Vidya Jyothi Institute of Technology

(An Autonomous Institution)

(Accredited by NAAC & NBA, Approved by AICTE New Delhi & Permanently Affiliated to JNTUH)

Aziz Nagar Gate, C.B. Post, Hyderabad-500 075

Vision of the Institution

- To develop into a reputed Institution at National and International level in Engineering, Technology and Management by generation and dissemination of knowledge through intellectual, cultural, and ethical efforts with human values.
- To foster Scientific temper in promoting the world class professional and technical expertise.

Mission of the Institution

- To create state-of-the-art infrastructure facilities for optimization of knowledge acquisition.
- To nurture the students holistically and make them competent to excel in the global scenario.
- To promote R&D and consultancy through strong industry-institute interaction to address the societal problems.

Name of the Faculty: P.Nagamuneendra **Designation:** Asst prof

Programme & Regulation: B.Tech & R18 **Academic Year:** 2020-21

Course Code: A24208 **Course Name:** Electrical machines-II **Credits:** 3.

Department: EEE II **Year** II **Semester** A **Section**

Vision of the Department

- Mould generations of Electrical Engineers with multidisciplinary perspective on global standards and stand as a reputed department in the field of Electrical and Electronics Engineering

Mission of the Department

- Imparting Quality Technical Education by provision of state-of-the-art laboratories.
- Preparing the students to think innovatively and find effective solutions to address engineering and societal problems with a multi-disciplinary approach maintaining continuous industry interaction
- Encouraging teamwork and preparing the students for lifelong learning with ethical responsibility for a successful professional career.

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Programme Educational Outcomes (PEOs)

PEO1: To provide the students with a sound foundation in the mathematics, science and engineering fundamentals necessary to become employable.

PEO2: Graduates should apply their technical knowledge to take up higher responsibilities in industry, academics and create innovative ideas in the field of Electrical and Electronics Engineering.

PEO3: Equip graduates with communication skills, leadership qualities with ethical values, team work with multi-disciplinary approach and zeal to provide solutions for engineering and societal problems.

Programme Outcomes (POs)

Engineering Graduates will be able to:

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

2. 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.

3. 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.

4. 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.

5. 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.

6. 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.

7. 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.

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

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

10. 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.

11. Project management and finance: 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. Life-long learning: 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)

PSO 1: Apply the fundamentals of Electrical and Electronics Engineering to analyze and synthesize problems of Electric Circuits, Electronic Circuits, Control Systems, Electrical Machines and Power Systems.

PSO 2: Apply the appropriate techniques and modern engineering hardware and software tools in Electrical Engineering to engage in life-long learning and to successfully adapt in multi-disciplinary environments.

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B.Tech II & III Year Revised Academic Calendar for the Academic Year 2020-21

SECOND SEMESTER		**Commencement of Class Work 30.03.2021**	
I Spell of Instructions	30.03.2021	12.06.2021	11 WEEKS
I Mid Examinations	14.06.2021	22.06.2021	8 DAYS
II Spell of Instructions	23.06.2021	14.08.2021	8 WEEKS
II Mid Examinations	16.08.2021	19.08.2021	4 DAYS
Practical Examinations	20.08.2021	24.08.2021	4 DAYS
Betterment Examinations	25.08.2021	28.08.2021	4 DAYS
End Semester Examinations	30.08.2021	18.09.2021	3 WEEKS
Commencement of class work for B. Tech., III & IV Year I Semester will be from 20.09.2021			

DEAN EXAMS. **DIRECTOR**

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ACADEMIC CALENDAR FOR II, III & IV B.Tech I SEMESTER FOR THE YEAR 2020-21

FIRST SEMESTER		Commencement of Class work : **13.07.2020**	
	FROM	**TO**	**DURATION**
I Spell of Instruction (Online)	13.07.2020	19.09.2020	10 Weeks
I Mid Examinations	21.09.2020	26.09.2020	1 Week
II Spell of Instructions (Online)	28.09.2020	16.10.2020	3 Weeks
Dussehra Holidays	17.10.2020	25.10.2020	9 Days
II Spell of Instructions Continuation (Online/Offline)	26.10.2020	14.11.2020	3 Weeks
II Mid Examinations	16.11.2020	21.11.2020	1 Week
Practical Examinations	23.11.2020	28.11.2020	1 Week
III Mid Examinations	01.12.2020	03.12.2020	3 Days
End Semester Examinations	04.12.2020	19.12.2020	2 Weeks

COE

DEAN,Exams.

DIRECTOR

Vidya Jyothi Institute of Technology ★ Office of Controller of Examinations ★ Himayatnagar Vill., C.B.Post, Hyderabad-75

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B.Tech II & III Year Revised Academic Calendar for the Academic Year 2020-21

FIRST SEMESTER		Commencement of Class Work 17.07.2020	
	FROM	TO	DURATION
I Spell of Instructions (Online)	17.07.2020	09.10.2020	12 WEEKS
Mid -II & End Semester Examinations of Previous Semester	14.10.2020	12.11.2020	5 WEEKS
Practical Examinations of Previous Semester	16.11.2020	21.11.2020	1 WEEK
Revision of Syllabi of Current Semester	23.11.202	05.12.2020	2 WEEKS
Betterment Examinations of Previous Semester	02.12.2020	05.12.2020	4 DAYS
I Mid Examinations of Current Semester	07.12.2020	15.12.2020	1 WEEK
Practical Classes of Current Semester	16.12.2020	19.12.2020	4 DAYS
II Spell of Instructions (Online)	21.12.2020	20.02.2021	9 WEEKS
Practical Examinations	24.02.2021	03.03.2021	1 WEEK
II Mid & End Semester Examinations	05.03.2021	22.03.2021	2 WEEKS
Betterment Examinations	24.03.2021	27.03.2021	4 DAYS
SECOND SEMESTER		**Commencement of Class Work 30.03.2021**	
I Spell of Instructions	30.03.2021	22.05.2021	8 WEEKS
I Mid Examinations	24.05.2021	29.05.2021	1 WEEK
II Spell of Instructions	31.05.2021	24.07.2021	8 WEEKS
II Mid Examinations	26.07.2021	31.07.2021	1 WEEK
Practical Examinations	02.08.2021	07.08.2021	1 WEEK
Betterment Examinations	09.08.2021	12.08.2021	4 DAYS
End Semester Examinations	13.08.2021	28.08.2021	2 WEEKS

COE **DEAN EXAMS.** **DIRECTOR**

B. Tech. EEE II Year II Semester

L	T	P	C
4	0	0	4

ELECTRICAL MACHINES – II

Prerequisite: Basic Electrical Engineering, Electrical Machines-I

Course Objectives:

- To deal with the detailed analysis of transformers and poly-phase induction motors
- To understand operation, construction and types of single phase motors and their applications.
- To introduce the concept of parallel operation of transformers.
- To introduce the concept of regulation and its calculations.

Course Outcomes: At the end of this course, students will demonstrate the ability to

CO1: Understand the concepts of rotating magnetic fields.

CO2: Analyze the operation of transformers and Induction motors.

CO3: Predict the performance characteristics of transformers and Induction motors.

CO4: Apply the concepts for testing the transformers and Induction motor.

UNIT-I SINGLE PHASE TRANSFORMERS

Principle of operation -Types - constructional details- Losses,Minimization of hysteresis and eddy current losses- E.M.F equation - operation on no load and on load - phasor diagrams- Problems.

Equivalent circuit – efficiency at different loads - Condition for maximum efficiency- All day efficiency -voltage regulation for different loads & different power factors - effect of variations of frequency & supply voltage on iron losses - Sumpner's test-separation of losses.

UNIT II THREE PHASE TRANSFORMERS

Three phase poly-phase connections - Y/Y, Y/Δ, Δ/Y, Δ/ Δand open Δ, Third harmonics in phase voltages-three winding transformers-tertiary windings - Determination of Zp, Zs and Zt - off load and on load tap changing, Scott connection.

PARALLEL OPERATION AND AUTOTRANSFORMERS

Parallel operation of Single Phase Transformers with equal and unequal voltage ratios - Auto transformers - equivalent circuit - comparison with two winding transformers.

UNIT III THREE PHASE INDUCTION MOTORS

Construction details of cage and wound rotor machines-production of a rotating magnetic field - principle of operation - rotor emf and rotor frequency - rotor reactance, rotor current and pf. at standstill and during operation. Rotor power input, rotor copper loss and mechanical power developed. Torque equation- expressions for maximum torque and starting torque - torque slip characteristics - double cage and deep bar rotors

UNIT IV PERFORMANCE OF THREE PHASE INDUCTION MOTORS

Equivalent circuit - phasor diagram - crawling and cogging.

Circle diagram-no load and blocked rotor tests-predetermination of performance. Methods of starting. Calculations of torque, efficiency at different loads from circle diagram.

Speed control - voltage control – variable voltage and variable frequency method- change of poles and methods of consequent poles; cascade connection, injection of an emf into rotor circuit (qualitative treatment only) -induction generator-principle of operation.

UNIT V SINGLE PHASE INDUCTION MOTORS

Single phase Induction motor – Constructional features- Double revolving field theory Equivalent circuit- spilt –Phase motors- Capacitor start Capacitor run motors, applications.

TEXT BOOKS:

1. Electric Machinery- P.S. Bimbra, Khanna Publishers, 7th edition, 2010.
2. Theory and Performance of Electrical Machines - JB Gupta, SK Kataria&ISons, 2009.

REFERENCE BOOKS:

1. Performance and Design of AC Machines - MG.Say, BPB Publishers, 1968.
2. Theory of Alternating Current Machinery- Langsdorf, Tata McGraw Hill Companies, 2nd edition, 2001.
3. Electro mechanics-II (transformers and induction motors) - S. Kamakashaiah, Hitech publishers.
4. Electric Machines – I.J.Nagrath&D.P.Kothari,Tata McGraw Hill, 7th Edition, 2005.
5. A Text Book of Electrical Technology – B.L. Theraja and A.K. Theraja,Vol2, S.Chand Publications

Course Objectives

To deal with the detailed analysis of Transformers and Ploy-Phase Induction Motors.

To understand operation, construction, and types of 1-Ø Induction Motors and their applications.

To introduce the concept of parallel operation of 1-Ø Transformers.

To introduce the concept of regulation and its calculations.

Course Outcomes (COs)

CO1	Understand the construction and working operations of single-phase transformers.
CO2	Understand different types of three phase transformers and able to obtain the load sharing of transformers.
CO3	Analyze the performance of induction motors and effect of harmonics.
CO4	Compare the operation of induction motor using different speed control methods and analyze the circle diagram.
CO5	Analyze the performance of single-phase induction motors.

COs Mapping with POs & PSOs

Course Outcomes	Program Outcomes												Program Specific Outcomes	
	1	2	3	4	5	6	7	8	9	10	11	12	PSO1	PSO2
CO1	3	2	1	1	1	-	-	-	-	-	-	1	3	-
CO2	3	2	2	1	1	-	-	-	-	-	-	1	3	-
CO3	3	3	2	2	1	-	-	-	-	-	-	1	3	-
CO4	3	2	2	2	1	-	-	-	-	-	-	1	3	-
CO5	3	2	2	2	1	-	-	-	-	-	-	1	3	-
Average	3	2.25	1.75	1.5	1	-	-	-	-	-	-	1	3	-

Assessment Plan

S.No.	Test/Examination	Units/ Topics Covered	COs covered	Proposed Date	Maximum Marks
1	Assignment I	2.5	1,2,3		5
2	Mid I	2.5	1,2,3		20
3	Assignment II	2.5	3,4,5		5
4	Mid II	2.5	3,4,5		20

Direct Assessment (Internal Examination & External Examination)	Indirect Assessment (Course End Survey)
2.24	2.733

Course Faculty	Course Co-Ordinator	HOD

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DEPARTMENT OF ELECTRICAL&ELECTRONICS ENGINEERING

Academic year: 2020-21 **Year& Semester: II B.Tech- II Sem**
Section: EEE-A **W. E. F: 30-03-2021**

ONLINE CLASSES TIME TABLE

Day/ Hours	9.30 AM to 10.30 AM	10.40 AM to 11.40 AM	11.50 AM to 12.50 PM	02.00 PM to 03.00 PM
MON	PS-II	NMPD	FMHM	CS
TUE	CS	EM-II	PS-II	NMPD
WED	NMPD	FMHM	EM-II	MC-2
THU	EM-II	CS	MC-2	PC
FRI	PC	PS-II	CS	FMHM
SAT	FMHM	EM-II	NMPD	PS-II

S.No.	Name of the Subject	Name of the Faculty
1	Numerical Methods and Partial Differential Equations(NMPD)	Mr.G.Chandu
2	Fluid Mechanics and Hydraulic Machinery(FMHM)	Mr.S.Raghavendra
3	Professional Communication(PC)	Dr.V.Murali
4	Electrical Machines –II(EM-II)	Mr.P.Naga Muneendra
5	Power Systems-II(PS-II)	Dr.D.B.G.Reddy
6	Control Systems(CS)	Mrs.V.Vijayalakshmi
7	Environmental Science(MC-2)	Mrs.Y.Sunitha

Class In charge **Mr.P.Naga Muneendra**

Time Table I/C **H.O.D**

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

Lesson Plan Schedule

(Regulation R-18)

Name of the Faculty: P.Nagamuneendra **Year/ Sem: II-II**

Course Name: ELECTRICAL MACHINES-II **Course Code:** A24208

S NO	Lecture Hour	Teaching Aids required	Topics to be covered	Books no./Page No.
			Unit-1: SINGLE PHASE TRANSFORMERS	
1	L1	PPT	Introduction - Principle of operation	TB1 / 4 - 5
2	L2	PPT	Types of transformers	TB1 / 2 - 4
3	L3	PPT	Constructional details Losses	TB1 / 2 - 4
4	L4	PPT	Minimization of hysteresis and eddy current losses	TB1 /49-50
5	L5	PPT	E.M.F equation	TB1 / 5 – 6
6	L6	PPT	Operation on no load	TB1 / 10-11
7	L7	PPT	Operation on load -phasor diagrams	TB1 / 12-13
8	L8	PPT	Equivalent circuit	TB1 / 20-22
9	L9	PPT	Efficiency at different loads	TB1 / 50
10	L10	PPT	Condition for maximum efficiency	TB1 / 51-52
11	L11	PPT	All day efficiency	TB1 / 53
12	L12	PPT	Voltage regulation for different loads & different power factors	TB1 /40-44
13	L13	PPT	Effect of variations of frequency & supply voltage on iron losses	TB1 /63-64
14	L14	PPT	Sumpner's test	TB1 / 66-68
15	L15	PPT	Separation of losses.	TB1 /63-64
			Unit-II: THREE PHASE TRANSFORMERS, PARALLEL OPERATION AND AUTO TRANSFORMERS	
16	L16	PPT	Three phase poly-phase connections	TB1/419-420
17	L17	PPT	Y/Y, Y/Δ, Δ/Y, Δ/ Δ connections	TB1/423-425
18	L18	PPT	Open Δ Connection	TB1/430-431
19	L19	PPT	Third harmonics in phase voltages	TB1/448-450
20	L20	PPT	Three winding transformers	TB1/441-443
21	L21	PPT	Tertiary windings	TB1/441
22	L22	PPT	Determination of Zp, Zs and Zt	TB1/442-443
23	L23	PPT	Off load tap changing	TB1/100-101
24	L24	PPT	ON load tap changing	TB1/102
25	L25	PPT	Scott connection.	TB1/431-432
26	L26	PPT	Parallel operation of 1-Ø Transformers with equal voltage ratios	TB1/ 85-86
27	L27	PPT	Parallel operation of 1-Ø Transformers with unequal voltage ratios	TB1/ 87-91

28	L28	PPT	Auto transformers	TB1/ 70-73
29	L29	PPT	Equivalent circuit	TB1/ 74-75
30	L30	PPT	Comparison with two winding transformers.	TB1/ 76-77
Unit-III: THREE PHASE INDUCTION MOTORS				
31	L31	PPT	Construction details of cage rotor	TB2/643-646
32	L32	PPT	Wound rotor machine	TB2/647-648
33	L33	PPT	Production of a rotating magnetic field	TB2/648-649
34	L34	PPT	Principle of operation	TB2/647-648
35	L35	PPT	Rotor emf	TB2/651
36	L36	PPT	Rotor frequency & rotor reactance	TB2/650
37	L37	PPT	Rotor current and pf. at standstill and during operation	TB2/651-652
38	L38	PPT	Rotor power input, rotor copper loss and mechanical power developed	TB2/662-663
39	L39	PPT	Torque equation	TB2/664
40	L40	PPT	Expressions for maximum torque	TB2/543-654
41	L41	PPT	Starting torque	TB2/654
42	L42	PPT	Torque slip characteristics	TB2/658
43	L43	PPT	Double cage rotor	TB2/694-695
44	L44	PPT	Deep bar rotors.	TB2/693-694
Unit- IV: PERFORMANCE OF THREE PHASE INDUCTION MOTORS				
45	L45	PPT	Equivalent circuit - phasor diagram	TB2/671-674
46	L46	PPT	Crawling and cogging	TB2/689-691
47	L47	PPT	Circle diagram-no load and blocked rotor tests	TB2/684-685
48	L48	PPT	Predetermination of performance, efficiency at different loads from circle diagram.	TB2/684-685
49	L49	PPT	Methods of starting.	TB2/711-713
50	L50	PPT	Methods of starting.	TB2/714-716
51	L51	PPT	Calculations of torque equation	TB2/720
52	L52	PPT	Speed control - voltage control	TB2/721-723
53	L53	PPT	Variable voltage and variable frequency method	TB2/724-726
54	L54	PPT	Change of poles and methods of consequent poles	TB2/727-728
55	L55	PPT	Cascade connection, injection of an emf into rotor circuit	TB2/728
56	L56	PPT	Induction generator-principle of operation.	TB2/801-804
Unit- V: SINGLE PHASE INDUCTION MOTORS				
57	L57	PPT	Single phase Induction motor - Introduction	TB2/752
58	L58	PPT	Constructional features	TB2/753
59	L59	PPT	Double revolving field cross field theory	TB2/754-756
60	L60	PPT	Equivalent circuit- spilt phasing	TB2/756-757
61	L61	PPT	Resistance split phasing motors	TB2/765-766
62	L62	PPT	Capacitor start induction run motors	TB2/766-767
63	L63	PPT	Capacitor start Capacitor run motors-applications.	TB2/768-769

A) TEXT BOOKS:

1. Electrical Machinery by P.S. Bimbra - Khanna Publishers - 7thedition.
2. Theory and Performance of Electrical Machines by JB Gupta - SK Kataria &Sons 14th edition

B) REFERENCES:

1. Performance and Design of AC machines by M.G. Say -BPB Publishers.
2. Electrical Machines by R.K Rajput -LP publications.

Faculty I/C

HOD

L - **Lecture**		**BB**	- **Black Board**
A - **Assignment**		**LCD**	- **Liquid Crystal Display**
T - **Text Books**		**MD**	- **Model Demo**
R - **References**		**FV**	- **Field Visit**

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

Course Delivery Plan & Record of class work

Unit-I SINGLE PHASE TRANSFORMERS.

S No	Proposed		Topics To Be Covered	Teaching Aids used	Execution	
	DATE	HOURS			DATE	HOURS
1	30/03/21	1	Introduction - Principle of operation	PPT	30/3/21	1
2	31/03/21	1	Types of transformers	PPT	1/4/21	1
3	01/04/21	1	Constructional details Losses	PPT	3/4/21	1
4	03/04/21	1	Minimization of hysteresis and eddy current losses	PPT	7/4/21	1
5	6/4/21	1	E.M.F equation	PPT	10/4/21	1
6	7/4/21	1	Operation on no load	PPT	15/4/21	1
7	8/4/21	1	Operation on load -phasor diagrams	PPT	17/4/21	1
8	10/4/21	1	Equivalent circuit	PPT	20/4/21	1
9	15/4/21	1	Efficiency at different loads .	PPT	22/4/21	1
10	17/4/21	1	Condition for maximum efficiency	PPT	24/7/21	1
11	20/4/21	1	All day efficiency	PPT	29/4/21	1
12	22/4/21	1	Voltage regulation for different loads & different power factors	PPT	1/5/21	1
13	24/4/21	1	Effect of variations of frequency & supply voltage on iron losses	PPT	5/5/21	1
14	27/4/21	1	Sumpner's test	PPT	8/5/21	1
15	28/4/21	1	Separation of losses.	PPT	11/5/21	1

Justification for deviation (if Any) –

Course faculty

HOD

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Unit-II THREE PHASE TRANSFORMERS,

PARALLEL OPERATION AND AUTO TRANSFORMERS

S No	Proposed		Topics To Be Covered	Teaching Aids used	Execution	
	DATE	HOURS			DATE	HOURS
1	29/4/21	1	Three phase poly-phase connections	PPT	13/5/21	1
2	01/5/21	1	Y/Y, Y/Δ, Δ/Y, Δ/ Δ connections	PPT	18/5/21	1
3	4/05/21	1	open Δ Connection	PPT	19/5/21	1
4	5/5/22	1	Third harmonics in phase voltages	PPT	20/5/21	1
5	6/5/21	1	three winding transformers	PPT	22/5/21	1
6	8/5/21	1	tertiary windings	PPT	25/5/21	1
7	11/5/21	1	Determination of Zp, Zs and Zt	PPT	26/5/21	1
8	12/5/21	1	off load tap changing	PPT	27/5/21	1
9	13/5/21	1	on load tap changing	PPT	29/5/21	1
10	18/5/21	1	Scott connection.	PPT		1
11	19/5/21	1	Parallel operation of 1-Ø Transformers with equal voltage ratios	PPT	1/6/21	1
12	20/5/21	1	Parallel operation of 1-Ø Transformers with unequal voltage ratios	PPT	1/6/21	1
13	22/5/21	1	Auto transformers	PPT	2/6/21	1
14	24/5/21	1	Equivalent circuit	PPT	2/6/21	1
15	25/5/21	1	Comparison with two winding transformers.	PPT	3/6/21	1

Justification for deviation (if Any)

Course faculty

HOD

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Unit-III - THREE PHASE INDUCTION MOTORS

S No	Proposed		Topics To Be Covered	Teaching Aids used	Execution	
	DATE	HOURS			DATE	HOURS
1	26/5/21	1	Construction details of cage rotor	PPT	5/6/21	1
2	27/5/21	1	Wound rotor machine	PPT	8/6/21	1
3	29/5/21	1	Production of a rotating magnetic field	PPT	9/6/21	1
4	1/06/21	1	Principle of operation	PPT	10/6/21	1
5	2/6/21	1	Rotor emf	PPT	12/6/21	1
6	3/6/21	1	Rotor frequency & rotor reactance	PPT	22/6/21	1
7	5/6/21	1	Rotor current and pf. at standstill and during operation	PPT	23/6/21	1
8	8/6/21	1	Rotor power input, rotor copper loss and mechanical power developed	PPT	24/6/21	1
9	9/6/21	1	Torque equation	PPT	30/6/21	1
10	10/6/21	1	Expressions for maximum torque	PPT	1/7/21	1
11	12/6/21	1	Starting torque	PPT	3/7/21	1
12	22/6/21	1	Torque slip characteristics	PPT	6/7/21	1
13	23/6/21	1	Double cage rotor	PPT	13/7/21	1
14	24/6/21	1	Deep bar rotors.	PPT	16/7/21	1

Justification for deviation (if Any)

Course faculty

HOD

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Unit-IV PERFORMANCE OF THREE PHASE INDUCTION MOTORS

S No	Proposed		Topics To Be Covered	Teaching Aids used	Execution	
	DATE	HOURS			DATE	HOURS
1	30/6/21	1	Equivalent circuit - phasor diagram	PPT	20/7/21	1
2	1/7/21	1	Crawling and cogging	PPT	22/7/21	1
3	3/7/21	1	Circle diagram-no load and blocked rotor tests	PPT	24/7/21	1
4	6/7/21	1	Predetermination of performance, efficiency at different loads from circle diagram.	PPT	27/7/21	1
5	7/7/21	1	Methods of starting.	PPT	28/7/21	1
6	8/7/21	1	Methods of starting.	PPT	29/7/21	1
7	10/7/21	1	Calculations of torque equation	PPT	29/7/21	1
8	13/7/21	1	Speed control - voltage control	PPT	3/8/21	1
9	14/7/21	1	Variable voltage and variable frequency method	PPT	4/8/21	1
10	16/7/21	1	Change of poles and methods of consequent poles	PPT	4/8/21	1
11	17/7/21	1	Cascade connection, injection of an emf into rotor circuit	PPT	5/8/21	1
12	20/7/21	1	Induction generator-principle of operation.	PPT	5/8/21	1

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Unit-V SINGLE PHASE INDUCTION MOTORS

S No	Proposed		Topics To Be Covered	Teaching Aids used	Execution	
	DATE	HOURS			DATE	HOURS
1	22/7/21	1	Single phase Induction motor – Introduction	PPT	10/8/21	1
2	24/7/21	1	Constructional features	PPT	11/8/21	1
3	27/7/21	1	Double revolving field cross field theory	PPT	13/8/21	1
4	28/7/21	1	Equivalent circuit-spilt phasing	PPT	18/8/21	1
5	29/7/21	1	Resistance split phasing motors	PPT	19/8/21	1
6	31/7/21	1	Capacitor start induction run motors	PPT	20/8/21	1
7	3/08/21	1	Capacitor start Capacitor run motors-applications.	PPT	21/8/21	1

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Syllabus Covered as Per Course Delivery Plan

Details/Duration	First 4 Weeks	Second 4 Weeks	Third 4 Weeks	End Of Semester
Percentage of Syllabus covered	25	50	75	100
Signature of staff with date				
Signature of HOD with date				
Signature of Auditor with date	C.N. Dam	C.N. Dam	C.N. Dam	C.N. Dam

47	20915A0207	GUMDALA MANIKANTA GOUD
48	20915A0208	KARUMURU HEPSIBHA
49	20915A0209	KONDOJU APARNA
50	20915A0210	KOPPULA AKANKSHA
51	20915A0211	KOTHURI ABHISHEK
52	20915A0212	KUMMARI YAMUNA
53	20915A0213	M RAGHAVULU

HOD(EEE)

VIDYA JYOTHI INSTITUTE OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

2020-21 II YEAR I SEM SECTION A

S.No	Roll.No	Name of the Student
1	19911A0201	A PAVANI
2	19911A0202	AHANKARI ADITYA
3	19911A0203	AJMEERA RAKESH
4	19911A0205	ALGUBELLI SINDHU
5	19911A0206	ANNALDAS ARAVIND
6	19911A0207	ANTHAMGARI SWATHI PRIYA
7	19911A0208	BADAGANI GANESH
8	19911A0209	BANDELA SUMITH
9	19911A0210	BANOTH SRAVAN
10	19911A0211	BHOOMA RAJASHEKAR GOUD
11	19911A0212	BHUKYA BHARGAV
12	19911A0213	BHUKYA NAVEEN
13	19911A0214	BUCHALWAR SWENNIK
14	19911A0215	CHAKALI PRAVEEN
15	19911A0216	CHENNAM ALEKHYA
16	19911A0217	CHITIKELA CHETANA
17	19911A0218	CHITTIPROLU ANUSHA
18	19911A0219	DARA UDAY BHARGAV
19	19911A0220	DASARI SRINIVAS
20	19911A0221	DEVARADESHI UDHAY KIRAN
21	19911A0222	EDULA BHARATH KUMAR GOUD
22	19911A0223	GADE SUPRATHIKA
23	19911A0224	GIDDALAPATI VAMSI RAM REDDY
24	19911A0225	GOLI SAI PRASHANTH
25	19911A0226	GONE MEGHANA
26	19911A0227	GORLA ANJALI RAJ
27	19911A0228	GOVINDREDDY ASRITHA
28	19911A0229	GUGULOTH KALYAN
29	19911A0230	GUGULOTHU RAHUL
30	19911A0231	JARPALA NAGESWARI
31	19911A0232	JATAVATH PAVAN
32	19911A0233	JOSHI SAI VIVEKANAND
33	19911A0234	KANAVENI AKHILA
34	19911A0235	KARIKE SRINU
35	19911A0236	KARUKURI SAI RAM
36	19911A0237	KATNA SRISAILAM
37	19911A0238	KOLLURU MAHESHWAR
38	19911A0239	KOPPERA VIJENDHAR
39	19911A0240	KOTTAPETA SANJEEV KUMAR GOUD
40	19911A0241	KURVA KRISHNA
41	20915A0201	BOINI RAMNESH
42	20915A0202	BONIKE NAVEEN
43	20915A0203	BOWRESHETTY SAI KIRAN
44	20915A0204	D HEMANTH SAGAR
45	20915A0205	G VISHNU VARDHAN
46	20915A0206	GANDHAM SREE CHARAN DEEP

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ASSIGNMENT – I (AY – 2020-21)

COURSE NAME: - ELECTRICAL MACHINES-II Year & Semester: II-II

S.No.	Questions	COs	POs	B.L
1	What is the basic function of transformer?	1	1,2,3	1
2	A 1- Φ transformer with a ratio of 440/110 V takes a no-load current of 5A at 0.2 p.f. lagging. If the secondary supplies a current of 120 A at a p.f. of 0.8 lagging, calculate the current taken by the primary.	1	2,3,4	3
3	Draw the phasor diagrams for a practical transformer for pure resistive, resistive-inductive & resistive-capacitive loads.	2	1,2,3	3
4	Compare a bank of three 1- Φ transformers and 3- Φ transformer.	2	1,2,3	2
5	Discuss the construction of 3-Ø Induction Motor.	3	1,2,3	2

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ASSIGNMENT – II (AY – 2020-21)

COURSE NAME: ELECTRICAL MACHINES – II Year & Semester: II-II

S.No.	Questions	COs	POs	B.L
1	Compare Squirrel Cage and Slipring 3- Ø Induction Motors.	3	1,2,3,4	2
2	Explain the circle diagram construction for 3-Ø Induction Motor.	4	1,2,3	2
3	Discuss the speed control methods of 3- Ø Induction Motor.	4	1,2,3	1
4	Explain the constructional features of 1-Ø Induction Motor.	5	1,2,3	2
5	Draw the equivalent circuit of 1-Ø Induction Motor.	5	1,2,3	2

Power factor Cos ϕ_0 is determined.

