Department of Electrical and Electronics Engineering

Laboratory Manual

Transformers and Generators Laboratory

BEEL305

Academic Year: 2024-25

Semester: III

Compiled by　　　　Verified by　　　　Approved by

ATME College of Engineering

13th km Stone, Mysuru-Kanakapura-Bengaluru Road, Mysuru-570028

Institutional Vision and Mission

Vision:

Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

Mission:

•To keep pace with advancements in knowledge and make the students competitive and capable at the global level.
•To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torchbearers of tomorrow's society.
•To strive to attain ever-higher benchmarks of educational excellence.

Department Vision and Mission

Vision:

To create Electrical and Electronics Engineers who excel to be technically competent and fulfill the cultural and social aspirations of the society.

Mission:

•To provide knowledge to students that builds a strong foundation in the basic principles of electrical engineering, problem solving abilities, analytical skills, soft skills and communication skills for their overall development.

•To offer outcome based technical education.

•To encourage faculty in training & development and to offer consultancy through research & industry interaction.

Program Educational Objectives (PEOs)

PEO1: To produce competent and ethical Electrical and Electronics Engineers who will exhibit the necessary technical and managerial skills to perform their duties in society.

PEO2: To make students continuously acquire and enhance their technical and socio-economic skills.

PEO3: To aspire students on R&D activities leading to offering solutions and excel in various career paths.

PEO4: To produce quality engineers who have the capability to work in teams and contribute to real time projects.

Program Outcomes (POs)

Engineering Graduates will be able to:

PO1: Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems

PO2: Problem Analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences and engineering sciences.

PO3: Design / Development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4: Conduct investigations of complex problems: 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.

PO5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO6: The engineer and society: 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.

PO7: Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9: Individual and team work: Function effectively as an individual and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10: Communication: 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.

PO11: Project management and finance: Demonstrate knowledge and understanding of the engineering 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.

PO12: Life-long learning: Recognize the need for and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.

Program Specific Outcomes (PSOs)

The students will develop an ability to produce the following engineering traits:

PSO1: Apply the concepts of Electrical & Electronics Engineering to evaluate the performance of power systems and also to control industrial drives using power electronics.

PSO2: Demonstrate the concepts of process control for Industrial Automation, design models for environmental and social concerns and also exhibit continuous self- learning.

Syllabus
Transformers and Generators Laboratory

Course Code:BEEL305	**IAMarks: 50**
Hrs/week:03	**ExamHours:03**
Total Hours:42	**ExamMarks: 50**

Sl No.	Name of the Experiment
1	Open Circuit and Short circuit tests on single phase step up or step down transformer and predetermination of (i) Efficiency and regulation (ii) Calculation of parameters of equivalent circuit.
2	Sumpner's test on similar transformers and determination of combined and individual transformer efficiency.
3	Parallel operation of two dissimilar single-phase transformers of different kVA and determination of load sharing and analytical verification given the Short circuit test data
4	Polarity test and connection of 3 single-phase transformers in star – delta and determination of efficiency and regulation under balanced resistive load.
5	Comparison of performance of 3 single-phase transformers in delta – delta and V – V (open delta) connection under load.
6	Separation of hysteresis and eddy current losses in single phase transformer
7	Investigate the voltage and current ratios of a multi-tapped transformer and verify the ideal transformer ratio
8	Voltage regulation of an alternator by EMF and MMF methods.
9	Power angle curve of synchronous generator or Direct load test on three phase synchronous generator to determine efficiency and regulation.
10	Performance of synchronous generator connected to infinite bus, under constant power and variable excitation & vice - versa.
11	Simulate power angle curve of generator in MATLAB
12	Model transformer in Simscape for Automatic Voltage Regulation.

List of Textbooks:

1. Electrical Machinery by P S Bhimra
2. Electrical machines by I J Nagrath and Kothari
3. AC and DC machines by B L Thereja

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Department of EEE
Emitting Elite Energy

Transformers and Generators Laboratory
Cycle of Experiments

Sl. No	Experiment Name	POs	COs
Cycle 1			
1	Open Circuit and Short circuit tests on single phase step up or step-down transformer and predetermination of (i) Efficiency and regulation (ii) Calculation of parameters of equivalent circuit.	1,2,3,4,9, 12	CO1
2	Model transformer in Simscape for Automatic Voltage Regulation.	1,2,3,4,5,9, 12	CO2
3	Sumpner's test on similar transformers and determination of combined and individual transformer efficiency.	1,2,3,4,5,9 ,12	CO2
4	Parallel operation of two dissimilar single-phase transformers of different kVA and determination of load sharing and analytical verification given the Short circuit test data	1,2,3,4,9, 12	CO3
5	connection of 3 single-phase transformers in Star – delta and determination of efficiency and regulation under balanced resistive load.	1,2,3,4,9, 12	CO5
6	Separation of hysteresis and eddy current losses in single phase transformer	1,2,3,4,9, 12	CO1
7	Polarity test and investigate the voltage and current ratios of a multi-tapped transformer and verify the ideal transformer ratio	1,2,3,4,9, 12	CO4
Cycle 2			
8	Comparison of performance of 3 single-phase transformers in delta – delta and V – V (open delta) connection under load.	1,2,3,4,9, 12	CO5
9	Power angle curve of synchronous generator or Direct load test on three phase synchronous generator to determine efficiency and regulation	1,2,3,4,5,9, 12	CO2
10	Simulate power angle curve of generator in MATLAB.	1,2,3,4,5,9 ,12	CO2
11	Voltage regulation of an alternator by EMF and MMF methods.	1,2,3,4,9, 12	CO6
12	Performance of synchronous generator connected to infinite bus, under constant power and variable excitation & vice - versa.	1,2,3,4,9, 12	CO7

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Caution

1. Do not play with electricity.
2. Carelessness not only destroys the valuable equipment in the lab but also costs your life.
3. Mere conducting of the experiments without a clear knowledge of the theory is of no value.
4. Before you close a switch, think of the consequences.
5. Do not close the switch until the faculty in charge checks the circuit.

General Instructions to Students

1. Students should come with thorough preparation for the experiment to be conducted.
2. Students will not be permitted to attend the laboratory unless they bring the practical record fully completed in all respects pertaining to the experiment conducted in the previous class.
3. Name plate details including the serial number of the machine used for the experiment should be invariably recorded.
4. Experiment should be started only after the staff-in-charge has checked the circuit diagram.
5. All the calculations should be made in the observation book. Specimen calculations for one set of readings have to be shown in the practical record.
6. Wherever graphs are to be drawn, A-4 size graphs only should be used and the same should be firmly attached to the practical record.
7. Practical record should be neatly maintained.
8. They should obtain the signature of the staff-in-charge in the observation book after completing each experiment.
9. Theory regarding each experiment should be written in the practical record before procedure in your own words

Experiment No.1

O.C & S.C Tests on 1φ Transformer

Learning Objective:

To predetermine the losses, efficiency and regulation of a 1Φ transformer and also to draw its equivalent circuit

Apparatus Required:

Sl No	Apparatus	Range	Quantity
1	1Φ Auto-transformer	[0 – 300V]	1 No.
2	1Φ transformer	[230/230V]	1 No.
3	AC Ammeter	[0 - 2A]	1 No.
		[0 – 10A]	1 No.
4	AC Voltmeter	[0 – 300V]	1 No.
		[0 – 50V]	1 No.
5	LPF wattmeter	[1/2A, 300V]	1 No.
6	UPF wattmeter	[10/20A, 300V]	1 No.
7	Connecting wires	[0 – 300V]	

Circuit Diagram:

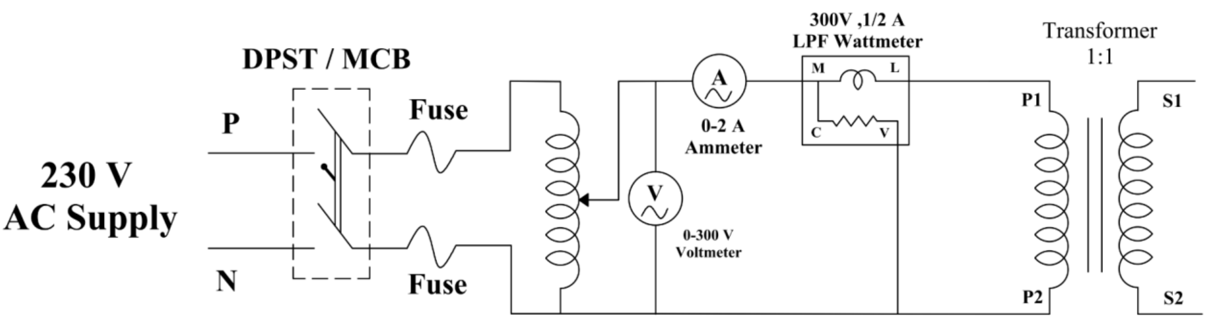


Fig 1.1 Open Circuit Test

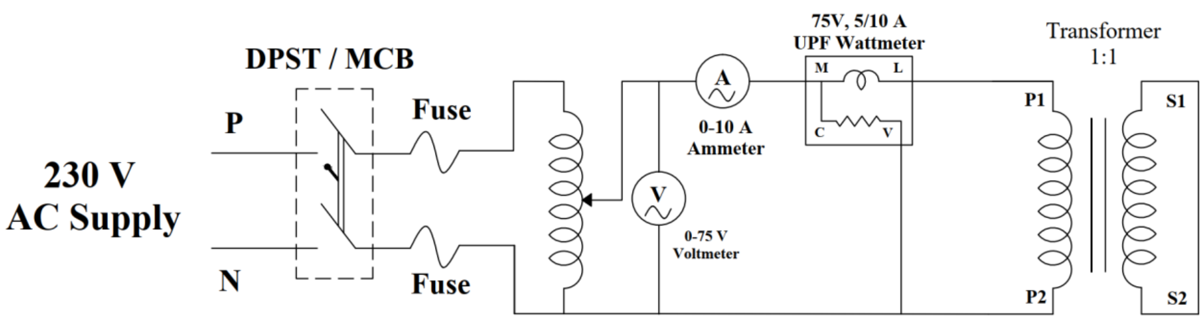


Fig 1.2. Short Circuit Test

Procedure:

O.C Test

1. Make the connections as shown in the circuit diagram as in Fig 1.1.
2. Supply switch is closed and the single-phase auto-transformer is adjusted to rated voltage of the transformer.
3. The readings of the ammeter, voltmeter and wattmeter are noted.
4. The single-phase auto-transformer voltage is reduced to zero and the supply switch is opened.

