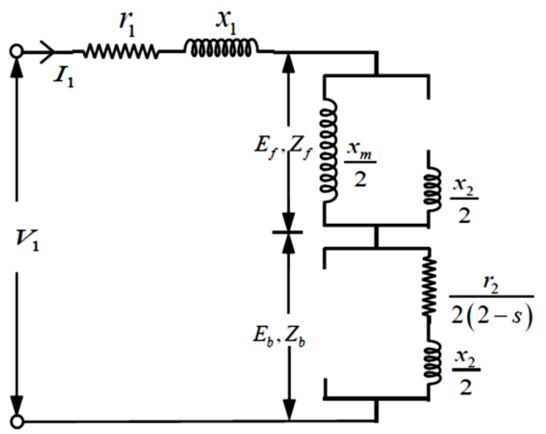


Fig-2- Equivalent circuit for no load test

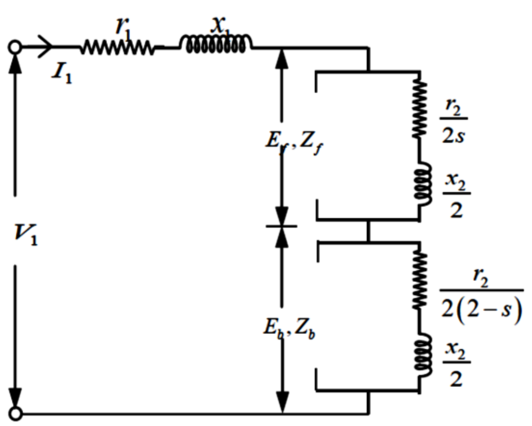


Fig-3 Equivalent circuit for block rotor test

2. Blocked Rotor Test :

With the rotor at rest, the single-phase voltage applied to the stator main winding is increased gradually from zero so that rated current flows in the main winding. Under these condition i.e. with rotor stationary, the slip s=1 and the voltage required to circulate full-load current is very low. Therefore, flux is small and the magnetizing current flowing to X_m is also very low. Given this, magnetizing reactance can be neglected and that gives the equivalent circuit as shown in Fig. 3.

Let consider

V_{sc} = Applied short circuit voltage on stator side.

I_{sc} = Short circuit current.

W_{sc} = Total ohmic loss.

Then the total equivalent resistance $R_{SC} = r_1 + 2(r_2/2) = W_{sc}/I^2_{sc}$

Since the resistance of the main winding is already measured,

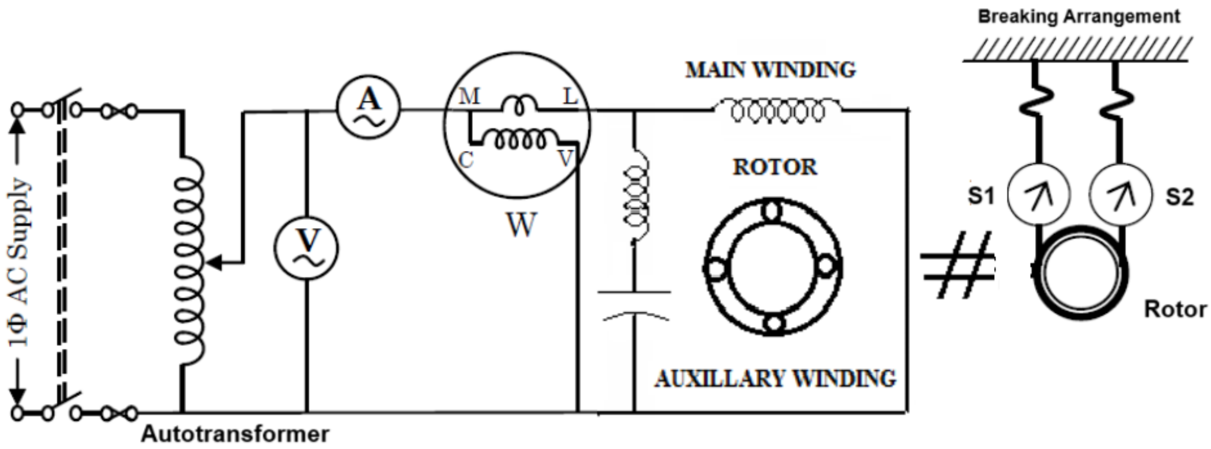
effective rotor resistance $r_2 = R_{sc} - r_1$

The total equivalent per phase impedance $Z_{sc} = V_{sc} / I_{sc}$

Therefore total equivalent per phase reactance $X_{sc} = x_1 + 2(x_2/2) = \sqrt{(Z^2_{sc} - R^2_{sc})}$

Since the leakage reactance x_1 and x_2 can't be separated out, it is assumed that $x_1 = x_2 = X_{sc}/2$

Circuit Diagram :



Procedure:

1. Connect the circuit as shown in Fig.
2. Switch ON the power supply and apply the rated voltage in the stator with the help of single-phase variac.
3. Note down the voltmeter, ammeter and wattmeter reading.
4. Disconnect the power supply and block the rotor with the help of a breaking arrangement that it cannot rotate. The rotor can be blocked by disconnecting the auxiliary or starting winding (SW) from the main or running winding (RW).
5. Apply very low voltage to the main winding only and then gradually increase the applied voltage until the rated current flows in the stator winding.
6. Note down the voltmeter, ammeter and wattmeter reading.
7. Switch OFF the power supply and disconnect the circuit.
8. Measure the stator resistance or main winding resistance by multi-meter.
9. Calculate the different parameters of a single-phase induction motor from the above data.

Observation Table:

No-load Test			Blocked Rotor Test		
Voltage V_o (volts)	**Current I_o (amp)**	**Power W_o (watt)**	**Voltage V_{sc} (volts)**	**Current I_{sc} (amp)**	**Power W_{sc} (watt)**

Main winding Resistance:___________

Aux. Winding Resistance: ___________

Calculations:

No-load Test:

$$W_o = V_o I_o \cos \emptyset_o$$

$$\cos \emptyset_o = \frac{W_o}{V_o I_o}$$

$$Z_o = \frac{V_o}{I_o}$$

$$X_o = Z_o \sin \emptyset_o$$

$$R_o = \frac{r_1 + r_2}{4}$$

$$X_o = x_1 + \frac{(x_2 + x_m)}{2}$$

$$x_m = 2(x_o - x_1) - x_2$$

Blocked rotor Test

$$Z_{sc} = \frac{V_{sc}}{I_{sc}}$$

$$R_{sc} = \frac{W_{sc}}{I_{sc}^2}$$

$$r_2 = R_{sc} - r_1$$

r_1 = stator DC resistance

$$X_{sc} = x_1 + x_2$$

Assume $x_1 = x_2$, (as leakage reactance can't be separated out)

$$x_1 = x_2 = \frac{X_{sc}}{2}$$

and

$$X_{sc} = \frac{1}{2}\sqrt{Z_{sc}^2 - R_{sc}^2}$$

Precautions:

1. Double-check all electrical connections before starting the experiment to prevent short circuits or incorrect readings.
2. Ensure all wires and connections are well insulated to prevent electrical shocks or short circuits.
3. Monitor the motor temperature during the tests to avoid overheating and allow the motor to cool down between tests if necessary.
4. Use properly calibrated and rated instruments (voltmeters, ammeters, wattmeters) for accurate measurements and to avoid damage to the instruments.
5. Ensure the motor shaft is completely free of mechanical load during the no-load test to get accurate results.
6. Maintain a stable supply voltage throughout the test to ensure consistent readings.
7. Ensure the motor runs smoothly without excessive vibration during the no-load test, as this can affect the accuracy of the readings and indicate potential mechanical issues.
8. Apply a reduced voltage (typically 10-20% of the rated voltage) during the blocked rotor test to avoid excessive current and potential motor damage.
9. Limit the test duration to a few seconds during the blocked rotor test to prevent overheating of the motor windings.
10. Continuously monitor the motor for any abnormal sounds, excessive heating, or unusual smells during the blocked rotor test, and stop the test immediately if any issues are observed.

Result: Thus the equivalent circuit parameters of a single-phase Induction Motor are determined by performing No-Load and Blocked rotor tests.

Viva Questions:

1. What is an equivalent circuit of a single-phase induction motor?
2. Why do we perform no-load and blocked rotor tests on a single-phase induction motor?
3. Can you explain the principle behind the no-load test?
4. What information do we obtain from the blocked rotor test?
5. How does the equivalent circuit of a single-phase induction motor differ from that of a three-phase induction motor?
6. What are the typical conditions of the motor during the no-load test?
7. How do you calculate the core loss resistance and magnetizing reactance from the no-load test?
8. What is the significance of the no-load current in determining the motor parameters?
9. Why is the power factor low during the no-load test?
10. What type of losses dominate in a no-load test?
11. Why is the rotor blocked during the blocked rotor test?
12. How do you calculate the equivalent rotor resistance and leakage reactance from the blocked rotor test?

13. What happens to the slip during the blocked rotor test, and why?
14. Why is the locked rotor test performed at reduced voltage?
15. What kind of losses are predominant during the blocked rotor test?
16. How do you separate the stator and rotor parameters using the test results?
17. What assumptions are made during these tests, and how do they affect accuracy?
18. How do these tests help in estimating the starting torque and efficiency of the motor?
19. What are the limitations of these tests in analyzing motor performance under load conditions?
20. What precautions should be taken while performing the no-load and blocked rotor tests?
21. Can these tests be performed on all types of single-phase motors? Why or why not?
22. What are the key differences in performing these tests on split-phase and capacitor-start motors?

Experiment No.:-7

AIM:- To determine voltage regulation of a three-phase alternator by direct loading.

Apparatus :

Sl No	Apparatus Name	Specification	Quantity
1.	Ammeter		
2.	Voltmeter		
3.	Frequency meter		
4.	Tachometer		
5.	Connecting leads		
6.	3-phase load		

Electrical Machine Specifications:

Synchronous Machine: Power: ________ Voltage:__________ Current: ____________
Speed: ____________

DC Motor: Power: ________ Voltage:__________ Current: ____________
Speed: ____________

Theory :

Voltage regulation of an alternator is defined as the percentage change in terminal voltage when the load is reduced from full-load to no-load while keeping the speed and field excitation constant. It is a critical parameter that indicates the alternator's ability to maintain a consistent output voltage under varying load conditions. A lower voltage regulation indicates better performance of the alternator.