From short circuit test I_{sc} corresponding to normal voltage applied to stator, short-circuit phase angle ϕ_{sc} are determined.

The voltage phasor V is taken along Y-axis. In the phasor diagram OV represents the normal voltage applied to the stator. Phasor OO' is drawn at an angle ϕ_0 from OV (lagging) representing no-load line current I_0 in magnitude as well as direction. Line OF is drawn perpendicular to OV.

OA is drawn at angle ϕ_{sc} from OV and equal to I_{sc} in magnitude. Thus the phasor OA represents the line current that would exist were the rated line voltage V impressed across the stator when the motor blocked and phasor O'A represents the corresponding rotor current I_1' as referred to primary.

Obviously O' and A lie on the circle. To determine the centre of the required circle, line O'G drawn parallel to OF. O'A is joined and line BC is drawn perpendicular to line O'A bisecting the line O'A at point B and intersecting line O'G at C. Now with centre C and O'C as radius the semicircle is drawn

Electrical Machines - II   19911A0228
Assignment - II (2020-21)   G. Asritha.

(1) Comparison of Squirrel cage and Slip ring Induction Motor

Characteristics	Squirrel cage I.M	Slip ring I.M.
1. Construction	Simple & rugged	Needs slip rings, brushes short circuiting device
2. Copper loss	Small	More
3. Starting	Simple	The motor needs sliprings brushgear, short-circuiting device and starting resistors etc.
4. Starting torque	It is low with large starting current	Possibility of increasing starting torque by insertion of external resistances in the rotor circuit.
5. Speed control	No possibility	Possible by insertion of external resistor in the rotor circuit.

(2) Explain the circle diagram construction of 3-ϕ Induction Motor.

Ans The operating characteristics of an induction motor can be computed by use of a circle diagram easily and conveniently.

From No-load test, line voltage V, line current I_o, and total power input are measured and no load

Speed of an induction motor, $N = \frac{120f}{P}(1-s)$.

$\therefore$ Speed of an induction motor depends on supply frequency f, no. of poles P and slip s. Hence to change the speed of an induction motor it is essential to change at least one of the above three factor.

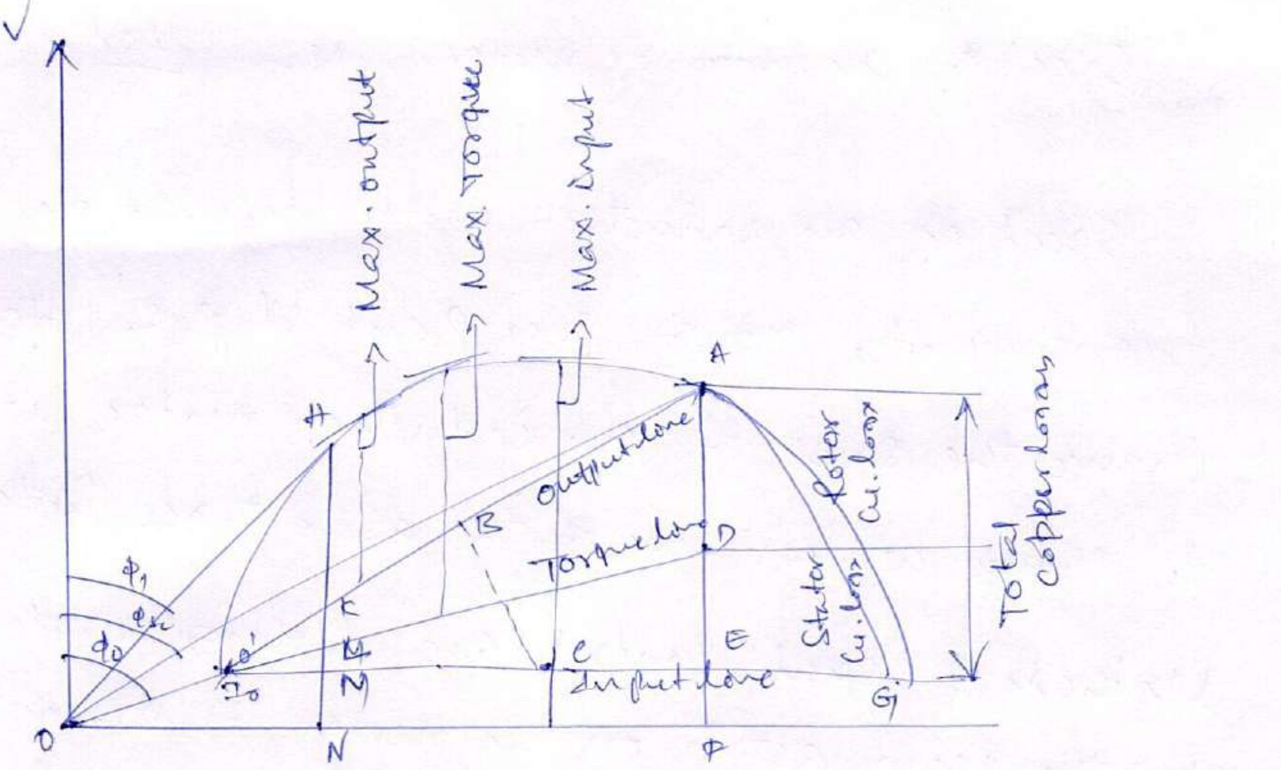
Methods of speed control are distinguished according to the main action on the motor. i) from the stator side and ii) from the rotor side.

Various methods of speed control from stator side are

a) Variation of supply frequency
b) Variation of applied voltage
c) by changing the no. of poles

From the rotor side the speed may be controlled

a) by changing the resistance in the rotor circuit
b) by introducing into the rotor circuit an additional emf of the same frequency as the fundamental emf of the rotor



Circle diagram for an induction motor

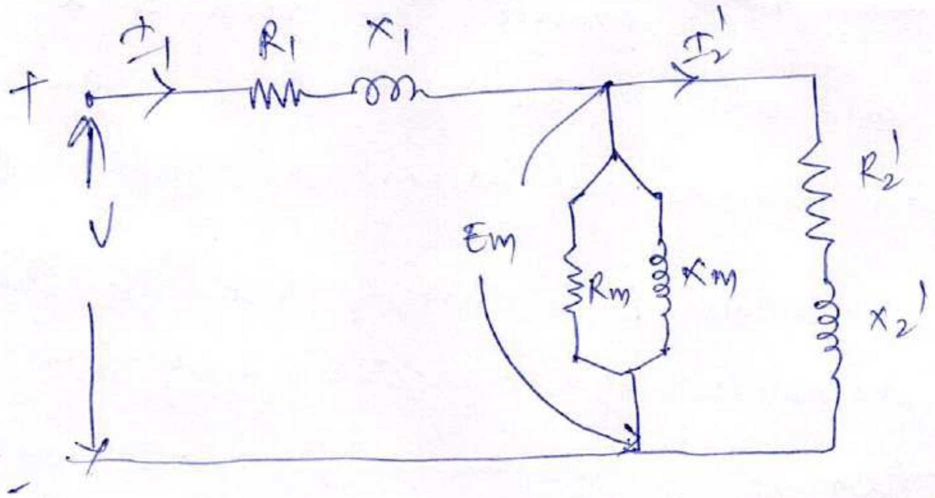
(3) Discuss the speed control methods of 3-ϕ Induction Motor.

The problem of speed control of electrical motor in general and of induction motor in particular is of great practical importance. In a number of industries motors must satisfy very strict speed characteristic requirement both w.r.t. range and smoothness of control and also w.r.t to economical operation.

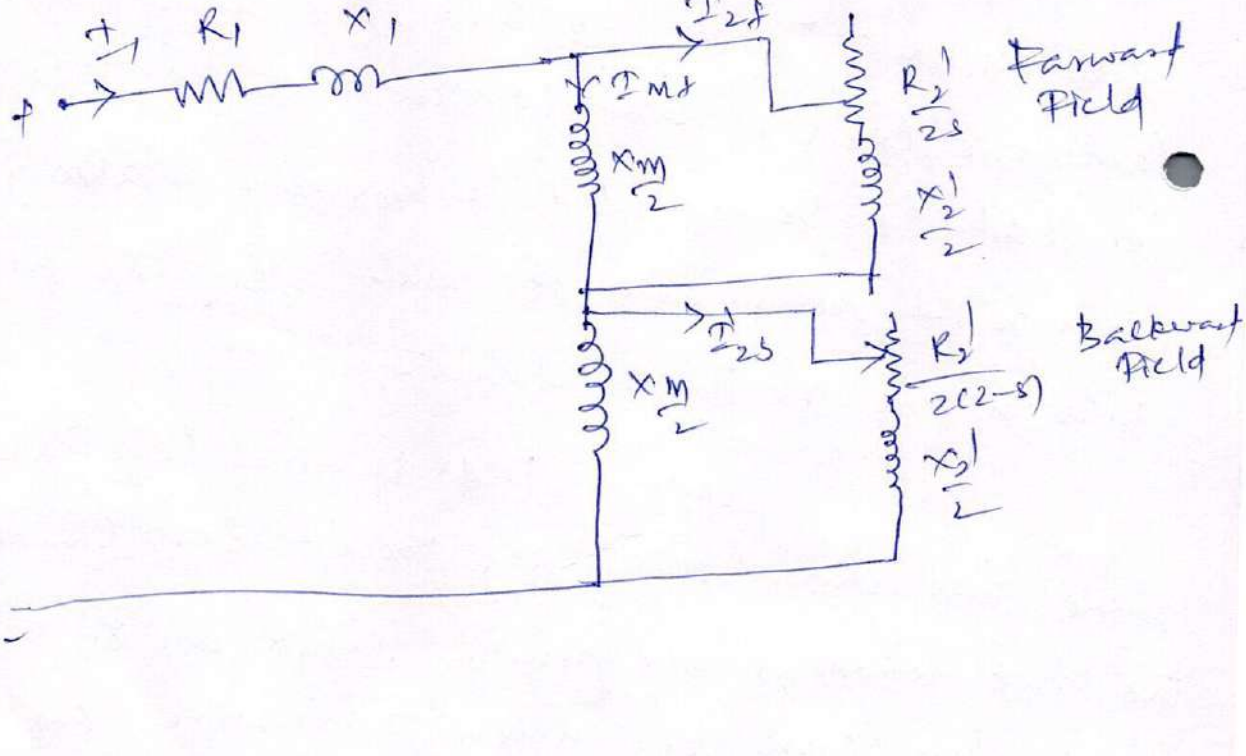
The speed control of dc shunt motor can be adjusted between wide range with good efficiency and speed regulation, but in induction motors speed cannot be varied without loosing efficiency and good speed regulation.

(5) Draw the equivalent circuit of 1-ϕ Induction Motor)

Ans



a) Equivalent circuit of a 1-ϕ I.M at standstill.



(4). Explain the Constructional features of ~~the~~ 1-ϕ Induction Motor

Ans A 1-ϕ Induction motor is similar to a 3-ϕ induction motor in physical appearance. The rotor of a 1-ϕ squirrel cage motor is essentially the same as that employed in 3-ϕ induction motors. and needs no further description.

There is uniform airgap between stator and rotor but no electrical Connection between them. 1-ϕ I.M. Can be wound for any even number of poles two, four, and six being most common. Like 3-ϕ machines adjacent poles have opposite magnetic polarity and synchronous speed equation ($N_s = \frac{120f}{P}$) also applies

The stator windings are distinctively different in two aspects. First 1-ϕ I.M. are usually provided with Concentric Coils. with Concentric Coils, the no. of turns per Coil Can be adjusted to provide an approximately sinusoidal distribution of mmf along the airgap and this is one of their advantages.

Second 1-ϕ squirrel Cage motors normally have two stator windings. Except for Shaded-pole motors, the two windings are similar, but one of them usually have few turns of much thin wire and the two windings are in space quadrature w.r.t each other

(2) A 1-ϕ T/F with a ratio of 440/110V takes a no-load current of 5A at 0.2 P.F lagging. If the secondary supplies a current of 120A at a p.f of 0.8 lagging. Calculate the current taken by the primary.

Ans

Transformation ratio, $K = \frac{E_2}{E_1} = \frac{110}{440} = 0.25$

Let the primary counterbalance current be I_1'.

Then $I_1' = K \cdot I_2 = 0.25 \times 120 = 30A$

Now $\cos\phi_0 = 0.2$, $\phi_0 = \cos^{-1} 0.2 = 78.46^\circ$

$\cos\phi_2 = 0.8$, $\phi_2 = \cos^{-1} 0.8 = 36.87$

$\theta = \phi_0 - \phi_2 = 78.46^\circ - 36.87^\circ = 41.59^\circ$

$I_1 = \sqrt{I_0^2 + (I_1')^2 + 2 I_0 I_1' \cos\theta}$

$= \sqrt{5^2 + 30^2 + 2 \times 5 \times 30 \times \cos(41.59)} = 33.9A$

Electrical Machines-II 19911A0228

Assignment -I (2020-21) G. Asritha

(1). What is the basic function of the transformer)

Ans A transformer is an electrical device which, by the principles of electromagnetic induction, transfers electrical energy from one circuit to other circuit, without change in the frequency. The energy transfer usually takes place with a change of voltage and current.

Transformer either increases or decreases AC voltage. Transformers are used to meet a wide variety of needs. Some transformers can be several stories high, like the type found at a generating station or small enough to hold in your hand, which might be used with a charging cradle for a video camara. No matter what the shape or size a transformer purpose remains the same, transforming electrical power from one type to another.

(4). Compare a bank of 3 1-ϕ transformers and 3-ϕ T/F's

Ans A single 3-ϕ T/F contains a single unit, if a 3-ϕ T/F but a 3-ϕ T/F bank contains 3 no. 1-ϕ T/F's joined together to form a 3-ϕ transformation circuit.

Cost wise a same capacity 3-ϕ T/F is cheaper than 3-ϕ, 1-ϕ transformer, But at some locations like dams and hills it become difficult for a 3-ϕ T/F to be transported to sites. At that sites 1-ϕ T/F are installed because of their small volume & more reliability feature. usually a 3-ϕ T/F bank has one fourth T/F as spare which can be taken into service at the time of fault in one of the three units, this facility is not available in single 3-ϕ T/F.

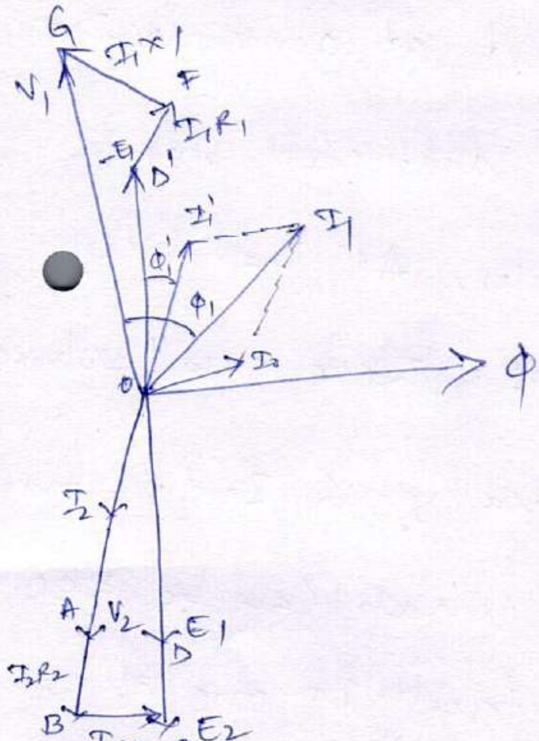
(5). Discuss the construction of 3-ϕ Induction Motor.

A The 3-ϕ Induction motor is very simple in construction compared to a dc motor or a synchronous motor. The essential features of a polyphase induction motor are : a laminated stator core carrying a

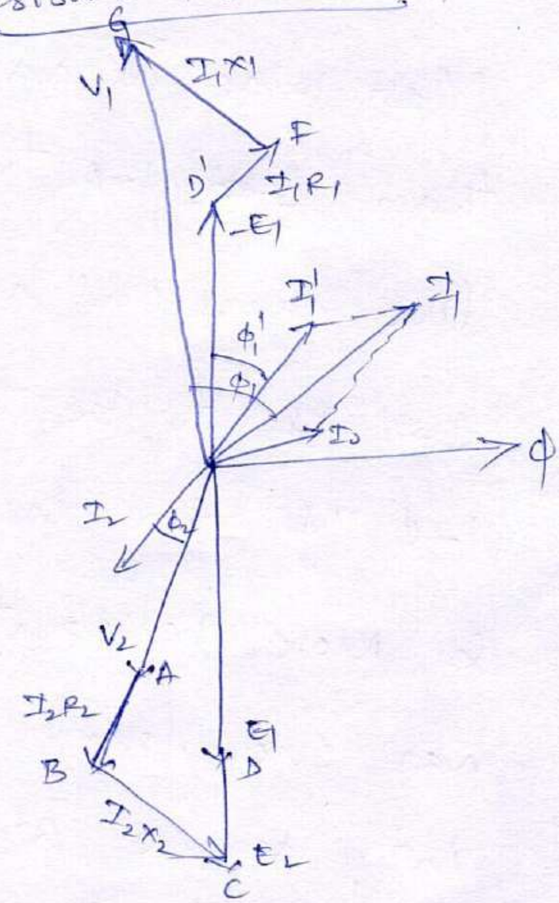
(3). Draw the phasor diagrams for a practical T/F for pure resistive, resistive-inductive & resistive capacitive loads.

Ans

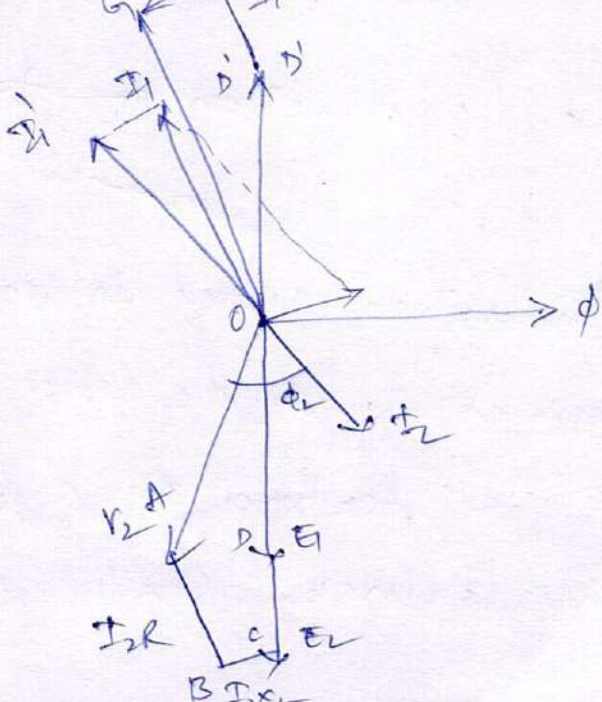
Pure resistive load



Resistive-inductive load



Resistive-capacitive load



polyphase winding, a laminated rotor core carrying either a cage or polyphase winding. The later with shaft mounted slip rings, a stiff shaft to preserve the very short air gap, a frame to form the stator housing and carry the end covers, bearings and terminal box.

It is not possible, as in the dc m/c's to use the frame as part of the magnetic circuit. The end covers receive the ball- or roller bearings with their clamping plates. Non-salient pole construction is used for all polyphase induction motors.

5. i.	Explain about open-delta connection of a 3-Ø Transformer?	2	1,2,3,6,10	IV	5
[OR]					
ii.a)	Draw and explain the following connections i)delta -star ii) star-star	2	1,3,5,6,10	III	3
b)	What are the advantages and disadvantages of autotransformer?	2	1,2,3,6,10	II	2
6.i)	Explain the concept of rotating magnetic field?	3	1,3,5,6,10	II	4
[OR]					
ii)	Write the differences between squirrel cage and slip ring induction motors?	3	1,2,3,6,10	I	4

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II Year B.Tech II Semester 1st Mid exam	
Branch: EEE	Duration: 90Min
Sub: EM-II	Marks: 20
Date: 16.06.2021	Session: I

Course Outcomes:

1.Understand the construction and working operations of single phase transformers

2.Understand different types of three phase transformers and able to obtain the load sharing of transformers

3.Analyze the performance of induction motors and effect of harmonics.

4.Compare the operation of induction motor using different speed control methods and analyze the circle diagram.

5.Analyze the performance of single phase induction motors

Bloom's Level:

Remember	I
Understand	II
Apply	III
Analyze	IV
Evaluate	V
Create	VI

SET-1

PART-A (3Q×2M =6Marks)		Course Outcomes		Bloom's Level	Marks
ANSWER ALL THE QUESTIONS		CO	PO		
1.i)	Define transformation ratio of the single phase Transformers?	1	1,2,3,6,10	I	2
[OR]					
ii)	Draw the equivalent circuit of a 1-ph transformer	1	1,3,5,6,10	III	2
2.i)	Comapre two winding transformer with auto transformer.	2	1,2,3,6,10	II	2
[OR]					
ii)	Draw the connection diagram of Star-Delta of 3-phase transformers?	2	1,3,5,6,10	IV	2
3.i)	why squirrel cage rotor is skewed w.r.t x-axis?	3	1,2,3,6,10	IV	2
[OR]					
ii)	Define slip and slip speed of 3ph induction motor?	3	1,3,5,6,10	I	2

PART-B (5+5+4= 14 Marks)		Course Outcomes		Bloom's Level	Marks
ANSWER ALL THE QUESTIONS		CO	PO		
4.i.a)	Draw the equivalent circuit of a single phase Transformer referred to the secondary side?	1	1,3,5,6,10	III	2
b)	A 200/400 V, 50 Hz single phase transformer on testing gave fallowing values O.C test on LV side 200V, 0.7A, 70W and S.C test on HV side 15V, 10A, 20W .Find the percentage voltage regulation at 0.8 p.f lagging at full load condition?	1	1,2,3,6,10	IV	3
[OR]					
ii.	Draw and explain the sumpners test of a 1-Ø Transformer and design the equivalent circuit?	1	1,3,5,6,10	III	5

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II B.Tech II Semester MID II Examination, August/Sep-2021

Subject: ELECTRICAL MACHINES-II **Branch: EEE**
Time: 90 Minutes **Max Marks: 20**

Note: This question paper contains two ***Parts A and B.***
Part A is compulsory which carries 6 Marks.
Part B consists of 3 questions. Answer all the questions.

Bloom's Level:

Remember	I
Understand	II
Apply	III
Analyze	IV
Evaluate	V
Create	VI

	PART-A (3Q×2M=6Marks)	**Outcomes**		**Bloom's Level**	**Marks**
ANSWER ALL THE QUESTIONS		**CO**	**PO**		
1.i)	Define crawling effect in 3 phase induction motor.	3	1,2	2	2
	[OR]				
ii)	Write the relation between stator and rotor frequency under running conditions.	3	1,2	2	2
2.i)	List out the starting methods of 3 phase inductions motor.	4	1	2	2
	[OR]				
ii)	List out the starting methods of 3-phse induction motor from rotor side.	4	1,2	2	2
3.i)	Why 1-phase induction motor is not self-started.	5	1,2	2	2
	[OR]				
ii)	Write the starting methods of 1-phae induction motor.	5	1,2	2	2
	PART-B (4+5+5=14Marks)				
ANSWER ALL THE QUESTIONS					
4. a)	Derive the torque expression for 3-phase induction motor	3	1,2,3	3	4M
	[OR]				
b)	Explain the constructional features of squirrel cage rotor of 3 phase induction motor.	3	1,2	2	4M
5.i)	Explain the following speed control methods of induction motors. a) voltage control b) cascading connection	4	1,2,3	3	5M
	[OR]				
ii.	Draw the equivalent circuit diagram of 3-phase Induction motor.	4	1,2	3	5 M
6.i)	Explain the construction and working of 1-phase induction motor.	5	1,2	2	5M
	[OR]				
ii)	Explain the operation of Capacitor start and Capacitor run 1-phae induction motor.	5	1,2	2	5M

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Subiect Code:A24208

II B.Tech.,II Semester Supplemenatry Examination March/April2021

SUBJECT: EM-II **BRANCH :EEE**

Time: 3 Hours **Max. Marks:75**

Bloom's Level:

Remember	L1	Apply	L3	Evaluate	L5
Understand	L2	Analyze	L4	Create	L6

ANSWER ANY FIVE QUESTIONS 5QX15M =75 M		Bloom' s Level	PO	CO	Marks
1.)	Develop the equivalent circuit of single phase transformer.	L2	1,2	1	7M
b)	A single phase transformer is connected to a 230V ,50Hz supply.The net cross sectional area of the core is 50cm^2.The number of turns of the primary is 460 and the secondary is 80.Determine (i) Transformation ratio (ii) peak value of flux density in core (iii) e.m.f in the secondary winding.	L5	2,3	1	8M
2.a)	Explain about various losses in a transformer.	L3	1	1	7M
b).	In a 25KVA,2000/200V,single phase transformer ,the iron and full load copper losses are 350 and 400w respectively.Calculate the efficiency at unity power factor on (i)full load (ii)half full load.	L5	2,3	1	8M
3.a)	Explian the following connection diagrams of three tranformer and give it applications.(i)Y-Y (ii)Y-A.	L4	1,4	2	8M
b)	Explain the operation of auto transformer and draw its equivalent circuit.	L2,L3	1,2	2	7M
4.a)	What are the advantages of poly phase transformers? Give different configurations.	L2,L3	1,3	2	8M
b	Explain the parallel operation of two single phase tranformers with unequal volatge ratios.	L3 L4	1,2,4	2	7M
5	Write the comparisons between the slip ring and squirrel cage induction motors.	L2,L3	1,2	3	15M
6.a)	Explain the concept of rotating magnetic field in a three phase induction motor.	L2,L3	1,2,3	3	8M
b)	Briefly explain the working of double Cage Induction motor.	L2,L3	1,3	3	7M

VJIT(A)

7.a)	Explain the following starting methods with neat sketch (i) DOL starter (ii)Y-LX starter.	L3	1,3	4	7M
b)	Expalin the conducting procedure of No-load & Blocked rotor test on three phase . induction motor.	L3,L4	1,2	4	8M
8.a)	Show that the starting torque of a 1-0 induction motor is zero.	L3	1,2	5	8M
b)	Draw the connection diagram & operation of capacitor start and capacitor run single phase induction motor and explain it.	L2,L3	1,2,3	5	7M

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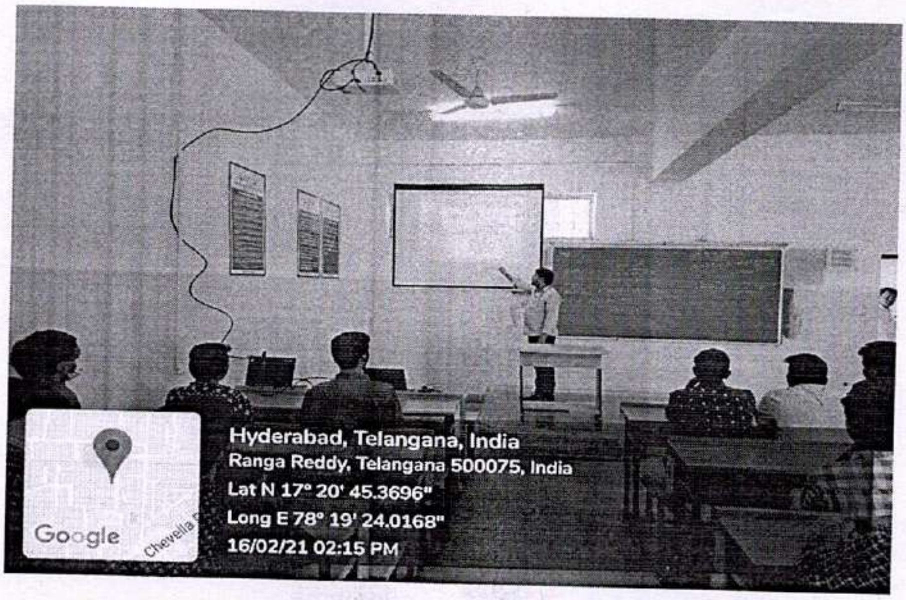
Aziz Nagar Gate, C.B. Post, Hyderabad-500 075