S.C Test

1. Make the connections as shown in the circuit diagram as in Fig 1.2.
2. Supply switch is closed and the single-phase auto-transformer is adjusted to rated current of the transformer. (Note: A small voltage has to be applied).
3. The readings of the ammeter, voltmeter and wattmeter are noted.
4. The single-phase autotransformer voltage is reduced to zero and the supply switch is opened.

$$K = \frac{VI\ Cos\emptyset}{Full\ Scale\ Reading} = \text{------------------------------}$$

Where K→ Wattmeter constant;

V → Voltage range ; I → Current range ; cos∅ → power factor

O.C TEST:

Sl. No.	V_o Volts	I_o Amps	W_{oc} = W x K Watts

S.C TEST:

Sl. No.	I_{SC} Amps	V_{SC} Volts	W_{SC} =W x K Watts

Calculations:

A) Calculation of parameters of equivalent circuit of the Transformer

I_{SC}= ----------------

Core loss W_{OC} = ------------------------------

Full load copper loss W_{SC} = ------------------------------

$Cos\emptyset 0 = \frac{W_{oc}}{V_{oc}\ I_{oc}} =$ ------------------------------

I_L = Loss component = I_0 $Cos\emptyset_0$= ________________________

$I\mu$ = Magnetizing component = I_0 $Sin\emptyset_0$= ____________________

R_0 = Shunt branch resistance = $\frac{V_0}{I_L}$ = ____________________

X_0 = Shunt branch resistance = $\frac{V_0}{I\mu}$ = ____________________

$Req = \frac{W_{sc}}{I_{sc}^2}$ = ____________________

$Zeq = \frac{V_{sc}}{I_{sc}}$ = ____________________

$Xeq = \sqrt{Z_{eq}^2 - R_{eq}^2}$

Equivalent Circuit:

B) Pre-determination of the efficiency and regulation of the 1Φ transformer for different loads and PF.

1. Percentage Efficiency:

The percentage efficiency can be calculated using the formula

$$\%\eta = \frac{Output}{Input} \text{ x } 100 \quad = \quad \frac{Output}{Input+Losses} \text{ x } 100$$

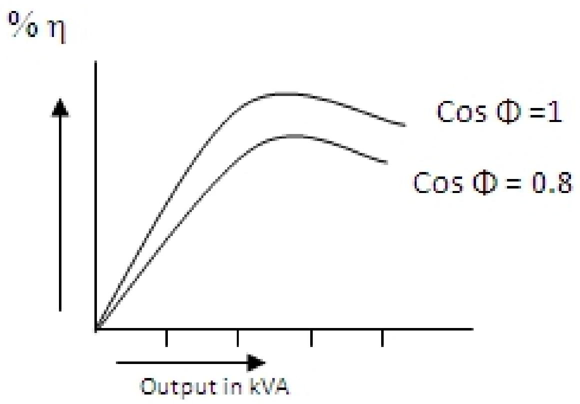
$$\%\eta = \frac{X\left(KVA\ Rating*10^{3}\right)Cos\emptyset}{X(KVA\ Rating*10^{3}Cos\emptyset+W_{oc}+X^{2}W_{sc}} \text{ x } 100$$

- X is the fraction of the full load KVA of the transformer at which efficiency is required to be calculated.
- cos∅ is the power factor of the load which can be assumed as 1, 0.8 etc.
- Wo is the Iron loss of the transformer which is obtained from O.C test.
- Wsc is the load copper losses of the transformer which is obtained from S.C test

The efficiency can be calculated for x = 1/8, 1/4, 1/2, 3/4 and 1 (full load) and the results are tabulated as under, (The p.f of the load is assumed as 1.0 & 0.8)

Sl. No	Fraction of F.L (X)	Output in KVA	Copper Losses Watts	Iron Losses Watts	Total Losses Watts	PF=1	PF=0.8
						%η	%η
1.	1/ 4						
2.	1/ 2						
3.	3/ 4						
4.	1.0						
5.	3/2						

The graph of %Efficiency v/s KVA output is plotted as shown.



2. Percentage Regulation:

The percentage regulation of the transformer can be calculated using the formula

$$\%Regulation = \frac{(I_{rated}R_{eq}Cos\emptyset) \pm (I_{rated}X_{eq}Sin\emptyset)}{V_{rated}}$$

• cos ∅ of the load which can be assumed as 0.2, 0.4, 0.6, 0.8 and 1.

• In the above equation, +ve sign is used if the p.f is lagging and -ve sign is used if the p.f is leading.

• Req = Equivalent resistance of the transformer reffered to secondary

The results are tabulated as shown

Sl. No.	PF	% Regulation
1	0.4 lag	
2	0.6 lag	
3	0.8 lag	
4	UPF	
5	0.8 lead	
6	0.6 lead	
7	0.4 lead	

The graph of % regulation V/s. p.f is drawn as shown

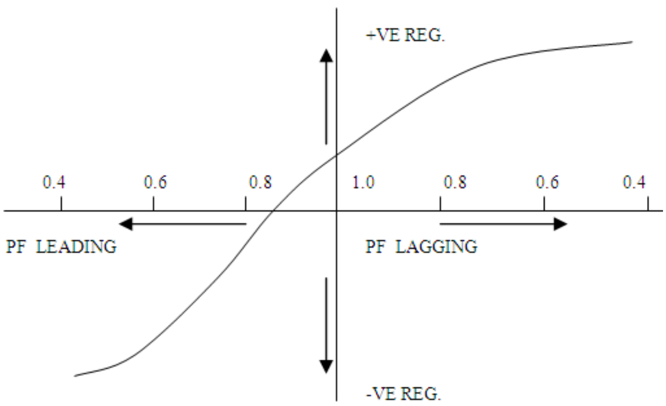


Fig 1.4: Power factor v/s regulation

Result:

Single phase Transformer losses, efficiency at different loads at 0.8 and unity power factor and regulation at different power factor is obtained.

Outcome:

At the end of the experiment student will be able

1. To find transformer losses, efficiency and regulation.
2. To find the parameters of the equivalent circuit of the transformer.

Viva:

1. Define transformer.
2. Why transformers are rated in KVA?
3. Name the losses that occur in a transformer?
4. In OC test why HV side should be opened?
5. In SC test why LV side should be shorted?

Experiment No.2

Sumpner's Test on 1φ Transformers

Learning Objective:

To conduct Sumpner's test on two identical transformers and obtain a graph of % Efficiency v/s Load & Regulation v/s power factor

Apparatus Required:

Sl No	Apparatus	Range	Quantity
1.	1ϕ transformer	1KVA, 230/230V	2 No.
2.	AC Ammeter	[0 - 2A]	1 No.
		[0 – 10A]	1 No.
3.	AC Voltmeter	[0 – 300V]	1 No.
		[0 – 600V]	1 No.
4.	LPF wattmeter	[1/2A, 75V]	1 No.
5.	UPF wattmeter	[5/10A, 300V]	1 No.
6.	1ϕ auto transformer	0 – 300V, 10A	1 No.
7.	Connecting wires		

Circuit Diagram:

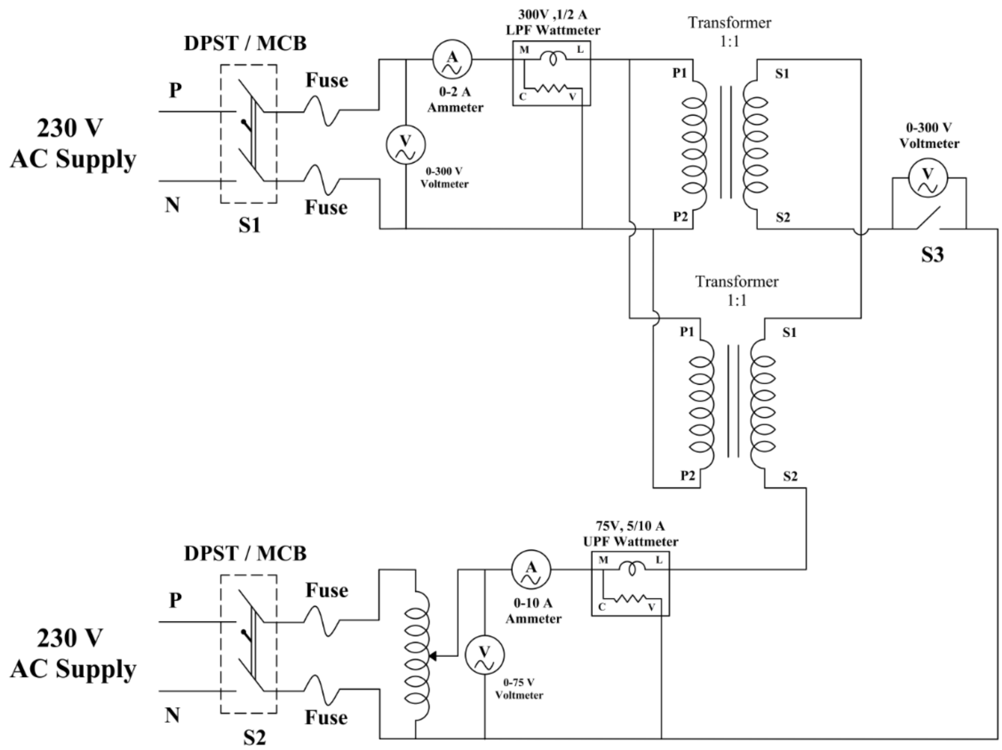


Fig: 2.1 - Circuit diagram for Sumpner's test

Procedure:

1. Make the connections as shown in the circuit diagram.
2. Supply switch S1 is closed. Keeping the single-phase autotransformer in minimum and single pole switch S3 open position, supply switch S2 is closed. Note down wattmeter reading(W1).
3. Observe the voltmeter connected across SPST. If it reads zero, then close the SPST. If it reads double the voltage of the transformer, then change any one of the secondary terminals of the transformer after opening the supply switches S1andS2.
4. Increase the autotransformer voltage such that the ammeter A2 reads the rated current of the transformer. Note down the readings of the wattmeter W2 and ammeter A2.
5. Auto-transformer voltage is reduced to zero. SPST is opened and then the supply switches S1and S2 are opened.

Note: Primary windings are in parallel & secondary windings are in series.

Sl. No.	**V_1 Volts**	**I_1 Amps**	**W_1 in watts**	**V_2 Volts**	**I_2 Amps**	**W_2 in watts**
1.						

$$\text{Wattmeter Constant} = \frac{VICos\emptyset}{Full\ Scale\ Reading}$$

Specimen Calculations:

Wi = W_1 x Constant = ________________watts

Iron losses of each transformer $\frac{W_1}{2}$ =______________watts

Wcu = W_2 x Constant = ________________

Full load copper loss of each transformer= $\frac{W_{cu}}{2}$ = ______________watts.