The **direct loading method** is one of the simplest ways to determine the voltage regulation of a three-phase alternator. In this method, the alternator is directly connected to a load, and measurements are taken at different load conditions to calculate the voltage regulation.

Principle:

The principle behind the direct loading method is to observe the change in the alternator's terminal voltage when the load is varied while maintaining constant speed and excitation. By comparing the no-load voltage (V_0) with the full-load voltage (V), the voltage regulation can be calculated.

This decrease in the terminal voltage of an alternator is due to the following three reasons.

1. Armature resistance.
2. Armature leakage reactance.
3. Decrease in flux/pole due to armature reaction.

The effect of armature reaction on the terminal voltage of the alternator can be accounted for by assuming a fictitious reactance X_a in the armature-windings. The voltage drop due to the armature reaction is represented by I Xa, where 'I' represents the load current and Xa, represents the equivalent (fictitious) reactance due to the armature reaction.

At this stage, we can define a new term, known as synchronous reactance, Xs as the sum of leakage reactance X_L and the fictitious reactance representing the armature reaction X_a. Thus

Xs = XL + Xa

Further, we define another term as synchronous impedance (Zs) as

Zs = Ra + jXs

The voltage regulation of an alternator is defined as the increase in the terminal voltage when full load is thrown off, provided field current and speed remain the same.

Mathematically,

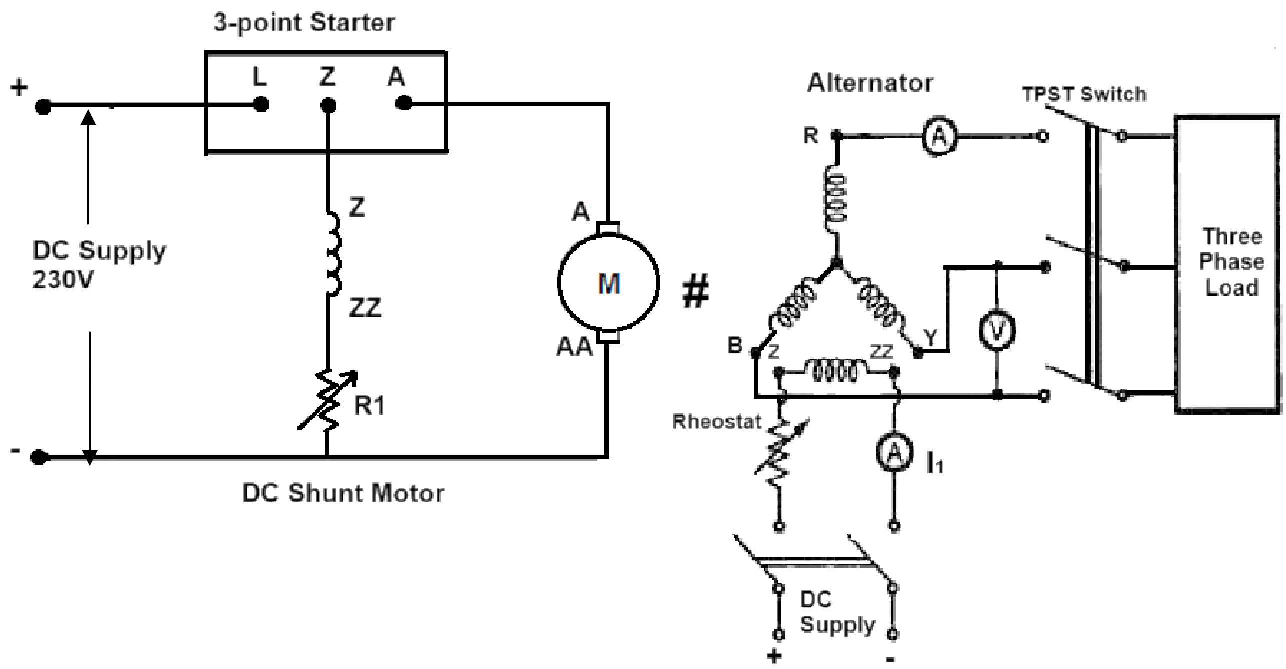
$$\text{Percentage regulation} = \frac{E_O - V}{V} \times 100$$

Where, Eo = No load terminal voltage

V = Full load terminal voltage

In case of a lagging power factor Eo is more than V and voltage regulation is positive whereas in case of a leading power factor Eo is less than V and voltage regulation is negative.

Circuit Diagram:-



Procedure: -

1) Connect the circuit as shown in the diagram.
2) Keep load zero, set field potential divider to zero output voltage position.
3) Keep field resistance of motor to its minimum value.
4) Start the motor with the help of starter.
5) With the field rheostat of motor adjust the speed to synchronous value.
6) Switch on DC supply of field (Alternator) and adjust the potential divider so that the voltmeter reads rated voltage of the alternator.

7) Increase the load in steps till rated current of alternator and set the voltage and speed rated.
8) Now sudden thrown off the load and set the speed rated. Keep the field current same as at full load.
9) Note down the no load voltage at same field current.

Observation: E = Terminal voltage at no load = volts.

Sr. No.	Full Load Voltage	No load Voltage	% Regulation

Calculations:

Percentage regulation = $\frac{E_o - V}{V} \times 100$

Precautions:

1) All connections should be perfectly tight and no loose wire should lie on the work table.
2) Before switching ON the dc supply, ensure that the starter's moving arm is at it's maximum resistance position.
3) Do not switch on the supply, until and unless the connection are checked by the teacher
4) Avoid errors due to parallax while reading the meters.
5) Hold the tachometer with both hands steady and in line with the motor shaft so that it reads correctly.

Result: The regulation at full load and ---- power factor is found to be ---------- %

Conclusion: As the load on the alternator increases the regulation also increases

Viva Questions:

1) Can the terminal voltage rise? Under which load?
2) If the speed of the driving motor falls due to loading what will be the effects?
3) Give the classification of alternators based on the rotor and their application.
4) Why is the excitation given to the alternator generally DC and not AC?
5) Mention the disadvantages of determining the regulation of an alternator by direct loading.
6) What is hunting in Alternator?
7) What is the role of damper winding in Alternator?
8) What is chording and write their advantages?

Experiment No: 8

AIM:- To find regulation of a three-phase alternator by synchronous impedance method (EMF method)

Apparatus :

Sr. No	Apparatus Name	Specification	Quantity
1.	Ammeter		
2.	Voltmeter		
3.	Frequency meter		
4.	Tachometer		
5.	Connecting leads		
6.	3-phase load		

Electrical Machine Specifications:

Synchronous Machine: Power: ________ Voltage:_________ Current: __________

Speed: ___________

DC Motor: Power: ________ Voltage:_________ Current: __________

Speed: ___________

Theory:

The synchronous impedance of a given three phase alternator can be determined from the following two experiments.

1. Open Circuit Test:

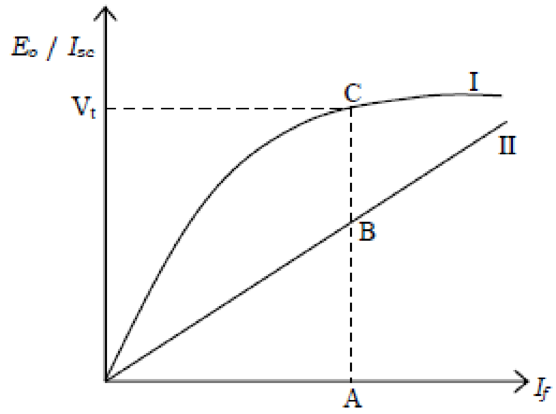
In this test, the alternator is run with the prime mover i.e. dc motor. The output terminals of the alternator are kept open i.e. alternator runs on no-load. The induced emf per phase corresponding to various values of field current is measured. The curve is drawn between the induced emf per phase and the field current as shown in Fig. This curve is known as open circuit characteristics (O.C.C.).

2. Short Circuit Test:

In this test, the output terminals of the alternator are short circuited through low resistance ammeter. The short circuit current is measured corresponding to various values of field current while speed is kept constant with the help of field rheostat. The curve is drawn between short circuit current and field current as shown in Fig. (Curve II). This curve is known as short circuit current (S.C.C.).

From the Fig. let OA represent the field current corresponding to rated terminal voltage. Then AB represents the rated short-circuited current and AC represents the induced emf per phase. Under the short circuit condition whole of the emf AC is used to create the short circuit current AB. Now, we can write

Synchronous impedance, Zs = AC (in volts)/ AB (in amp)



The value of armature resistance per phase R_a can be determined by an accurate ohmmeter. The effective value of armature resistance can be determined by increasing the measured value by 20% to account for the skin effect and effect of temperature rise. Then, synchronous reactance X_s can be calculated using the following relation

$$X_s = \sqrt{(Z_s^2 - R_a^2)}$$

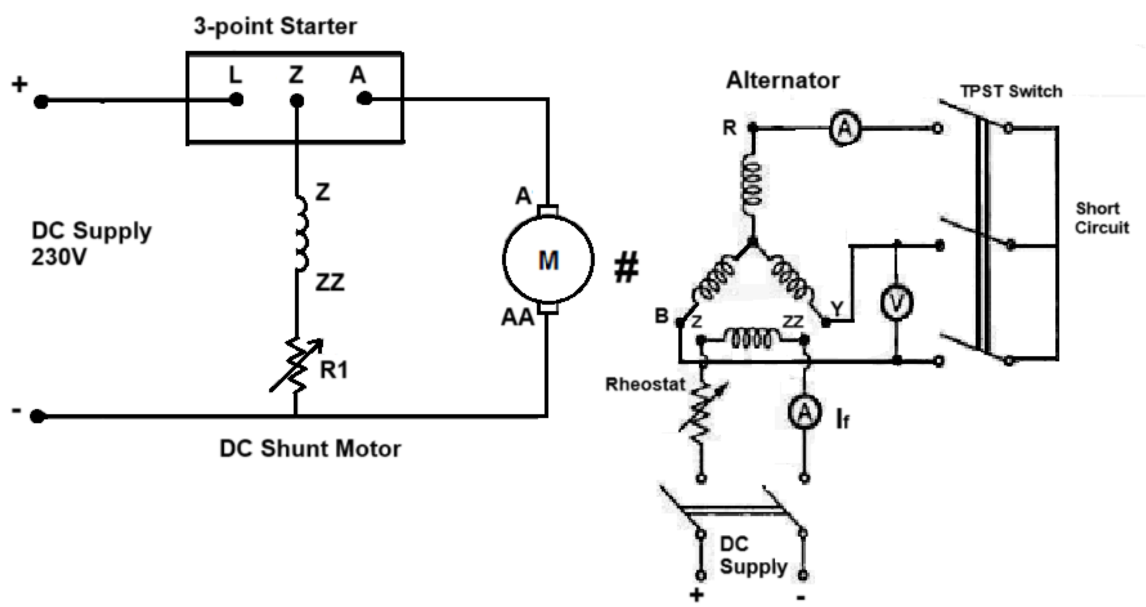
No load-induced emf per phase

$$E_o = \sqrt{(V\cos\emptyset + IR_a)^2 + (V\ \sin\emptyset + IX_s)^2}$$

Percentage Regulation

$$\frac{E_o - V}{V} \times 100$$

Circuit Diagram:



Procedure:

Open Circuit Test

1) Connect the circuit as shown in the circuit diagram. Keep the TPST switch in the open position.
2) Set the potential divider to zero output position and motor field rheostat to minimum value.
3) Switch on the DC supply and start the motor.
4) Adjust motor speed to synchronous value by motor field rheostat and note the meter readings.
5) Increase the field excitation of the alternator and note the corresponding readings.
6) Repeat step 5 till 10% above the rated terminal voltage of the alternator.
7) Maintain constant rotor speed for all readings.

[A] Short Circuit Test

1) Close the TPST switch and short-circuit the armature winding.
2) Start the motor with its field rheostat at minimum resistance and the potential divider set to zero output.
3) Adjust the motor speed to synchronous value.
4) Increase the alternator field excitation and note ammeter readings.
5) Repeat step 4 for different values of excitations (field current). Take readings up to the rated armature current. Maintain constant speed for all readings
6) Measure the value of armature resistance per phase Ra by multimeter or ammeter-voltmeter method.
7) Plot the characteristics and find the synchronous impedance.

Observations:

Sr. No.	Open-circuit Test		Short-circuit Test	
	Field Current (I_f) (amp)	Terminal Voltage (volts)	Field Current (I_f) (amp)	Short-circuit Current I_{sc} (amp)

Armature resistance per phase =
Effective armature resistance =

Calculations:

Calculate the excitation emf Eo and voltage regulation at full-load and power factor

1. 0.8 lagging p.f. 2. UPF 3. 0.8 leading p.f.

$Eo = \sqrt{[(V \cos\varphi + I_a R_a)^2 + (V \sin \varphi \pm I_a X_s)^2]}$

+ sign is for lagging pf load. - sign is for leading pf load.

V = rated terminal voltage per phase of alternator

$\%Regulation = \frac{E_O - V}{V} \times 100$

Precautions:

1. All connections should be perfectly tight and no loose wire should lie on the work table.
2. Before switching ON the DC supply, ensure that the starter's moving arm is at its maximum resistance position.
3. Do not switch on the supply, until and unless the connections are checked by the teacher.
4. Avoid errors due to parallax while reading the meters.
5. Hold the tachometer with both hands steady and in line with the motor shaft so that it reads correctly.
6. Ensure that the winding currents do not exceed their rated values.

Result:

Regulation of alternator at full load is found to be,

At unity pf = --------------

At 0.8 lagging = ---------------

At 0.8 leading = --------------

Synchronous Impedance varies for different values of excitation.

Viva Questions:

1. What is voltage regulation in an alternator?
2. Why is voltage regulation important in alternators?
3. Define synchronous impedance. How is it related to voltage regulation?
4. What is the difference between the EMF method and other methods of determining voltage regulation?
5. Explain the significance of the open-circuit and short-circuit tests in determining voltage regulation.
6. Why is the EMF method also called the synchronous impedance method?
7. What assumptions are made in the EMF method?
8. Why is the EMF method considered to give a higher value of voltage regulation compared to other methods?
9. Explain the nature of the open circuit and short-circuit characteristics of an alternator.

10. What are the advantages of the synchronous impedance method over the direct loading method of determination of voltage regulation?
11. What do you understand by the negative regulation of an alternator?
12. What are the different indirect methods for determining the voltage regulation of an alternator?
13. Why emf method for the determination of voltage regulation called the pessimistic method?

Experiment No.:- 9

AIM:- To determine voltage regulation of a three-phase alternator by the ZPF method.

Apparatus:

Sr. No	Apparatus Name	Specification	Quantity
1.	Ammeter		
2.	Voltmeter		
3.	Frequency meter		
4.	Tachometer		
5.	Connecting leads		
6.	3-phase highly inductive load		

Electrical Machine Specifications:

Synchronous Machine: Power: ________ Voltage:__________ Current: ____________

Speed: _____________

DC Motor: Power: ________ Voltage:__________ Current: ____________

Speed: _____________

Theory :

The regulation obtained by the synchronous impedance method is based on total synchronous reactance i.e. sum of armature leakage flux reactance and reactance due to armature reaction. But in the Zero Power Factor (ZPF) or Potier reactance method regulation calculation is based on the separation of reactance due to leakage flux and that due to armature reaction flux.

To determine the voltage regulation by this method, a curve between terminal voltage and field excitation while the machine is being run on synchronous speed and delivering full load at zero power factor (lagging) have to be drawn along with no load characteristic as shown in figure-1. The ZPF characteristic curve is of exactly same shape as the OCC but it is shifted vertically downward by leakage reactance drop IX_L and horizontally by armature reaction mmf.

Point A is obtained from a short circuit test with full load armature current. Hence OA represents excitation (field current) required to overcome the demagnetizing effect of armature reaction and to balance leakage reactance drop at full load. Point B is obtained when full load current flows through the armature. From B, line BC is drawn and parallel to OA. Then a line is drawn through c parallel to the initial straight part of OCC (parallel to OG), intersecting the OCC at D. BD is joined and a perpendicular DF is dropped on BC. The triangle BFD is imposed at various points OCC to obtain corresponding points on the ZPF curve. The length BF in ▯BFD represents armature reactance and the length DF represents leakage reactance drop IX_L. This is known as the Potier reactance voltage drop and the triangle is known as the Potier Triangle.

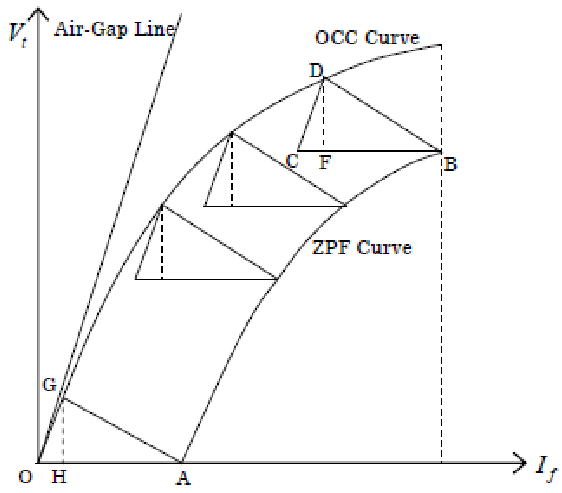


Fig-1: ZPF characteristic curve

The Potier reactance is given as

$$X_p = \frac{Voltage\ drop\ per\ phase\ (DF)}{Zero\ power\ factor\ current\ per\ phase}$$

In case of cylindrical rotor machines, potier reactance is nearly equal to armature leakage reactance. In the case of the salient pole machine, the magnetizing circuit is more saturated and the armature leakage reactance is smaller than the potier reactance.

Potier Regulation Diagram:

OV is drawn horizontally to represent full load terminal voltage, and V and OI is drawn to represent full load current at a given power factor. VE is drawn perpendicular to phasor OI and equal to reactance drop (IX_L), neglecting resistance drop. Now phasor OE represents generated emf E. From the OCC field excitation I_1 corresponding to generated emf E is determined, OI_1 is drawn perpendicular to phasor OE to represent excitation required to induce emf OE on an open circuit. I_1I_2 is drawn parallel to load current phasor OI to represent excitation equivalent to full load armature reaction. OI_2 gives the total excitation required. If the load is thrown off, then terminal voltage will be equal to the generated emf corresponding to field excitation OI_2. Hence OE_o will lag behind phasor OI_2 by 90°. EE_o represents voltage drop to armature reaction. So, regulation can be obtained from the relation below

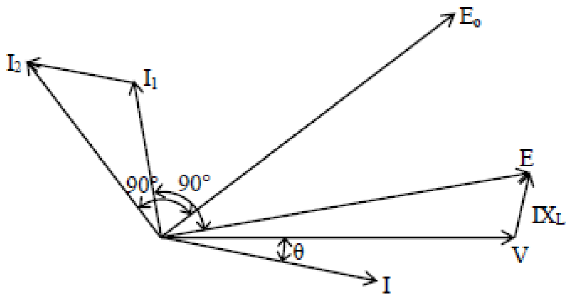
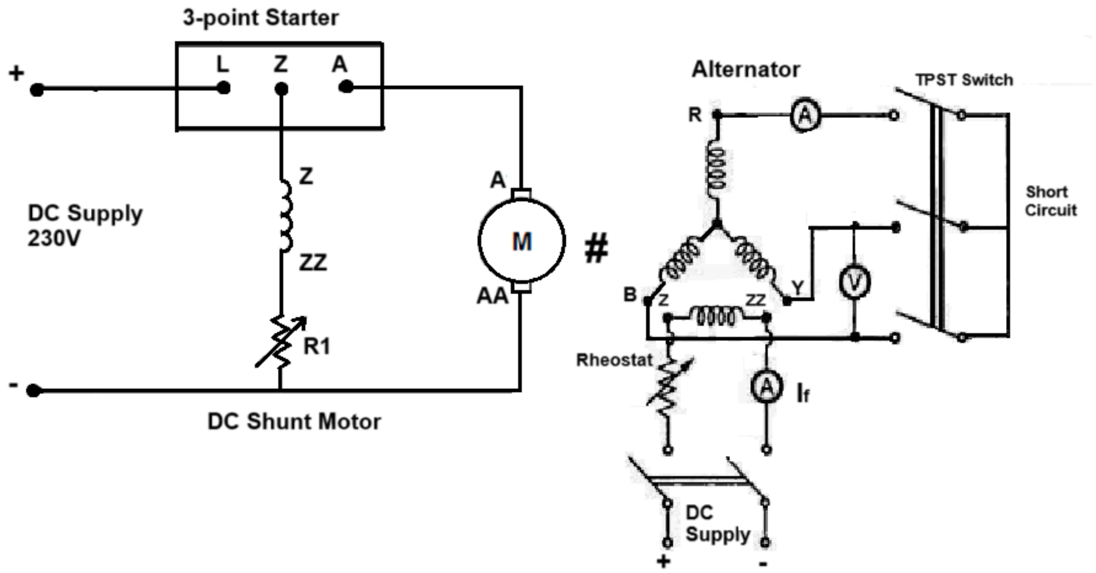