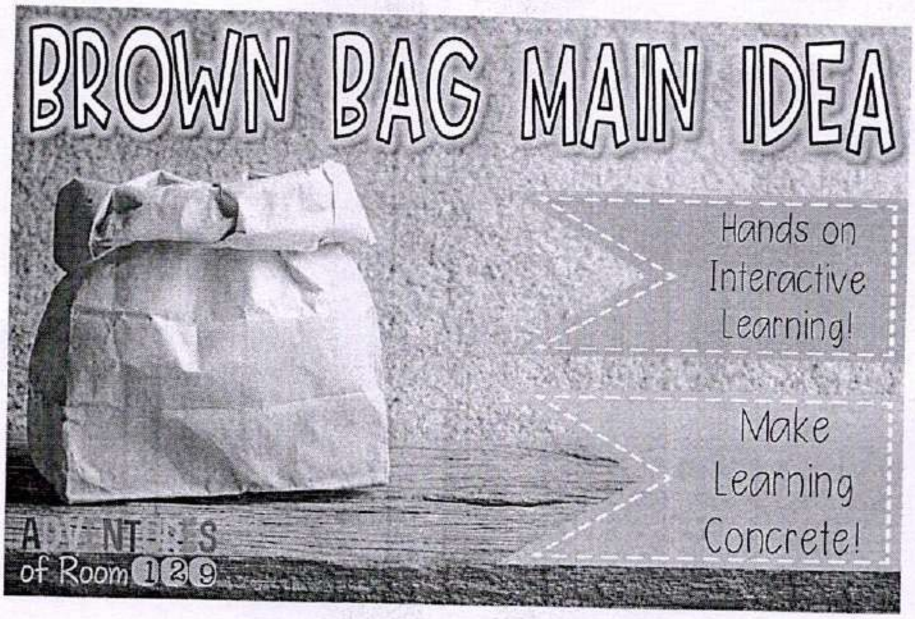
CONTENT BEYOND SYLLABUS

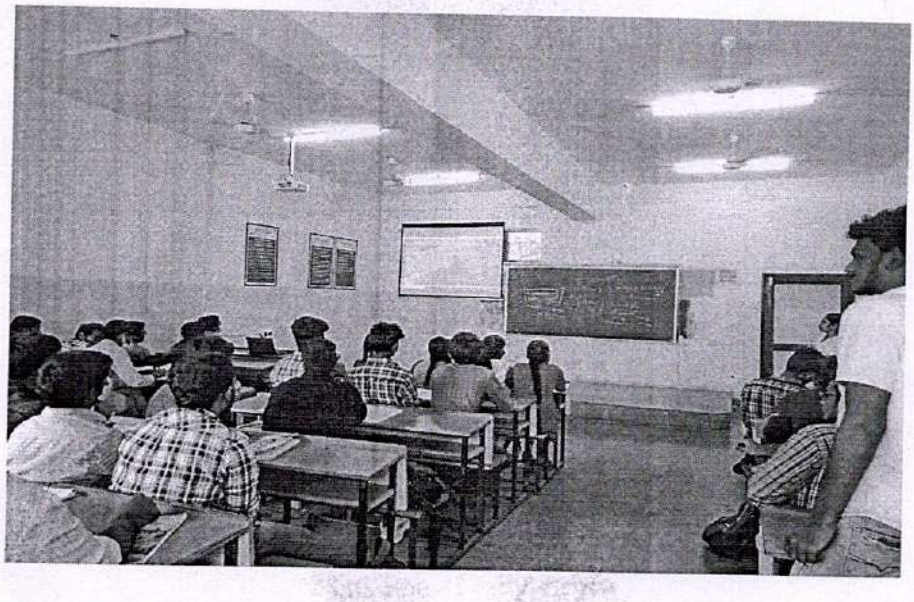
S.No.	Date	Topics Covered	Details of the Resource Person	Mapping With POs,PSOs
1	11.5.2021	Sequence impedances of 3-Ø Transformer.	Prof. A. K. Sinha, Department of Electrical Engineering, IIT Kharagpur.	1,2,3

TUTORIAL CLASSES

S.No.	Date	Period	Topics Covered	Related Cos


Hyderabad, Telangana, India
Ranga Reddy, Telangana 500075, India
Lat N 17° 20' 45.3696"
Long E 78° 19' 24.0168"
16/02/21 02:15 PM
Google


BROWN BAG MAIN IDEA
Hands on Interactive Learning!
Make Learning Concrete!
of Room 129



Vidya Jyothi Institute of Technology

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Aziz Nagar Gate, C.B. Post, Hyderabad-500 075

Department of Electrical &Electronics Engineering

2020-21

BROWN BAG APPROACH

Prepared by:

P Nagamuneendra

Assistant Professor

Subject: Electrical Machines-II

Academic Year: 2020-21

Title of Innovative method/activity: Brown Bag Approach

Description: Introduce the concept of Brown Bag Approach which provide a great opportunity to share many different topics and to learn fresh concepts from each other

Aim of the method: To allow the students to explain the concept which is taken from bag on black board/PPT such that logical skills, creativity and cognition is improved?

Implementation/Portrayal of method:

In this teaching method we have prepared list of topics. These topics are written on slips and slips are placed in brown bag. Students have to take one slip from it and then spontaneously give a lecture on that topic.

Topic: Types of transformers

- Shell type
- Core type
- Step-up
- Step down
- Power transformer
- Distribution transformers

24	19911A0219	5	1	2	1	4	3	4	5	AB	AB	AB	AB	AB	AB	55
25	19911A0220	5	1	2	1	4	4	3	5	2	2	1	5	5	4	9
26	19911A0221	5	1	2	1	5	4	3	5	AB	AB	AB	AB	AB	AB	57
46	19911A0222	5	2	2	2	5	4	3	5	1	2	1	4	3	3	9
47	19911A0223	5	1	2	1	5	4	3	5	2	2	2	5	5	4	51
48	19911A0224	5	2	2	2	5	4	4	5	2	2	2	5	5	4	53
49	19911A0226	5	1	2	1	5	4	3	5	2	2	1	5	5	4	0
50	19911A0227	5	2	2	2	4	5	4	5	1	2	1	4	5	3	56
51	19911A0228	5	2	2	2	5	5	4	5	1	2	1	4	5	3	46
52	19911A0229	5	1	2	1	2	3	3	5	2	2	2	4	5	4	0
34	19911A0230	5	1	2	1	3	2	3	5	2	2	1	4	5	4	0
35	19911A0231	5	1	2	1	3	3	3	5	2	2	2	4	5	3	49
36	19911A0232	5	AB	AB	AB	AB	AB	AB	5	1	2	1	4	5	3	14
37	19911A0233	5	2	2	2	4	5	4	5	2	2	2	4	5	3	10
38	19911A0234	5	2	2	2	5	5	4	5	2	2	2	5	5	4	50
39	19911A0235	5	2	2	2	5	5	4	5	2	2	1	5	5	4	47
40	19911A0236	5	2	2	2	5	5	4	5	2	2	1	5	5	4	0
41	19911A0237	5	2	2	2	4	4	3	5	2	2	2	5	5	4	50
42	19911A0238	5	2	2	2	5	5	4	5	2	2	2	5	5	4	51
43	19911A0239	5	2	2	2	5	5	4	5	2	2	1	5	5	4	46
44	19911A0240	5				2	2	2	5			2	2	2	2	48
45	19911A0241	5							5	2	2	2	4	4	3	47
46	19911A0242	5	2	2	2	4	4	3	5	2	2	2	5	5	4	46
47	19911A0243	5	2	2	2	5	5	4	5	2	2	2	5	5	4	51
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51	19911A0247	5	1	1	1	3	3	2	5	2	2		5	5	4	52
52	19911A0248	5	2	2	1	2	3	3	5	1	2	1	4	5	4	54
53	19911A0249	5	2	2	1	2	3	3	5	1	2	1	4	3	3	53
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56	19911A0252	5	2	2	2	5	5	4	5	2	2	2	5	5	4	15
57	19911A0253	5	1	2	1	2	3	3	5	1	2	2	4	5	3	46
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60	19911A0256	5	1	2	1	4	3	4	5	2	2	2	4	5	4	52

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(Aziz Nagar, C.B.Post, Hyderabad -500075)

Academic Year: 2020-21 **BATCH: 2019-2023**

II B.Tech- II Sem

Course: EM-II

Faculty: P Nagamuneendra

S.No	Reg.No	MID I Threshold 60%							MID II Threshold 60%							Threshold 60% (45M)
		ASM - I (5)	PART-A			PART-B			ASM - II (5)	PART-A			PART-B			End Exam (75M)
			Q1(2M)	Q2(2M)	Q3(2M)	Q4(5M)	Q5(5M)	Q6(4M)		Q1(2M)	Q2(2M)	Q3(2M)	Q4(5M)	Q5(5M)	Q6(4M)	
1	18911A0244	5	2	2	2	5	5	4	5	2	2	2	5	5	4	42
2	18911A0233	5	2	2	2	5	5	4	5	2	2	2	5	5	4	54
3	18911A0279	5	2	2	2	4	4	3	5	2	2	2	5	5	4	52
4	18911A0251	5	2	2	2	4	5	4	5	2	2	2	5	5	4	56
5	18911A0229	5	2	2	2	5	5	4	5	1	2	2	4	5	4	47
6	18911A0217	5				2	2	2	5				2	2	2	46
7	18911A0239	5							5	2	2		4	4	3	49
8	19911A0201	5	2	2	2	4	4	3	5	2	2	2	5	5	4	49
9	19911A0202	5	2	2	2	4	5	4	5	2	2	2	5	5	4	15
10	19911A0205	5	2	2	2	5	5	4	5	1	2	2	4	5	4	48
11	19911A0206	5				1	1		5	1	1	2	3	3	2	52
12	19911A0207	5	1	1	1	4	4	3	5	2	2	2	5	5	4	16
13	19911A0208	5	1	1	1	3	3	2	5	2	2	2	5	5	4	46
14	19911A0209	5	AB	AB	AB	AB	AB	AB	5	1	2	2	2	3	3	49
15	19911A0210	5	2	2	2	5	5	4	5	1	2	1	4	3	4	10
16	19911A0211	5	1	2	1	2	3	3	5	1	2	2	4	4	3	49
17	19911A0212	5	1	2	1	4	3	4	5	1	2	2	5	4	3	48
18	19911A0213	5	1	2	1	2	3	3	5	1	2	2	4	5	4	1
19	19911A0214	5	1	2	1	4	3	4	5	2	2	1	4	5	4	6
20	19911A0215	5	2	2	2	5	5	4	5	2	1	2	4	5	4	16
21	19911A0216	5	2	2	2	4	5	4	5	2	2	2	5	5	4	48
22	19911A0217	5	2	2	2	5	5	4	5	1	2	2	4	5	3	49
23	19911A0218	5	1	2	1	2	3	3	5	1	2	2	4	5	3	53

97	20915A0218	5	1	2	1	4	3	4	5	2	2	2	4	5	4	43
98	20915A0219	5	2	2	2	4	5	4	5	2	2	2	5	5	4	57
99	20915A0220	5	2	2	2	5	5	4	5	1	2	1	4	5	4	54
100	20915A0221	5	2	2	1	2	3	3	5	2	1	1	4	5	3	37
101	20915A0222	5	2	2	2	4	5	4	5	2	2	1	5	5	4	40
102	20915A0223	5	2	2	2	5	5	4	5	2	2	1	4	5	4	46
103	20915A0224	5	2	2	2	4	5	4	5	2	2	2	5	5	4	35
104	20915A0225	5	2	2	2	5	5	4	5	1	2	2	4	5	4	57
Average marks		**5.0**	**1.7**	**1.9**	**1.5**	**3.9**	**4.0**	**3.5**	**5.0**	**1.7**	**1.9**	**1.6**	**4.2**	**4.5**	**3.5**	**40.0**
No of students attempted		**103**	**92**	**91**	**91**	**95**	**95**	**93**	**103**	**98**	**96**	**93**	**100**	**100**	**100**	**103**
%of students scored 60% and above		100.00	71.74	92.31	60.44	76.84	82.11	90.32	100.00	72.45	91.67	65.59	91.00	90.00	90.00	67.96
CO ATTAINMENT LEVEL		**3.0**	**3.0**	**3.0**	**2.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**3.0**	**2.0**	**3.0**	**3.0**	**3.0**	**2.0**

ASSESSMENT OF COs FOR THE COURSE

CO	Method	value	Average	Internal Exam	External Exam	Overall CO Attainment
CO 1	**MID I Q1**	3.0	2.75			
	MID I Q3A	2.0				
	MID I Q4	3.0				
	ASM-I	3.0				
CO 2	**MID I Q2**	3.0	3.00			
	MID1 Q4	3.0				
	MID I Q5	3.0				
	ASM-I	3.0				
	MID I Q6	3.0				

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62	19911A0258	5	2	2	2	4	5	4	5	1	2	1	4	5	3	49
63	19911A0259	5	2	2	2	5	5	4	5	2	2	1	4	5	3	46
64	19911A0260	5	1	2	1	2	3	3	5	2	2	2	5	5	4	48
65	19911A0261	5	2	2	1	4	3	4	5	2	2	2	4	5	4	47
66	19911A0262	5	2	2	2	5	5	4	5	2	2	1	5	5	4	51
67	19911A0263	5	2	2	2	5	5	4	5	2	2	2	5	5	4	47
68	19911A0264	5	2	2	2	4	4	3	5	2	2	2	5	5	4	48
69	19911A0265	5	AB	AB	AB	AB	AB	AB	5	1	1		3	3	2	49
70	19911A0266	5	1	2	1	2	3	3	5	2			2	2	2	57
71	19911A0267	5	AB	AB	AB	AB	AB	AB	5	2			2	2	2	37
72	19911A0268	5	2	2	2	4	5	4	5	2	2	1	5	5	4	28
73	19911A0269	5	2	2	2	5	5	4	5	1	2	2	4	5	4	5
74	19911A0270	5	2			1	1	1	5	1	1	2	4	4	3	32
75	19911A0271	5	2	2	2	5	5	4	5	2	2	2	5	5	4	43
76	19911A0272	5	2	2	2	5	5	4	5	2	2	2	5	5	4	14
77	19911A0273	5	2	1	1	4	4	3	5	2	2	2	5	5	4	42
78	19911A0274	5	1	1	1	3	3	2	5	2	2	2	5	5	4	50
79	19911A0275	5	2	2	1	4	3	4	5	1	0	2	3	2	2	34
80	20915A0201	5	2	2	2	5	5	4	5	2	1	1	3	2	2	39
81	20915A0202	5	2	2	2	4	5	4	5	2	2	1	5	4	4	46
82	20915A0203	5	2	2	2	5	5	4	5	1	2	2	4	3	3	45
83	20915A0204	5	1	2	1	2	3	3	5	2	2	2	5	5	4	51
84	20915A0205	5	1	2	1	4	3	4	5	2	2	1	5	5	4	45
85	20915A0206	5	2	2	2	5	4	4	5	2	2	2	5	5	4	49
86	20915A0207	5	2	1	0	3	4	3	5	1	2	2	4	5	3	47
87	20915A0208	5	2	2	0	3	3	0	5	2	2	1	4	5	3	46
88	20915A0209	5	1	1	1	5	5	4	5	2	2	2	4	5	4	50
89	20915A0210	5	2	2	1	4	4	4	5	2	2	2	4	5	4	44
90	20915A0211	5	2	1	1	4	3	2	5	2	2	1	4	5	3	34
91	20915A0212	5	2	2	2	4	4	3	5	2	2	2	5	5	4	46
92	20915A0213	5	2	2	2	4	4	3	5	1	1	2	3	3	2	49
93	20915A0214	5	1	1	1	3	3	2	5	2	1	2	3	3	2	46
94	20915A0215	5	2	2	2	2	1		5	1	1		3	3	2	63
95	20915A0216	5	2	2	2	5	5	4	5	AB	AB	AB	AB	AB	AB	55
96	20915A0217	5	1	2	1	2	3	3	5	2	2	2	5	5	4	42

CO 3	**MID 2 Q4**	3.0	3.00	2.95	2.00	2.24
	ASM-I	3.0				
	ASM-II	3.0				
CO 4	**MID 2 Q1**	3.0	3.00			
	MID 2 Q4	3.0				
	MID 2 Q5	3.0				
	ASM-II	3.0				
CO5	**MID 2 Q2**	3.0	3.00			
	MID 2 Q4	3.0				
	MID 2 Q6	3.0				
	ASM-II	3.0				

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46	19911A0242	2	3	2	3	2
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49	19911A0245	3	3	3	2	3
50	19911A0246	3	2	3	3	3
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54	19911A0250	2	3	3	3	3
55	19911A0251	2	3	3	3	2
56	19911A0252	3	3	2	3	3
57	19911A0253	3	3	2	2	3
58	19911A0254	3	3	2	3	3
59	19911A0255	2	3	3	3	3
60	19911A0256	3	3	3	3	3
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65	19911A0261	3	3	3	3	3
66	19911A0262	3	2	3	3	3
67	19911A0263	3	2	3	3	3
68	19911A0264	2	2	3	3	3
69	19911A0265	3	2	3	2	3
70	19911A0266	2	3	3	3	3
71	19911A0267	3	3	2	2	3
72	19911A0268	3	3	3	2	2
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76	19911A0272	2	3	3	2	3
77	19911A0273	3	3	3	2	3
78	19911A0274	3	2	3	3	3
79	19911A0275	3	3	2	2	3
80	20915A0201	3	3	3	2	2
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82	20915A0203	2	3	2	3	2
83	20915A0204	3	3	2	2	2
84	20915A0205	2	3	3	2	3
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87	20915A0208	3	2	3	3	3
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90	20915A0211	3	2	3	2	3
91	20915A0212	2	3	3	3	3
92	20915A0213	3	2	3	3	3
93	20915A0214	3	2	3	3	3
94	20915A0215	2	2	3	3	3

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Indirect Attainment(IDA) BACTH 2019-23 AY 2020-21

S.No	Reg.No	II EEE-II sem				
		EM-II				
		CO1	CO2	CO3	CO4	CO5
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2	18911A0233	3	3	3	3	3
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5	18911A0229	3	3	2	3	3
6	18911A0217	3	3	3	2	3
7	18911A0239	3	3	3	2	3
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9	19911A0202	3	3	2	3	2
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17	19911A0212	3	3	3	3	3
18	19911A0213	3	3	3	3	3
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22	19911A0217	3	3	3	2	3
23	19911A0218	3	3	3	2	3
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36	19911A0232	3	2	2	3	3
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38	19911A0234	3	2	3	3	3
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40	19911A0236	2	2	3	3	3
41	19911A0237	3	2	3	2	3
42	19911A0238	2	3	3	3	3
43	19911A0239	3	3	2	2	3

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96	20915A0217	2	3	3	3	3	
97	20915A0218	3	3	2	2	3	
98	20915A0219	3	3	3	2	2	
99	20915A0220	3	3	2	2	2	
100	20915A0221	2	3	2	3	2	
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102	20915A0223	2	3	3	2	3	
103	20915A0224	3	3	3	2	3	
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		2.76923	2.75962	2.72115	2.625	2.78846	**2.733**

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

Batch 2020-21

COURSE CLOSURE REPORT

S.No	Parameters	Section	A SEC	B SEC
		Course Name	Electrical Machines-II	
		Allotted Faculty	Mr P.N.Munand	Mr L.Raju
1	Quality of I/II-mid question papers (As per Blooms Taxonomy or not) submitted to the exam section		Yes	Yes
2	No of students registered for the exam		53	53.
3	No of students appeared for the exam		51	51
4	No of students passed		41	36
5	**Pass percentage**		80.39%	70.58%
6	End exam result analysis (pass percentage > 90%)		0	0
7	End exam result analysis (pass percentage 80% to 90%)		02	01
8	End exam result analysis (pass percentage 70% to 80%)		10	05
9	End exam result analysis (pass percentage 60% to 70%)		13	12
10	End exam result analysis (pass percentage <60%)		16	18

Faculty

HOD

UNIT-I

Single Phase Transformers

Introduction

The transformer is a device that transfers electrical energy from one electrical circuit to another electrical circuit. The two circuits may be operating at different voltage levels but always work at the same frequency. Basically transformer is an electro-magnetic energy conversion device. It is commonly used in electrical power system and distribution systems. It can change the magnitude of alternating voltage or current from one value to another. This useful property of transformer is mainly responsible for the widespread use of alternating currents rather than direct currents i.e., electric power is generated, transmitted and distributed in the form of alternating current. Transformers have no moving parts, rugged and durable in construction, thus requiring very little attention. They also have a very high efficiency as high as 99%.

Single Phase Transformer

A transformer is a static device of equipment used either for raising or lowering the voltage of an a.c. supply with a corresponding decrease or increase in current. It essentially consists of two windings, the primary and secondary, wound on a common laminated magnetic core as shown in Fig 1. The winding connected to the a.c. source is called primary winding (or primary) and the one connected to load is called secondary winding (or secondary). The alternating voltage V1 whose magnitude is to be changed is applied to the primary.

Depending upon the number of turns of the primary (N1) and secondary (N2), an alternating e.m.f. E2 is induced in the secondary. This induced e.m.f. E2 in the secondary causes a secondary current I2. Consequently, terminal voltage V2 will appear across the load.

If $V2 > V1$, it is called a step up-transformer.

If $V2 < V1$, it is called a step-down transformer.

LECTURE NOTES

ON

ELECTRICAL MACHINES - II

II B. Tech II semester

ELECTRICAL AND ELECTRONICS ENGINEERING

Core

The core is built-up of thin steel laminations insulated from each other. This helps in reducing the eddy current losses in the core, and also helps in construction of the transformer. The steel used for core is of high silicon content, sometimes heat treated to produce a high permeability and low hysteresis loss. The material commonly used for core is CRGO (Cold Rolled Grain Oriented) steel. Conductor material used for windings is mostly copper. However, for small distribution transformer aluminum is also sometimes used. The conductors, core and whole windings are insulated using various insulating materials depending upon the voltage.

Insulating Oil

In oil-immersed transformer, the iron core together with windings is immersed in insulating oil. The insulating oil provides better insulation, protects insulation from moisture and transfers the heat produced in core and windings to the atmosphere.

The transformer oil should possess the following qualities:

(a) High dielectric strength,

(b) Low viscosity and high purity,

(c) High flash point, and

(d) Free from sludge.

Transformer oil is generally a mineral oil obtained by fractional distillation of crude oil.

Tank and Conservator

The transformer tank contains core wound with windings and the insulating oil. In large transformers small expansion tank is also connected with main tank is known as conservator. Conservator provides space when insulating oil expands due to heating. The transformer tank is provided with tubes on the outside, to permits circulation of oil, which aides in cooling. Some additional devices like breather and Buchholz relay are connected with main tank. Buchholz relay is placed between main tank and conservator. It protect the transformer under extreme heating of transformer winding. Breather protects the insulating oil from moisture when the cool transformer sucks air inside. The silica gel filled breather absorbs moisture when air enters the tank. Some other necessary parts are connected with main tank like, Bushings, Cable Boxes, Temperature gauge, Oil gauge, Tapings, etc.

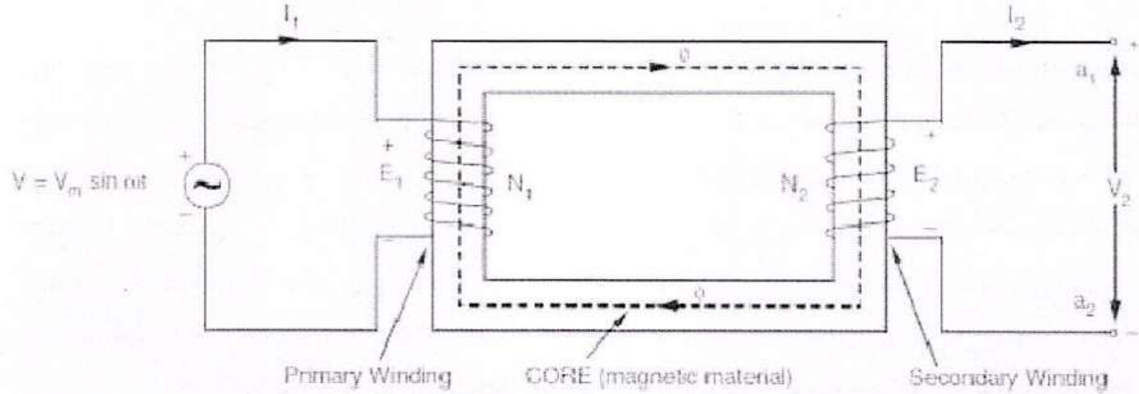


Fig. 2.1 Schematic diagram of single phase transformer

Constructional Details

Depending upon the manner in which the primary and secondary windings are placed on the core, and the shape of the core, there are two types of transformers, called (a) core type, and (b) shell type.

Core-type and Shell-type Construction

In core type transformers, the windings are placed in the form of concentric cylindrical coils placed around the vertical limbs of the core. The low-voltage (LV) as well as the high-voltage (HV) winding are made in two halves, and placed on the two limbs of core. The LV winding is placed next to the core for economy in insulation cost. Figure 2.1(a) shows the cross-section of the arrangement. In the shell type transformer, the primary and secondary windings are wound over the central limb of a three-limb core as shown in Figure 2.1(b). The HV and LV windings are split into a number of sections, and the sections are interleaved or sandwiched i.e. the sections of the HV and LV windings are placed alternately.

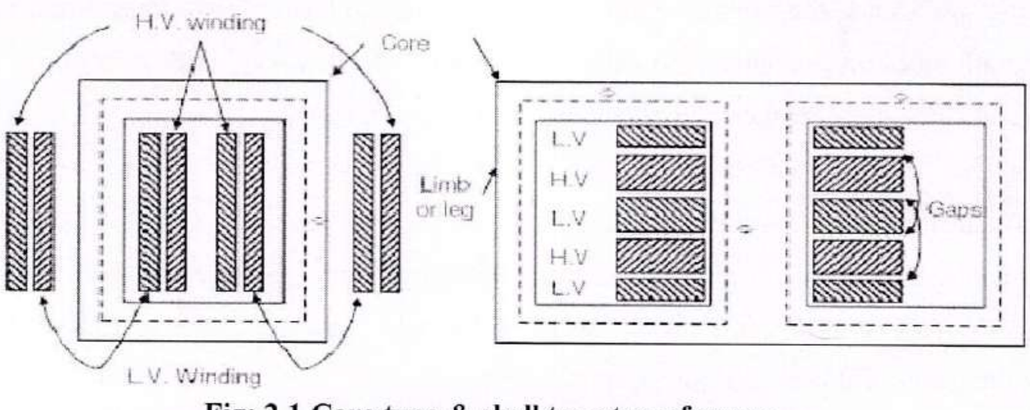


Fig: 2.1 Core type & shell type transformer

input power.

(e) The losses that occur in a transformer are:

(a) ***core losses***—eddy current and hysteresis losses
(b) ***copper losses***—in the resistance of the windings

In practice, these losses are very small so that output power is nearly equal to the input primary power. In other words, a transformer has very high efficiency.

E.M.F. Equation of a Transformer

Consider that an alternating voltage V1 of frequency f is applied to the primary as shown in Fig.2.3. The sinusoidal flux ϕ produced by the primary can be represented as:

$\phi = \phi m \sin\omega t$

When the primary winding is excited by an alternating voltage V1, it is circulating alternating current, producing an alternating flux ϕ.

ϕ - Flux

ϕm - maximum value of flux

N1 - Number of primary turns

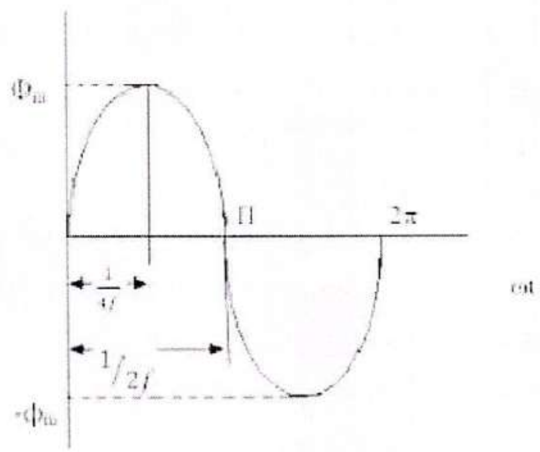
N2 - Number of secondary turns

f - Frequency of the supply voltage

E1 - R.M.S. value of the primary induced e.m.f

E2 - R.M.S. value of the secondary induced e.m.f

The instantaneous e.m.f. e1 induced in the primary is -



Principle of Operation

When an alternating voltage V1 is applied to the primary, an alternating flux ϕ is set up in the core. This alternating flux links both the windings and induces e.m.f.s E1 and E2 in them according to

Faraday's laws of electromagnetic induction. The e.m.f. E1 is termed as primary e.m.f. and e.m.f. E2 is termed as secondary e.m.f.

Clearly, $$E_1 = -N_1 \frac{d\phi}{dt}$$

and $$E_2 = -N_2 \frac{d\phi}{dt}$$

$$\therefore \quad \frac{E_2}{E_1} = \frac{N_2}{N_1}$$

Note that magnitudes of E2 and E1 depend upon the number of turns on the secondary and primary respectively.