R_{eq} of each transformer = $\frac{1}{2}(\frac{W_{cu}}{I_2^2})$

Z_{eq} of each transformer = $\frac{1}{2}(\frac{V_{SC}}{I_{SC}})$

X_{eq} of each transformer = $\sqrt{(Z_{eq}^2 - R_{eq}^2)}$

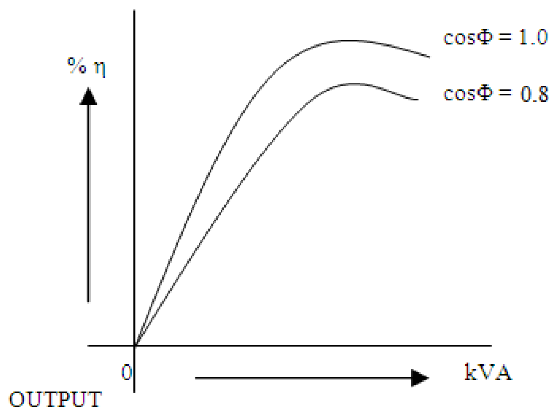
1. To determine efficiency at different load: The percentage efficiency of each of the transformers can be pre-calculated using the equation.

$$\frac{X(KVA\ Rating * 10^3)Cos\emptyset}{X(KVA\ Rating * 10^3 Cos\emptyset + W_i + X^2 W_{sc}}$$

- Where $x$is the fraction of full load KVA at which %η is to be predetermined and $cos\ \phi$ is the p.f of load.
- The $\%\eta$ is pre-determined for $x = \frac{1}{8}, \frac{1}{4}, \frac{1}{2}, \frac{3}{4}, 1$ and assumed load p.f of 1.0 as well as 0.8
- The results are tabulated as under.

Sl. No.	**Fraction of F.L (X)**	**Output in kVA**	**Copper Losses Watts (X^2W_{cu})**	**Iron Losses Watts (W_i)**	**Total Losses Watts**	$\boldsymbol{cos\ \phi = 1.0}$	$\boldsymbol{cos\ \phi = 0.8}$
						$\%\eta$	$\%\eta$
1.	1/ 4	0.25					
2.	1/ 2	0.5					
3.	3/ 4	0.75					
4.	1.0	1.0					
5.	3/2	1.25					

Graphs: The efficiency curves are drawn as shown



2. **To determine regulation for different power factor** : The percentage regulation of the transformer can be calculated using the formula.

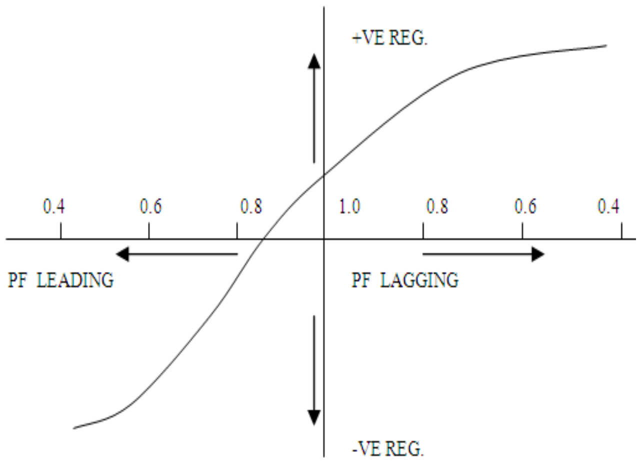
$$\%Regulation = \frac{I_{rated}R_{eq}\cos\phi \pm I_{rated}X_{eq}\sin\phi}{V_{rated}} \times 100$$

- $\cos\phi = p.f$ of the load which can be assumed as 0.4, 0.6, 0.8 and 1.
- In the above equation, +ve sign is used if the p.f is lagging and –ve sign is used if the p.f is leading.
- R_{eq} = Equivalent resistance of the transformer referred to secondary.
- X_{eq} = Equivalent reactance of the transformer referred to secondary.

The results are tabulated as shown.

Sl. No.	PF	% Regulation
1	0.4 lag	
2	0.6 lag	
3	0.8 lag	
4	UPF	
5	0.8 lead	
6	0.6 lead	
7	0.4 lead	

The graph of % regulation V/s. p.f is drawn as shown below.



Note: The above test is also known as "Heat run test" and is mainly conducted to pre-determine the efficiency of the transformer as well as the temperature rise during loaded conditions.

Result: Single phase Transformer losses simultaneously, efficiency at different loads at 0.8 and unity power factor and regulation at different power factor is obtained.

Outcome: At the end of the experiment student will be able

1. To find transformer losses, efficiency and regulation.
2. To find the temperature rise of a transformer.

Viva:

1. What are the advantages of Sumpner's test?
2. What are the disadvantages of Sumpner's test?
3. Why SPST switch has been used in the circuit diagram?
4. Why Sumpner test is called back to back test?

Experiment No.3

Parallel Operation of Two Dissimilar 1φ Transformers

Learning Objective:

To connect two single phase transformers of different ratings in parallel and to study how they share a common load.

Apparatus Required:

Sl No	Apparatus	Range	Quantity
1	1Φ transformer	2KVA, 230/230	1 No.
		1KVA, 230/230	1 No.
2	AC Ammeter	0 - 20A	1 No.
		0 – 10A	1 No.
		0 – 5A	1 No.
3	AC Voltmeter	0 – 300V	2 No.
4	UPF wattmeter	10/20A, 300V	2 No.
5	1Φ Lamp Load / Resistive Load	10A	1 No.
6	Connecting wires		

Circuit Diagram:

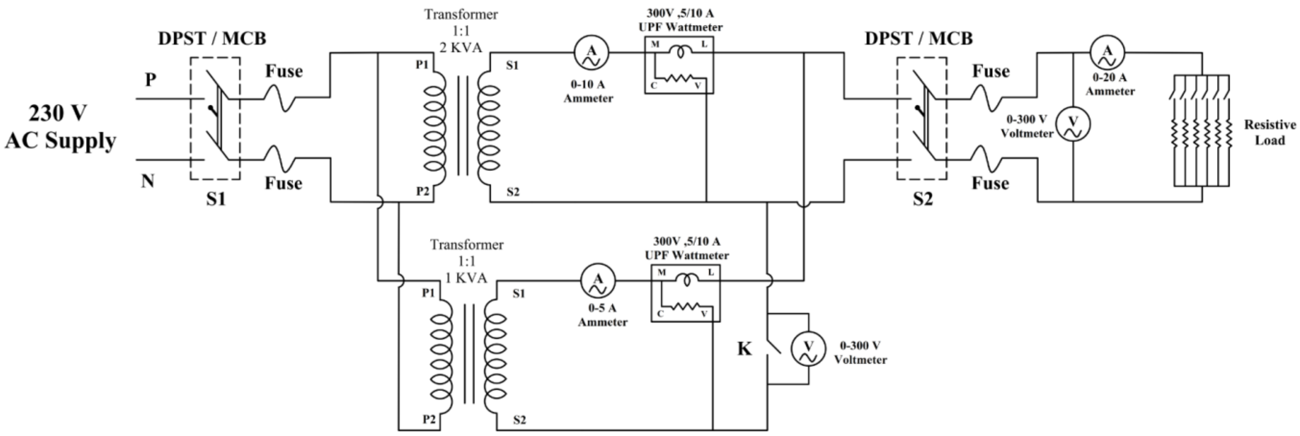


Fig.3.1: Circuit diagram for parallel operation of two transformers of different rating

Procedure:

1. Make connection as shown in circuit diagram.
2. Keeping the load switch S_2 and Switch K open, supply switch S1is closed
3. Observe the voltmeter connected across switch K. If it reads zero, then close the switch K. If it reads double the voltage of the transformer, then change any one of the secondary terminals of the transformer after opening he supply switch S_1.

4. Close the load switch S_2.

5. Apply load till the rated current of each transformer.

6. Load switches are opened one by one, load switch S2 is opened then the supply switch S1 is opened.

Tabular Column:

Sl. No.	I_1 Amps	I_2 Amps	W_1 Watts	W_2 Watts	I_L Amps	V_L Volts	$S_L = (V_L \times I_L)$	$I_A^!$	$I_B^!$	$S_A^!$	$S_B^!$	$S_L^!$

Short Circuit Tests:

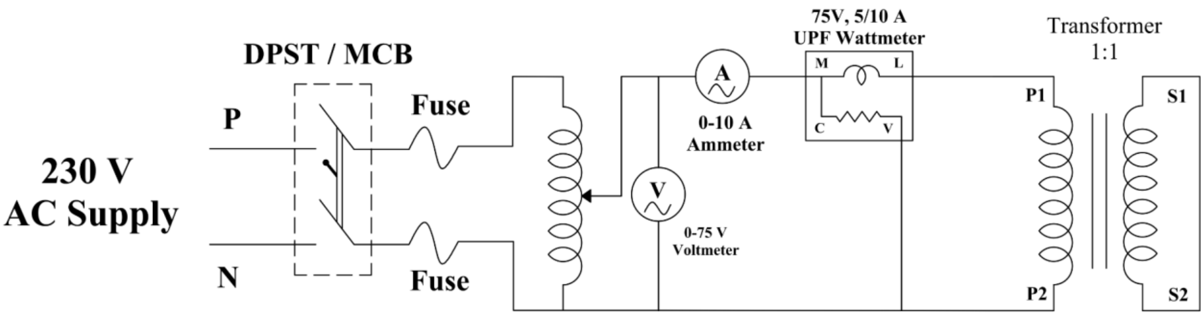


Fig.3.2: Circuit diagram for SC test on Transformer

Short circuit test is conducted on each of the two transformers separately with the meters connected on the secondary and the readings are tabulated as under.

Transformer 'A' (2 KVA)

I_{SC} Amps	V_{SC} Volts	W_{SC} Watts

Transformer 'B' (1 KVA)

I_{SC} Amps	V_{SC} Volts	W_{SC} Watts

Calculations:

Transformer 'A' (2KVA):

From the S.C. test readings, the following can be calculated.