Fig-2 Potier regulation diagram

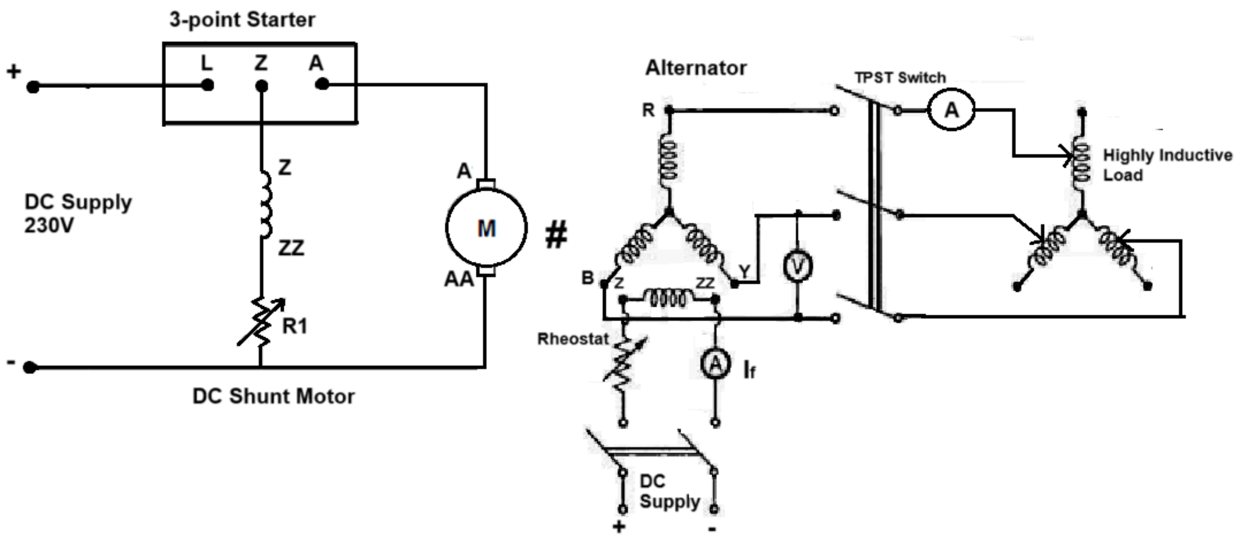
Percentage Regulation = $\frac{E_O - V}{V} \times 100\%$

Circuit Diagram:-

i) Open Circuit Test (Fig-3)



ii) Set up for ZPF Curve (Fig-4)



Procedure: -

Open Circuit test:

1. Connect the circuit as shown in the circuit diagram (Fig-3). Keep the TPST switch in the open position.
2. Set the potential divider to zero output position and motor field rheostat to minimum value.
3. Switch on the DC supply and start the motor.
4. Adjust motor speed to synchronous value by motor field rheostat and note the meter readings.
5. Increase the field excitation of the alternator and note the corresponding readings.
6. Repeat step 5 till 10% above the rated terminal voltage of the alternator.
7. Maintain constant rotor speed for all readings.

Short circuit test

1. Close the TPST switch and short-circuit the armature winding.
2. Start the motor with its field rheostat at minimum resistance and the potential divider set to zero output.
3. Adjust the motor speed to synchronous value.
4. Increase the alternator field excitation and note ammeter readings.
5. Repeat step 4 for different values of excitations (field current). Take readings up to the rated armature current. Maintain constant speed for all readings
6. Measure the value of armature resistance per phase Ra by multimeter or ammeter-voltmeter method.
7. Plot the characteristics and find the synchronous impedance.

To Plot ZPF Curve

1) Connect the circuit as shown in the figure-4.
2) Start the motor and run it at synchronous speed.
3) Vary the inductive load in steps and adjust the field current to a value till the full load armature current is flowing.
4) Every time note down the field current and the terminal voltage of the alternator.
5) Plot the ZPF curves and draw a potier triangle.

Observation:

Sr. No.	Open-circuit Test		Short-circuit Test		ZPF Test	
	Field Current (I_f) (amp)	Terminal Voltage (volts)	Field Current (I_f) (amp)	Short-circuit Current I_{sc} (amp)	Field Current (I_f) (amp)	Terminal Voltage (volts)

Armature resistance per phase =

Effective armature resistance =

Field resistance =

Calculation:

Potier reactance =

No load voltage E_o =

%age regulation = $\frac{E_o - V}{V} \times 100$

Result: The regulation at full load ____________________

Precautions:

1. All connections should be neat and tight.
2. Verify that the power supply is turned off before making any adjustments to the circuit or connecting the equipment.
3. Double-check the ratings of the instruments and devices being used to ensure they can handle the expected voltage and current levels without being damaged.
4. Before switching on the DC supply to DC motor keep the field rheostat to its minimum position.
5. Gradually increase the load during the experiment, and observe the readings to avoid overloading the equipment or causing damage to the machine.
6. After completing the experiment, turn off the power supply and disconnect all equipment safely, ensuring no residual voltage is present in the circuit.

Viva questions:

1. Why is the ZPF method preferred for calculating voltage regulation?
2. How is the ZPF condition achieved in an alternator during testing?
3. Why is it important to keep the power factor at zero during the ZPF test?
4. What are the steps involved in performing the ZPF test?
5. What do you mean by Potier reactance?
6. What information can be found from the Potier triangle?
7. How is the field current related to the terminal voltage under ZPF conditions?
8. What is the role of armature reaction in the ZPF method?
9. How ZPF method for determining voltage regulation is different from other methods?
10. How is the synchronous reactance determined using the ZPF method?
11. Can you explain how voltage regulation is calculated from the ZPF test results?
12. How does the voltage regulation obtained from the ZPF method compare with other methods?
13. What are the limitations of the ZPF method?
14. How does load affect the accuracy of voltage regulation measured by the ZPF method?

Experiment No: 10

AIM:- To determine the sub-transient direct axis (X_d'') and quadrature axis (X_q'') synchronous reactance of a three-phase synchronous machine.

Apparatus :

Sr. No	Apparatus Name	Specification	Quantity
1.	Ammeter		
2.	Voltmeter		
3.	Connecting leads		
4.	Autotransformer		
5.			

Electrical Machine Specifications:

Synchronous Machine: Power: ________ Voltage:__________ Current: ____________

Speed: _____________

Theory:

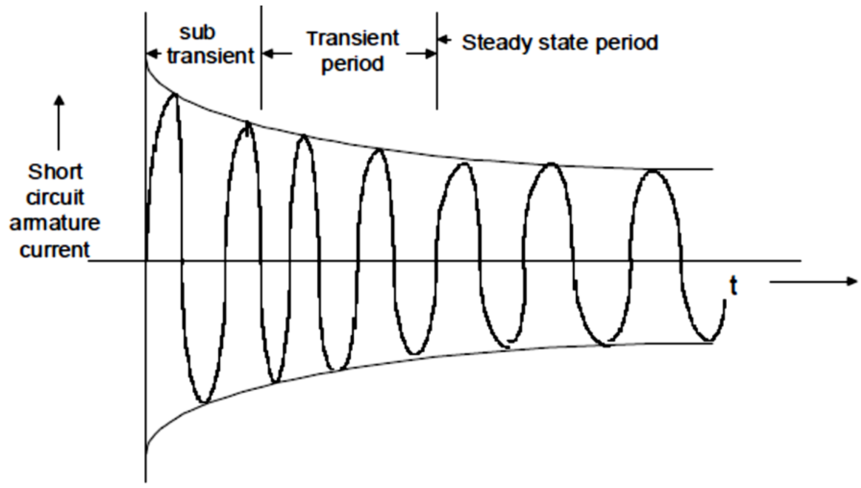
In the analysis of an alternator's behavior during transient conditions, it's common to assume that the armature and field resistances are negligibly small. This simplification is useful because, in a purely inductive closed circuit, the total flux linkages cannot change instantaneously when a disturbance occurs.

Consider an unloaded alternator with normal excitation. If all three phases are suddenly short-circuited, a short-circuit current will flow through the armature. Since resistance is assumed to be zero, this current will lag the excitation voltage by 90 degrees. The magnetic motive force (mmf) produced by this current aligns with the d-axis, meaning that the current is primarily influenced by the d-axis parameters: X_d, X_d', and X_d''.

Additionally, the short-circuit current has a demagnetizing effect on the armature. However, because the flux linkages with the field cannot change instantaneously, this demagnetizing effect must be countered by a proportional increase in the field current. This induced field current component leads to greater excitation during the transient state, resulting in a higher short-circuit current compared to the steady-state condition.