If N2 > N1, then E2 > E1 (or V2 > V1) and we get a step-up transformer. If N2 < N1, then E2 < E1

(or V2< V1) and we get a step-down transformer.

If load is connected across the secondary winding, the secondary e.m.f. E2 will cause a current I2 to flow through the load. Thus, a transformer enables us to transfer a.c. power from one circuit to another with a change in voltage level.

The following points may be noted carefully

(a) The transformer action is based on the laws of electromagnetic induction.

(b) There is no electrical connection between the primary and secondary.

(c) The a.c. power is transferred from primary to secondary through magnetic flux.

(d) There is no change in frequency i.e., output power has the same frequency as the

This ratio of secondary induced e.m.f to primary induced e.m.f is known as voltage transformation ratio

$$E_2 = KE_1 \qquad \text{where } K = \frac{N2}{N1}$$

1. If N2>N1 i.e. K>1 we get E2>E1 then the transformer is called step up transformer.

2. If N2< N1 i.e. K<1 we get E2< E2 then the transformer is called step down transformer.

3. If N2= N1 i.e. K=1 we get E2= E2 then the transformer is called isolation transformer or 1:1 Transformer

Current Ratio

Current ratio is the ratio of current flow through the primary winding (I1) to the current flowing through the secondary winding (I2). In an ideal transformer -

Apparent input power = Apparent output power.

$$V1I1 = V2I2$$

$$\frac{I1}{I2} = \frac{V2}{V1} = \frac{N2}{N1} = K$$

Volt-Ampere Rating

i) The transformer rating is specified as the products of voltage and current (VA rating).

ii) On both sides, primary and secondary VA rating remains same. This rating is generally expressed in KVA (Kilo Volts Amperes rating)

$$\frac{V1}{V2} = \frac{I2}{I1} = K$$

$$V_1I_1 = V_2I_2$$

$$\text{KVA Rating of a transformer} = \frac{V1I1}{1000} = \frac{V2I2}{1000} \quad \text{(1000 is to convert KVA to VA)}$$

V_1 and V_2 are the V_t of primary and secondary by using KVA rating we can calculate I_1 and I_2 Full load current and it is safe maximum current.

$$I_1 \text{ Full load current} = \frac{KVA\ Rating\ X\ 1000}{V1}$$

$$I_2 \text{ Full load current} = \frac{KVA\ Rating\ X\ 1000}{V2}$$

From Faraday's law of electromagnetic induction -

$$\text{Average e.m.f per turns} = \frac{d\phi}{dt}$$

$d\phi$ = change in flux
dt = time required for change in flux

The flux increases from zero value to maximum value ϕm in 1/4f of the time period that is in 1/4f seconds.

The change of flux that takes place in 1/4f seconds = $\phi m - 0 = \phi m$ webers

Voltage Ratio

$$\frac{d\phi}{dt} = \frac{dt}{1/4f} = 4f\phi_m \text{ Wb/sec.}$$

Since flux ϕ varies sinusoidally, the R.m.s value of the induced e.m.f is obtained by multiplying the average value with the form factor

$$\text{Form factor of a sinwave} = \frac{\text{R.m.s value}}{\text{Average value}} = 1.11$$

R.M.S Value of e.m.f induced in one turns = $4\phi_m f \times 1.11$ Volts.

= $4.44\phi_m f$ Volts.

R.M.S Value of e.m.f induced in primary winding = $4.44\phi_m f N1$Volts.

R.M.S Value of e.m.f induced in secondary winding = $4.44\phi_m f N2$Volts.

The expression of E_1 and E_2 are called e.m.f equation of a transformer

$$V_1 = E_1 = 4.44\phi_m f N_1 \text{ Volts.}$$
$$V_2 = E_2 = 4.44\phi_m f N_2 \text{ Volts.}$$

Voltage transformation ratio is the ratio of e.m.f induced in the secondary winding to the e.m.f induced in the primary winding.

$$\frac{E2}{E1} = \frac{4.44\phi mf\, N2}{4.44\phi mf\, N1}$$

$$\frac{E2}{E1} = \frac{N2}{N1} = K$$

Consider an ideal transformer on no load i.e., secondary is open-circuited as shown in *Fig.2.4 (i)*. under such conditions, the primary is simply a coil of pure inductance. When an alternating voltage V1 is applied to the primary, it draws a small magnetizing current Im which lags behind the applied voltage by 90°. This alternating current Im produces an alternating flux ϕ which is proportional to and in phase with it. The alternating flux ϕ links both the windings and induces e.m.f. E1 in the primary and e.m.f. E2 in the secondary. The primary e.m.f. E1 is, at every instant, equal to and in opposition to V1 (Lenz's law). Both e.m.f.s E1 and E2 lag behind flux ϕ by 90°.However, their magnitudes depend upon the number of primary and secondary turns. *Fig. 2.4 (ii)* shows the phasor diagram of an ideal transformer on no load. Since flux ϕ is common to both the windings, it has been taken as the reference phasor. The primary e.m.f. E1 and secondary e.m.f. E2 lag behind the flux ϕ by 90°. Note that E1 and E2 are in phase. But E1 is equal to V1 and 180° out of phase with it.

$$\frac{E2}{E1} = \frac{V2}{V1} = K$$

Phasor Diagram

i) Φ (flux) is reference

ii) Im produce ϕ and it is in phase with ϕ, V1 Leads Im by 90°

E1 and E2 are in phase and both opposing supply voltage V1, winding is purely inductive So current has to lag voltage by 90°.

iii) The power input to the transformer

P = V1.I1. cos (90°)....................(cos90° = 0)

P= 0 (ideal transformer)

***b)i) Practical Transformer* on no load**

A practical transformer differs from the ideal transformer in many respects. The practical

Transformer on No-load

a) Ideal transformer

b) Practical transformer

a) Ideal Transformer

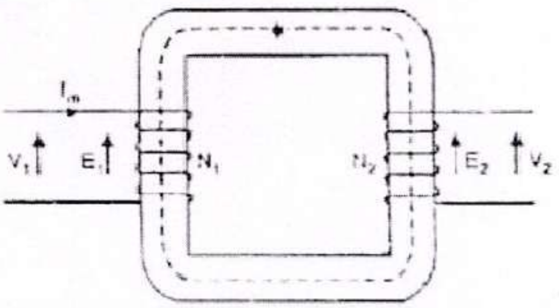
An ideal transformer is one that has

(i) No winding resistance

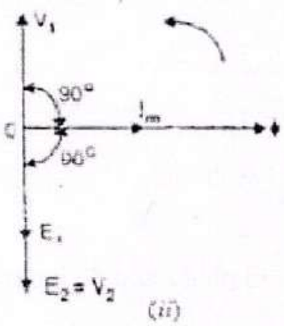
(ii) No leakage flux i.e., the same flux links both the windings

(iii) No iron losses (i.e., eddy current and hysteresis losses) in the core

Although ideal transformer cannot be physically realized, yet its study provides a very powerful tool in
the analysis of a practical transformer. In fact, practical transformers have properties that approach very close to an ideal transformer.



(i)



(ii)

(i) The component Ic in phase with the applied voltage V1. This is known as active or working or iron loss component and supplies the iron loss and a very small primary copper loss.

$$I_c = I_0 \cos \phi_0$$

The component Im lagging behind V1 by 90° and is known as magnetizing component. It is this component which produces the mutual flux ϕ in the core.

$$I_m = I_0 \sin \phi_0$$

Clearly, Io is phasor sum of Im and Ic, $I_o = \sqrt{Im^2 + Ic^2}$.

$$\text{No load P.F., } \cos\phi_o = \frac{Ic}{Io}$$

The no load primary copper loss (i.e. Io^2R1) is very small and may be neglected.

Therefore, the no load primary input power is practically equal to the iron loss in the transformer i.e., No load input power, W0 = V1Iocosϕo = Pi = Iron loss

***b) ii)Practical Transformer* on Load**

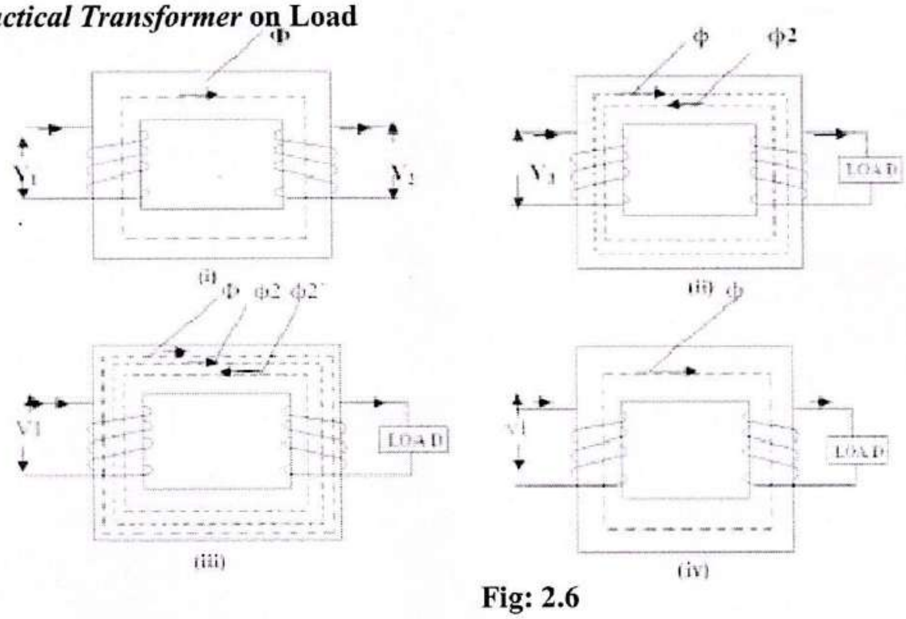


Fig: 2.6

At no load, there is no current in the secondary so that V2 = E2. On the primary side, the drops in R1 and X1, due to I0 are also very small because of the smallness of I0. Hence, we can say that at no load, V1 = E1.

i) When transformer is loaded, the secondary current I2 is flows through the secondary winding.

transformer has (i) iron losses (ii) winding resistances and (iii) Magnetic leakage

(i) Iron losses. Since the iron core is subjected to alternating flux, there occurs eddy current and hysteresis loss in it. These two losses together are known as iron losses or core losses. The iron losses depend upon the supply frequency, maximum flux density in the core, volume of the core etc. It may be noted that magnitude of iron losses is quite small in a practical transformer.

(ii) Winding resistances. Since the windings consist of copper conductors, it immediately follows that both primary and secondary will have winding resistance. The primary resistance R1 and secondary resistance R2 act in series with the respective windings as shown in Fig. When current flows through the windings, there will be power loss as well as a loss in voltage due to IR drop. This will affect the power factor and E1 will be less than V1 while V2 will be less than E2.

Consider a practical transformer on no load i.e., secondary on open-circuit as Shown in Fig 2.5.

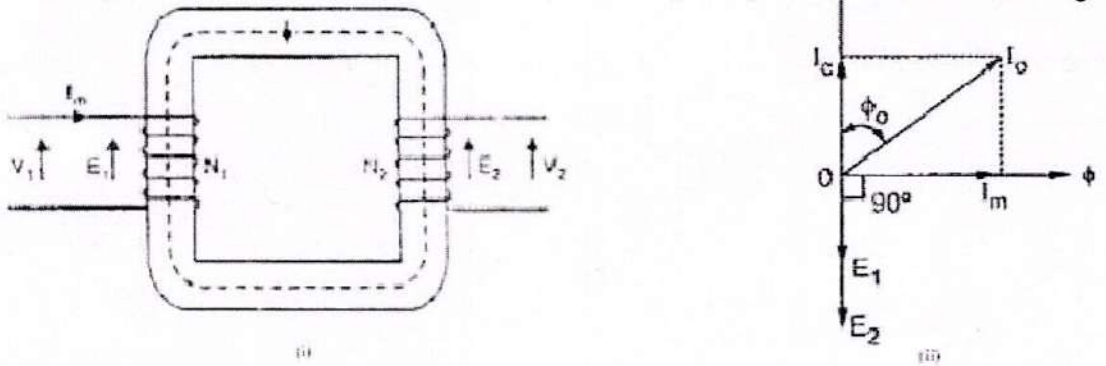


Fig: 2.5 Phasor diagram of transformer at noload

Here the primary will draw a small current I0 to supply -

(i) The iron losses and

(ii) A very small amount of copper loss in the primary.

Hence the primary no load current I0 is not 90° behind the applied voltage V1 but lags it by an angle $\phi 0 < 90°$ as shown in the phasor diagram. No load input power, W0 = V1 I0 cos ϕ0

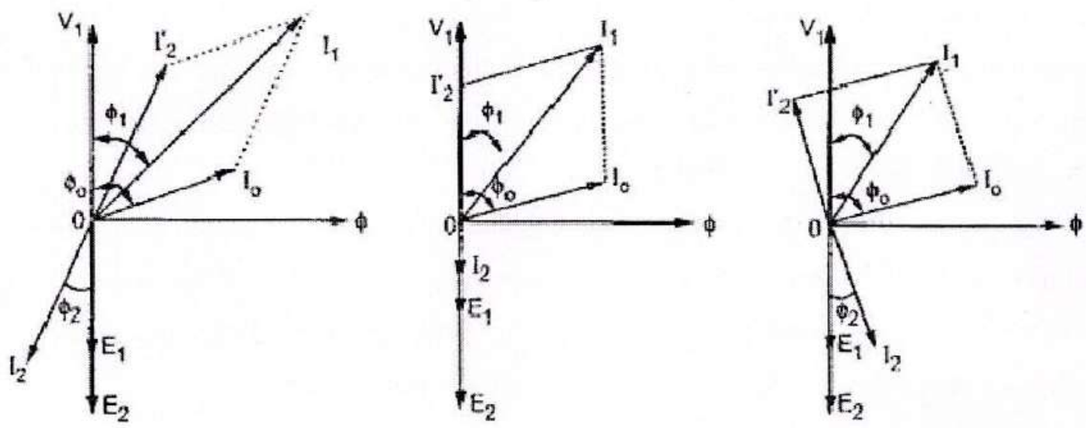
As seen from the phasor diagram in Fig.2.5 (ii), the no-load primary current I0

a) If load is Inductive, I2 lags E2 by ϕ2, shown in phasor diagram fig 2.7 (a).

b) If load is resistive, I2 in phase with E2 shown in phasor diagram fig. 2.7 (b).

c) If load is capacitive load, I2 leads E2 by ϕ2 shown in phasor diagram fig. 2.7 (c).

For easy understanding at this stage here we assumed E2 is equal to V2 neglecting various drops.



(a) Inductive load (b) Resistive load (c) Capacitive load

Fig: 2.7

$$\vec{I_1} = \vec{I_o} + \vec{I_2'}$$

$$I_1 \cong I_2' \qquad I_1 = \sqrt{Io^2 + I2'^2}$$

Balancing the ampere – turns

$$N_1 I_2' = N_1 I_1 + N_2 I_2$$

$$\frac{I1}{I2} = \frac{N2}{N1} = K$$

Now we going to construct complete phasor diagram of a transformer (shown in Fig: 2.7.b)

ii) Already Im magnetizing current flow in the primary winding fig. 2.6(i).

iii) The magnitude and phase of I2 with respect to V2 is determined by the characteristics of the load. a) I2 in phase with V2 (resistive load)

b) I2 lags with V2 (Inductive load)
c) I2 leads with V2 (capacitive load)

iv) Flow of secondary current I2 produce new Flux $\phi 2$ fig.2.6 (ii)
v) $\Phi$is main flux which is produced by the primary to maintain the transformer as constant magnetising component.
vi) $\Phi 2$ opposes the main flux ϕ, the total flux in the core reduced. It is called demagnetising Ampere- turns due to this E1 reduced.
vii) To maintain the ϕ constant primary winding draws more current (I2') from the supply (load component of primary) and produce $\phi 2'$ flux which is oppose $\phi 2$ (but in same direction as ϕ), to maintain flux constant flux constant in the core fig.2.6 (iii).
viii) The load component current I2' always neutralizes the changes in the load.
ix) Whatever the load conditions, the net flux passing through the core is approximately the same as at no-load. An important deduction is that due to the constancy of core flux at all loads, the core loss is also practically the same under all load conditions fig.2.6 (iv).

$$\Phi_2 = \phi_2' \quad N_2I_2 = N_1I_2' \quad I_2' = \frac{N2}{N1} XI_2 = KI_2$$

Phasor Diagram

i) Take (ϕ) flux as reference for all load

ii) The no load I_o which lags by an angle ϕo. $Io = \sqrt{Ic^2 + Im^2}$.

ii) The load component I2', which is in anti-phase with I2 and phase of I2 is decided by the load.

iii) Primary current I1 is vector sum of Io and I2'

$$\vec{I_1} = \vec{I_o} + \vec{I_2'}$$

$$I_1 = \sqrt{Io^2 + I2'^2}$$

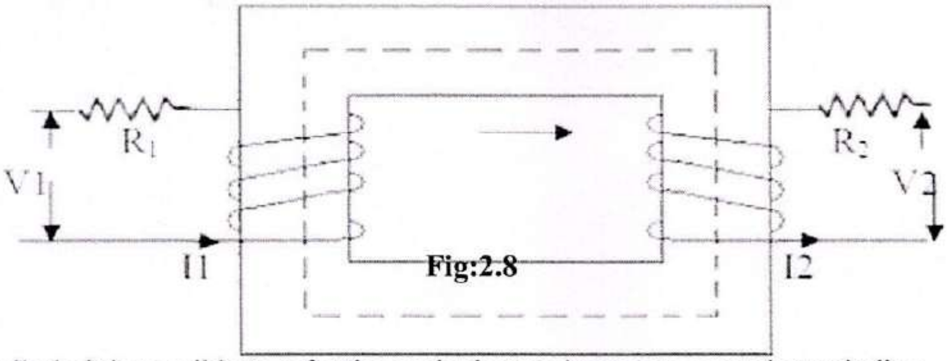


Fig:2.8

Similarly it is possible to refer the equivalent resistance to secondary winding.

Total copper loss $= I_1^2R_1 + I_2^2R_2 = I_2^2[\frac{I1^2}{I2^2}R_1 + R_2]$

$= I_2^2[K^2R_1 + R_2]$

K^2R1 is primary resistance referred to secondary denoted as R1'.

$R_1' = K^2R_1$

Equivalent resistance of transformer referred to secondary, denoted as R2e

$R_{2e} = R_2 + R_1' = R_2 + K^2R_1$

(ii)

Total copper loss $= I_2^2 R_{2e}$

Note:

i) When a resistance is to be transferred from the primary to secondary, it must be multiplied by K^2, it must be divided by K^2 while transferred from the secondary to primary.

High voltage side ➡ low current side ➡ high resistance side Low voltage side ➡ high current side ➡ low resistance side

Effect of Leakage Reactance

i) It has been assumed that all the flux linked with primary winding also links the secondary winding. But, in practice, it is impossible to realize this condition.

Effect of Winding Resistance

In practical transformer it process its own winding resistance causes power loss and also the voltage drop.

R1 – primary winding resistance in ohms.

R2 – secondary winding resistance in ohms.

The current flow in primary winding make voltage drop across it is denoted as I1R1 here supply voltage V1 has to supply this drop primary induced e.m.f E1 is the vector difference between V1 and I1R1.

$$\vec{E_1} = \vec{V_1} - \vec{I_1R_1}$$

Similarly the induced e.m.f in secondary E2, The flow of current in secondary winding makes voltage drop across it and it is denoted as I2R2 here E2 has to supply this drop.

The vector difference between E2 and I2R2

$\vec{V_2} = \vec{E_2} - \vec{I_2R_2}$ (Assuming as purely resistive drop here)

<u>Equivalent Resistance</u>

1) It would now be shown that the resistances of the two windings can be transferred to any one of the two winding.

2) The advantage of concentrating both the resistances in one winding is that it makes calculations very simple and easy because one has then to work in one winding only.

3) Transfer to any one side either primary or secondary without affecting the performance of the transformer.

The total copper loss due to both the resistances

$$\text{Total copper loss} = I_1^2R_1 + I_2^2R_2$$
$$= I_1^2[R_1 + \frac{I2^2}{I1^2}]$$
$$= I_1^2[R_1 + \frac{1}{K^2}R_2]$$

$\frac{R2}{K^2}$ is the resistance value of R_2 shifted to primary side and denoted as R_2'.

R_2' is the equivalent resistance of secondary referred to primary

$$R_2' = \frac{R2}{K^2}$$

Equivalent resistance of transformer referred to primary fig (ii)

$$R_{01} = R_1 + R_2' = R_1 + \frac{R2}{}$$

secondary. The relation through K^2 remains same for the transfer of reactance as it is studied earlier for the resistance

X1 – leakage reactance of primary.

X2 - leakage reactance of secondary.

Then the total leakage reactance referred to primary is X1e given by

$$X_{1e} = X_1 + X_2'$$

$$X_2' = \frac{X2}{K^2}$$

The total leakage reactance referred to secondary is X_{2e} given by

$$X_{2e} = X_2 + X_1'$$
$$X_1' = K^2X_1$$

$$X_{1e} = X_1 + X_2'$$
$$X_{2e} = X_2 + X_1'$$

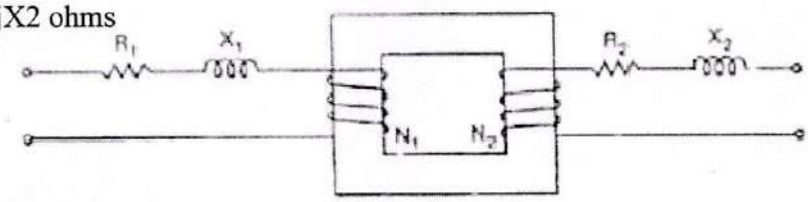
Equivalent Impedance

The transformer winding has both resistance and reactance (R1, R2, X1,X2).Thus we can say that the total impedance of primary winding isZ1 which is,

Z1 = R1 + jX1 ohms

On secondary winding,

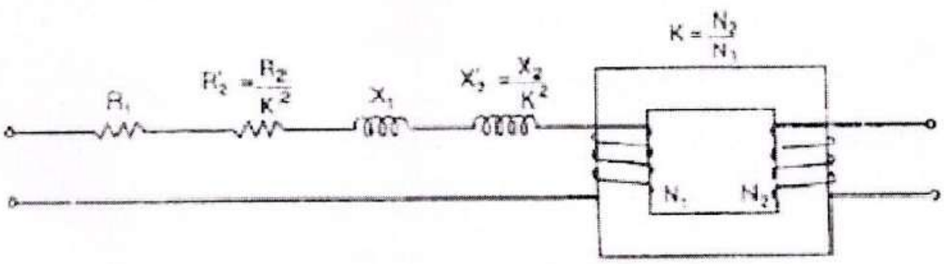
Z2 = R2 + jX2 ohms



Individual magnitude of Z1 and Z2 are

$$Z_1 = \sqrt{R1^2 + X1^2}$$
$$Z_2 = \sqrt{R2^2 + X2^2}$$

Similar to resistance and reactance, the impedance also can be referred to any one side,



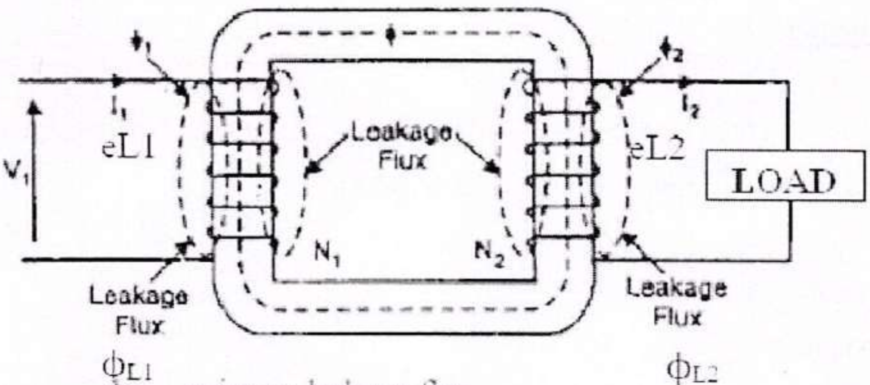
Z_{1e} = total equivalent impedance referred to primary

$$Z_{1e} = R_{1e} + jX_{1e} = Z_1 + Z_2' = Z_1 + \frac{Z2}{K^2}$$

ii) However, primary current would produce flux ϕ which would not link the secondary winding. Similarly, current would produce some flux ϕ that would not link the primary winding.

iii) The flux $\phi L1$ complete its magnetic circuit by passing through air rather than around the core, as shown in fig.2.9. This flux is known as primary leakage flux and is proportional to the primary ampere – turns alone because the secondary turns do not links the magnetic circuit of $\phi L1$. It induces an e.m.f eL1 in primary but not in secondary.

iv) The flux $\phi L2$ complete its magnetic circuit by passing through air rather than around the core, as shown in fig. This flux is known as secondary leakage flux and is proportional to the secondary ampere– turns alone because the primary turns do not links the magnetic circuit of $\phi L2$. It induces an e.m.f eL2 in secondary but not in primary.



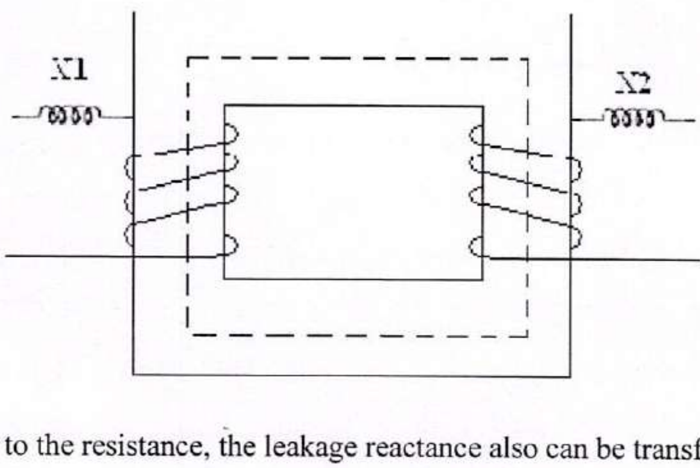
ϕ_{L1} – primary leakage flux

ϕ_{L2} – secondary leakage flux

e_{L1} – self induced e.m.f (primary)

e_{L2} – self induced e.m.f (secondary)

Equivalent Leakage Reactance



Similarly to the resistance, the leakage reactance also can be transferred from primary to

i) Im produces the flux and is assumed to flow through reactance Xo called no load reactance while Ic is active component representing core losses hence is assumed to flow through the resistance R0

ii) Equivalent resistance is shown in fig.2.12.

iii) When the load is connected to the transformer then secondary current I2 flows causes voltage drop across R2 and X2. Due to I2, primary draws an additional current.

$$I_2' = \frac{I2}{K}$$

I1 is the phasor addition of Io and I2'. This I1 causes the voltage drop across primary resistance R1 and reactance X1.

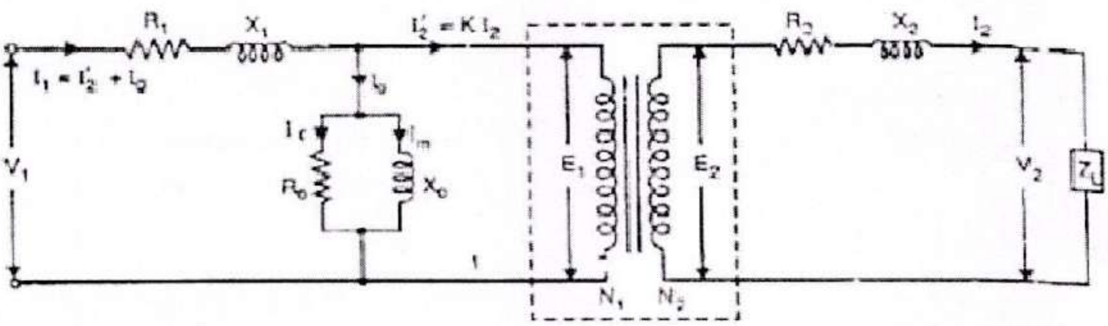


Fig: 2.12

To simplified the circuit the winding is not taken in equivalent circuit while transfer to one side.