Z_A =equivalent impedance of transformer 'A' referred to its secondary $= \frac{V_{SC}}{I_{SC}}$ ohms

R_A =equivalent resistance of transformer 'A' referred to its secondary $= \frac{W_{SC}}{I_{SC}^2}$ ohms

X_A =equivalent reactance of transformer 'A' referred to its secondary $= \sqrt{Z_A^2 - R_A^2}$ ohms

Z_B =equivalent impedance of transformer 'B' referred to its secondary $= \frac{V_{SC}}{I_{SC}}$ ohms

R_B =equivalent resistance of transformer 'B' referred to its secondary $= \frac{W_{SC}}{I_{SC}^2}$ ohms

$\therefore X_B$ =equivalent reactance of transformer 'B' referred to its secondary $= \sqrt{Z_B^2 - R_B^2}$ ohms

$\therefore Z_A = (R_A + JX_A) Ohms = Z_A \angle \phi_A.$

$\therefore Z_B = (R_B + JX_B) Ohms = Z_B \angle \phi_B.$

The current $I_A^!$ shared by transformer 'A' when the total load current is I_L is given by

$$I_A^! = I_L \angle - \phi_L \times \frac{Z_B \angle \phi_B}{Z_A \angle \phi_A + Z_B \angle \phi_B} = I_A^! \angle - \phi_A$$

Where $Z_B \angle \phi_B$ is the equivalent impedance of the transformer 'B' referred to its secondary which can be calculated using a similar procedure explained above. ϕ_L is the p.f angle of the load which can be calculated using the equation

$$cos\, \phi_L = \frac{W_L}{V_L I_L}$$

The Volt-amps shared by transformer 'A' is given by

$$S_A^! = S_L \angle - \phi_L \times \frac{Z_B \angle \phi_B}{Z_A \angle \phi_A + Z_B \angle \phi_B} = S_A^! \angle - \phi_A^! \; Volt - Amps$$

Where S_L is the total load Volt-amps given by $V_L I_L$

The power supplied transformer 'A' is then given by

$$W_A^! = S_A^! \cos\phi_A^! \, Watts.$$

Transformer 'B' (1 KVA) :

In a similar way, the current $I^!_B$ and the power $W^!_B$ shared by the transformer 'B' are calculated using the equations.

$$I_B^! = I_L\angle-\phi_L \times \frac{Z_A\angle\phi_A}{Z_B\angle\phi_B + Z_A\angle\phi_A} = I_B^!\angle-\phi_B$$

$$S_B^! = S_L\angle-\phi_L \times \frac{Z_A\angle\phi_A}{Z_B\angle\phi_B + Z_A\angle\phi_A} = S_B^!\angle-\phi_B^! \; Volt-Amps$$

$$W_B^! = S_B^! \cos\phi_B^! \; Watts.$$

The calculated values of $I_A^!, W_A^!$ & $I_B^!, W_B^!$ are compared with the actual values I_A, W_A & I_B, W_B respectively as shown in the tabular column.

Result: Load current and power shared by transformers A and B are obtained for different load conditions.

Outcome: Students have obtained:

1. The load current shared by transformer A & transformer B for different load condition.
2. The power shared by transformer A & transformer B for different load conditions.

Viva:

1. What are the conditions for the transformers connected in parallel?
2. Out of two transformer rated 2KVA & 1KVA which will take the load first?
3. What are the advantages of connecting two transformers in parallel?
4. What are the disadvantages of connecting two transformers in parallel?

Experiment No.4

Polarity Tests & Connection of 3 Single-Phase Transformers in Star –Delta and Determination of Efficiency and Regulation under Balanced Resistive Load.

Learning Objective:

A) To conduct AC polarity test on the given 230V/230V single phase transformer to mark the relative polarities.

B) To conduct load test on three 1∅ transformers connected in Star-Delta to determine efficiency and regulations.

Apparatus Required:

Sl No	Apparatus	Range	Quantity
1.	3ϕ auto transformer	0 – 470V	1 No.
2.	1ϕ transformer	1KVA, 230/230V	3 Nos.
3.	AC Ammeter	0 – 5A	2 Nos.
4.	AC Voltmeter	0 – 600V	2 Nos.
5.	UPF wattmeter	10/20A, 600V	4 Nos.
6.	1ϕ Resistive Load	0 – 10A	1 No.
7.	Connecting wires		

Circuit Diagram:

Part A: Polarity test:

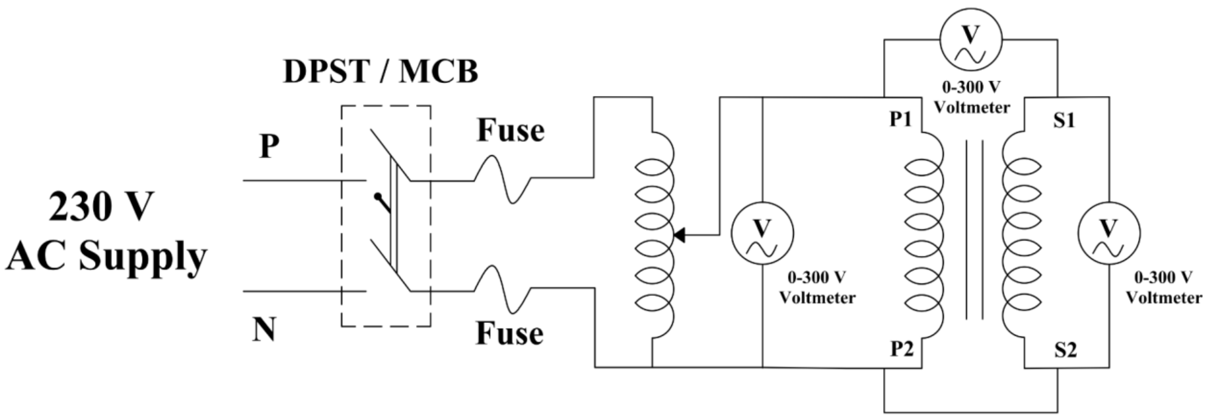


Fig 4.1: Subtractive Polarity

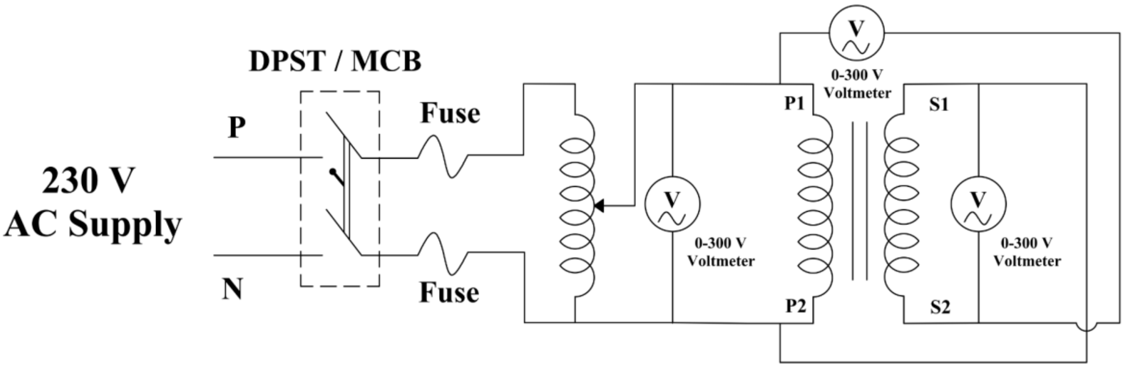


Fig 4.2: Additive Polarity

Tabular Column:

A.C Polarity Test:

1. Subtractive Polarity

Sl. No.	V_1 Volts	V_2 Volts	V Volts	(V_1-V_2) Volts)

2. Additive Polarity

Sl. No.	V_1 Volts	V_2 Volts	V Volts	(V_1+V_2) Volts)

Procedure:

1. Make the connections as shown in the circuit diagram, circuit diagram(a).
2. With autotransformer in minimum position, supply switch S1 is closed.
3. Apply the rated primary voltage by varying the auto-transformer.
4. Note down the voltmeter readings. If the polarities of transformer is same, then the resultant voltage (V-between primary and secondary)should be the difference of the two voltmeters V_1 and V_2 i.e.,$V = V_1 \sim V_2$
5. If the polarities of transformer are different, then the resultant voltage(V-between primary and secondary)should be the sum of the two voltmeters V_1 and V_2 i.e.,$V = V_1 + V_2$

Part B: Three 1ϕ transformers connected in Star-Delta

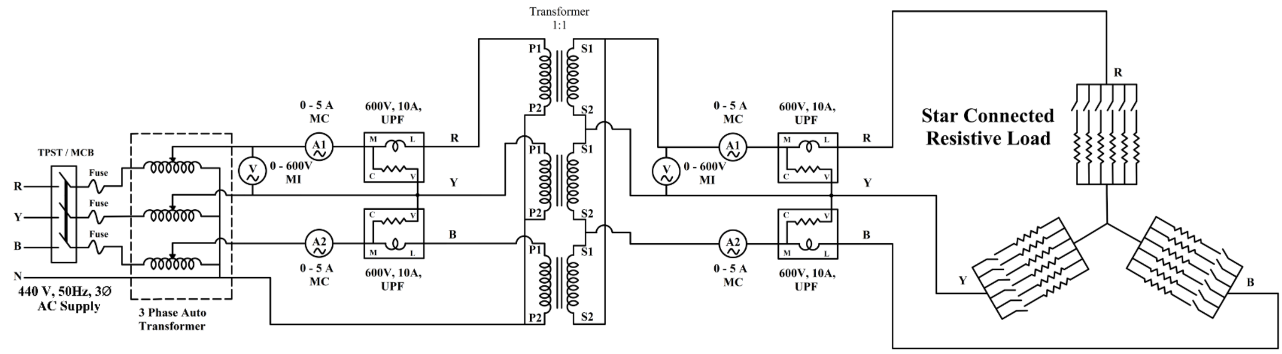


Fig 4.3: Three single-phase transformers connected in star-delta and load is star-connected

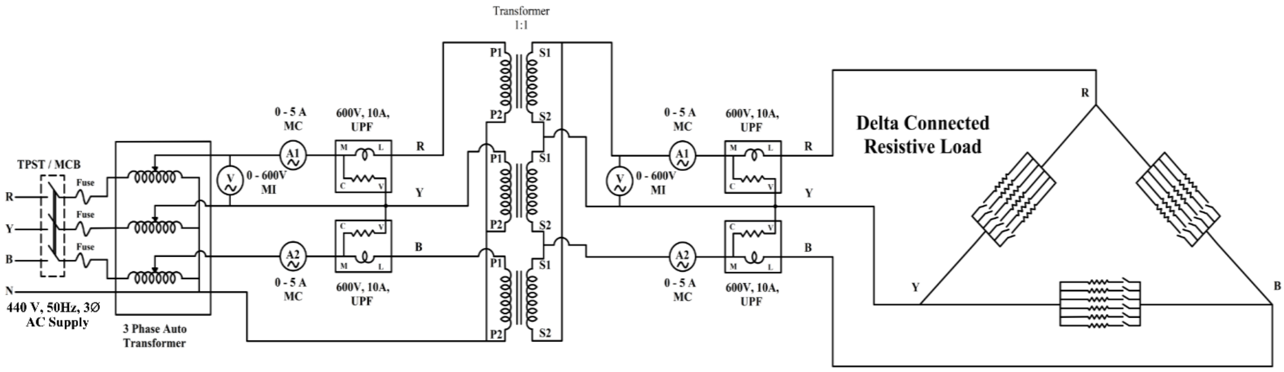


Fig 4.4: Three single phase transformers connected in star-delta and load is delta connected

Procedure:

1. The connections are made as shown in the circuit diagram. Care should be taken to see that the star points on the primary side are obtained by connecting all similar terminals.
2. With the 3Ø auto-transformer at minimum position, the supply switch is closed. Using the 3Ø auto-transformer apply the rated voltage. (Say phase to phase as 415V& phase to neutral as 220V)
3. Now the transformer is loaded using a 3Ø resistive load. The load is increased in steps of about 2A. At each step the readings of all the meters are noted and tabulated as shown. The load on the transformer is increased till the full load current.
4. The load is removed step by step, load switch is opened, the 3Ø auto-transformer voltage is reduced to zero and supply switch is opened.