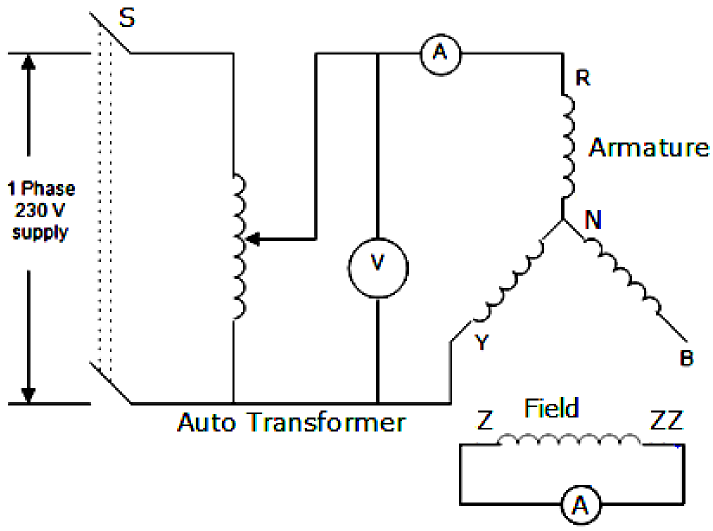
If the alternator is equipped with damper bars, the situation becomes even more interesting. At the moment of a three-phase short circuit, the demagnetizing armature mmf induces currents in the damper bars. These induced currents produce a field in the same direction as the main field, further boosting the excitation. As a result, the short-circuit current in the armature temporarily increases.

This increase in current is brief, typically lasting for 3 to 4 cycles, a period known as the sub-transient period. Since the field voltage remains constant during this time, there isn't any additional voltage to sustain the increased excitation. Consequently, the effect of the increased field current diminishes over time, decaying with a time constant determined by the field and armature circuit parameters. Accordingly, the short-circuit armature current also decays following the same time constant.



The figure illustrates a symmetrical waveform for the armature short-circuit current in one phase of a three-phase alternator. In this depiction, the DC component is assumed to be zero.
The reactances presented by the alternator during the sub-transient period are known as sub-transient reactances. Along the direct axis, this is referred to as the direct axis sub-transient reactance (X_d''), and along the quadrature axis, it is called the quadrature axis sub-transient reactance (X_q'').

Circuit Diagram:



Procedure:

1) Make the connections as shown in the circuit diagram

2) Set the autotransformer output to zero and put on the supply.

3) Adjust the stator current to 50% of the rated value rotate the rotor slowly with hands and note down the current through field winding and respective readings.

When

- The current flowing through field winding is Maximum.
- The current flowing through field winding is Minimum.

4) Repeat the step three for other applied voltage Take care that armature current does not go beyond its rated value during the experiment.

Observations:

S. No.	Armature Voltage (V)	Armature Current	
		at If max.	at If min.

Calculations:

Sub-transient direct axis ($X_d^{"}$) = $\frac{\textbf{Armature Voltage (V)}}{2 \times \textbf{Field Current } (I_f)_{max}}$

Sub-transient quadrature axis ($X_q^{"}$) = $\frac{\textbf{Armature Voltage (V)}}{2 \times \textbf{Field Current } (I_f)_{min}}$

Result:

The average values and per unit are found as follows.

Sub-transient direct axis ($X_d^{"}$) =………………Ω

Sub-transient quadrature axis ($X_q^{"}$) =…………Ω

Viva questions:

1. In this experiment why 1-phase supply is used and not three phase?
2. What is the purpose of damper winding in synchronous machines?
3. Generally whether Xd” > Xq” or Xd”< Xq” and why?
4. What is the frequency of rotor-induced emf in this test and why?
5. What is meant by Xd” and Xq”?
6. Out of Xq, Xq’, Xq” which one is minimum? Why?
7. Out of Xd, Xd’, Xd” which one is minimum? Why?
8. What is the hunting of the synchronous machine?
9. What happens if there is a sudden short circuit on the alternator?
10. What is meant by transient stability?

Experiment No: 11

AIM:- To determine the direct axis (X_d) and quadrature axis (X_q) synchronous reactance of a three-phase synchronous machine by slip test.

Apparatus:

Sr No	Apparatus Name	Specification	Quantity
1.	Ammeter		
2.	Voltmeter		
3.	Autotransformer		
4.	Tachometer		
5.			

Electrical Machine Specifications:

Synchronous Machine: Power: _________ Voltage:___________ Current: _____________
Speed: ______________

DC Motor Power: _________ Voltage:___________ Current: _____________
Speed: ______________

Theory:

In normal operating conditions of a three-phase synchronous alternator, the resultant armature magnetomotive force (mmf) remains stationary relative to the field mmf. To study the impact of armature mmf, it is necessary to decompose it into two components: one aligned with the pole axis, known as the direct axis, and the other perpendicular to this axis, known as the quadrature axis. The armature mmf component along the direct axis encounters less reluctance and thus can generate a greater flux compared to the component along the quadrature axis, which faces higher reluctance and, therefore, produces less flux. Consequently, in the steady-state operation of the synchronous machine, we define two reactances as follows:

Direct axis reactance = X_d

Quadrature axis reactance = X_q

To determine the values of X_d and X_q, apply a balanced, reduced external voltage to an unexcited synchronous machine while operating at a speed slightly below the synchronous speed. The applied voltage to the stator terminals will produce a current, resulting in a stator magnetomotive force (mmf). This stator mmf moves slowly relative to the machine's poles, inducing an electromotive force (emf) in the field circuit, similar to the induction process in an induction motor operating at slip frequency. Consequently, the stator mmf will exhibit a slow relative motion compared to the

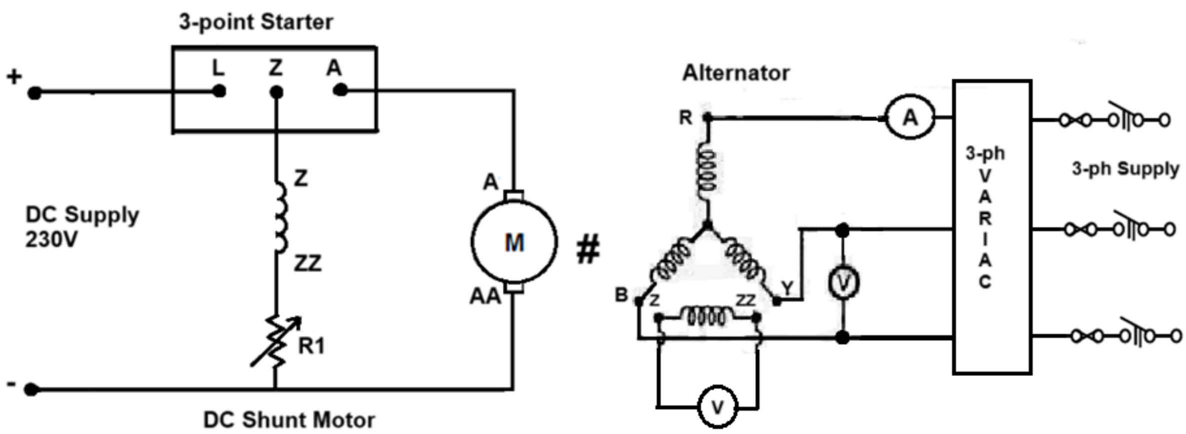
poles. As a result, the physical poles and the armature-reaction mmf will alternate between being in phase and out of phase, with this phase shift occurring at slip frequency.
When axis of the pole and axis of armature reaction mmf wave coincide, the armature mmf acts through the field circuit. Therefore, the corresponding reactance is direct axis reactance and is given by

$$X_d = \frac{maximum\ value\ of\ armature\ voltage\ (phase\ value)}{minimum\ value\ of\ armature\ current\ (phase\ value)}$$

When armature reaction mmf is in quadrature with the field poles, the applied voltage is equal to the leakage reactance drop plus the equivalent voltage drop of the cross-magnetizing field component. Therefore, the corresponding reactance is quadrature axis reactance and is given by

$$X_q = \frac{minimum\ value\ of\ armature\ voltage\ (phase\ value)}{maximum\ value\ of\ armature\ current\ (phase\ value)}$$

Circuit Diagram:



Procedure:

1. Connect the circuit as shown in Fig.
2. Bring the field circuit rheostat of the D.C. motor to its minimum value and switch ON the supply.
3. Start the D.C. motor with the help of a three-point stater.
4. Check the direction of rotation of the synchronous machine. The direction of rotation of a synchronous machine, when run by a D.C. motor, should be the direction of rotation when run as an induction motor. If it is not the same, change either the direction of rotation of the D.C. motor or the phase sequence of the synchronous machine.
5. Increase the speed of the D.C. motor by increasing the field rheostat so that the speed reaches a little less than the synchronous speed of the machine. Maintain the slip to be less than 5%.
6. Check that the three-phase variac is set to zero position. Switch ON the AC supplies with the opening field circuit and apply it to the stator of the synchronous machine.

7. Increase the supply voltage using a three-phase variac so that the machine draws the rated current.
8. It will be observed that induced voltage, applied voltage to the stator winding, and current in stator winding will fluctuate from their minimum values to maximum values.
9. Note down the reading.
10. Repeat the steps 5, 7, and 8 for some other suitable speeds.
11. Reduce the applied voltage to the stator winding of the synchronous machine using a three-phase variac to zero and switch OFF the AC supply.
12. Reduce the speed of the DC motor by decreasing its field resistance and switching OFF the DC supply.

Observations:

Sr. No.	Speed N (rpm)	Slip (s) %	Armature Voltage		Armature Current	
			Max (V)	Min (V)	Max (A)	Min (A)

Calculations:

$$\text{direct axis reactance } (X_d) = \frac{maximum\ value\ of\ armature\ voltage\ (phase\ value)}{minimum\ value\ of\ armature\ current\ (phase\ value)}$$

$$\text{quadrature axis reactance } (X_q) = \frac{minimum\ value\ of\ armature\ voltage\ (phase\ value)}{maximum\ value\ of\ armature\ current\ (phase\ value)}$$

Result:

The average direct axis reactance X_d = _______Ω

The average quadrature axis reactance X_q = _____Ω

Precautions:

1. All connections should be tight and clean.
2. The zero setting of all the meters should be checked before connecting them.
3. The slip of the synchronous machine should be kept below 5%.
4. During the experiment all the time the voltage induced in the rotor should remain below the rating of the voltmeter connected there.t

Viva questions

1. What do you understand by the direct axis and quadrature axis reactances of the synchronous machine?
2. What should be the value of X_q/X_d for the salient pole machine?