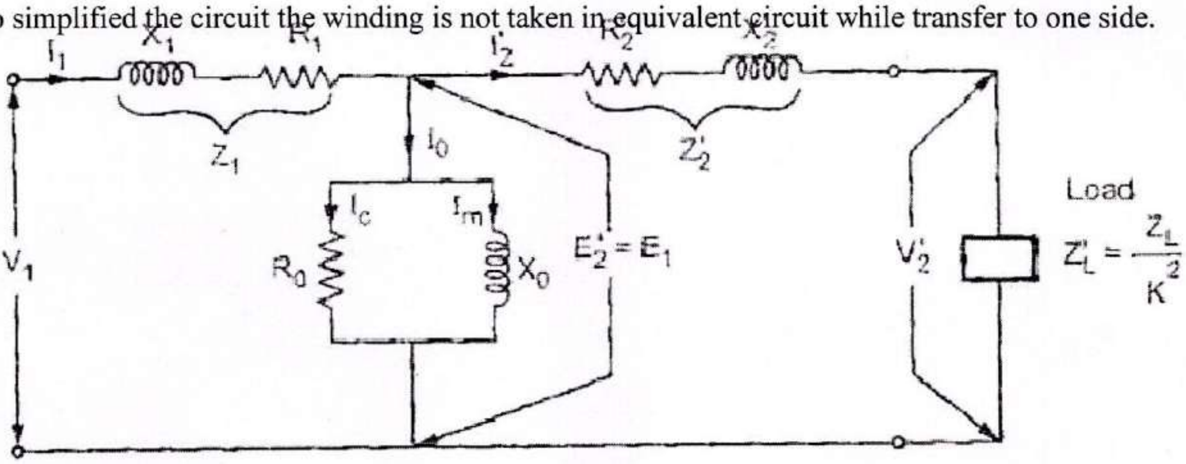


Fig: 2.13

Exact equivalent circuit referred to primary

Transferring secondary parameter to primary -

$$R_2' = \frac{R2}{K^2},\ X_2' = \frac{X2}{K^2},\ Z_2' = \frac{Z2}{K^2},\ E_2' = \frac{E2}{K},\ I_2' = KI_2,\ K = \frac{N2}{N1}$$

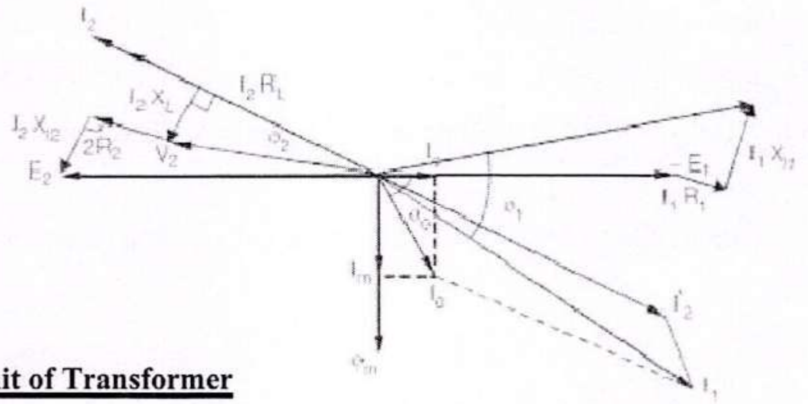
Complete Phasor Diagram of a Transformer *(for Inductive Load or Lagging pf)*

We now restrict ourselves to the more commonly occurring load i.e. inductive along with resistance,

which has a lagging power factor. For drawing this diagram, we must remember that

$$\bar{V}_2 = \bar{E}_2 - \bar{I}_2 (R_2 + j X_{l2})$$

and $$\bar{V}_1 = -\bar{E}_1 + \bar{I}_2 (R_1 + j X_{l1})$$



Equivalent Circuit of Transformer

No load equivalent circuit

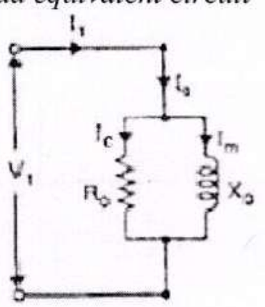


Fig:11

$I_m = I_o \sin \phi_o$ = magnetizing component

$I_c = I_o \cos \phi_o$ = Active component

$R_o = \frac{V1}{Ic}$ $X_o = \frac{V1}{Im}$

Approximate Equivalent Circuit

i) To get approximate equivalent circuit, shift the no load branch containing Ro and Xo to the left of R1 and X1.

ii) By doing this we are creating an error that the drop across R1 and X1 to Io is neglected due to this circuit because simpler.

iii) This equivalent circuit is called approximate equivalent circuit Fig: 2.15 & Fig: 2.16.

In this circuit new R1 and R2' can be combined to get equivalent circuit referred to primary R1e,similarly

X1 and X2' can be combined to get X1e.

$$R_{1e} = R_1 + R_2' = R_1 + \frac{R2}{K^2}$$

$$X_{1e} = X_1 + X_2' = X_1 + \frac{X2}{K^2}$$

$$Z_{1e} = R_{1e} + jX_1E. \qquad R_0 = \frac{V1}{Ic}, \quad \text{and } X_0 = \frac{V1}{Im}$$

$$I_c = I_0 \cos\phi_0 \quad \text{and } I_m = I_0 \sin\phi_0$$

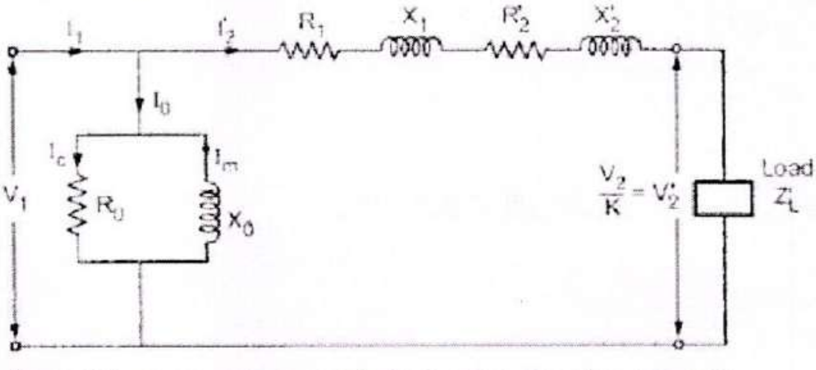
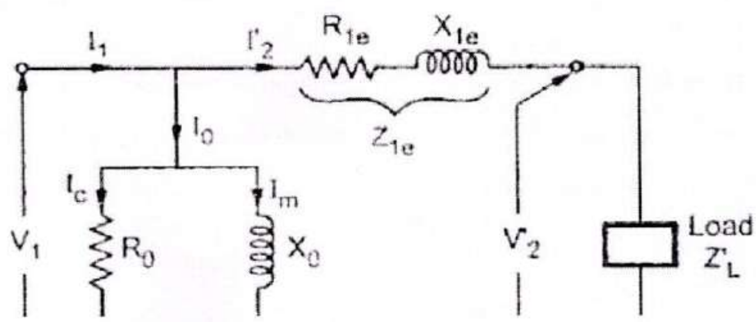


Fig: 2.15Approximate equivalent circuit referred to primary



High voltage winding	low current	high impedance
Low voltage winding	high current	low impedance

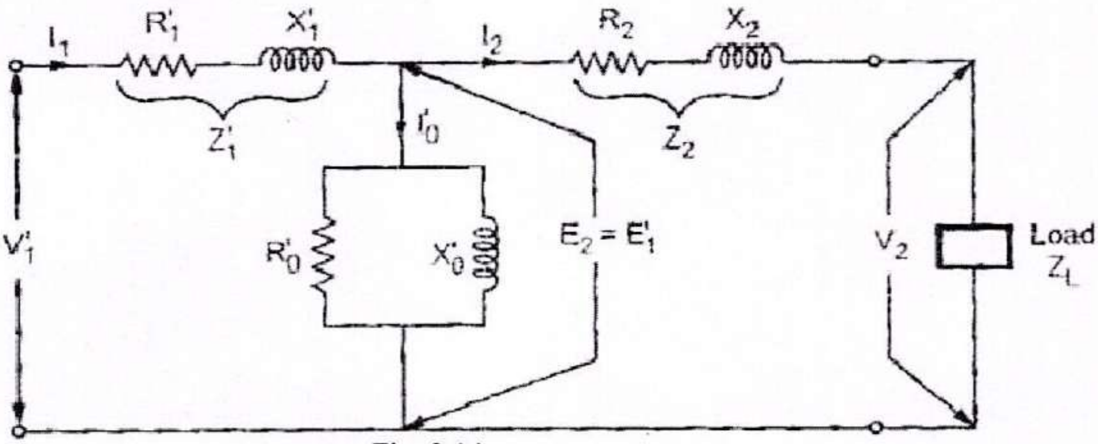


Fig: 2.14

Exact equivalent circuit referred to secondary

$$R_1' = R_1K^2, X_1' = K^2X_1 , E_1' = KE_1$$

$$Z_1' = K^2Z1 , I_1' = \frac{I1}{K}, I_o = \frac{Io}{K}$$

Now as long as no load branch i.e. exciting branch is in between Z1 and Z2', the impedances cannot be combined. So further simplification of the circuit can be done. Such circuit is called approximate equivalent circuit.

v) The total voltage drop is $AM = I_2Z_{2e}$.

vi) The angle α is practically very small and in practice M&N are very close to each other. Due to this the approximate voltage drop is equal to AN instead of AM

AN – approximate voltage drop

To find AN by adding

AD& DN $AD = AB\cos\phi$

$= I_2R_{2e}\cos\phi$ $DN = BL$

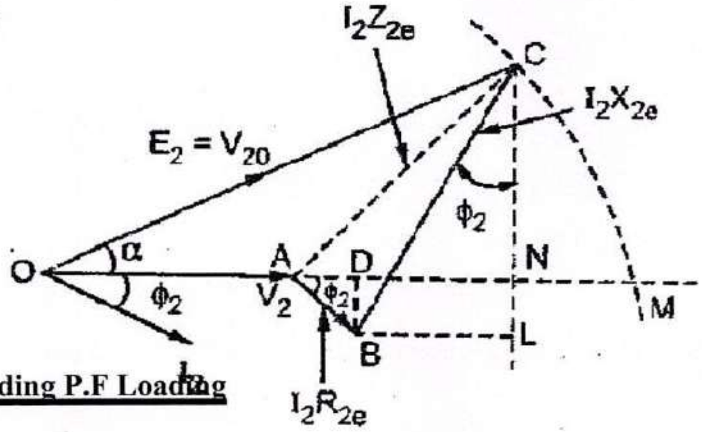
$\sin\phi = I_2X_{2e}\sin\phi$

$AN = AD + DN = I_2R_{2e}\cos\phi_2 + I_2X_{2e}\sin\phi_2$

Assuming: $\phi_2 = \phi_1 = \phi$

Approximate voltage drop $= I_2R_{2e}\cos\phi + I_2X_{2e}\sin\phi$ (referred to secondary)

Similarly: Approximate voltage drop $= I_1R_{1e}\cos\phi + I_1X_{1e}\sin\phi$ (referred to primary)

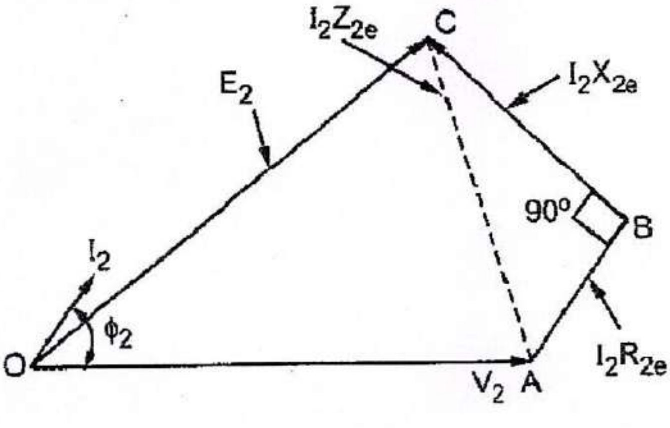


For Leading P.F Loading

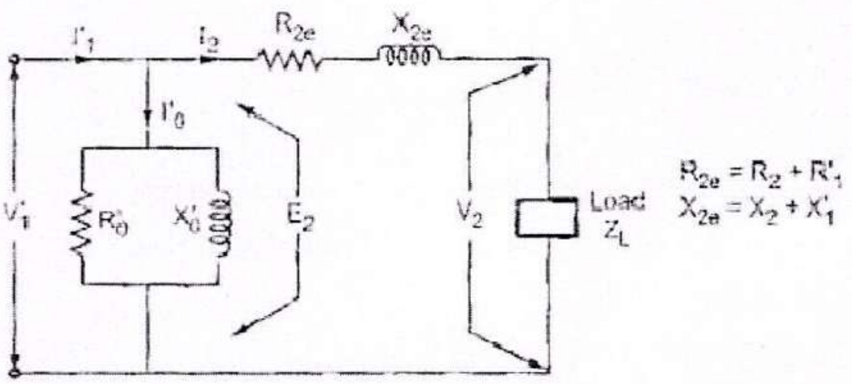
I_2 leads V_2 by angle ϕ_2

Approximate voltage drop $= I_2R_{2e}\cos\phi - I_2X_{2e}\sin\phi$ (referred to secondary)

Similarly: Approximate voltage drop $= I_1R_{1e}\cos\phi - I_1X_{1e}\sin\phi$ (referred to primary)



Approximate Voltage Drop in a Transformer



$$\vec{E_2} = \overrightarrow{I_2R_{2e} + I_2X_{2e}} + \vec{V_2} = \vec{V_2} + \vec{I_2}(R_{2e} + jX_{2e}). \quad \vec{E_2} = \vec{V_2} + \overrightarrow{I_2Z_{2e}}$$

Fig. 2.17

Primary parameter is referred to secondary there are no voltage drop in primary. When there is no load,

I2 = 0 and we get no load terminal voltage drop in

V2o = E2 = no load terminal voltage

V2 = terminal voltage on load

For Lagging P.F.

i) The current I2 lags V2 by angle ϕ2

ii) Take V2 as reference

iii) I2R2e is in phase with I2 while I2 X2e leads I2 by 90°

iv) Draw the circle with O as centre and OC as radius cutting extended OA at M.

as OA = V2 and now OM = E2.

Ke – eddy current constant

t - Thickness of the core

Both hysteresis and eddy current losses depend upon

(i) Maximum flux density Bm in the core

(ii) Supply frequency f. Since transformers are connected to constant-frequency, constant voltage supply, both f and Bm are constant. Hence, core or iron losses are practically the same at all lods.

Iron or Core losses, Pi = Hysteresis loss + Eddy current loss = Constant losses (Pi)

The hysteresis loss can be minimized by using steel of high silicon content .Whereas eddy current loss can be reduced by using core of thin laminations.

Copper losses (Pcu)

These losses occur in both the primary and secondary windings due to their ohmic resistance. These can be determined by short-circuit test. The copper loss depends on the magnitude of the current flowing

through the windings.

$$\text{Total copper loss} = I_1^2R_1 + I_2^2R_2 = I_1^2(R_1 + R_2') = I_2^2(R_2 + R_1')$$

$$\boxed{\text{Total loss} = \text{iron loss} + \text{copper loss} = Pi + Pcu}$$

Efficiency of a Transformer

Like any other electrical machine, the efficiency of a transformer is defined as the ratio of output power (in watts or kW) to input power (watts or kW) i.e.

Power output = power input – Total losses

Power input = power output + Total losses

= power output + Pi + Pcu

$$\text{Efficiency} = \frac{power\ output}{power\ input}$$

$$\text{Efficiency} = \frac{power\ output}{power\ input + Pi + Pcu}$$

Power output = $V_2I_2\cos\phi$. Cos ϕ = load power factor

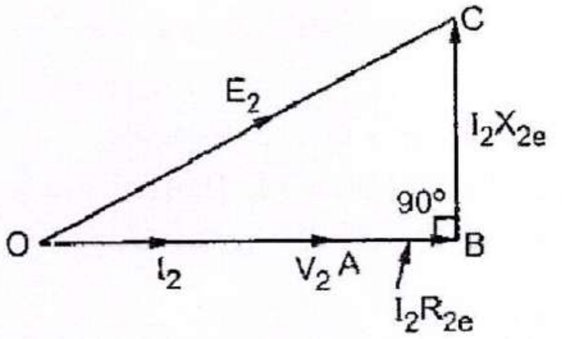
Transformer supplies full load of current I_2 and with terminal voltage V_2

Pcu = copper losses on full load = $I_2^2R_{2e}$

For Unity P.F. Loading

Approximate voltage drop = I2R2e (referred to secondary)

Similarly: Approximate voltage drop = I1R1e (referred to primary)



Cosϕ = 1
Sinϕ = 0

Fig: 2.20

Approximate voltage drop = E2 – V2

= I2R2e cosϕ ± I2X2e sinϕ (referred to secondary)

= I1R1e cosϕ ± I1X1e sinϕ (referred to primary)

Losses in a Transformer

The power losses in a transformer are of two types, namely;

1. Core or Iron losses

2. Copper losses

These losses appear in the form of heat and produce (i) an increase in Temperature and (ii) a drop in efficiency.

Core or Iron losses (Pi)

These consist of hysteresis and eddy current losses and occur in the transformer core due to the alternating flux. These can be determined by open-circuit test.

Hysteresis loss = kh f $Bm^{1.6}$ watts $/m^3$

Kh – hysteresis constant depend on material

f - Frequency

Bm – maximum flux density

Eddy current loss = Ke f^2 Bm^2t^2 watts $/m^3$

Load output = $V_1 I_1 \cos\phi 1$

Copper loss = $I_1^2 R_{1e}$ or $I_2^2 R_{2e}$

Iron loss = hysteresis + eddy current loss = Pi

$$\text{Efficiency} = \frac{V1I1\cos\phi1 - \text{losses}}{V1I1\cos\phi1} = \frac{V1I1\cos\phi1 - I1^2R1e + Pi}{V1I1\cos\phi1}$$

$$= 1 - \frac{I1R1e}{V1I21\cos\phi1} - \frac{Pi}{V1I1\cos\phi1}$$

Differentiating both sides with respect to I2, we get

$$\frac{d\eta}{dI2} = 0 - \frac{R1e}{V1\cos\phi1} - \frac{Pi}{V1I1^2\cos\phi1}$$

For η to be maximum, $\frac{d\eta}{dI2} = 0$. Hence, the above equation becomes

$$\frac{R1e}{V1\cos\phi1} = \frac{Pi}{V1I1^2\cos\phi1} \text{ or } P_i = I_1^2 R_{1e}$$

Pcu loss = Pi iron loss

The output current which will make Pcu loss equal to the iron loss. By proper design, it is possible to make the maximum efficiency occur at any desired load.

Load current I2m at maximum efficiency

KVA Supplied at Maximum Efficiency

For constant V2 the KVA supplied is the function of load current.

For η_{max} $I_2^2 R_{2e} = P_i$ but $I_2 = I_{2m}$

$$I_{2m}^2 R_{2e} = Pi \qquad I_{2m} = \sqrt{\frac{Pi}{R2e}}$$

This is the load current at η_{max}.

$(I_2)F.L$ = full load current

$$\frac{I2m}{(I2)F.L} = \frac{1}{(I2)F.L}\sqrt{\frac{Pi}{R2e}}$$

$$\frac{I2m}{(I2)F.L} = \sqrt{\frac{Pi}{[(I2)F.L]^2 R2e}} = \sqrt{\frac{Pi}{[Pcu]F.L}}$$

$$\boxed{I_{2m} = (I_2)F.L\sqrt{\frac{Pi}{[Pcu]F.L}}}$$

This is full load efficiency and I2 = full load current.

We can now find the full-load efficiency of the transformer at any p.f. without actually loading the transformer.

$$\text{Full load Efficiency} = \frac{(\text{Full load VA rating})X\cos\phi}{(\text{Full load VA rating})X\cos\phi + Pi + I2^2 R2e}$$

Also for any load equal to n x full-load,

Corresponding total losses = $P_i + n^2 P_{cu}$

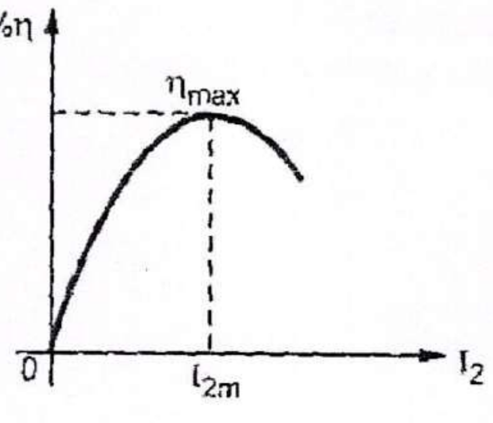
$$n = \text{fractional by which load is less than full load} = \frac{actual\ load}{full\ load}$$

$$n = \frac{half\ load}{fullload} = \frac{(\frac{1}{2})}{1} = 0.5$$

$$\text{Corresponding (n) \% Efficiency} = \frac{n(\text{VA rating})X\cos\phi}{n(\text{VA rating})X\cos\phi + Pi + n^2 Pcu} X\ 100$$

Condition for Maximum Efficiency

Voltage and frequency supply to the transformer is constant the efficiency varies with the load. As load increases, the efficiency increases. At a certain load current, it loaded further the efficiency start decreases as shown in fig. 2.21.



The load current at which the efficiency attains maximum value is denoted as I_{2m} and maximum efficiency is denoted as ηmax, now we find -

(a) condition for maximum efficiency

(b) load current at which ηmax occurs

(c) KVA supplied at maximum efficiency Considering primary side,

i) Load test on transformer

This method is also called as direct loading test on transformer because the load is directly connected to the transformer. We required various meters to measure the input and output reading while change the load from zero to full load. Fig. 2.22 shows the connection of transformer for direct load test. The primary is connected through the variac to change the input voltage as we required. Connect the meters as shown in the figure below.

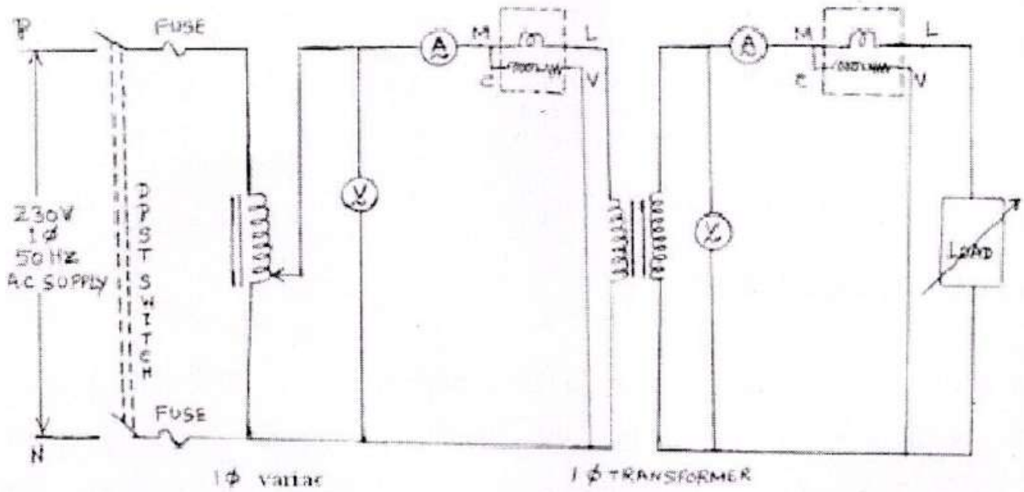


Fig: 2.22

The load is varied from no load to full load in desired steps. All the time, keep primary voltage V1 constant at its rated value with help of variac and tabulated the reading. The first reading is to be noted on no load for which I2 = 0 A and W2 = 0W.

<u>**Calculation**</u>

From the observed reading

W1 = input power to the transformer
W2 = output power delivered to the load

$$\% \eta = \frac{W2}{W1} X\ 100$$

The first reading is no load so $V2 = E_2$
The regulation can be obtained as

$$\% R = \frac{E2 - V2}{} X\ 100$$

KVA Supplied at Maximum Efficiency

For constant V2 the KVA supplied is the function of load current.

$$\text{KVA at } \eta_{max} = I_{2m} V_2 = V_2 (I_2)_{F.L.} \times \sqrt{\frac{P_i}{[P_{cu}]_{F.L}}}$$

$$\boxed{\text{KVA at } \eta_{max} = (\text{KVA rating}) \times \sqrt{\frac{P_i}{[P_{cu}]_{F.L}}}}$$

Substituting condition for η_{max} in the expression of efficiency, we can write expression for η_{max} as ,

as $P_{cu} = P_i$

$$\% \eta_{max} = \frac{V2\ I2m \cos\phi}{V2\ I2m \cos\phi + 2 Pi} \times 100$$

All Day Efficiency (Energy Efficiency)

In electrical power system, we are interested to find out the all-day efficiency of any transformer because the load at transformer is varying in the different time duration of the day. So all day efficiency is defined as the ratio of total energy output of transformer to the total energy input in 24 hours.

$$\text{All day efficiency} = \frac{\text{kWh output during a day}}{\text{kWh input during the day}}$$

Testing of Transformer

The testing of transformer means to determine efficiency and regulation of a transformer at any load and at any power factor condition.

There are two methods

i) Direct loading test

ii) Indirect loading test

a. Open circuit test

b. Short circuit test

winding) while the secondary is left open circuited. The applied primary voltage V1 is measured by the voltmeter, the no load current I0 by ammeter and no-load input power W0 by wattmeter as shown in Fig.2.24.a. As the normal rated voltage is applied to the primary, therefore, normal iron losses will occur in the transformer core. Hence wattmeter will record the iron losses and small copper loss in the primary. Since no-load current I0 is very small (usually 2-10 % of rated current). Cu losses in the primary under no-load condition are negligible as compared with iron losses. Hence, wattmeter reading practically gives the iron losses in the transformer. It is reminded that iron losses are the same at all loads.

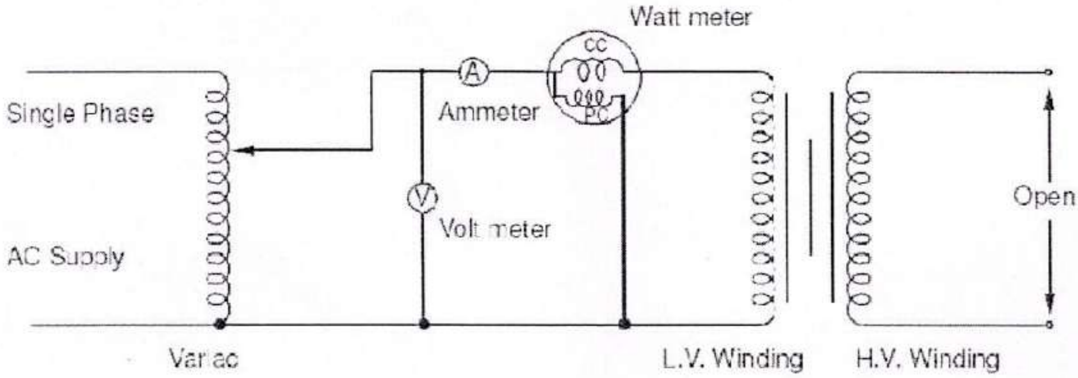


Fig: 2.24.a

Iron losses, P_i = Wattmeter reading = W_0
No load current = Ammeter reading = I_0
Applied voltage = Voltmeter reading = V_1

Input power, $W_0 = V_1 I_0 \cos \phi_0$

No - load p.f., $\cos\phi = \frac{Wo}{Vo\,Io}$ = no load power factor

$I_m = I_o \sin \phi_o$ = magnetizing component
$I_c = I_0 \cos \phi_0$ = Active component

$R_0 = \frac{Vo}{Ic}\ \Omega$, $X_0 = \frac{Vo}{Im}\ \Omega$

The graph of % η and % R on each load against load current IL is plotted as shown in fig. 2.23.

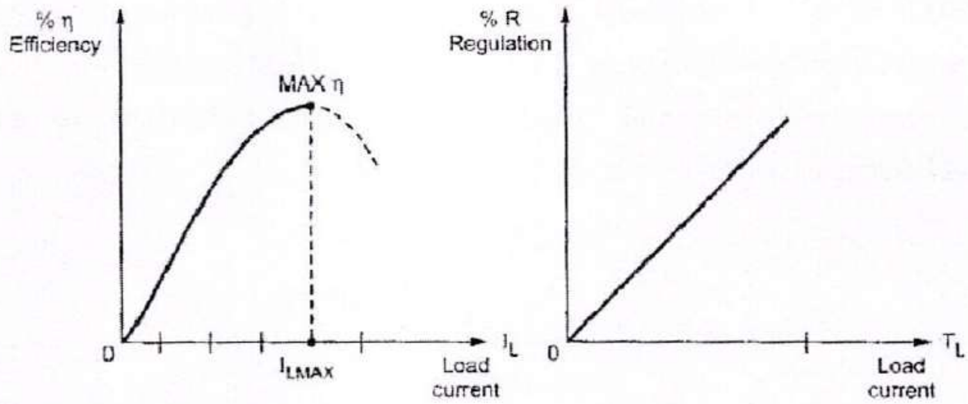


Fig: 2.23

Advantages:

1) This test enables us to determine the efficiency of the transformer accurately at any load.

2) The results are accurate as load is directly used.

Disadvantages:

1) There are large power losses during the test.

2) Load not avail in lab while test conduct for large transformer.

ii) a. Open-Circuit or No-Load Test

This test is conducted to determine the iron losses (or core losses) and parameters R0 and X0 of the transformer. In this test, the rated voltage is applied to the primary (usually low-voltage

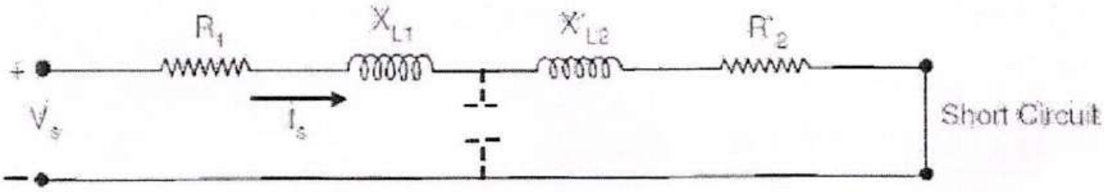
Fig: 2.25.a

Full load Cu loss, PC = Wattmeter reading = W_{sc}
Applied voltage = Voltmeter reading = V_{sc}
F.L. primary current = Ammeter reading = I_1

$Pcu = I_1^2 R_1 + I_1^2 R_2' = I_1^2 R_{1e}$ ∴ $R_{1e} = \frac{Pcu}{I1^2}$
Where R_{1e} is the total resistance of transformer referred to primary.