Note: When the transformer is loaded, the primary voltage VP (applied voltage) will decrease slightly due to Auto-transformer. Using the auto transformer, the primary voltage is brought back to 415V at each step of loading and then the readings of all the meters are noted.

Sl. No.	V_1 Volts	I_1 Amps	W_1 Watts	W_2 Watts	V_2 Volts	I_3 Amps	W_3 Watts	W_4 Watts	%η	% Reg

Note: As the 3∅ balanced load is resistive, PF=1 and hence W_1 and W_2 always indicate equal readings

Calculations:

The $\%\eta$ under different loaded conditions can be calculated using the equation,

$$\%\eta = \frac{(W_3 + W_4)}{(W_1 + W_2)} \times 100$$

The % regulation at different load currents, can be calculated using the equation,

$$\%Regulation = \frac{V_S(no\ load) - V_S(load)}{V_S(no\ load)} \times 100$$

Where V_S (no load) is the secondary voltage V_S when I_S=0 and V_S (load) is the secondary voltage V_S noted for different values of I_S.

Graph:

A graph of %η v/s output in KW is drawn as shown

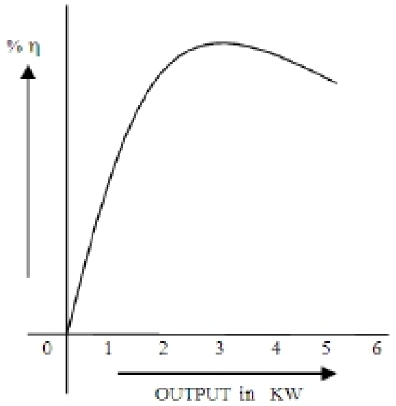


Fig 4.5: Typical graph

Result: Efficiency and regulation of a 3-phase transformer connected in star-delta has been obtained for star and delta load.

Outcome: Student will be able:

1. To analyse star-delta voltage and current relation for star and delta connected load.
2. To obtain the efficiency and regulation of a 3-phase transformer connected in star-delta has been obtained.

Viva:

1. Give the phase voltage and line voltage relation for star connected system.
2. Give the phase voltage and line voltage relation for delta connected system.
3. Define regulation
4. What should be the supply voltage for the delta-delta connected system? Why?
5. What should be the supply voltage for the star-delta connected system? Why?

Experiment No.5

Comparison of performance of 3 single-phase transformers in delta-delta and V-V (open-delta) connection under load.

Learning Objective:

A) To conduct load test on three 1∅ transformers connected in Delta-Delta to determine efficiency and regulations.

B) To conduct load test on three 1∅ transformers connected in V-V (open – delta) to determine efficiency and regulations.

Apparatus Required:

Sl No	Apparatus	Range	Quantity
1.	3ϕ auto transformer	0 – 470V	1 No.
2.	1ϕ transformer	1KVA, 230/230V	3 Nos.
3.	AC Ammeter	0 – 5A	2 Nos.
4.	AC Voltmeter	0 – 600V	2 Nos.
5.	UPF wattmeter	10/20A, 600V	4 Nos.
6.	1ϕ Resistive Load	0 – 10A	1 No.
7.	Connecting wires		

Three 1∅ transformers connected in V-V (open delta)

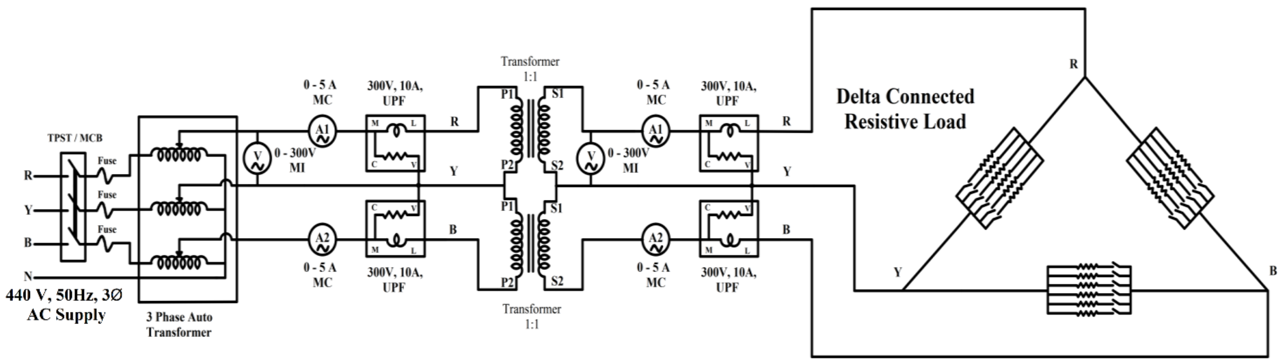


Fig 5.3: Three single phase transformers connected in V – V and load is delta connected

Procedure:

1. The connections are made as shown in the circuit diagram.
2. With the 3 Ø auto-transformer at minimum position, the supply switch is closed. Using the 3Ø auto-transformer apply the rated voltage. (say phase to phase as 220V& phase to neutral as 127V).
3. Now the transformer is loaded using a 3Ø resistive load. The load is increased in steps of about 2A. At each step the readings of all the meters are noted and tabulated as shown. The load on the transformer is increased till the full load current.
4. The load is removed step by step, load switch is opened, the 3Ø auto-transformer voltage is reduced to zero and supply switch is opened.

Tabular Column:

Sl. No.	V_1 Volts	I_1 Amps	W_1 Watts	W_2 Watts	V_2 Volts	I_3 Amps	W_3 Watts	W_4 Watts	%η	% Reg

Calculations:

The %η under different loaded conditions can be calculated using the equation,

$$\%\eta = \frac{(W_3 + W_4)}{(W_1 + W_2)} \times 100$$

The % regulation at different load currents, can be calculated using the equation

$$\% \text{ Regulation} = \frac{V_S(No\ Load) - V_S(Load)}{V_S(No\ Load)} \times 100$$

Where V_S (no load) is the secondary voltage V_s when I_S=0 and V_S (load) is the secondary voltage V_S noted for different values of I_S.

A graph of %η v/s output in KW is drawn as shown.

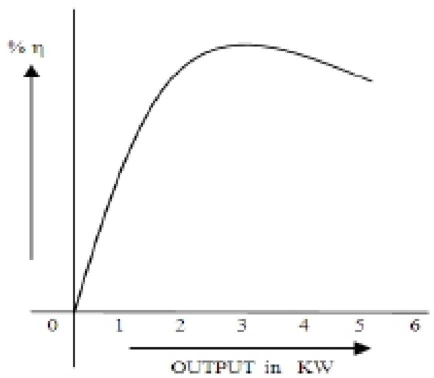


Fig 5.4: Graph of %η v/s output in KW

Result:

Efficiency and regulation of a 3-phase transformer connected in star-delta has been obtained for star and delta load.

Outcome:

At the end of the experiment student will be able to find the efficiency and regulation of three 1Øtransformers connected in Delta-Delta & V-V for a delta and star connected load.

Viva:

1. What are the advantages of delta-delta connected system? Where it is used in real time application?
2. What are the advantages of V-V (open –delta) connected system? Where it is used in real time application?
3. Why polarity test has to be done?

Experiment No.6

Separation Of Hysteresis and Eddy Current Losses in Single Phase Transformer

Learning Objective:

To separate the iron losses occurring in a transformer into its component.

Apparatus Required:

Circuit Ref.	Description	Rating	Quantity
A_2	Moving iron Ammeter (AC)	0-5A,0-2A	2
V_1,	Moving iron Voltmeter (AC)	0-600V	1
R_{fm}	Rheostat	1.5KΩ,1A	1
	1phase transformer	290Ω,1.5A	1
	LPF wattmeter	1/2A,300V	1

Name Plate Details of the Machines:

Machine	Machine Type	Machine Rating HP / KW	Voltage Rating Volts	Current Rating Amps	Speed Rating rpm
DC Motor					
Alternator					

Circuit Diagram:

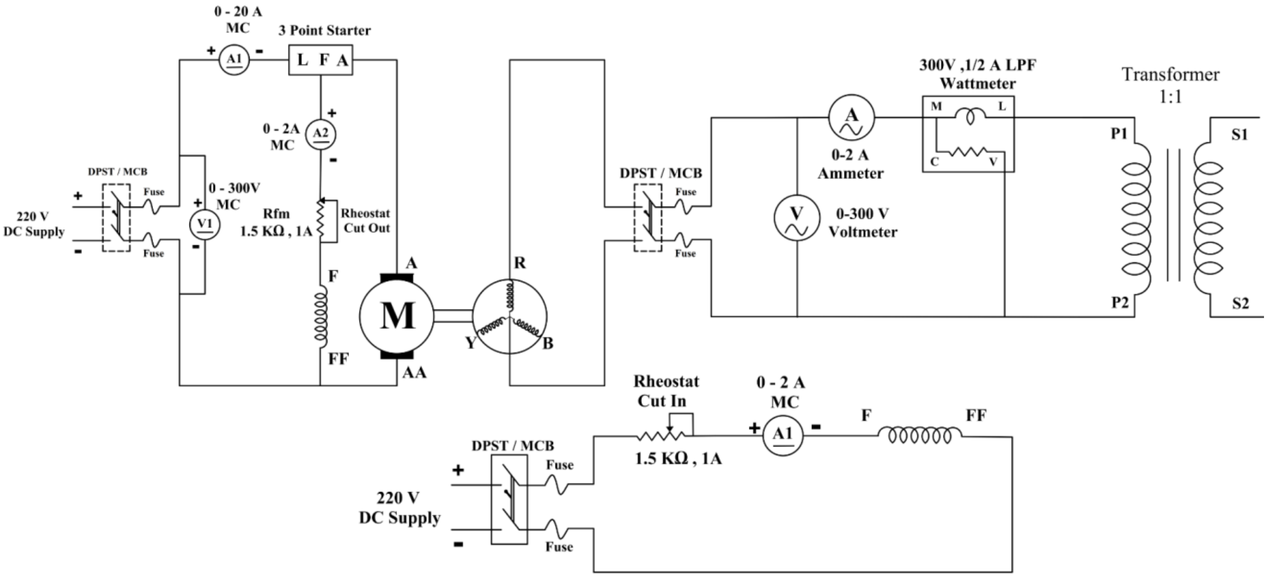


Fig.6.1: Circuit diagram to find hysteresis and eddy current loss

Note:

1. The ratings of DC Motor-Alternator set and Transformer are noted.
2. The EMF/Frequency of the Transformer is maintained constant during the experiment.
3. The rated Voltage 'V' of the Transformer is taken instead of EMF: 220V.
4. The rated Frequency 'f' of the Transformer: 50Hz.
5. V/f ratio is calculated: 4.44
6. The Alternator has poles 'P'=4
7. The frequency of EMF developed by the Alternator is rated to speed 'N' in rpm as f =PN/120

Procedure:

1. Connections are made as per the circuit diagram.
2. Main Supply switch 'S1' is closed and the DC Motor is brought to its rated speed of 1500rpm.
3. Alternator Field switch 'S2' is closed to excite the Alternator to the rated voltage of the Transformer (220V).
4. Transformer switch 'S3' is closed to supply 220V at 50Hz to the Transformer. As V/f ratio is 4.44 the Iron losses read by the wattmeter is recorded.
5. Reduce the speed of the DC Motor-Alternator set to 1300rpm (say). Calculate f = PN/120 for this speed.
6. Adjust the Alternator Field current to get the voltage built up to V = 4.44*f and record the wattmeter reading.
7. Repeat steps 5 & 6 for different speeds: 1100rpm and 900rpm (say).
8. To turn off the experimental set up:

• Switch off 'S3'

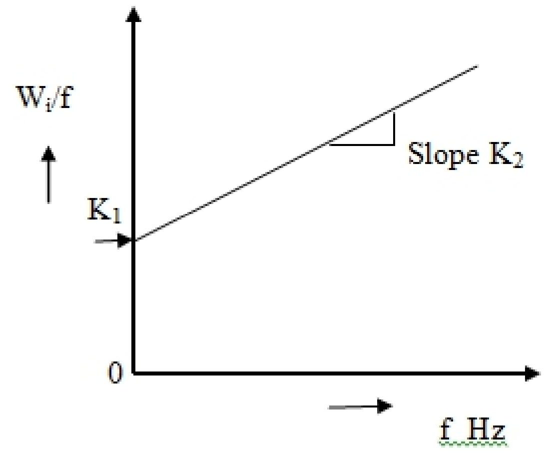
• Bring Alternator field rheostat to fully cut in position and switch off 'S2'

• Bring DC Motor armature and field rheostats to their respective position and switch off 'S1'

Tabulations:

Sl.No.	Speed 'N' rpm	Frequency f = PN/120 Hz	V = 4.44*f Volts	Iron Losses Wi Watts	Wi /f Loss/Cycle	Hysteresis Loss in Watts Wh=K1*f	Eddy Current Loss Watts $W_e=K_2*f^2$
1							
2							
3							
4							

Typical Graph:



Result:

Iron losses, Hysteresis and eddy current losses are obtained by varying the alternator speed thereby varying the frequency.

Outcome:

1. Student have gained the knowledge by using motor generator set required variable frequency has obtained by keeping V/f constant.
2. Students will obtain Iron losses, Hysteresis loss and eddy current loss of a 1Φ transformer.

Viva:

1. On what factors hysteresis and eddy current losses are dependent?
2. Why iron losses are constant losses?
3. Why V/f has to be maintained constant?
4. How the frequency will be varied in an alternator?

Experiment No.7

To investigate the voltage and current ratios of a multi-tapped transformer and verify the ideal transformer ratio.

Learning Objective:

To investigate the voltage and current ratios of a multi-tapped transformer and verify the ideal transformer

Apparatus Required:

Sl No	Apparatus	Range	Quantity
1	1Φ transformer	1KVA, 230/230V	1 Nos.
2	AC Ammeter	0 – 5A	2 Nos.
3	AC Voltmeter	0 – 600V	2 Nos.
4	1Φ Resistive Load	0 – 10A	1 No.
5	Rheostat	18 Ohms, 2A	1 Nos
6	Connecting wires	--	--

Circuit Diagram:

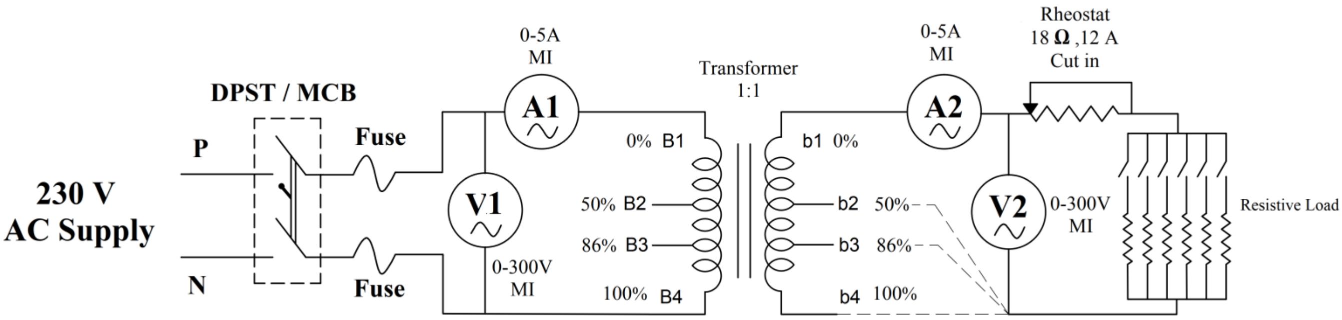


Fig: 7.1 Circuit diagram to investigate Voltage and Current Ratio

Tabular column:

Procedure:

Sl No.	Primary winding Tapping	V_1	I_1	Secondary winding Tapping's	V_2	I_2	V_1/V_2	I_2/I_1
1	B1-B4			b1-b2				
2				b1-b3				
3				b1-b4				

1. Connections are made as per the circuit diagram shown in Fig 7.1.
2. The power supply of 230V is given to the primary of the transformer (B1 and B4).
3. Apply the rated current of the transformer for different tapping's (b1-b2, b1-b3 and b1-b4).
4. Note down the corresponding voltage and current readings and calculate the voltage and current ratio.
5. Verify the Voltage and Current ratio of the transformer.

Verification of Ideal transformer:

$$\frac{V_2}{V_1} = \frac{I_1}{I_2}$$

Outcome:

At the end of the experiment, the student will be able to verify the ideal transformer from the experimental results.

Experiment No.8

Regulation of an Alternator by EMF and MMF Method

Learning Objective:

To determine the voltage regulation by EMF and MMF method by conducting open circuit and short circuit test on a given alternator.

Name Plate Details of the Machines:

Machine	Machine Type	Machine Rating HP / KW	Voltage Rating Volts	Current Rating Amps	Speed Rating rpm
DC Motor					
AC Generator					

Apparatus Required:

Circuit Reference	Description	Rating	Quantity
A1	Moving coil ammeter	0-2A	1
A2	Moving iron ammeter	0-10A	1
V1	Moving iron Voltmeter	0-500V	1
Rfm	Rheostat	1.5KΩ,1A	1
R1	Rheostat	290Ω,1.8A	1
S1	TPST	32A/220V DC	1

Procedure for EMF and MMF method:

Open circuit test:

1. Connections are made as shown in the Circuit Diagram.
2. Field rheostat of DC motor is kept in cut-out position and the field rheostat of alternator is kept in cut-in position.
3. Supply is given to the DC motor by closing the switch S1 and the DC motor is started.
4. Bring the motor speed to that of the rated speed of synchronous machine by cutting in motor field rheostat.
5. Close the DPST switch to excite the field of the alternator.
6. Rheostat of the alternator field is cut-out gradually in steps and the corresponding field current (If) and open circuit voltage of the alternator are tabulated, till the rated voltage of the synchronous machine is reached.
7. The field rheostat of the alternator is brought back to its original position. (Cut-in position).

Circuit Diagram:

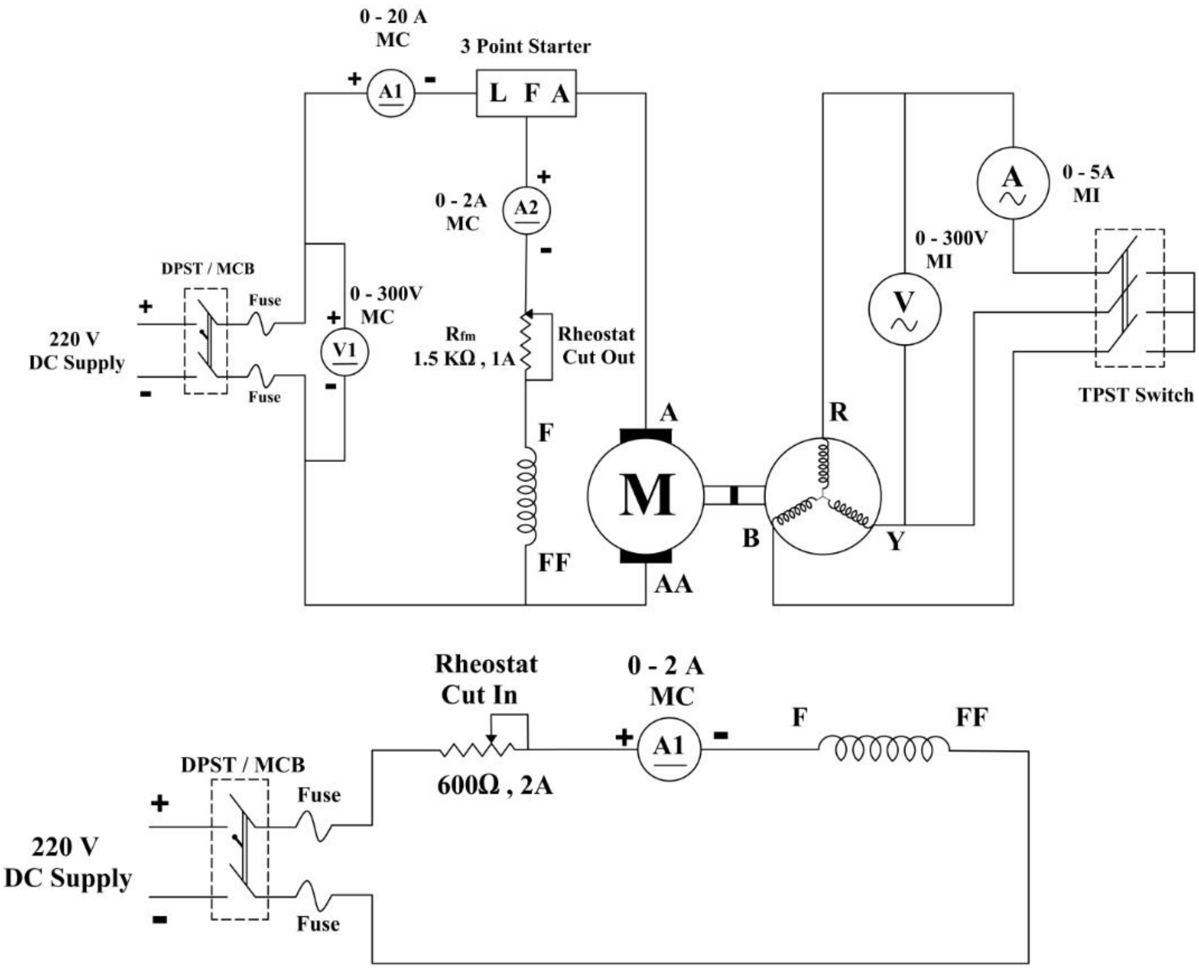


Fig: 8.1 – Circuit diagram for an OC test & SC test of an Alternator

Short circuit test:

1. The TPST switch is closed, so that the stator terminals are short circuited.
2. Field rheostat of alternator is cut-out gradually in steps till rated armature current is obtained then armature current (Ia) and corresponding field current are noted down.