3. What should be the value of X_q/X_d for a non-salient pole machine?
4. What assumption has been made in slip test?
5. What should be the permissible value of slip for this experiment?
6. Why the readings of the Voltmeter and Ammeter are fluctuating?

Experiment No: 12

AIM:- To study the effect of variation of field current upon the stator current and power factor of a synchronous motor at various loads and draw V-curves and invert V-curves.

Apparatus :

Sl No	Apparatus Name	Specification	Quantity
1.	Ammeter		
2.	Voltmeter		
3.	Wattmeters		
4.	3-phase Autotransformer		
5.	Rheostats		
6.			

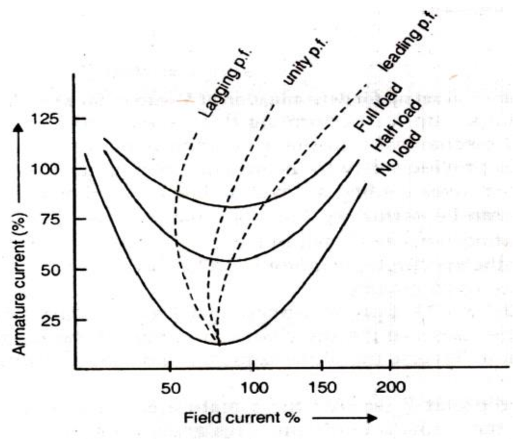
Electrical Machine Specifications:

Synchronous Motor: Power: _________ Voltage:___________ Current: _____________

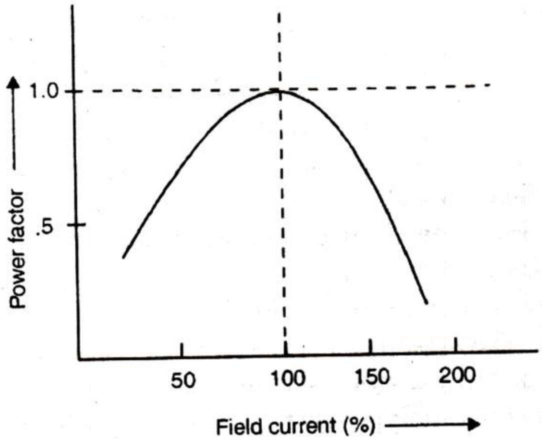
Speed: ______________

Theory:

V-curve of a synchronous machine shows its performance in terms of variation of armature current with field current when the load and input voltage to the machine is constant. When a synchronous machine is connected to an infinite bus, the current input to the stator depends upon the shaft load and excitation (field current). At a constant load, if excitation is changed the power factor of the machine changes, i.e. when the field current is small (the machine is under-excited) the P.F. is low and as the excitation is increased the P.F. improves so that for a certain field current the P.F. will be unity and machine draws minimum armature current. This is known as normal excitation. If the excitation is further increased the machine will become overexcited and it will draw more line current and P.F. becomes leading and decreases. Therefore, if the field current is changed keeping load and input voltage constant, the armature current changes to make $VI\cos\varphi$ constant. Because of their shape as the English letter 'V', graphs of variation of armature current with excitation are called 'V' curves. If the 'V' curves at different load conditions are plotted and points on different curves having the same P.F. are connected the resulting curve is known as a "compounding curve".

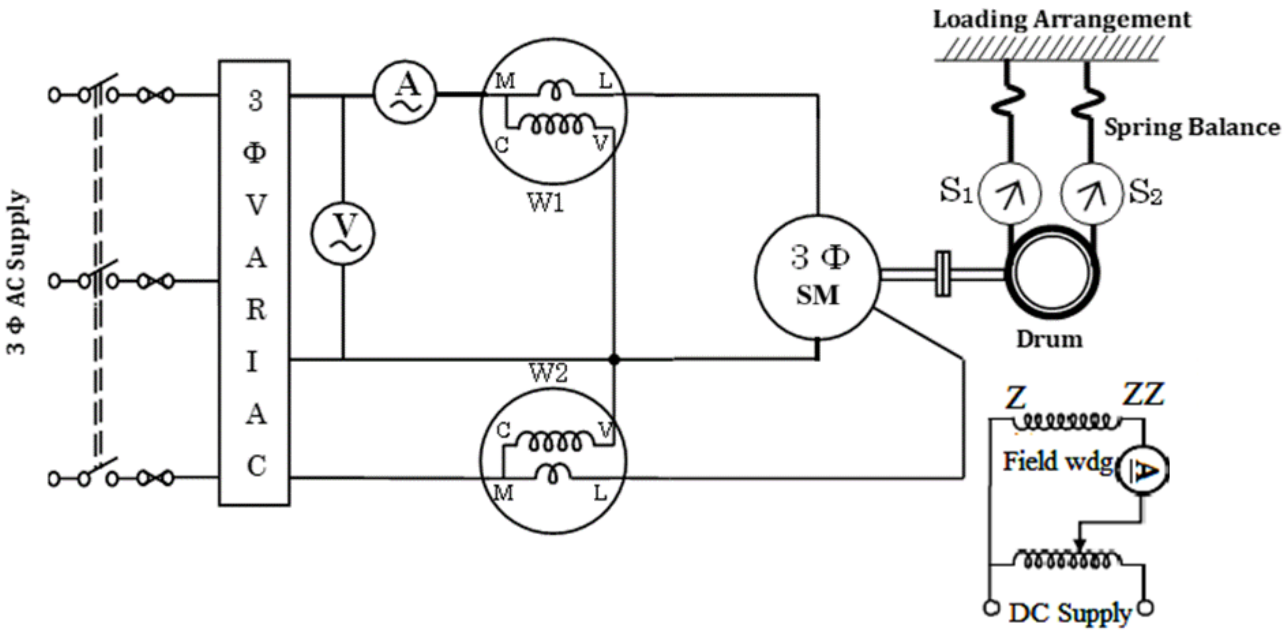


V-curves for Synchronous motor



Invert V-curves for Synchronous motor

Circuit Diagram:



Procedure:

1) Make the connections as shown in the circuit diagram.
2) Adjust the field rheostat of the DC generator at the maximum position, the potential divider at zero output position, and the load at off condition.
3) Switch on the 3-ph. supply, start the synchronous motor, and let it run at its rated speed.
4) Switch on the DC supply and adjust the generator field current to a suitable value so that it generates the rated voltage.
5) Increase the alternator field current and note down the corresponding power factor and armature current covering a range from low lagging to low leading power factor through a unity power factor. Note that armature current is minimum when the p.f. is in unity.
6) Increase load on the synchronous motor and repeat step no.5.

Observations:

S. No.	Supply Voltage V	Exciter Current If	Power input			Power Factor cosφ
			W1	W2	P=W1+W2	

Results: Plot the curves between armature current (I_a) vs field current (I_f) and power factor (cosΦ) vs field current (I_f).

Precautions:

1. All connections should be tight and clean.
2. The zero setting of all the meters should be checked before connecting them.
3. Gradually adjust the excitation voltage and load to avoid sudden surges that could damage the motor or associated equipment.
4. Monitor the temperature of the motor and other components closely to prevent overheating and potential damage.
5. Record all data carefully and consistently, and verify measurements at multiple points to ensure accuracy and reliability of the plotted curves.

Viva questions:

1. With what condition synchronous motor can be used as a synchronous condenser**?**
2. What are the special applications of an over-excited synchronous motor?
3. Explain the effect of change of excitation of a synchronous motor on its armature current.
4. Explain the effect of change of excitation of a synchronous motor on its power factor.
5. With the given excitation a synchronous motor draws a unity power factor current. If the mechanical load is increased what will be the power factor and current for the same excitation?
6. Why V curve shift upwards and the inverted V curve shift right as the load increases?
7. Explain the effect of change of excitation of a synchronous generator on its armature current.
8. Explain the effect of change of excitation of a synchronous generator on its power factor

Experiment No: 13

AIM:- To determine the symmetrical impedances of a synchronous machine.

Apparatus :

Sr. No	Apparatus Name	Specification	Quantity
1.	Ammeter		
2.	Voltmeter		
3.	Connecting leads		
4.	Autotransformer		

Electrical Machine Specifications:

Synchronous Machine: Power: ________ Voltage:__________ Current: ____________
Speed: ____________

DC Shunt Motor Power: ________ Voltage:__________ Current: ____________
Speed: ____________

Theory:

Various sequence impedances are defined for equipment or a component of a power system. The sequence impedance of equipment is defined as the impedance offered by the equipment to the flow of the corresponding sequence current. This means the positive sequence impedance of an equipment is the impedance offered by the equipment to the flow of positive sequence currents. Similarly, the negative sequence impedance of an equipment is the impedance offered by the equipment to the flow of negative sequence currents. Further, the zero-sequence impedance of equipment is the impedance offered by the equipment to the flow of zero-sequence currents.

The positive, negative, and zero sequence impedances are represented by Z_1, Z_2, and Z_0 respectively. It is important to mention here that for symmetrical systems, there is no mutual coupling between the sequence networks. Therefore, the three-sequence systems can be considered separately. The resultant phase currents and voltages can be determined by superposing their symmetrical components of currents and voltages respectively.

Positive Sequence Impedance: The value of positive sequence impedance depends upon the working of machine 1.e., whether it is working under sub-transient, transient, or steady-state conditions. The impedance under steady-state conditions is termed synchronous impedance.