Total impedance referred to primary, $Z1e = \sqrt{Z1e^2 - R1e^2}$.

short – circuit P.F. $\cos \Phi = \frac{Pcu}{Vsc\, I1}$ Thus short-circuit test gives full-load Cu loss, R1e and X1e.



$$\text{equivalent resistance } R_{eq} = \frac{W_s}{I_s^2} = R_1 + R_2'$$

$$\text{and equivalent impedance } Z_{eq} = \frac{V_s}{I_s}$$

So we calculate equivalent reactance

$$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2} = X_{L1} + X_{L2}'$$

These R_{eq} and X_{eq} are equivalent resistance and reactance of both windings referred in HV side. These are know as equivalent circuit resistance and reactance.

Voltage Regulation of Transformer

Under no load conditions, the voltage at the secondary terminals is E2 and

$$E_2 \approx V_1 \cdot \frac{N_2}{N_1}$$

(This approximation neglects the drop *R*1 and *Xl*1 due to small no load current). As load is applied

Under no load conditions the PF is very low (near to 0) in lagging region. By using the above data we can draw the equivalent parameter shown in Figure 2.24.b.

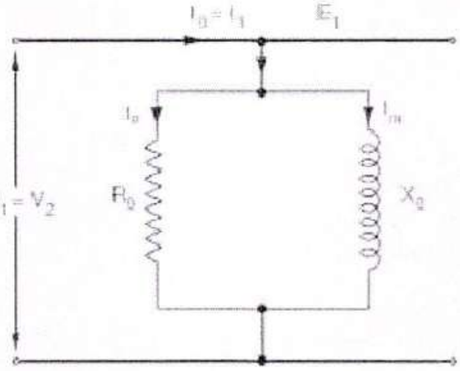
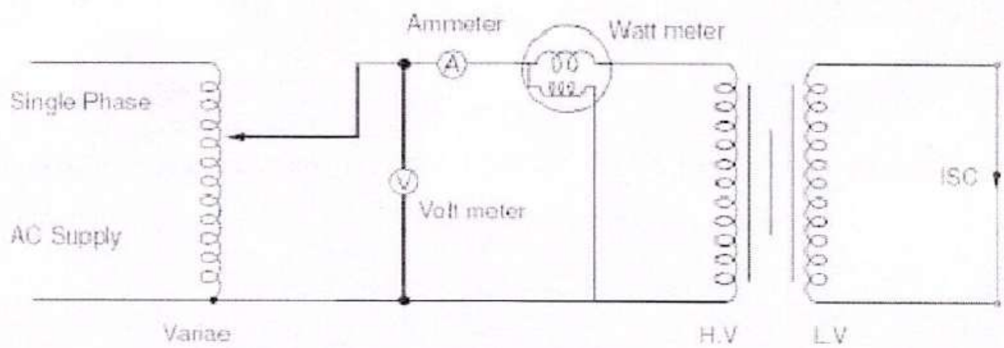


Fig: 2.24.b

Thus open-circuit test enables us to determine iron losses and parameters R0 and X0 of the transformer

ii) b. Short-Circuit or Impedance Test

This test is conducted to determine R1e (or R2e), X1e (or X2e) and full-load copper losses of the transformer. In this test, the secondary (usually low-voltage winding) is short-circuited by a thick conductor and variable low voltage is applied to the primary as shown in Fig.2.25. The low input voltage is gradually raised till at voltage VSC, full-load current I1 flows in the primary. Then I2 in the secondary also has full-load value since I1/I2 = N2/N1. Under such conditions, the copper loss in the windings is the same as that on full load. There is no output from the transformer under short-circuit conditions. Therefore, input power is all loss and this loss is almost entirely copper loss. It is because iron loss in the core is negligibly small since the voltage VSC is very small. Hence, the wattmeter will practically register the full load copper losses in the transformer windings.



UNIT - II

THREE PHASE TRANSFORMERS

Introduction

Electric power is generated in generating stations, using three phase alternators at 11 K This voltage is further stepped up to 66 KV, 110 KV, 230 KV or 400 KV using 3 phase power transformers and power is transmitted at this high voltage through transmission lines. At the receiving substations, these high voltages are stepped down by 3 phase transformers to 11 KV. This is further stepped down to 400 volts at load centers by means of distribution transformers. For generation, transmission and distribution, 3 phase system is economical. Therefore 3 phase transformers are very essential for the above purpose. The sectional view of a 3 phase power transformer is shown in Fig.4.1.

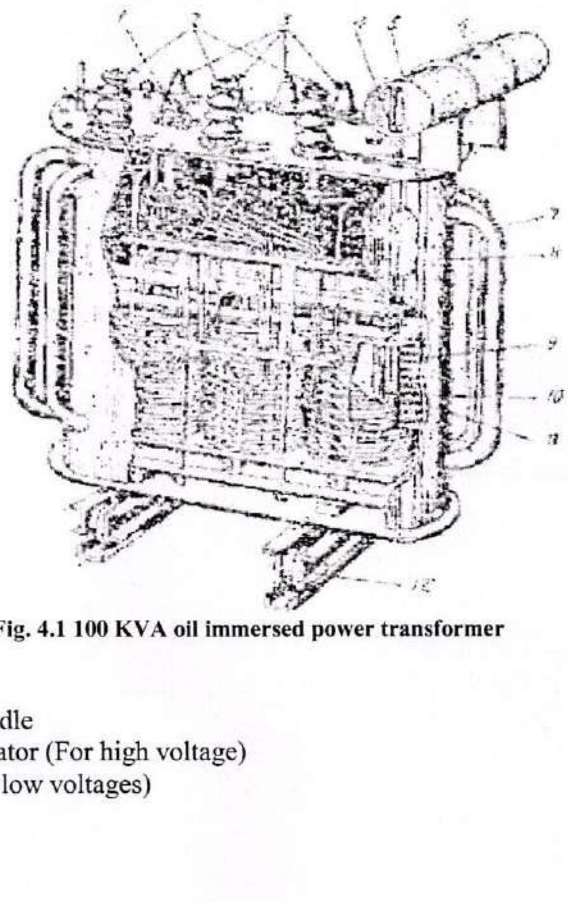


Fig. 4.1 100 KVA oil immersed power transformer

1. Tap-changer switch handle
2. Porcelain-bushing insulator (For high voltage)
3. Bushing insulators (For low voltages)
4. Oil gauge
5. Oil tank
6. Breather plug
7. Cooling pipes
8. Tank front wall

to the transformer, the load current or the secondary current increases. Correspondingly, the primary current $I1$ also increases. Due to these currents, there is a voltage drop in the primary and secondary leakage reactances, and as a consequence the voltage across the output terminals or the load terminals changes. In quantitative terms this change in terminal voltage is called Voltage Regulation.

Voltage regulation of a transformer is defined as the drop in the magnitude of load voltage (or secondary terminal voltage) when load current changes from zero to full load value. This is expressed as a fraction of secondary rated voltage.

$$\text{Regulation} = \frac{\text{Secondary terminal voltage at no load} - \text{Secondary terminal voltage at any load}}{\text{Secondary rated voltage}}$$

The secondary rated voltage of a transformer is equal to the secondary terminal voltage at no load (i.e. E2), this is as per IS.

Voltage regulation is generally expressed as a percentage.

$$\text{Percent voltage regulation (\% VR)} = \frac{E_2 - V_2}{E_2} \times 100.$$

Note that E2, V2 are magnitudes, and not phasor or complex quantities. Also note that voltage regulation depends not only on load current, but also on its power factor. Using approximate equivalent circuit referred to primary or secondary, we can obtain the voltage regulation. From approximate equivalent circuit referred to the secondary side and phasor diagram for the circuit.

$$E_2 = V_2 + I_2\, r_{eq} \cos \phi_2 \pm I_2\, x_{eq} \sin \phi_2$$

where $r_{eq} = r_2 + r_1^1$ (referred to secondary) $x_e = x_2 + x_1^1$ (+ sign applies lagging power factor load and – sign applies to leading pf load).

So
$$\frac{E_2 - V_2}{E_2} = \frac{I_2\, r_{eq} \cos \phi_2 \pm I_2\, x_{eq} \sin \phi_2}{E_2}$$

$$\frac{E_2 - V_2}{E_2} = \frac{I_2\, r_{eq}}{E_2} \cos \phi_2 \pm \frac{I_2\, x_{eq}}{E_2} \sin \phi_2$$

% Voltage regulation = (% resistive drop) cos ϕ_2 ± (% reactive drop) sin ϕ_2.

The core type transformers are usually wound with circular cylindrical coils. The construction and assembly of laminations and yoke of a three phase core type transformer is shown in fig 4.4 one method of arrangement of windings in a three phase transformer is shown.

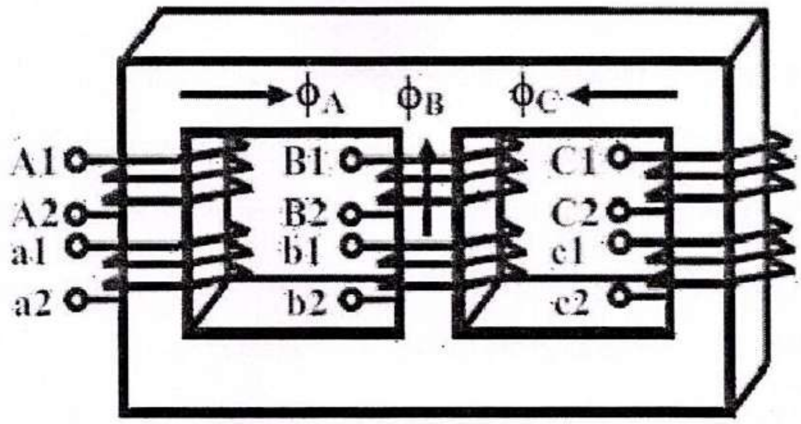


Fig. 4.3 A practical core type three phase transformer

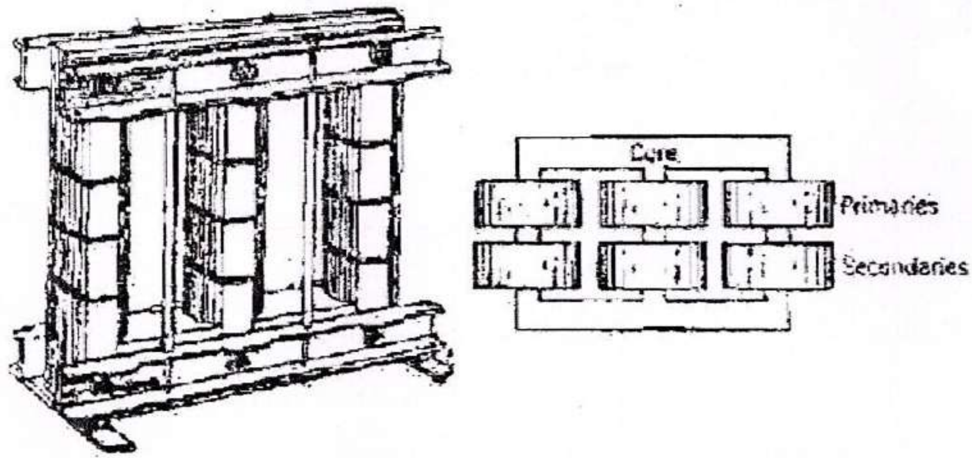


Fig. 4.4 Core type transformer windings and construction

In the other method the primary and secondary windings are wound one over the other in each limb. The low-tension windings are wound directly over the core but are, of course, insulated for it. The high tension windings are wound over the low— tension windings and adequate insulation is provided between the two windings.

9. Core,
10. High voltage winding
11. Low voltage winding
12. Wheels or rollers.

Construction of Three phase Transformer

Three phase transformers comprise of three primary and three secondary windings. They are wound over the laminated core as we have seen in single phase transformers. Three phase transformers are also of core type or shell type as in single phase transformers. The basic principle of a three phase transformer is illustrated in fig 4.2 in which the primary windings and secondary windings of three phases are shown. The primary windings can be inter connected in star or delta and put across three phase supply.

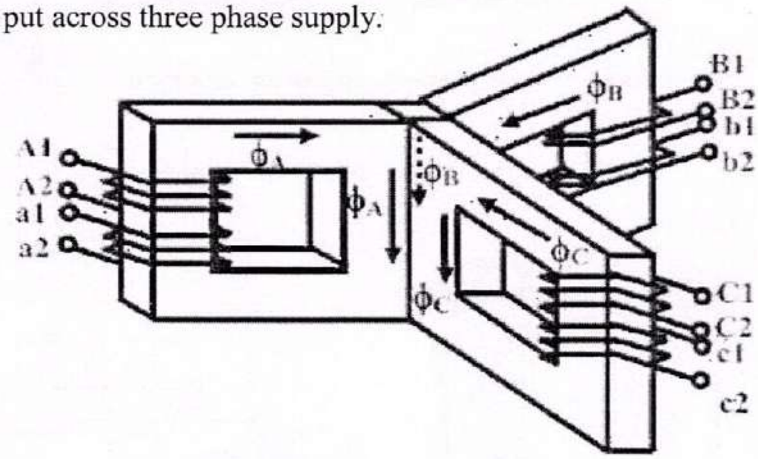


Fig. 4.2 3-phase core-type Transformer

The three cores are 120° apart and their unwound limbs are shown in contact with each other. The center core formed by these three limbs, carries the flux produced by the three phase currents I_R, I_Y and I_B. As at any instant $I_R+I_y+I_B=0$, the sum of three fluxes (flux in the center limb) is also zero.

Therefore it will make no difference if the common limb is removed. All the three limbs are placed in one plane in case of a practical transformer as shown in fig 4.3.

Fig. 4.6 Delta-delta connection

The primary and secondary windings of the three phase transformer can also be interconnected as star or delta.

Three Phase Transformer connections:-

The identical single phase transformers can be suitably inter-connected and used instead of a single unit 3—phase transformer. The single unit 3 phase transformer is housed in a single tank. But the transformer bank is made up of three separate single phase transformers each with its own, tanks and bushings. This method is preferred in mines and high altitude power stations because transportation becomes easier. Bank method is adopted also when the voltage involved is high because it is easier to provide proper insulation in each single phase transformer.

As compared to a bank of single phase transformers, the main advantages of a single unit 3-phase transformer are that it occupies less floor space for equal rating, less weight costs about 20% less and further that only one unit is to be handled and connected.

There are various methods available for transforming 3 phase voltages to higher or lower 3 phase voltages. The most common connections are (i) star — star (ii) Delta—Delta (iii) Star —Delta (iv) Delta — Star.

Fig 4.5 Star-star connection

Fig. 4.8 Delta-star connection

The star-star connection is most economical for small, high voltage transformers because the number of turns per phase and the amount of insulation required is minimum (as phase voltage is only 1/3 of line voltage. In fig. 4.5 a bank of three transformers connected in star on both the primary and the secondary sides is shown. The ratio of line voltages on the primary to the secondary sides is the same as a transformation ratio of single phase transformer.

The delta— delta connection is economical for large capacity, low voltage transformers in which insulation problem is not a serious one. The transformer connection are as shown in fig. 4.6.

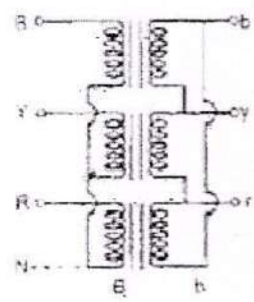


Fig. 4.7 Star-delta connection

The main use of star-delta connection is at the substation end of the transmission line where the voltage is to be stepped down. The primary winding is star connected with grounded neutral as shown in Fig. 4.7. The ratio between the secondary and primary line voltage is 1/3 times the transformation ratio of each single phase transformer. There is a 30° shift between the primary and secondary line voltages which means that a star-delta transformer bank cannot be paralleled with either a star-star or a delta-delta bank.

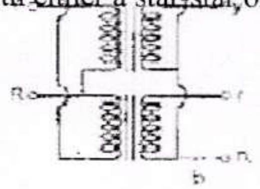
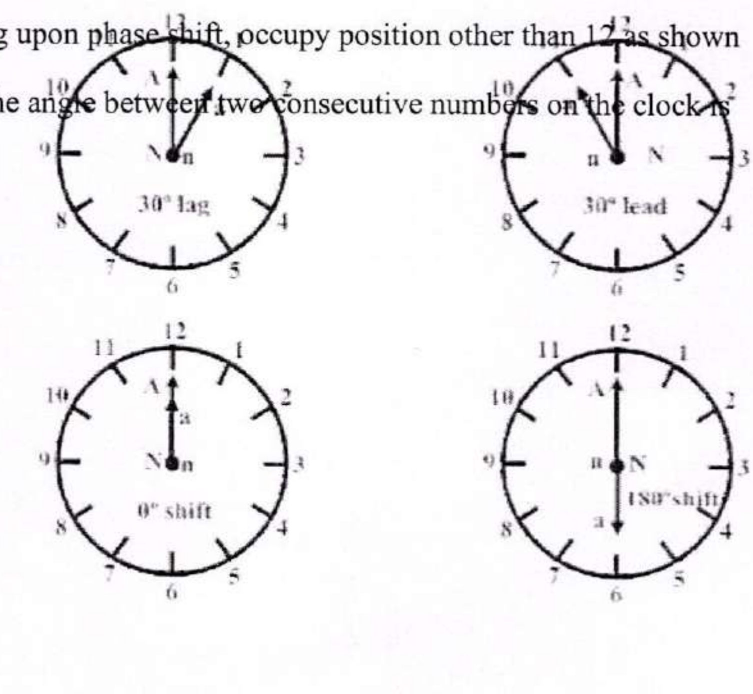


Fig. 4.9 Clock convention representing vector groups

Delta-Star connection is generally employed where it is necessary to step up the voltage. The connection is shown in fig. 4.8. The neutral of the secondary is grounded forproviding 3-phase, 4-wire service. The connection is very popular because it can be used to serve both the 3-phase power equipment and single phase lighting circuits.

4.2Vector Group of 3-phase transformer

The secondary voltages of a 3-phase transformer may undergo a *phase shift* of either +30° leading or - 30° lagging or 0° i.e, no phase shift or 180° reversal with respective line or phase to neutral voltages. On the name plate of a three phase transformer, the vector group is mentioned. Typical representation of the vector group could be Ydl or Dy 11 etc. The first capital latter Y indicates that the primary is connected in star and the second lower case latter d indicates delta connection of the secondary side. The third numerical figure conveys the angle of phase shift based on *clock convention.* The minute hand is used to represent the primary phase to neutral voltage and always shown to occupy the position 12. The hour hand represents the secondary phase to neutral voltage and may, depending upon phase shift, occupy position other than 12 as shown in the figure 4.9. The angle between two consecutive numbers on the clock is 30°.



Application

Suitable for large, low voltage transformers.

This Type of Connection is normally uncommon but used in some industrial facilities to reduce impact of SLG faults on the primary system

It is generally used in systems where it need to be carry large currents on low voltages and especially when continuity of service is to be maintained even though one of the phases develops fault.

4.2.2 Star/star (YyO, Yy6) connection

This is the most economical one for small high voltage transformers. Insulation cost is highly reduced. Neutral wire can permit mixed loading. Triplen harmonics are absent in the lines. These triplen harmonic currents cannot flow, unless there is a neutral wire. This connection produces oscillating neutral. Three phase shell type units have large triplen harmonic phase voltage. However three phase core type transformers work satisfactorily. A tertiary mesh connected winding may be required to stabilize the oscillating neutral due to third harmonics in three phase banks.

The connection of Yy0 is shown in fig. 4.12 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle difference between the phase voltage of high voltage side and low voltage side is zero degree (0°).

fault on one phase.

component of current. The flux remains sinusoidal which results in sinusoidal voltages.

Suitable for Unbalanced Load: Even if the load is unbalanced the three phase voltages remains constant. Thus it suitable for unbalanced loading also.

Carry 58% Load if One Transfer is Faulty in Transformer Bank : If there is bank of single phase transformers connected in delta-delta fashion and if one of the transformers is disabled then the supply can be continued with remaining tow transformers of course with reduced efficiency.

No Distortion in Secondary Voltage: there is no any phase displacement between primary and secondary voltages. There is no distortion of flux as the third harmonic component of magnetizing current can flow in the delta connected primary windings without flowing in the line wires .there is no distortion in the secondary voltages.

Economical for Low Voltage: Due to delta connection, phase voltage is same as line voltage hence winding have more number of turns. But phase current is $(1/\sqrt{3})$

times the line current. Hence the cross-section of the windings is very less. This makes the connection economical for low voltages transformers.

Reduce Cross section of Conductor: The conductor is required of smaller Cross section as the phase current is $1/\sqrt{3}$ times of the line current. It increases number of turns per phase and reduces the necessary cross sectional area of conductors thus insulation problem is not present.

Absent of Third Harmonic Voltage: Due to closed delta, third harmonic voltages are absent.

The absence of star or neutral point proves to be advantageous in some cases.

Disadvantages

Due to the absence of neutral point it is not suitable for three phase four wire system.

More insulation is required and the voltage appearing between windings and core will be equal to full line voltage in case of earth

4.2.1 Delta/delta (Dd0, Dd6) connection

The connection of Dd0 is shown in fig. 4.10 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle

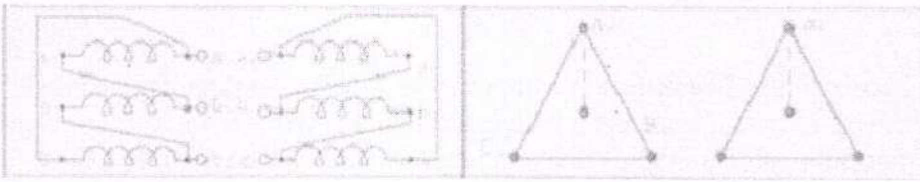


Fig 4.10 Dd0 connection and phasor diagram

The connection of Dd6 is shown in fig. 4.11 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle difference between the phase voltage of high voltage side and low voltage side is 180°.

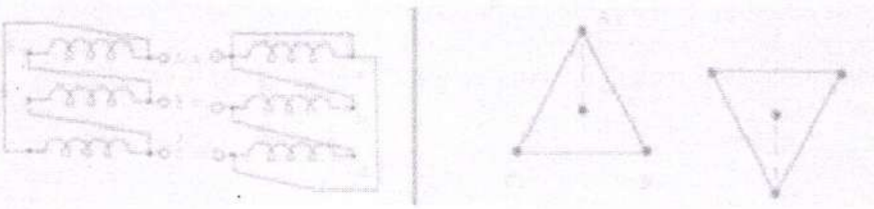


Fig 4.11 Dd6 connection and phasor diagram

This connection proves to be economical for large low voltage transformers as it increases number of turns per phase. Primary side line voltage is equal to secondary side line voltage. Primary side phase voltage is equal to secondary side phase voltage. There is no phase shift between primary and secondary voltages for Dd0 connection. There is 180° phase shift between primary and secondary voltages for Dd6 connection.

Advantages

Sinusoidal Voltage at Secondary:

difference between the phase voltage of high voltage side and low voltage side is zero degree (0°).

In order to get secondary voltage as sinusoidal, the magnetizing current of transformer must contain a third harmonic component. The delta connection provides a closed path for circulation of third harmonic

Neutral give path to flow
Triple frequency current to

systems operating at 800, 440, 220, and 66 kV that need to be interconnected. Substations can be constructed using Y-Y transformer connections to interconnect any two of these voltages. The 800 kV systems can be tied with the 66 kV systems through a single 800 to 66 kV transformation or through a series of cascading transformations at 440,220 and 66 kV.

Required Few Turns for winding: Due to star connection, phase voltages is $(1/\sqrt{3})$ times the line voltage. Hence less number of turns is required. Also the stress on insulation is less. This makes the connection economical for small high voltage purposes.

Required Less Insulation Level: If the neutral end of a Y-connected winding is grounded, then there is an opportunity to use reduced levels of insulation at the neutral end of the winding. A winding that is connected across the phases requires full insulation throughout the winding.

Handle Heavy Load:

Due to star connection, phase current is same as line current. Hence windings have to carry high currents. This makes cross section of the windings high. Thus the windings are mechanically strong and windings can bear heavy loads and short circuit current.

Use for Three phases Four Wires System: As neutral is available, suitable for three phases four wiresystem.

Eliminate Distortion in Secondary Phase Voltage: The connection of primary neutral to the neutral

Sinusoidal voltage on secondary side: of generator eliminates distortion in the secondary phase voltages by giving path to triple frequency currents toward to generator.

The connection of Yy6 is shown in fig. 4.13 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle difference between the phase voltage of high voltage side and low voltage side is 180°.

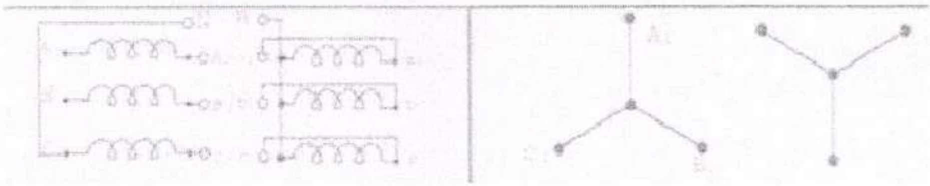


Fig 4.13. Yy6 connection and phasor diagram

In Primary Winding Each Phase is120°electrical degrees out of phase with the other two phases.

In Secondary Winding Each Phase is120°electrical degrees out of phase with the other two phases.

Each primary winding is magnetically linked to one secondary winding through a common core leg. Sets of windings that are magnetically linked are drawn parallel to each other in the vector diagram. In the Y-Y connection, each primary and secondary winding is connected to a neutral point.

The neutral point may or may not be brought out to an external physical connection and the neutral may or may not be grounded.

Advantages of Y-y connection

No Phase Displacement: The primary and secondary circuits are in phase; i.e., there are no phase angle displacements introduced by the Y-Y connection. This is an important advantage when transformers are used to interconnect systems of different voltages in a cascading manner. For example, suppose there are four

Fig .4.12 Yy0 connection and phasor diagram

Principles of Torque Production

In the earlier section, we saw how a rotating flux is produced. Now let us consider a rotor, which is placed in this field. Let the rotor have a coil such that the coil sides are placed diametrically opposite each other. This is shown in the fig. 1. Since the flux generated by the stator rotates flux linked by this rotor coil also changes.

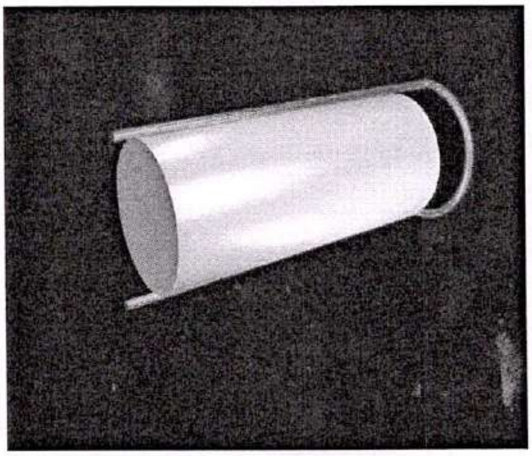


Figure 1: A Coil on the rotor

Since the flux pattern is varying sinusoidally in space, as the flux waveform rotates, the flux linkage varies sinusoidally. The rate of variation of this flux linkage will then be equal to the speed of rotation of the air gap flux produced. This sinusoidal variation of the flux linkage produces a sinusoidal induced emf in the rotor coil. If the coil is short circuited, this induced emf will cause a current flow in the coil as per Lenz's law.

Now imagine a second coil on the rotor whose axis is 120° away from the first. This is shown in fig. 2. The flux linkage in this coil will also vary sinusoidally with respect to time and therefore cause an induced voltage varying sinusoidally with time. However the flux linkages in these two coils will have a phase difference of 120° (the rotating flux wave will have to travel 120° in order to cause a similar flux linkage variation as in the first coil), and hence the time varying voltages induced in the coils will also have a 120° phase difference.

A third coil placed a further 120° away is shown in fig. 3. This will have a time varying induced emf lagging 240° in time with respect to the first.

- This plot shows the pulsating wave at the zero degree axes. The amplitude is maximum at zero degree axes and is zero at 90° axis. Positive parts of the waveform are shown in red while negative in blue. Note that the waveform is pulsating at the $0 - 180^\circ$ axis and red and blue alternate in any given side. This corresponds to the sinewave current

changing polarity. Note that the maximum amplitude of the sinewave is reached only along the $0 - 180^\circ$ axis. At all other angles, the amplitude does not reach a maximum of this value. It however reaches a maximum value which is less than that of the peak occuring at the $0 - 180^\circ$ axis. More exactly, the maximum reached at any space angle θ would be equal to $\cos\theta$ times the peak at the $0 - 180^\circ$ axis. Further, at any space angle θ, the time variation is sinusoidal with the frequency and phase lag being that of the excitation, and amplitude being that corresponding to the space angle.