3.Field rheostat of alternator is brought back to cut-in position and DPST switch is open.

4. Armature rheostat & Field rheostat of the motor is brought back to their original position.
5. Supply is switched off.
6. The DC resistance (Rdc) per phase of the stator winding are measured by VA method.

Tabulations:

Open circuit test

Sl. No.	V_{ph} in volts	I_f in amps

Short circuit test

Sl. No.	I_f in amps	I_{sc} in amps

Typical Graph

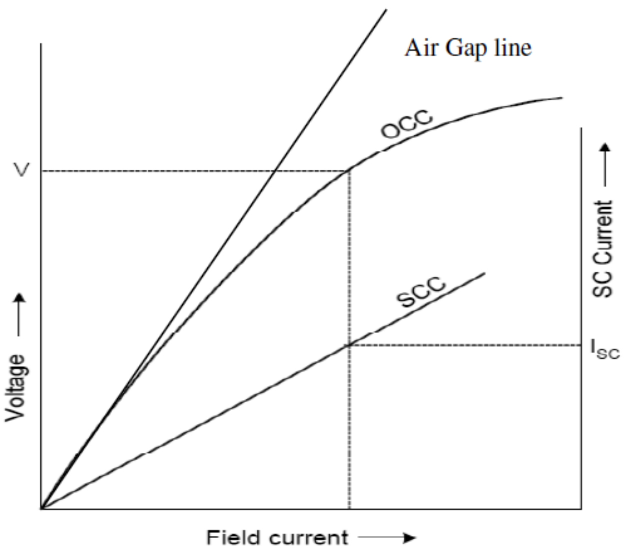


Fig: 8.2 – Graph of phase voltage v/s field current

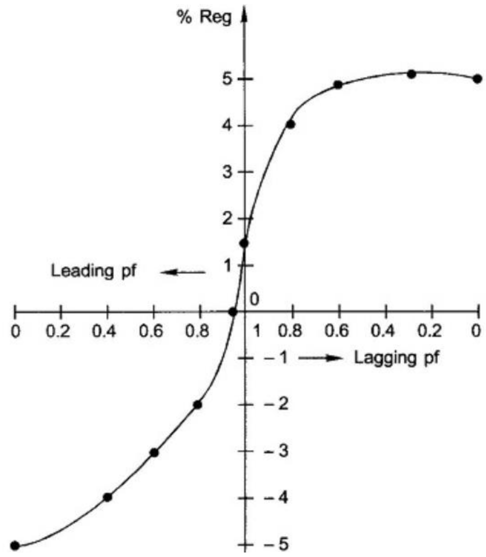


Fig: 8.3 –Graph of Power factor v/s Regulation

Calculations:

EMF method or synchronous impedance method:

$\mathbf{Z_s} = \frac{Voc}{Isc} =$ _______ Ω

$R_a =$ ________Ω

$X_s = \sqrt{Zs^2 - Ra^2}$ = _________Ω

$E_o = \sqrt{(Vcos\Phi + I_aR_a)^2 + (Vsin\Phi \pm IX_s)^2} =$ ________ Volts

(Note: + ⟶ for lagging PF, - ⟶ for leading PF)

Percentage regulation = $\frac{Eo-Vph}{Vph}$ X 100 = ________%

MMF or ampere turn method

1. I_{f1}→ Field current corresponding to the voltage E1 from the graph of OCC

   E_1 =V + IaRa cosΦ

   I_{f1} =__________ Amps

2. I_{f2}→ Field current required to circulate the rated armature current during short circuit

   (From graph corresponding to Isc)

   I_{f2} = __________ Amps

3. I_{ft} = $\sqrt{I_{f1}{}^2 - 2I_{f1}I_{f2}cos(90 \pm \emptyset) + I_{f2}{}^2}$ + ⟶ for lagging pf.

   $\emptyset = cos^{-1}(0.2,0.4,0.6,0.8,1.0)$ − ⟶ For leading pf.

4. % Regulation = $\frac{E-V_{ph}}{V_{ph}} * 100$_____%

⟶ For each voltage E_1, I_{f1} is noted from the graph

⟶ For each I_{fT} , E is noted from the graph.

Tabulations for regulation:

CosΦ	% Reg (lag)	% Reg (lead)
0.2		
0.4		
0.6		
0.8		
1.0		

Result:

Regulation of an alternator is obtained by EMF and MMF methods using the OC & SC test values. Plotted the regulation v/s power factor.

Outcomes:

Students are expected to:

1. Perform OC & SC test on a given alternator.
2. Estimate the synchronous impedance of the alternator.
3. Understand to estimate voltage regulation by MMF method
4. Understand to estimate voltage regulation by EMF method

Experiment No.9

Power angle curve of synchronous generator

Learning Objective:

To draw the graph of power angle v/s 3phase power of a generator (non-salient pole).

Apparatus Required:

Circuit Reference	Description	Rating	Quantity
A2	Moving iron Ammeter (AC)	2-5A,0-2A	1
V1,	Moving iron Voltmeter (AC)	0-600V	1
Rfm	Rheostat	1.5KΩ,1A	1
	Rheostat	290Ω,1.5A	1
	UPF wattmeter	10/20A,600V	2
	Resistive load	0-10A	1
	Inductive load	32A/220V DC	1

Name Plate Details of the Machines:

Machine	Machine Type	Machine Rating HP / KW	Voltage Rating Volts	Current Rating Amps	Speed Rating rpm
DC Motor					
AC Generator					

Procedure:

1. Connections are made as shown in the circuit diagram.
2. Close the supply switch and adjust the rated speed by varying the rheostat.
3. Apply the load one by one maintain the rated speed constant.
4. Apply the load up to the rated current 4.5Amps. Now note down the value of voltmeter, ammeter and wattmeter.
5. Decrease the speed and open the switch.

Circuit Diagram:

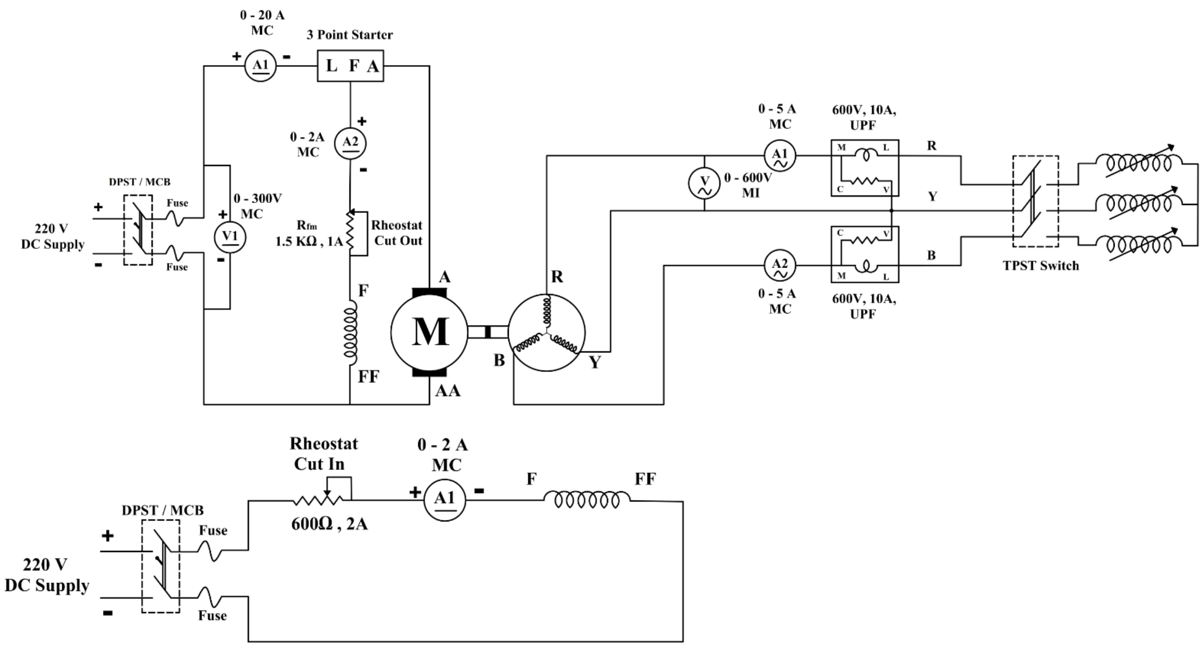


Fig.9.1: Circuit diagram

Tabular Column

W_1*K Watts	W_2*K Watts	P=W_1+W_2	V_{min} Volts	V_{max} Volts	I_L Amps	V_p Volts	E (lag) Volts

Calculation

R_A=__________ Ω

$X_S = \sqrt{Z_S - R_A}$ =_________

$Z = \frac{V_{oc}}{I_{sc}}$ = __________

$V_{ph} = \frac{V_L}{\sqrt{3}}$ = __________

$E_{(ang\partial)}$ = V_{ph}(ang 0) + P(ang (-0)) * (R_a+jX_S)

Result: Load angle δ is obtained and is plotted with respect to power.

Outcome:

Student will gain the knowledge about the load angle δ and its performance in an alternator at different loading condition.

Viva:

1. What is load angle?
2. Comment on the stability of a non-salient alternator based on power angle curve.
3. What do you mean by stability in power system?
4. What is swing curve?

Experiment No.10

Performance of Synchronous Generator Connected to an Infinite bus, Under Constant Power and Variable Excitation

Learning Objective:

Synchronize the alternator to an infinite bus bar.