Negative Sequence Impedance: The negative sequence impedance of a machine is the impedance offered to the flow of negative sequence current. In this test, the synchronous machine under test is driven at the rated speed by a prime mover. The field circuit is short-circuited. A reduced voltage is applied to circulate approximately the rated current. Only negative sequence current flow under this condition. There is a possibility of hunting due to which the pointer of the ammeter may oscillate. In such a case mean reading of the ammeter should be recorded. Then negative sequence impedance can be calculated using the following equation

$$Z_2 = \frac{V}{\sqrt{3} * I}$$

Zero Sequence impedance. Zero-sequence impedance is the impedance offered by the machine to the flow of the zero-sequence current. Zero sequence impedance is much smaller than positive and negative sequence impedance. The zero sequences has a meaning for a star-connected system only, because otherwise no zero sequence current flows. To perform this test the machine remains at stands still. A reduced A.C. voltage is impressed across the three windings (connected in series). The zero-sequence impedance is calculated using the following relation

$$Z_0 = \frac{V}{3I}$$

Circuit Diagram:

1. **Negative Sequence Impedance**

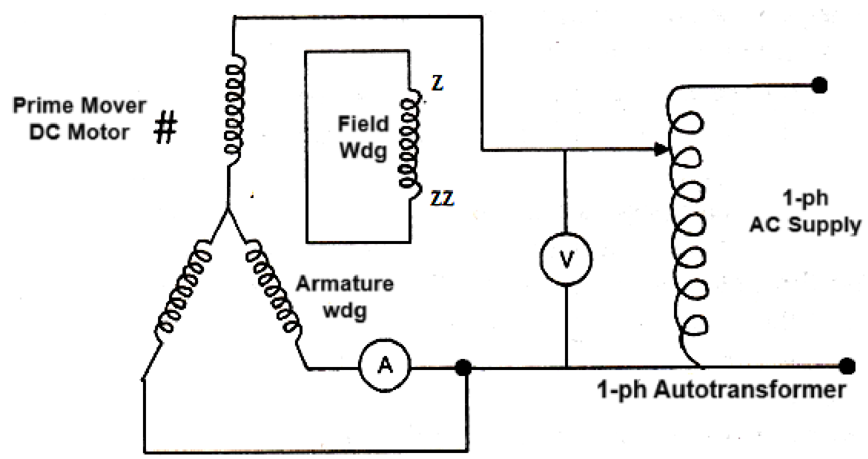


Fig-1 Experimental setup for negative sequence impedance.

2. **Zero Sequence Impedance**

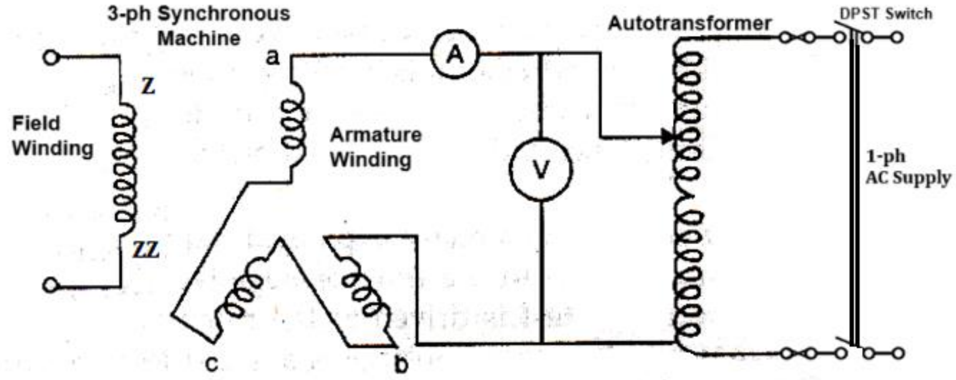


Fig-2 Experimental setup for zero sequence impedance.

Procedure:

Negative Sequence Impedance.

1. Connect the circuit as Per Fig.1.
2. Here we use a D.C. shunt motor as a prime mover to the synchronous Generator. Ensure that the external resistance in the field circuit of the D.C. shunt motor is zero.
3. Switch on the D.C. supply to the D.C. shunt motor. Start the motor using a starter.
4. Adjust the field resistance of the D.C. shunt motor so that it runs at the rated speed of the synchronous machine.
5. Adjust the variac so that the rated current flows through the stator windings of the alternator.
6. Record the readings of voltmeter and ammeter.
7. Switch off A.C. supply. Switch off the D.C. supply.

Zero Sequence Impedance.

1. Connect the circuit as given in Fig. 2.
2. Ensure that the variac is at zero position. Switch-on A.C. supply
3. Increase the variac position so that the ammeter reads the rated current of the synchronous machine.
4. Record the readings of voltmeter and ammeter.
5. Switch off A.C. supply.

Observation and Calculation:

Negative Sequence Impedance.

Voltmeter reading (V) = ____________volts

Ammeter readings (I) =____________ amps

Negative-sequence Impedance, $\boldsymbol{Z_2} = \frac{\boldsymbol{V}}{\sqrt{3}*\boldsymbol{I}}$

Zero-sequence Impedance, .

Voltmeter reading (V) = ____________volts

Ammeter reading (I) = _____________ amps

Zero-sequence Impedance, $\boldsymbol{Z_0} = \frac{\boldsymbol{V}}{\boldsymbol{3I}}$

Result:

Negative Sequence Impedance =………………

Zero Sequence Impedance =…………………..

Precautions.

Following precautions should be taken care of while performing this

1. All connections should be neat and tight.
2. Zero settings of the meters should be checked before connecting them to the circuit.

3. Avoid exceeding the rated voltage and current limits of the synchronous machine to prevent overheating or damage.

Viva questions

1. How do you measure the synchronous machine's positive sequence impedance?
2. What method is used to calculate the negative sequence impedance of the synchronous machine?
3. Why is the zero-sequence impedance different from the positive and negative sequence impedances?
4. How do you connect the synchronous machine for the zero-sequence impedance test?
5. What instruments are required to measure the symmetrical impedances?
6. How do variations in the field excitation affect the symmetrical impedances of the synchronous machine?
7. How is the rotor winding affected due to negative sequence current?
8. How is the rotor winding affected due to zero sequence current?
9. What are the various positive, negative, and zero sequence reactances defined for a synchronous machine?
10. Which of the sequence reactances has the highest value?

Experiment No: 14

AIM:- To perform the parallel operation of two alternators.

Apparatus:

Sl No	Apparatus Name	Specification	Quantity
1.	Ammeter		
2.	Voltmeter		
3.	Frequency meter		
4.	Tachometer		
5.	Synchronizing lamps		
6.	Synchroscope		

Electrical Machine Specifications:

Synchronous Machine: Power: _________ Voltage:____________ Current: ______________
Speed: _______________

DC Motor: Power: _________ Voltage:____________ Current: ______________
Speed: _______________

Theory:

The procedure of connecting an alternator in parallel with another or with common bus bars to which the number of alternators is already connected is called **synchronization of alternators**.

The need for parallel operation of A.C. alternators may arise out of any one or more of the following reasons.

i. The demand may exceed the current generation.
ii. Alternators operating in parallel permit one or more units to be shut down for scheduled or emergency maintenance while the demand is being met.
iii. Future increases in load can be managed by adding more machines without disturbing the existing installation.
iv. Economic operation of the Power system as a whole can be managed.

For proper synchronization of the alternator, the following conditions must be fulfilled:

i. The voltage should be equal at the paralleling point/junction (even though may not be the same at the alternators).
ii. The phase sequence should be the same at the paralleling point/junction.
iii. The line frequencies should be the same at the paralleling point. In general, it implies the same frequency at the generators too, because frequency changing is neither economic nor suitable for technical reasons. Maintaining exactly the same frequency may not be possible at the instant of paralleling. However, a small frequency difference (of the order of a fraction of Hz) may be tolerated provided all other conditions of paralleling are satisfied.

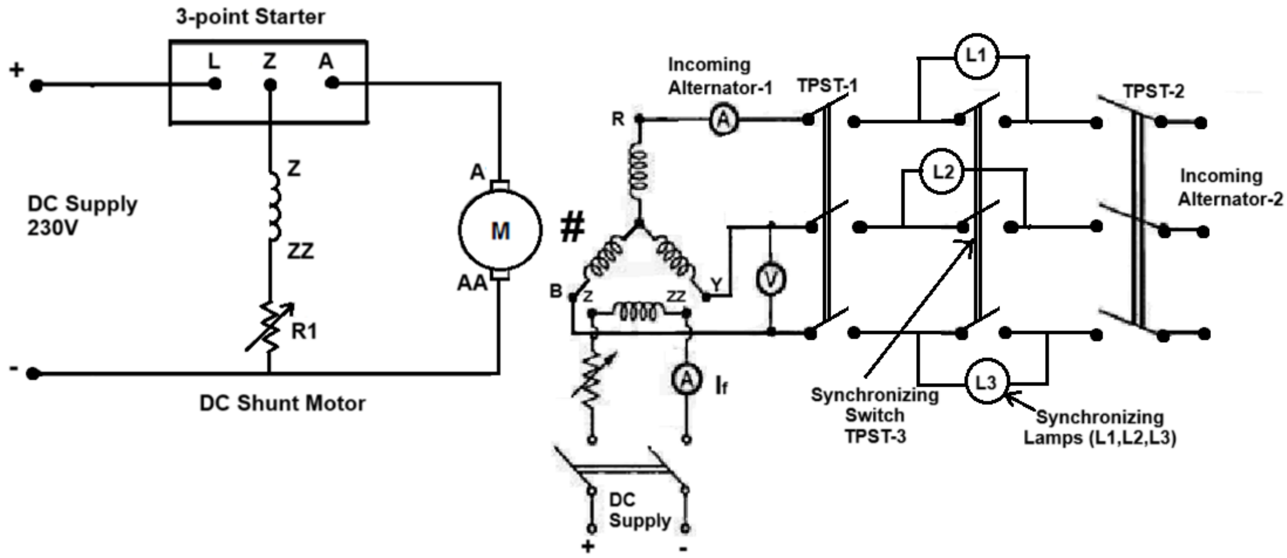
Methods for synchronization of alternators:

There are three methods for the synchronization of alternators. These methods check whether the above-mentioned conditions for the **synchronization of alternators** are satisfied or not. The three methods are.