- This plot shows the pulsating waveforms of all three cosines. Note that the first is pulsating about the $0 - 180^\circ$ axis, the second about the $120^\circ - 300^\circ$ axis and the third at $240^\circ - 360^\circ$ axis.

- This plot shows the travelling wave in a circular trajectory. Note that while individual pulsating waves have maximum amplitude of 10, the resultant has amplitude of 15.

If f_l is the amplitude of the flux waveform in each phase, the travelling wave can then be represented as

$$f(t) = f_l \cos\omega t \cos\theta + f_l \cos(\omega t - \frac{2\pi}{3}) \cos(\theta - \frac{2\pi}{3}) + f_l \cos(\omega t - \frac{4\pi}{3}) \cos(\theta - \frac{4\pi}{3})$$

$$= \frac{3}{2} f_l \cos(\omega t - \theta) \quad (4)$$

the space around b′ and c coil sides. The situation is shown in fig. 6.

The resulting flux pattern causes a tendency to move in the anticlockwise direction. This is easy to see through the so called whiplash rule. Alternatively, since the force on a current

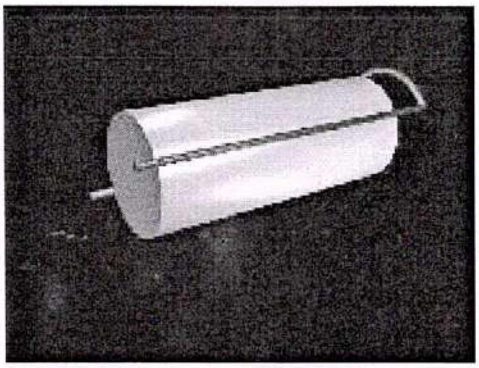


Figure 3: A coil displaced 240° from the first

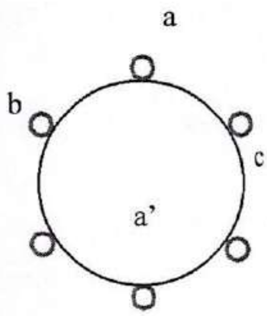


Figure 4: Coils on the rotor

carrying conductor is F = q(v X B), it can be seen that the torque produced tends to rotate the rotor counter-clockwise. The magnitude of the torque would increase with the current magnitude in the coils. This current is in turn dependent on the magnitude of the main field flux and its speed of rotation. Therefore one may say that motion of the main field tends to drag the rotor along with it.

When the rotor is free to move and begins moving, the motion reduces the relative speed between the main field and the rotor coils. Less emf would therefore be induced and the torque would come down. Depending on the torque requirement for the load, the difference in speed between the rotor and the main field settles down at some particular value.

From the foregoing, the following may be noted.

1. The torque produced depends on a non-zero relative speed between the field and the rotor.

When these three coils are shorted upon themselves currents flow in them as per Lenz's law. The mechanism by which torque is produced may now be understood as follows. The diagram in fig. 4 shows a view of the rotor seen from one end. Positive current is said to

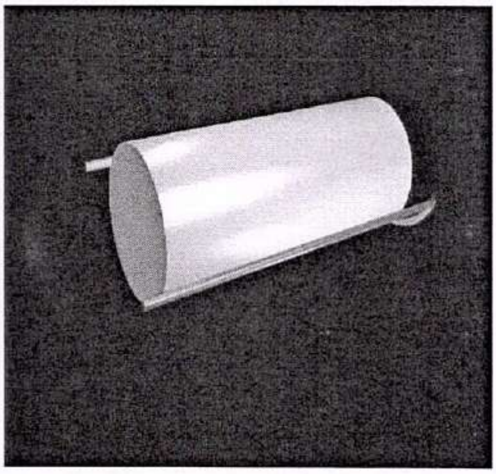


Figure 2: A coil displaced 120° from the first

flow in these coils when current flows out of the page in a, b, c conductors and into a′ , b′ and c′ respectively.

If we look at the voltage induced in these coils as phasors, the diagram looks as shown in fig. 5. The main flux is taken as the reference phasor. Considering that the induced emf is $-d\psi/dt$ where ψ is the flux linkage, the diagram is drawn as shown.

As usual, the horizontal component of these phasors gives the instantaneous values of the induced emf in these coils.

Let these coils be purely resistive. Then these emf phasors also represent the currents flowing in these coils. If we consider the instant t = 0, it can be seen that

1. The field flux is along 0° axis.

2. The current in a phase coil is zero.
3. The current in c phase coil is $+ {}_2{}^3$ units.

These currents act to produce mmf and flux along the axes of the respective coils. Let us consider

Figure 9: stator of an induction machine

the stator of an induction machine is shown in fig. 9. A close up of the windings is shown in fig. 10.the several turns that makeup a coil are seen in this picture. The three terminations are connected to rings on which three brushes make a sliding contact. As the rotor rotates the brushes slip over the rings and provide means of connecting stationary external circuit elements to the rotating windings. A schematic of these arrangements is shown in fig. 13. A photograph of a wound rotor for an induction machine is shown in fig. 11. Fig. 12 shows a close up of the slip ring portion. Brushes are not shown in this picture.

Induction machines, which have these kinds of windings and terminals that are brought out, are called slip ring machines. The reader may note that in order that torque is produced current must flow in the rotor. To achieve that, the stationary brush terminals must either be shorted, or connected to a circuit allowing current flow. Sometimes a star connected resistor bank is connected so that the developed starting torque is higher. There are also other forms of power electronic circuitry that may be connected to the rotor terminals to achieve various functions.

The popularity of the induction machine however, stems from another variety of rotor

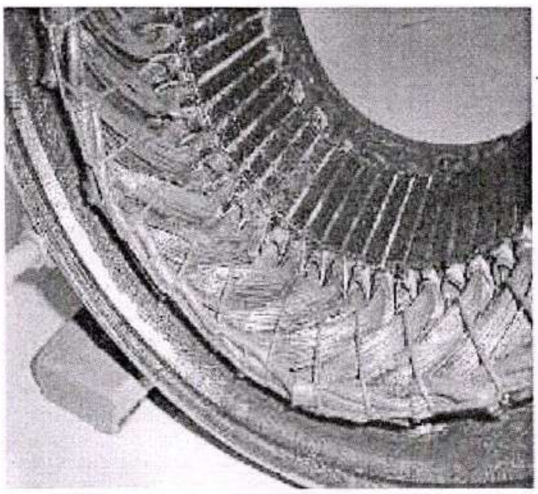
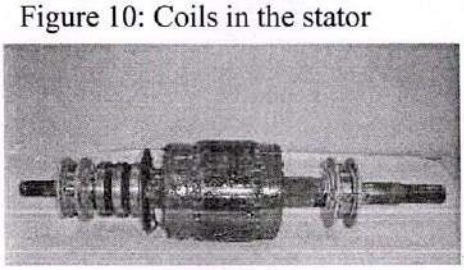


Figure 10: Coils in the stator



2. It is therefore not possible for the rotor to run continuously at the same speed of the field. This is so because in such a condition, no emf would be induced in the rotor and hence no rotor current, no torque.

3. The frequency of currents induced in the rotor coils and their magnitude depends on this difference in speed.

These are important conclusions. The speed of the main field is known as the synchronous speed, n_s. If the actual speed of the rotor is n_r then the ratio is known as slip and is frequently expressed as a percentage. Typically induction machines are designed to operate at about less than 4 percent slip at full load.

$$s = \frac{n_s - n_r}{n_s} \qquad (5)$$

It is instructive to see the situation if the rotor resistance is neglected and is considered to be purely inductive. The phasor diagram of voltages and the currents would then look as shown in fig. 7.

At t = 0, one can see that current in a phase coil is at negative maximum, while b and c phases have positive current of 0.5 units. Now if we consider the current flux profiles at coil sides a, b′ , c, the picture that emerges is shown in fig. 8.

Since main flux at the a coil side is close to zero, there is very little torque produced from there. There is a tendency to move due to the b′ and c coil sides, but they are in opposite directions however. Hence there is no net torque on the rotor. This brings up another important conclusion — the resistance of the rotor is an important part of torque production in the induction machine. While a high resistance rotor is better suited for torque production, it would also be lossy.

Construction

In actual practice, the three coils form three windings distributed over several slots. These windings may be connected in star or delta and three terminations are brought out. These are conventional three phase windings which are discussed in greater detail in the chapters on alternators. Such windings are present n the stator as well as rotor. A photograph of

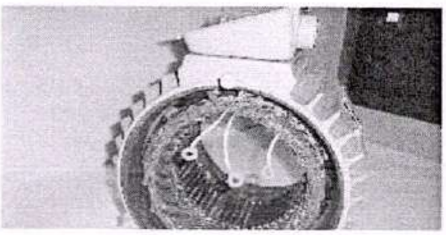


Figure 14: Squirrel cage rotor — a schematic

Such a rotor is called squirrel cage rotor. This rotor behaves like a short-circuited winding and hence the machine is able to perform electromechanical energy conversion. This type of rotor is easy to manufacture, has no sliding contacts and is very robust. It is this feature that makes induction machine suitable for use even in hazardous environments and reliable operation is achieved. The disadvantage of this type of rotor is that the motor behavior cannot be altered by connecting anything to the rotor — there are no rotor terminals.

Fig. 15 shows a photograph of a squirrel cage rotor. The rotor also has a fan attached to it. This is for cooling purposes. The bars (white lines on the surface) are embedded in the rotor iron which forms the magnetic circuit. The white lines correspond to the visible portion of the rotor bar.

Sometimes two rotor bars are used per slot to achieve some degree of variability in the starting and running performances. It is to make use of the fact that while high rotor

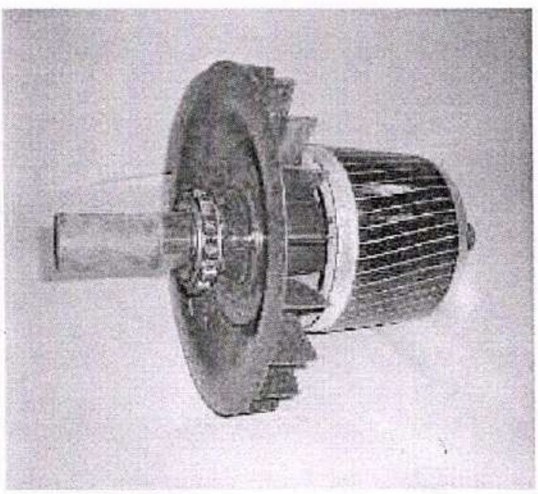


Figure 15: squirrel cage rotor

resistance is desirable from the point of view of starting torque, low rotor resistance is desirable

Figure 11: A wound rotor with slip rings

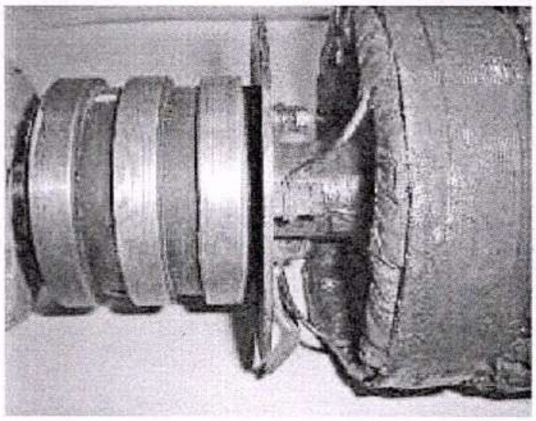


Figure 12: slip rings

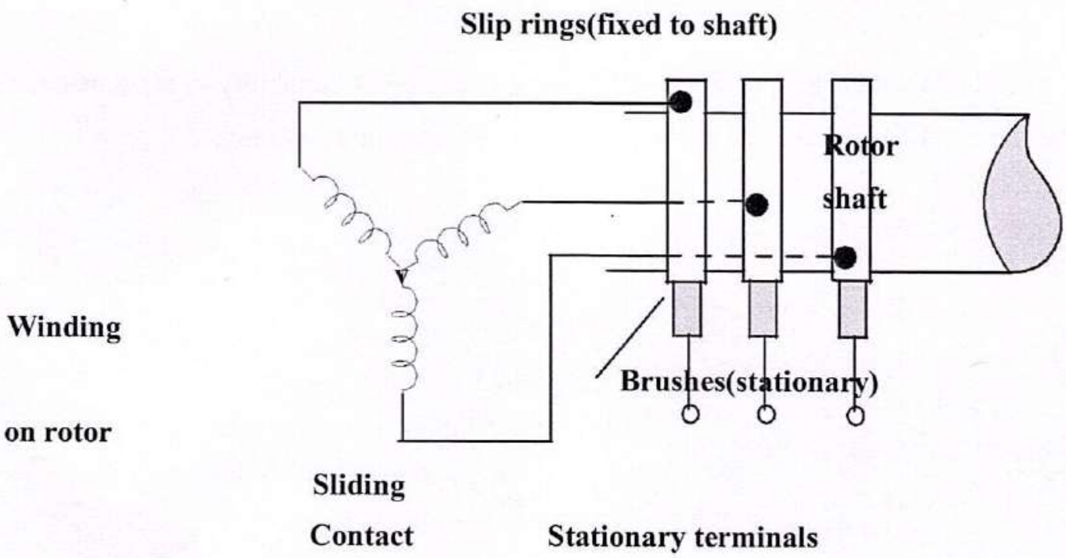


Figure 13: Slip rings and brushes in induction machines — a schematic

That is used. This rotor has slots into which copper or aluminum bars are inserted. These bars are then shorted by rings that are brazed on to each of the rotor ends. Figure 14 shows a simple schematic.

R_m X_m

Figure 16: Induction machine with the rotor open

This is just the normal transformer equivalent circuit (why?). Measurements aregenerally made on the stator side and the rotor, in most circumstances, is shorted (if required, through some external circuitry). Since most of the electrical interaction is from the stator, it makes sense to refer all parameters to the stator.

Let us consider the rotor to be shorted. Let the steady speed attained by the rotor be ω_r and the synchronous speed be ω_s. The induced voltage on the rotor is now proportional to the slip i.e., slip times the induced voltage under open circuit (why?). Further, the voltage induced and the current that flows in the rotor is at a frequency equal to slip times the stator excitation frequency (why?). The equivalent circuit can be made to represent this by shorting the secondary side and is shown in fig. 17.

R_r' and X_{lr}' refer to the rotor resistance and leakage resistance referred to the stator side (using the square of the turns ratio, as is done in transformer). The secondary side loop is excited by a voltage sE_1 , which is also at a frequency sf_1 . This is the reason why the rotor

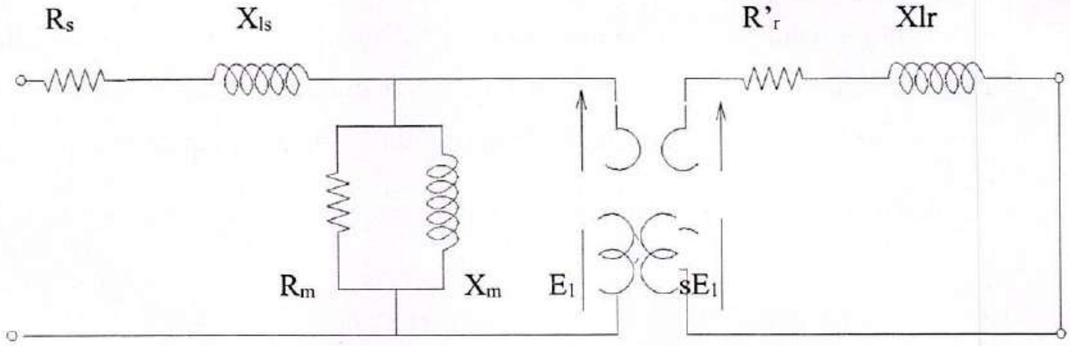


Figure 17: Equivalent circuit : rotor at its own frequency

leakage is sX_{lr}' now . The current amplitude in the rotor side would therefore be from efficiency considerations while the machine is running. Such rotors are called double cage rotors or deep-bar rotors.

To summarize the salient features discussed so far,

1. The stator of the 3 - phase induction machine consists of normal distributed AC wind-ings.

2. Balanced three phase voltages impressed on the stator, cause balanced three phase currents to flow in the stator.

3. These stator currents cause a rotating flux pattern (the pattern is a flux distribution which is sinusoidal with respect to the space angle) in the air gap.

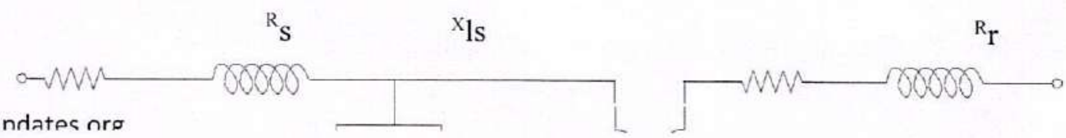
4. The rotating flux pattern causes three phase induced e.m.f.s in rotor windings (again normal ac windings). These windings, if shorted, carry three phase-balanced currents. Torque is produced as a result of interaction of the currents and the air gap flux.

5. The rotor may also take the form of a squirrel cage arrangement, which behaves in a manner similar to the short-circuited three phase windings.

Equivalent Circuit

It is often required to make quantitative predictions about the behavior of the induction machine, under various operating conditions. For this purpose, it is convenient to represent the machine as an equivalent circuit under sinusoidal steady state operating conditions. Since the operation is balanced, a single-phase equivalent circuit is sufficient for most purposes.

In order to derive the equivalent circuit, let us consider a machine with an open circuited rotor. Since no current can flow and as a consequence no torque can be produced, the situation is like a transformer open-circuited on the secondary (rotor). The equivalent circuit under this condition can be drawn as shown in fig. 16.



Consequently, as far as voltage, current converting properties are concerned, the autotransformer of Figure: 26 behaves just like a two-winding transformer. However, in the autotransformer we don't need two separate coils, each designed to carry full load values of current.

Parallel Operation of Transformers

It is economical to install numbers of smaller rated transformers in parallel than installing bigger rated electrical power transformers. This has mainly the following advantages,
To maximize electrical power system efficiency: Generally electrical power transformer gives the maximum efficiency at full load. If we run numbers of transformers in parallel, we can switch on only those transformers which will give the total demand by running nearer to its full load rating for that time. When load increases, we can switch none by one other transformer connected in parallel to fulfill the total demand. In this way we can run the system with maximum efficiency.

To maximize electrical power system availability: If numbers of transformers run in parallel, we can shut down any one of them for maintenance purpose. Other parallel transformers in system will serve the load without total interruption of power.

To maximize power system reliability: if any one of the transformers run in parallel, is tripped due to fault of other parallel transformers is the system will share the load, hence power supply may not be interrupted if the shared loads do not make other transformers over loaded.
To maximize electrical power system flexibility: There is always a chance of increasing or decreasing future demand of power system. If it is predicted that power demand will be increased in future, there must be a provision of connecting transformers in system in parallel to fulfil the extra demand because, it is not economical from business point of view to install a bigger rated single transformer by forecasting the increased future demand as it is unnecessary investment of money. Again if future demand is decreased, transformers running in parallel can be removed from system to balance the capital investment and its return.

$$(N_A - N_B)\,\bar{I}_A + (\bar{I}_A - \bar{I}_B)\,N_B = 0$$

or

$$N_A\,\bar{I}_A - N_B\,\bar{I}_B = 0$$

Hence, just as in a two-winding transformer,

$$\frac{\bar{I}_A}{\bar{I}_B} = \frac{N_B}{N_A}$$

directions of induced secondary emf in two transformers are opposite to each other when same input power is fed to both of the transformers, the transformers are said to be in opposite polarity. If the instantaneous directions of induced secondary e.m.f in two transformers are same when same input power is fed to the both of the transformers, the transformers are said to be in same polarity.

Same Phase Sequence

The phase sequence or the order in which the phases reach their maximum positive voltage, must be identical for two parallel transformers. Otherwise, during the cycle, each pair of phases will be short circuited.

The above said conditions must be strictly followed for parallel operation of transformers but totally identical percentage impedance of two different transformers is difficult to achieve practically, that is why the transformers run in parallel may not have exactly same percentage impedance but the values would be as nearer as possible.

Why Transformer Rating in kVA?

An important factor in the design and operation of electrical machines is the relation between the life of the insulation and operating temperature of the machine. Therefore, temperature rise resulting from the losses is a determining factor in the rating of a machine. We know that copper loss in a transformer depends on current and iron loss depends on voltage. Therefore, the total loss in a transformer depends on the volt-ampere product only and not on the phase angle between voltage and current i.e., it is independent of load power factor. For this reason, the rating of a transformer is in kVA and not kW.

Conditions for Parallel Operation of Transformers

When two or more transformers run in parallel, they must satisfy the following conditions for satisfactory performance. These are the conditions for parallel operation of transformers.

- ***Same voltage ratio of transformer.***
- ***Same percentage impedance.***
- ***Same polarity.***
- ***Same phase sequence.***

- ***Same Voltage Ratio***

Same voltage ratio of transformer

If two transformers of different voltage ratio are connected in parallel with same primary supply voltage, there will be a difference in secondary voltages. Now say the secondary of these transformers are connected to same bus, there will be a circulating current between secondary's and therefore between primaries also. As the internal impedance of transformer is small, a small voltage difference may cause sufficiently high circulating current causing unnecessary extra I2R loss.

Same Percentage Impedance

The current shared by two transformers running in parallel should be proportional to their MVA ratings. Again, current carried by these transformers are inversely proportional to their internal impedance. From these two statements it can be said that, impedance of transformers running in parallel are inversely proportional to their MVA ratings. In other words, percentage impedance or per unit values of impedance should be identical for all the transformers that run in parallel.

Same Polarity

Polarity of all transformers that run in parallel, should be the same otherwise huge circulating current that flows in the transformer but no load will be fed from these transformers. Polarity of transformer means the instantaneous direction of induced emf in secondary. If the instantaneous

- Similarly consider a third sine wave, which is at 240° lag. . .
- and allow its amplitude to change as well with a 240° time lag. Now we have three pulsating sine waves.

$$i_{cpk} = I_m \cos(2\pi.50.t - 240^\circ) \quad (3)$$

Let us see what happens if we sum up the values of these three sine waves at every angle. The result really speaks about Tesla's genius. What we get is a constant amplitude travelling sine wave! In a three phase induction machine, there are three sets of windings — phase A winding, phase B and phase C windings. These are excited by a balanced three-phase voltage supply. This would result in a balanced three phase current. Equations 1 — 3 represent the currents that flow in the three phase windings. Note that they have a 120° time lag between them.

Further, in an induction machine, the windings are not all located in the same place. They are distributed in the machine 120° away from each other (more about this in the section on alternators). The correct terminology would be to say that the windings have
their axes separated in space by 120°. This is the reason for using the phase A, B and C since waves separated in space as well by 120°.
When currents flow through the coils, they generate mmfs. Since mmf is proportional to current, these waveforms also represent the mmf generated by the coils and the total mmf. Further, due to magnetic material in the machine (iron), these mmfs generate magnetic flux, which is proportional

to the mmf (we may assume that iron is infinitely permeable and non-linear effects such as hysterisis are neglected). Thus the waveforms seen above would also represent the flux generated within the machine. The net result as we have seen is a travelling flux wave. The x-axis would represent the space angle in the machine as one travels around the air gap. The first pulsating waveform seen earlier would then represent the a-phase flux, the second represents the b-phase flux and the third represents the c-phase.

This may be better visualized in a polar plot. The angles of the polar plot represent the space angle in the machine, i.e., angle as one travels around the stator bore of the machine. Click on the links below to see the development on a polar axes.

UNIT-III

Poly Phase Induction Machines

Introduction

The induction machine was invented by NIKOLA TESLA in 1888. Right from its incep-tion its ease of manufacture and its robustness have made it a very strong candidate for electromechanical energy conversion. It is available from fractional horsepower ratings to megawatt levels. It finds very wide usage in all various application areas. The induction machine is an AC electromechanical energy conversion device. The machine interfaces with the external world through two connections (ports) one mechanical and one electrical. The mechanical port is in the form of a rotating shaft and the electrical port is in the form of terminals where AC supply is connected. There are machines available to operate from three phase or single phase electrical input. In this module we will be discussing the three phase induction machine. Single phase machines are restricted to small power levels.

The Rotating Magnetic Field

The principle of operation of the induction machine is based on the generation of a rotating magnetic field. Let us understand this idea better.

Click on the following steps in sequence to get a graphical picture. It is suggested that the reader read the text before clicking the link.

- Consider a cosine wave from 0 to 360°. This sine wave is plotted with unit amplitude.

- Now allow the amplitude of the sine wave to vary with respect to time in a simisoidal fashion with a frequency of 50Hz.Let the maximum value of the amplitude is, say, 10 units. This waveform is a pulsating sine wave.

$$i_{apk} = I_m \cos 2\pi.50.t \qquad (1)$$

- Now consider a second sine wave, which is displaced by 120° from the first (lagging)...

- and allow its amplitude to vary in a similar manner, but with a 120°time lag.

$$i_{bpk} = I_m \cos(2\pi.50.t - 120^\circ) \qquad (2)$$

be suitable for supplying a three, two and single phase load simultaneously, but such loads are not found together in modern practice.

The primary three-phase currents are balanced; i.e., the phase currents have the same magnitude and their phase angles are 120° apart. The apparent power supplied by the main transformer is greater than the apparent power supplied by the teaser transformer. This is easily verified by observing that the primary currents in both transformers have the same magnitude; however, the primary voltage of the teaser transformer is only 86.6% as great as the primary voltage of the main transformer. Therefore, the teaser transforms only 86.6% of the apparent power transformed by the main.

The total real power delivered to the two phase load is equal to the total real power supplied from the three-phase system, the total apparent power transformed by both transformers is greater than the total apparent power delivered to the two-phase load.

The apparent power transformed by the teaser is 0.866 X IH1= 1.0 and the apparent power transformed by the main is 1.0X IH2 =1.1547 for a total of 2.1547 of apparent power transformed.

The additional 0.1547 per unit of apparent power is due to parasitic reactive power owing between the two halves of the primary winding in the main transformer.

Single-phase transformers used in the Scott connection are specialty items that are virtually impossible to buy "off the shelf" nowadays. In an emergency, standard distribution transformers can be used.

If desired, a three phase, two phase, or single phase load may be supplied simultaneously using scott-connection. The neutral points can be available for grounding or loading purposes. The Scott T connection in theory would

Fig. 4.24 Open delta connection of transformer at noload

If one of the transformers fails in Δ - Δ bank and if it is required to continue the supply even though at reduced capacity until the transformer which is removed from the bank is repaired or a new one is installed then this type of connection is most suitable.

When it is anticipated that in future the load increase, then it requires closing of open delta. In such cases open delta connection is preferred. It can be noted here that the removal of one of the transformers will not give the total load carried by V - V bank as two third of the capacity of Δ - Δ bank.

The load that can be carried by V - V bank is only 57.7% of it.

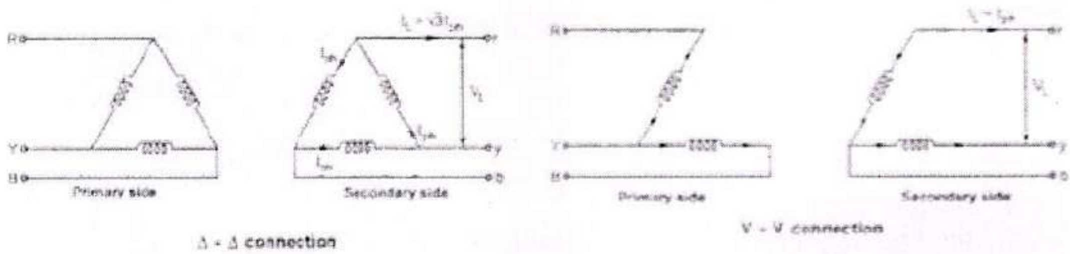


Fig. 4.25 Delta-delta and V-V connection

It can be seen from the Fig. 4.25 of delta delta connection that

$\Delta - \Delta$ capacity $= \sqrt{3}\, V_L I_L = \sqrt{3}\, V_L (\sqrt{3}\, I_{ph})$

$\Delta - \Delta$ capacity $= 3\, V_L I_{ph}$

It can also be noted from the Fig. 4.25 V-V connection that the secondary line current I_L is equal to the phase current I_{ph}.

V- V capacity $= \sqrt{3}\, V_L I_L = \sqrt{3}\, V_L I_{ph}$

$$\text{So, } \frac{\text{V-V capacity}}{\Delta-\Delta \text{ capacity}} = \frac{\sqrt{3} V_L I_{ph}}{3 V_L I_{ph}} = \frac{1}{\sqrt{3}} = 0.577 \quad 58\%$$

The Scott T would not be recommended as a connection for 3 phase to 3 phase applications for the following reasons:

The loads of modern buildings and office buildings are inherently unbalanced and contain equipment that can be sensitive to potential voltage fluctuations that may be caused by the Scott T design.