Name Plate Details of the Machines:

Machine	Machine Type	Machine Rating HP / KW	Voltage Rating Volts	Current Rating Amps	Speed Rating rpm
DC Motor					
AC Generator					

Apparatus Required:

Circuit Reference	Description	Rating	Quantity
A1	Moving coil ammeter	0-2.5A	1
A2	Moving iron ammeter	0-10A	1
V1	Moving coil Voltmeter	0-500V	1
W_1,W_2	Watt meters	10A-600V	2
R_{fm} , R_1	Rheostat	360Ω,1.8A	2
R_{am}	Rheostat	38Ω,8.5A	1
SP	Synchronizing panel		1

Circuit Diagram:

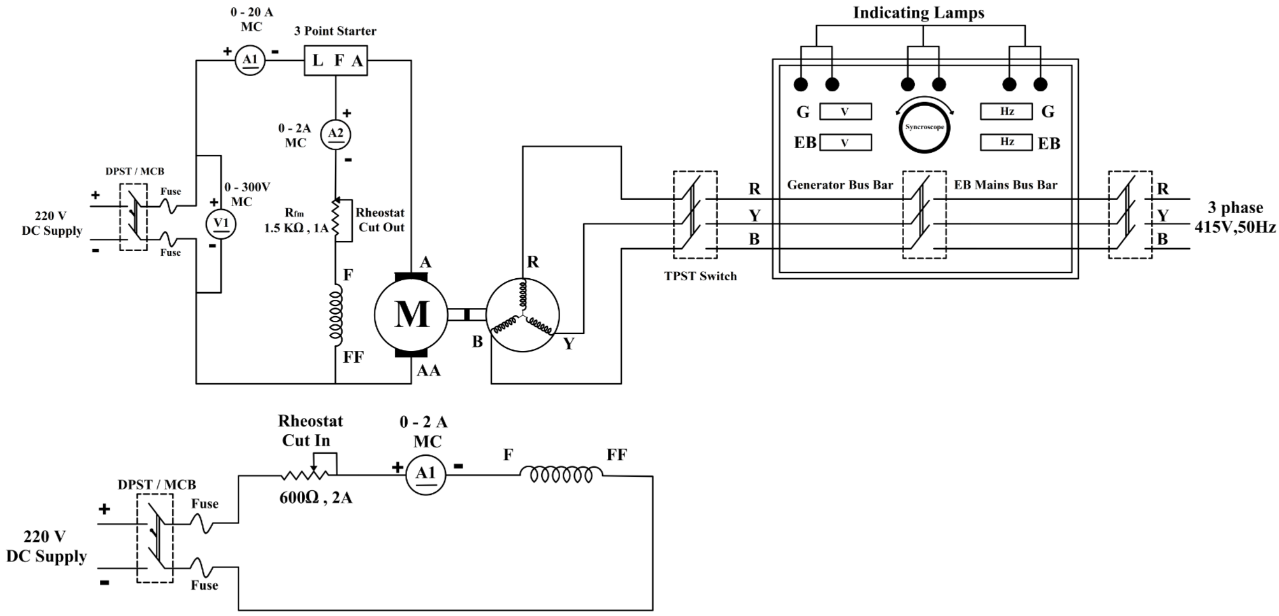


Fig: 10.1 - Circuit Diagram for Synchronization of an alternator with infinite bus

Procedure:

1. Connections are made as per the Circuit Diagram.
2. Keeping motor field rheostat in cutout, motor armature rheostat in cutin and alternator field rheostat in cutin S1,S2,S3 and S4 open ,the supply switch S1 is closed.
3. The DC motor is started by gradually cutting out 38Ω rheostat and brought to the rated speed by gradually cutting in the 360Ω rheostat.
4. Close supply switch S2 and build up the voltage of the alternator to rated line voltage.
5. Close switch S3. Apply 3 phase supply to one side of the synchronizing panel by closing switch S4. If all the lamps glow/flicker simultaneously, then the phase sequence is okay. However if the lamps glow/flicker in a sequence, then the supply phase sequence needs to be changed by interchanging any 2 wires. (Warning: S3 and S4 should be open when you attempt this)
6. Now make the lamps dark by adjusting the field rheostats of the DC motor and alternator. Then close the synchronizing switch.
7. The alternator has been successfully synchronized with infinite bus.

Result: Synchronization of an alternator with infinite bus bar is achieved.

Outcomes:

Students are expected to:

1. Understand the conditions for synchronization.
2. Understand to use dark lamp method or synchronoscope to synchronize the alternator with bus bar.
3. Export active power for slight increase in frequency of the alternator.
4. Export reactive power for slight increase in excitation of the alternator.

Viva Questions:

1. What are the conditions required to synchronize an alternator with. KEB supply?
2. How can you increase the share of an alternator when it is connected to an infinite bus?
3. At what condition the power output of a synchronous generator connected to an infinite bus?
4. How can we run a synchronous motor as synchronous condenser?
5. What is the role of damper windings?

Experiment No.11

Simulate Power Angle cure of Generator using MATLAB

Learning Objective:

Determination of power angle curve for salient and non-saline pole synchronous machine.

Problem statement:

A 34.64 kV 60MVA synchronous generator has a direct axis reactance of 13.5 ohms and a quadrature axis reactance of 9.33 ohm is operating at 0.8 pf. Determine the excitation emf, regulation, non-salient power, reluctance power, salient power and plot the power angle curves for the non-salient pole and salient pole synchronous machine.

Procedure:

1. Double-click on the MATLAB icon on the desktop.
2. Type edit, and press enter to get the Editor window.
3. Type the program.
4. Save and run the program.
5. Enter the inputs in the command window and see the output response.
6. Note down the simulated results.

Program:

```
%Power Angle Curve
clear;
clc;
p=input('power in mw=');
pf=input('power factor=');
vt=input('line to line voltage in kv=');
xd=input('xd in ohms=');
xq=input('xq in ohms=');
vt_ph=vt*1000/sqrt(3);
pf_a=acos(pf);
q=p*tan(pf_a);
i=(p-j*q)*1000000/(3*vt_ph);
delta=0:1:180;
```

```
delta_rad=delta*(pi/180);
if xd==xq
 % Non-Salient Pole Synchronous Motor
 ef=vt_ph+(j*i*xd);
 excitation_emf=abs(ef)
 reg=(abs(ef)-abs(vt_ph))*100/abs(vt_ph)
 power_non=abs(ef)*vt_ph*sin(delta_rad)/xd;
 net_power=3*power_non/1000000;
 plot(delta,net_power);
 xlabel('delta(deg)-->');
 ylabel('three phase power(mw)->');
 title('Plot:Power Angle Curve for Non Salient Pole Synchronous m/c');
 legend('Non Salient Power')
end
if xd~=xq
 %salient pole synchronous motor
 eq=vt_ph+(j*i*xq);
 id_mag=abs(i)*sin(angle(eq)-angle(i));
 ef_mag=abs(eq)+((xd-xq)*id_mag)
 excitation_emf=ef_mag
 reg=(ef_mag-abs(vt_ph))*100/abs(vt_ph)
 pp=ef_mag*vt_ph*sin(delta_rad)/xd;
 reluct_power=vt_ph^2*(xd-xq)*sin(2*delta_rad)/(2*xd*xq);
 net_reluct_power=3*reluct_power/1000000;
 power_sal=pp+reluct_power;
 net_power_sal=3*power_sal/1000000;
 plot(delta,net_reluct_power,'k');
 hold on
 plot(delta,net_power_sal,'r');
 xlabel('delta(deg)-->');
 ylabel('three phase power(pu)-->');
 title('Plot: Power Angle Curve for Salient Pole Synchronous m/c');
 legend('Reluctance Power','Salient Power')
end
grid;
```

Inputs in the command window

For Non-Salient Pole Synchronous Machine

Inputs:

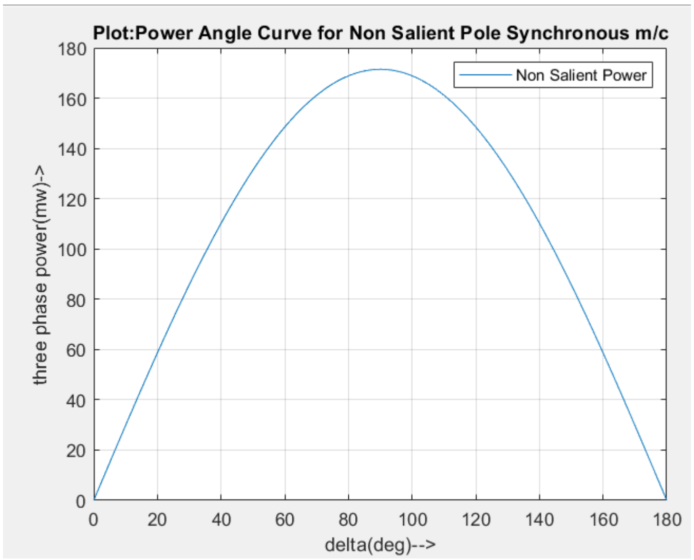
Power in mw=48

Power factor=0.8

Line to line voltage in kv=34.64

Xd in ohms=9.33

Xq in ohms=9.33



Output response

Excitation_emf = 2.6664e+004

Reg = 33.3222

For Salient Pole Synchronous Machine

Inputs:

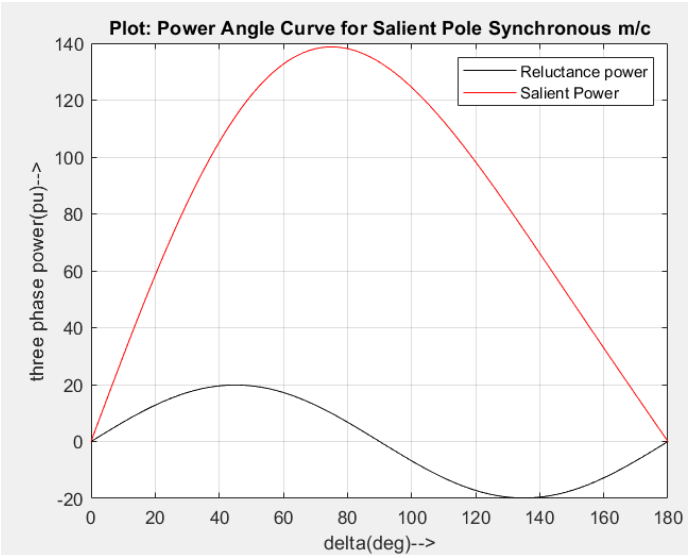
Power in MW=48

Power factor=0.8

Line to line voltage in kV=34.64

Xd in ohms=13.5

Xq in ohms=9.33



Output response:

Excitation_emf = 3.0000e+004

Reg = 50.0024