1. Three dark lamps method.
2. Two bright, One dark method.
3. Synchroscope method.

1. Three dark lamps method

Circuit Diagram:



Procedure:

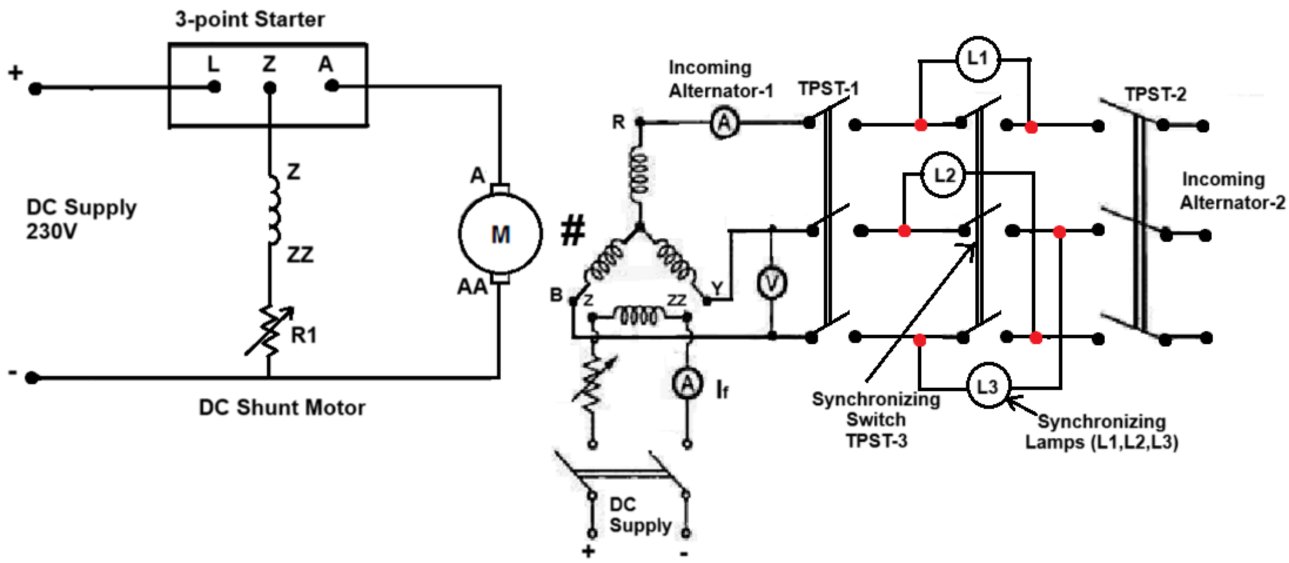
1. Start by running alternator-1 and bringing it to the rated speed and voltage.
2. Start alternator-2 and gradually increase its speed until it approaches the synchronous speed.
3. Close the TPST-1 switch of alternator-1 to connect it to the bus bar.
4. Now close the TPST-2 switch of alternator-2 and observe the three lamps (L1, L2, L3) connected across the third TPST-3 (synchronizing switch).
5. Adjust the speed of alternator-2 using its prime mover until the frequency of alternator-2 matches that of alternator-1.
6. Observe the flickering of the lamps. The lamps will flicker at a rate corresponding to the frequency difference between the two alternators.
7. Gradually adjust the speed until the lamps flicker slowly, indicating that the frequency difference is small.
8. Now adjust the voltage of alternator-2 to match the bus voltage.
9. When the lamps are flickering very slowly and approaching simultaneous darkness, the phase difference is minimal.

10. At the point when all three lamps are dark (or very dim) simultaneously, quickly close the synchronizing switch (TPST-3) to connect alternator 2 to the bus bar.
11. Both alternators are now synchronized and share the load according to their ratings.

Disadvantages of the three dark lamps method

- Flickering only says the difference between the frequency of voltages of an alternator and bus bar but the correct value of the frequency of voltage of the alternator cannot be found.
- For example, if the bus bar frequency of voltage is 50 HZ and the difference in frequency of voltage of the bus bar and alternator is 1 HZ the alternator frequency of voltage can be either 49 HZ or 51 HZ.

2. Two bright and one dark lamp method



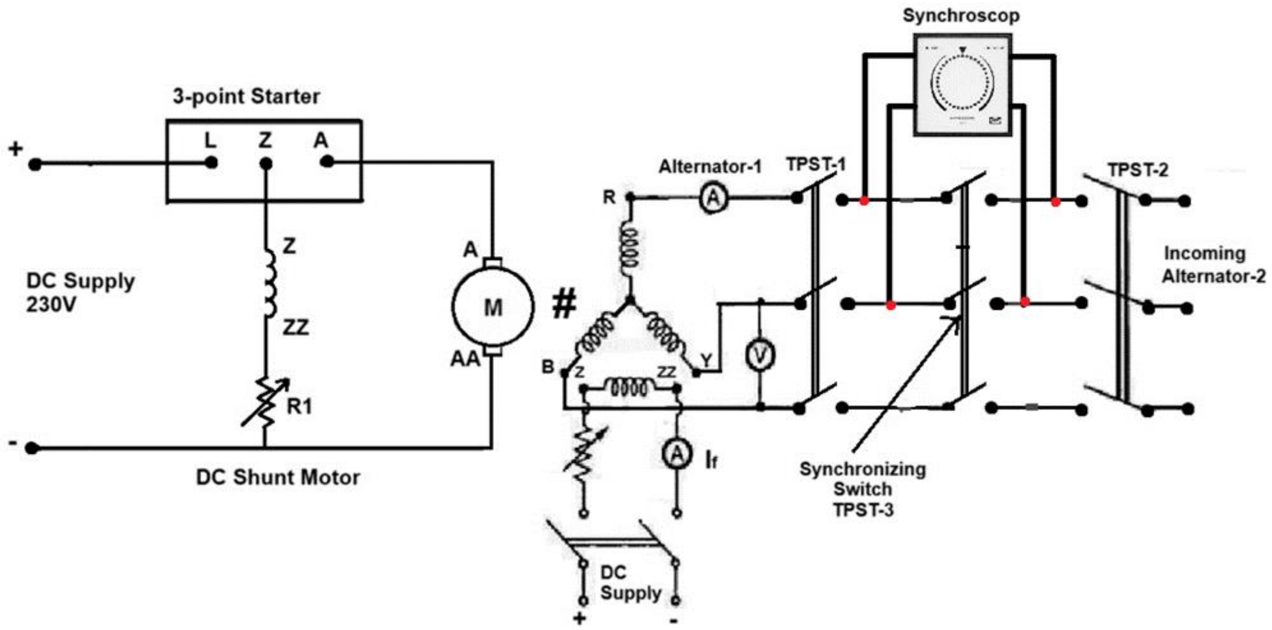
Procedure:

1. Start by running alternator-1 and bringing it to the rated speed and voltage.
2. Ensure the incoming alternator-2 is also brought to its rated speed and voltage.
3. Close the TPST switch connected to alternator-1.
4. Gradually increase the speed of alternator-2 to bring its frequency closer to that of alternator-1.
5. Observe the three lamps (L1, L2, and L3) connected across the synchronizing TPST switch.
6. Adjust the speed of alternator-2 so that L1 (one dark lamp) appears dark, and L2 and L3 (two bright lamps) become bright simultaneously.
7. As the lamps indicate synchronization (L1 dark and L2, L3 bright), close the synchronizing TPST switch to connect alternator-2 with the bus bar.
8. Once synchronized, check for any load sharing between alternator-1 and alternator-2 and make necessary adjustments.

Disadvantage of the two bright and one dark lamp method

- The phase sequence of the alternator cannot be checked by this method.

3. Synchroscope method for synchronization of alternators:



Procedure:

1. A synchroscope is used to achieve synchronization accurately.
2. It is similar to the two bright and one dark lamp method and tells whether the frequency of the incoming alternator is higher or lower than the bus bar frequency.
3. This contains two terminals they are a) the existing terminal and b) the incoming terminal.
4. Existing terminals are to be connected to the bus bar or existing alternator here in the diagram it is alternator-1 and incoming terminals are connected to the incoming alternator which is alternator-2 according to the diagram that we have considered.
5. Synchroscope has a circular dial inside which a pointer is present and it can move both in the clockwise and anti-clockwise direction.
6. To match the terminal voltage of alternator-2 with the bus-bar voltage we need to adjust the field current of alternator-2 until the terminal voltage of alternator-2 matches with the bus-bar voltage. The required value of voltage can be seen in the voltmeter connected to the bus bar.
7. Depending upon the rate at which the pointer is rotating the difference in frequency of voltage between the incoming alternator and bus bar can be known.
8. And also, if the pointer moves anti-clockwise then the incoming alternator is running slower and has a frequency less than the bus bar or existing alternator frequency and if the pointer moves clock-wise then the incoming alternator is running faster and has a frequency greater

than the bus-bar or existing alternator frequency. So, by adjusting the speed of the prime mover of the incoming alternator, we can match the frequency with the bus-bar or existing alternator frequency. Frequency matches when the pointer is straight upwards. At this point close the synchronizing switch(TPST-3.

9. Now both the alternators are in synchronism.

Viva questions:

1. What is the primary reason for operating two alternators in parallel?
2. What is the significance of synchronizing alternators before paralleling them?
3. What different conditions should be satisfied for synchronizing two alternators?
4. Name the key parameters that must match for successful parallel operation of alternators.
5. What is the principle behind the three-dark lamp method for synchronizing alternators?
6. What are the conditions for
7. How does the three-dark lamp method help in determining the correct phase sequence of alternators?
8. What are the main advantages of using the three-dark lamps method for synchronizing alternators?
9. What are the disadvantages of the three dark lamps method in terms of equipment and accuracy?
10. Describe the procedure for synchronizing alternators using the one dark two bright lamp method.
11. How does the one dark two bright lamp method differ from the three-dark lamp method in terms of accuracy and ease of use?
12. What are the key advantages of the one dark two bright lamp method for synchronizing alternators?
13. What limitations or disadvantages are associated with the one dark two bright lamp method?
14. Explain how a synchroscope can be used to synchronize two alternators.
15. What are the primary advantages of using a synchroscope for synchronizing alternators?
16. Discuss any disadvantages or limitations of using a synchroscope in comparison to the lamp methods.
17. In the three dark lamp method, what does it indicate if all three lamps remain dark during synchronization?
18. How does the phase difference between two alternators affect the lamp indications in the one dark two bright lamp method?
19. What steps should be taken if the synchroscope needle does not show the expected behavior during synchronization?

20. How does the use of the synchroscope contribute to the prevention of damage during the parallel operation of alternators?
21. In the three dark lamp method, what are the implications of incorrect synchronization on the performance of the alternators?
22. Compare the response time of the three dark lamp method and the synchroscope method in synchronizing alternators.
23. How does the one dark two bright lamp method address the issue of frequency matching between alternators?
24. What safety precautions should be observed when using the three dark lamp method for synchronization?
25. Discuss the impact of incorrect synchronization on the mechanical and electrical components of the alternators.