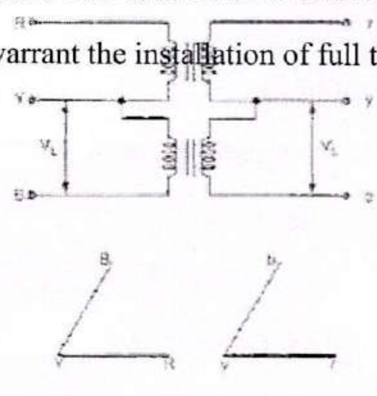
A properly sized Scott T transformer will have to be a minimum of 7.75% larger than the equivalent Delta-Wye transformer. Properly sized, it would be a bulkier and heavier option and should not be considered a less expensive solution.

4.6 Open Delta or V-Connection

As seen previously in connection of three single phase transformers that if one of the transformers is unable to operate then the supply to the load can be continued with the remaining two transformers at the cost of reduced efficiency. The connection that obtained is called V-V connection or open delta connection.

Consider the Fig. 4.24 in which 3 phase supply is connected to the primaries. At the secondary side three equal three phase voltages will be available on no load.

The voltages are shown on phasor diagram. The connection is used when the three phase load is very very small to warrant the installation of full three phase transformer.



With a bank of tow single phase transformers connected in V-V fashion supplying a balanced

Thus the three phase load that can be carried without exceeding the ratings of the transformers is 57.5 percent of the original load. Hence it is not 66.7 % which was expected otherwise.

The reduction in the rating can be calculated as {(66.67 - 57.735)/(57.735)}x 100 = 15.476 Suppose that we consider three transformers connected in Δ - Δ fashion and supplying their rated load. Now one transformer is removed then each of the remaining two transformers will be overloaded. The overload on each transformer will be given as,

$$\frac{\text{Total load in V-V}}{\text{VA rating of each transformer}} = \frac{\sqrt{3} V_L I_{ph}}{V_L I_{ph}} = \sqrt{3} = 1.73$$

This overload can be carried temporarily if provision is made to reduce the load otherwise overheating and breakdown of the remaining two transformers would take place.

The limitation with V -V connection are given below :

- The average p.f. at which V- V bank is operating is less than that with the load . This power p.f is 86.6 % of the balanced load p.f.

- The two transformers in V -V bank operate at different power factor except for balanced unity p.f .load.

- The terminals voltages available on the secondary side become unbalanced. This may happen even though load is perfectly balanced.

Thus in summary we can say that if tow transformers are connected in V - V fashion and are loaded to rated capacity and one transformer is added to increase the total capacity by √3 or 173.2 %. Thus the increase in capacity is 73.2 % when converting from a V - V system to a Δ-Δ system.

voltages and currents and increase the power loss. Thus the study of harmonics is of great practical significance in the operation of transformers.

In the case of single phase transformers connected to form three phase bank, each transformer is magnetically decoupled from the other. The flow of harmonic currents are decided by the type of the electrical connection used on the primary and secondary sides. Also, there are three fundamental voltages in the present case each displaced from the other by 120 electrical degrees. Because of the symmetry of the a.c. wave about the time axis only odd harmonics need to be considered. The harmonics which are triplen(multiples of three) behave in a similar manner as they are co-phasal or in phase in the three phases. The non-triplen harmonics behave in a similar manner to the fundamental and have ±120° phase displacement between them.

When the connection of the transformer is Yy without neutral wires both primary and secondary connected in star no closed path exists. As the triplen harmonics are always in phase, by virtue of the Y connection they get canceled in the line voltages. Non-triplen harmonics like fundamental, become 0 times phase value and appear in the line voltages. Line currents remain sinusoidal except for non-triplen harmonic currents. Flux wave in each transformer will be flat topped and the phase voltages remain peaked. The potential of the neutral is no longer steady. The star point oscillates due to the third harmonic voltages. This is termed as "oscillating neutral".

4.8 Tertiary winding

Apart from the Primary & Secondary windings, there sometimes placed a third winding in power transformers called "Tertiary Winding". Its purpose

3 phase load with cosΦ asp.f., one of the transformer operate at a p.f. of cos (30-Φ) and other at cos (30+Φ). The powers of tow transformers are given by,

$$P_1 = KVA \cos(30-\Phi)$$

$$P_2 = KVA \cos(30+\Phi)$$

4.7Oscillating Neutral

In addition to the operation of transformers on the sinusoidal supplies, the harmonic behavior becomes important as the size and rating of the transformer increases. The effects of the harmonic currents are

1. Additional copper losses due to harmonic currents
2. Increased core losses
3. Increased electro-magnetic interference with

communication circuits. On the other hand the harmonic voltages of the transformer cause

1. Increased dielectric stress on insulation
2. Electro static interference with communication circuits.
3. Resonance between winding reactance and feeder capacitance.

In the present times a greater awareness is generated by the problems of harmonic voltages and currents produced by non-linear loads like the power electronic converters. These combine with non-linear nature of transformer core and produce severe distortions in all voltages are balanced and there is no floating of neutral or oscillating neutral. The floating of neutral is developed in the case star-star connection only. The transformers are sometimes constructed with three windings. The main windings are connected to form star-star connection and the third winding known as tertiary winding is used to make a closed delta connection to stabilize the neutrals of both primary and secondary circuits.

The tertiary winding carries the third-harmonic currents.

4.9 Three Winding Transformers

Thus far we have looked at transformers which have one single primary winding and one single secondary winding. But the beauty of transformers is that they allow us to have more than just one winding in either the primary or secondary side. Transformers which have three winding are known commonly as **Three Winding Transformers.**

The principal of operation of a *three winding transformer* is no different from that of an ordinary transformer. Primary and secondary voltages, currents and turns ratios are all calculated the same, the difference this time is that we need to pay special attention to the voltage polarities of each coil winding, the dot convention marking the positive (or negative) polarity of the winding, when we connect them together.

Three winding transformers, also known as a three-coil, or three-winding transformer, contain one primary and two secondary coils on a common laminated core. They can be either a single-phase transformer or a three-phase transformer, (three-winding, three-phase transformer) the operation is the same.

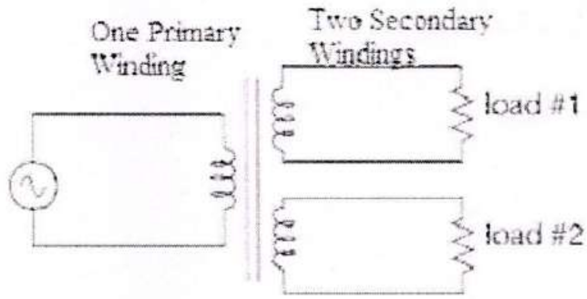
is to provide a circulating path for the harmonics (especially third harmonics) produced in the transformers along with power frequency (50Hz. third harmonic means 150 Hz oscillations). In delta-delta, delta-star and star-delta transformers

transformers

have two secondary windings on the same core with each one providing a different voltage or current level output.

As transformers operate on the principal of mutual induction, each individual winding of a three winding transformer supports the same number of volts per turn, therefore the volt-ampere product in each winding is the same, that is $N_P/N_S = V_P/V_S$ with any turns ratio between the individual coil windings being relative to the primary supply.

In electronic circuits, one transformer is often used to supply a variety of lower voltage levels for different components in the electronic circuitry. A typical application of three winding transformers is in power supplies and Triac Switching Converters. So a transformer have two secondary windings, each of which is electrically isolated from the others, just as it is electrically isolated



from the primary. Then each of the secondary coils will produce a voltage that is proportional to its number of coil turns.

Fig. 4.27 A three winding transformer

Three Winding Transformers can also be used to provide either a step-up, a step-down, or a combination of both between the various windings. In fact a three winding transformers increased future demand as it is unnecessary investment of money. Again if future demand is decreased, transformers running in parallel can be removed from system to balance the capital investment and its return.

4.10.2 Conditions for parallel operation

Certain conditions have to be met before two or more transformers are connected in parallel and share a common load satisfactorily. They are,

1. The voltage ratio must be the same.

2. The per unit impedance of each machine on its own base must be the same.

3. The polarity must be the same, so that there is no circulating current between the transformers.

4. The phase sequence must be the same and no phase difference must exist between the voltages of the two transformers.

Same voltage ratio : Generally the turns ratio and voltage ratio are taken to be the same. If the ratio is large there can be considerable error in the voltages even if the turns ratios are the same. When the primaries are connected to same bus bars, if the secondaries do not show the same voltage, paralleling them would result in a circulating current between the secondaries. Reflected circulating current will be there on the primary side also. Thus even without connecting a load considerable current can be drawn by the transformers and they produce copper losses. In two identical transformers with percentage impedance of 5 percent, a no-load voltage difference of one percent will result in a circulating current of 10 percent of full load current. This circulating current gets added to the load current when the load is connected resulting in unequal sharing of the load. In such cases the combined full load of the two

The secondary windings can be connected together in various configurations producing a higher voltage or current supply. It must be noted that connecting together transformer windings is only possible if the two windings are electrically identical. That is their current and voltage ratings are the same.

4.10 Parallel operation of three phase transformer

4.10.1 Advantages of using transformers in parallel

~~To maximize electrical power system efficiency:~~ Generally electrical power transformer gives the maximum efficiency at full load. If we run numbers of transformers in parallel, we can switch on only those transformers which will give the total demand by running nearer to its full load rating for that time. When load increases, we can switch none by one other transformer connected in parallel to fulfill the total demand. In this way we can run the system with maximum efficiency.

2. To maximize electrical power system availability: If numbers of transformers run in parallel, we can shut down any one of them for maintenance purpose. Other parallel transformers in system will serve the load without total interruption of power.

3. To maximize power system reliability: If any one of the transformers run in parallel, is tripped due to fault of other parallel transformers is the system will share the load, hence power supply may not be interrupted if the shared loads do not make other transformers over loaded.

4. To maximize electrical power system flexibility: There is always a chance of increasing or decreasing future demand of power system. If it is predicted that power demand will be increased in future, there must be a provision of connecting transformers in system in parallel to fulfill the extra demand because, it is not economical from business point of view to install a bigger rated single transformer by forecasting the

to be the same by virtue of their connection at the input and the output ends. Thus the larger machines have smaller impedance and smaller machines must have larger ohmic impedance. Thus the impedances must be in the inverse ratios of the ratings. As the voltage drops must be the same the per unit impedance of each transformer on its own base, must be equal. In addition if active and reactive power are required to be shared in proportion to the ratings the impedance angles also must be the same. Thus we have the requirement that per unit resistance and per unit reactance of both the transformers must be the same for proper load sharing.

Polarity of connection: The polarity of connection in the case of single phase transformers can be either same or opposite. Inside the loop formed by the two secondaries the resulting voltage must be zero. If wrong polarity is chosen the two voltages get added and short circuit results. In the case of polyphase banks it is possible to have permanent phase error between the phases with substantial circulating current. Such transformer banks must not be connected in parallel. The turns ratios in such groups can be adjusted to give very close voltage ratios but phase errors cannot be compensated. Phase error of 0.6 degree gives rise to one percent difference in voltage. Hence poly phase transformers belonging to the same vector group alone must be taken for paralleling.

Transformers having —30° angle can be paralleled to that having +30° angle by reversing the phase sequence of both primary and secondary terminals of one of the transformers. This way one can overcome the problem of the phase angle error.

Phase sequence- The phase sequence of operation becomes relevant only in the case of poly phase systems. The poly phase banks belonging to same vector group

can be connected in parallel. A transformer with +30° phase angle transformers can never be met without one transformer getting overloaded.

- **Per unit impedance:** Transformers of different ratings may be required to operate in parallel. If they have to share the total load in proportion to their ratings the larger machine has to draw more current. The voltage drop across each machine has

4.11 Load Sharing

When the transformers have equal voltage ratios, the magnitudes of secondary no-load voltages are equal. Further if the primary leakage impedance drops due to exciting currents are also equal, then

$\overline{E}_a$ $\overline{E}_b$ and the circulating current at no load is zero.

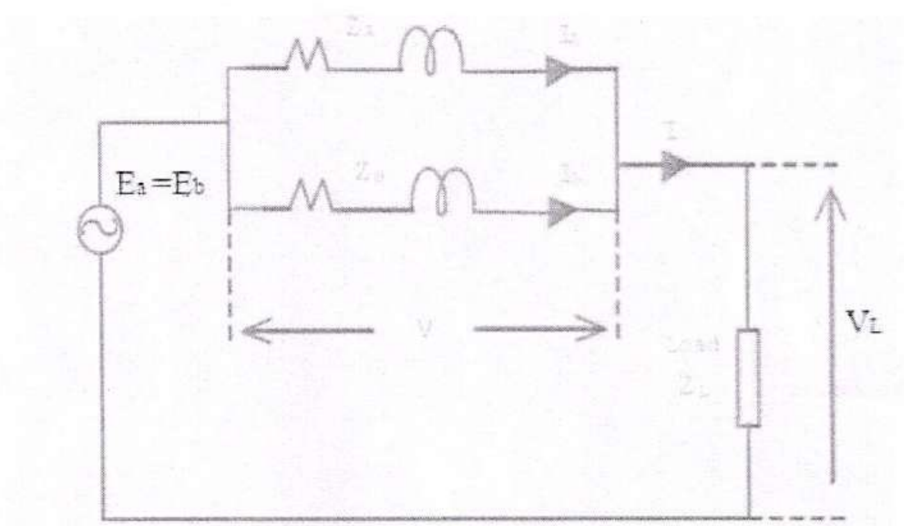


Fig. 4.28 Circuit modelling of two transformer in parallel

The equivalent circuit of two three phase transformer connected in parallel connected with a load of

Z_L impedance on per phase basis is drawn in fig 4.28. In this figure transformer A and B are operating in parallel. I_A and I_B are the load current of the two transformer.

The voltage equation of transformer A is

$E_a\ I_aZ_aV_L$ IZ_L

Since $E\ _aE_b$; $E\ _b$ I_aZ_a V_L IZ_L

however can be paralleled with the one with — 30° phase angle, the phase sequence is reversed for

one of them both at primary and secondary terminals. If the phase sequences are not the same then the two transformers cannot be connected in parallel even if they belong to same vector group. The phase sequence can be found out by the use of a phase sequence indicator.

Auto Transformer & Parallel Operation

Auto-transformers

The transformers we have considered so far are two-winding transformers in which the electrical circuit connected to the primary is electrically isolated from that connected to the secondary. An auto-transformer does not provide such isolation, but has economy of cost combined with increased efficiency. Fig.2.26 illustrates the auto-transformer which consists of a coil of NA turns between terminals 1 and 2, with a third terminal 3 provided after NB turns. If we neglect coil resistances and leakage fluxes, the flux linkages of the coil between 1 and 2 equals NA ϕm while the portion of coil between 3 and 2 has a flux linkage NB ϕm. If the induced voltages are designated as EA and EB, just as in a two winding transformer,

$$\frac{\bar{E}_A}{\bar{E}_B} = \frac{N_A}{N_B}$$

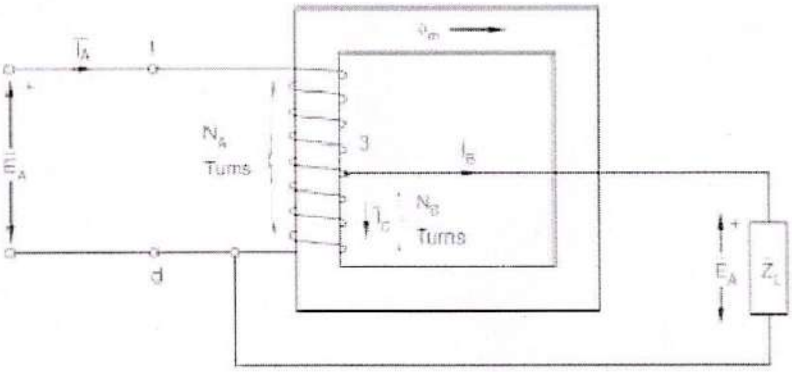


Fig: 2.26

Neglecting the magnetizing ampere-turns needed by the core for producing flux, as in an ideal transformer, the current *IA* flows through only (*NA* – *NB*) turns. If the load current is *IB*, as shown by

Kirchhoff's current law, the current *IC* flowing from terminal 3 to terminal 2 is (*IA* - *IB*). This current flows through *NB* turns. So, the requirement of a net value of zero ampere-turns across the core demands that

The voltage equation of transformer B is

$E_b I_b Z_b V_l I Z_L$
$E_b I_a Z_a E_b I_b Z_b I_a Z_a I_b Z_b$
According to the voltage drops across the two equivalent leakage impedance Za and Zb are equal.

According to KCL we can write
$I \quad I_a \quad I_b$
$I_a \quad I_a Z$
$a\, Z_b$
Z_b
I_a
$I \quad Z_a Z_b$
Z_a
similarly, I_b
$I Z_a Z_b$
Multiplying both the current equations by terminal voltage we get,

Z_b
S_a
$S \quad Z_a Z_b$
Z_a
similarly, S_b
$S Z_a Z_b$
Thus the power sharing in between two transformer is given in above equation in VA rating.

Delta-zigzag and Star zigzag connections (Dz0/Dz6 & Yz1/Yz6) –

The connection of Dz0 is shown in fig. 4.18 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle difference between the phase voltage of high voltage side and low voltage side is 0°.

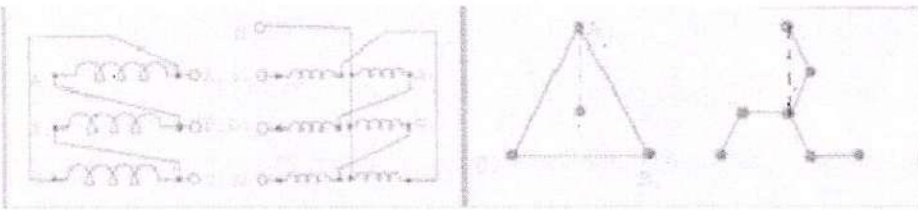


Fig 4.18. Dz0 connection and phasor diagram

The connection of Dz6 is shown in fig. 4.19 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle difference between the phase voltage of high voltage side and low voltage side is 180°.

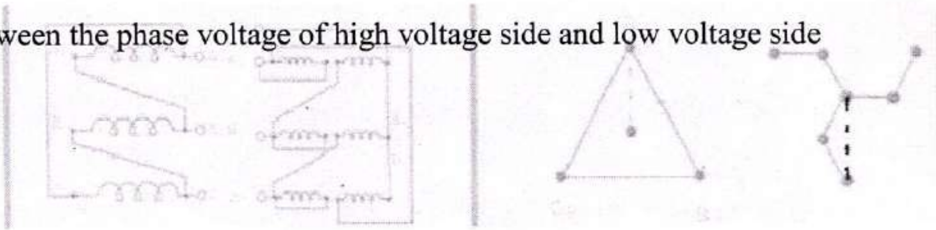
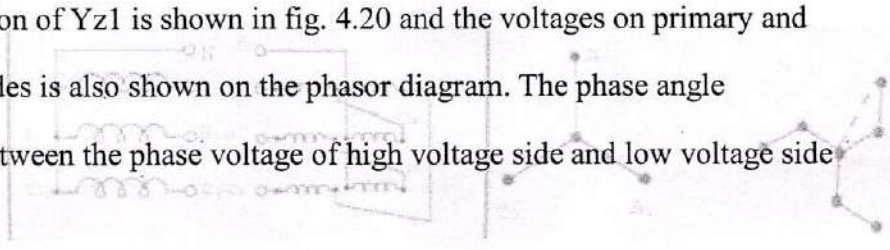


Fig 4.19. Dz6 connection and phasor diagram

The connection of Yz1 is shown in fig. 4.20 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle difference between the phase voltage of high voltage side and low voltage side is -30°.



If secondary of this transformer should be paralleled with secondary of another transformer without phase shift, there would be a problem.

Application

Commonly used in a step-up transformer: As for example, at the beginning of a HT transmission

line. In this case neutral point is stable and will not float in case of unbalanced loading. There is no distortion of flux because existence of a -connection allows a path for the third-harmonic components. The line voltage ratio is √3 times of transformer turn-ratio and the secondary voltage leads the primary one by 30°. In recent years, this arrangement has become very popular for distribution system as it provides 3- Ø, 4-wire system.

Commonly used in commercial, industrial, and high-densityresidential locations: To supply three-

phase distribution systems. An example would be a distribution transformer with a delta primary, running on three 11kV phases with no neutral or earth required, and a star (or wye) secondary providing a 3-phase supply at 400 V, with the domestic voltage of 230 available between each phase and an earthed neutral point.

Used as Generator Transformer: The Δ-Y transformer connection is used universally for connecting generators to transmission systems.

The connection of Yz11 is shown in fig. 4.21 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle difference between the phase voltage of high voltage side and low voltage side is 30°.

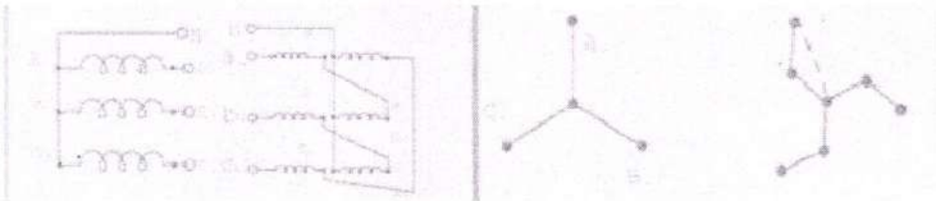


Fig 4.22 Yz11 connection and phasor diagram

These connections are employed where delta connections are weak. Interconnection of phases in zigzag winding effects a reduction of third harmonic voltages and at the same time permits unbalanced loading.

This connection may be used with either delta connected or star connected winding either for step-up or step-down transformers. In either case, the zigzag winding produces the same angular displacement as a delta winding, and at the same time provides a neutral for earthing purposes.

The amount of copper required from a zigzag winding in 15% more than a corresponding star or delta winding. This is extensively used for earthing transformer.

Due to **zigzag** connection (interconnection between phases), third harmonic voltages are reduced. It also allows unbalanced loading. The zigzag connectionis employed for LV winding. For a given total voltage per phase, the zigzag side requires 15% more turns as compared to normal phase connection. In cases where delta connections are weak due to large number of turns and small cross

Fig 4.20. Yz1 connection and phasor diagram

There are two main reasons for the need to transform from three phases to two phases,

1. To give a supply to an existing two phase system from a three phasesupply.
2. To supply two phase furnace transformers from a three phase source.

Two-phase systems can have 3-wire, 4-wire, or 5-wire circuits. It is needed to be considering that a two-phase system is not 2/3 of a three-phase system. Balanced three- wire, two-phase circuits have two phase wires, both carrying approximately the same amount of current, with a neutral wire carrying 1.414 times the currents in the phase wires. The phase-to-neutral voltages are 90° out of phase with each other.

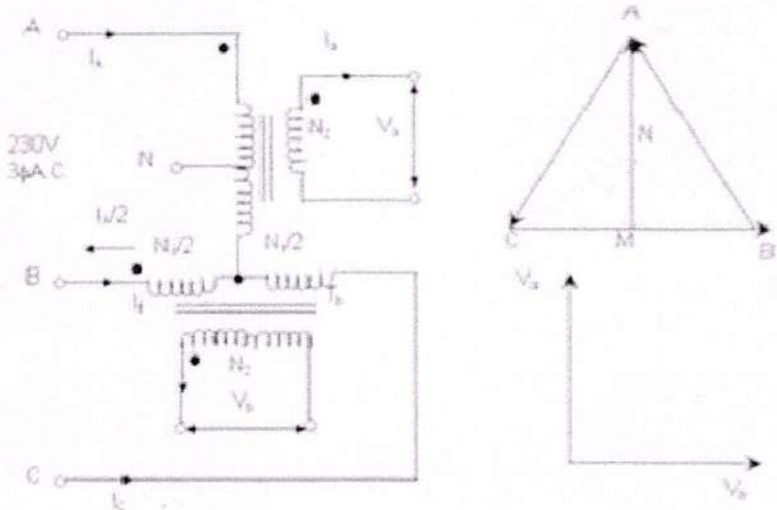
Two phase 4-wire circuits are essentially just two ungrounded single-phase circuits that are electrically 90° out of phase with each other. Two phase 5-wire circuits have four phase wires plus a neutral; the four phase wires are 90° out of phase with each other.

A Scott-T transformer (also called a Scott connection) is a type of circuit used to derive two-phase power from a three-phase source or vice-versa. The Scott connection evenly distributes a balanced load between the phases of the source. Scott T Transformers require a three phase power input and provide two equal single phase outputs called Main and Teaser. The MAIN and Teaser outputs are 90 degrees out of phase. The MAIN and the Teaser outputs must not be connected in parallel or in series as it creates a vector current imbalance on the primary side. MAIN and Teaser outputs are on separate cores. An external jumper is also required to connect the primary side of the MAIN and Teaser sections. The schematic of a typical Scott T Transformer is shown below:

sections, then zigzag star connection is preferred. It is also used in rectifiers.

4.3 Scott connection

winding, calculating the primary currents separately and superimposing the results.



4.23 Connection diagram of Scott-connected transformer and vector relation of input and output

From the phasor diagram it is clear that the secondary voltages are of two phases with equal magnitude and 90° phase displacement.

Scott T Transformer is built with two single phase transformers of equal power rating. Assuming the desired voltage is the same on the two and three phase sides, the Scott-T transformer connection consists of a center-tapped 1:1 ratio main transformer, T1, and an 86.6% (0.5√3) ratio teaser transformer, T2. The center-tapped side of T1 is connected between two of the phases on the three-phase side. Its center tap then connects to one end of the lower turn count side of T2, the other end connects to the remaining phase. The other side of the transformers then connects directly to the two pairs of a two-phase four- wire system.

If the main transformer has a turn's ratio of 1: 1, then the teaser transformer requires a turn's ratio of

0.866: 1 for balanced operation. The principle of operation of the Scott connection can be most easily seen by first applying a current to the teaser secondary windings, and then applying a current to the main secondary

Used as Auto Transformer: A Y-Y transformer may be constructed as an autotransformer, with the possibility of great cost savings compared to the two- winding transformer construction.

Better ProtectiveRelaying: The protective relay settings will be protecting better on the line to ground faults when the Y-Y transformer connections with solidly grounded neutrals are applied.

Disadvantages

The Third harmonic issue:

The voltages in any phase of a Y-Y transformer are 1200 apart from the voltages in any other phase. However, the third-harmonic components of each phase will be in phase with each other. Nonlinearities in the transformer core always lead to generation of third harmonic. These components will add up resulting in large (can be even larger than the fundamental component) third harmonic component.

Overvoltage at Lighting Load: The presence of third (and other zero-sequence) harmonics at an ungrounded neutral can cause overvoltage conditions at light load. When constructing a Y-Y transformer using single-phase transformers connected in a bank, the measured line-to-neutral voltages are not 57.7% of the system phase-to- phase voltage at no load but are about 68% and diminish very rapidly as the bank is loaded. The effective values of voltages at different frequencies combine by taking the square root of the sum of the voltages squared. With sinusoidal phase- to-phase voltage, the third-harmonic component of the phase-to-neutral voltage is about 60%.

Voltage drop at Unbalance Load: There can be a large voltage drop for unbalanced phase- to-neutral loads. This is caused by the fact that phase-to-phase loads cause a voltage drop through the leakage reactance of the transformer whereas phase-to-neutral flow Generator side thus sinusoidal voltage on primary will give sinusoidal voltage on secondary side.

Overheated Transformer Tank:

Under certain circumstances, a Y-Y connected three-phase trans-can produce severe tank overheating that can quickly destroy the transformer. This usually occurs with an open phase on the primary circuit and load on the secondary.

Over Excitation of Core in Fault Condition: If a phase-to-ground fault occurs on the primary circuit with the primary neutral grounded, then the phase-to-neutral voltage on the un faulted phases increases to 173% of the normal voltage. This would almost certainly result in over excitation of the core, with greatly increased magnetizing currents and core losses

If the neutrals of the primary and secondary are both brought out, then a phase- to-ground fault on the secondary circuit causes neutral fault current to flow in the primary circuit. Ground protection re- laying in the neutral of the primary circuit may then operate for faults on the secondary circuit

Neutral Shifting:

If the load on the secondary side unbalanced then the performance of this connection is not satisfactory then the shifting of neutral point is possible. To prevent this, star point of the primary is required to be connected to the star point of the generator.

Distortion of Secondary voltage:

Even though the star or neutral point of the primary is earthed, the third harmonic present in the alternator voltage may appear on the secondary side. This causes distortion in the secondary phase voltages.

Over Voltage at Light Load: The presence of third (and other zero-sequence) harmonics at an ungrounded neutral can cause overvoltage conditions at light load.

loads cause a voltage drop through the magnetizing reactance, which is 100 to 1000 times larger than the leakage reactance.

Increase Healthy Phase Voltage under Phase to ground Fault: If a phase-to-ground fault occurs on the

primary circuit with the primary neutral grounded, then the phase-to-neutral voltage on the UN faulted phase's increases to 173% of the normal voltage. If the neutrals of the primary and secondary are both brought out, then a phase-to-ground fault on the secondary circuit causes neutral fault current to flow in the primary circuit.

Trip the T/C in Line-Ground Fault: All harmonics will propagate through the transformer, zero-sequence current path is continuous through the transformer, one line-to-ground fault will trip the transformer.

Suitable for Core Type Transformer: The third harmonic voltage and current is absent in such type of connection with three phase wire system or shell type of three phase units, the third harmonic phase voltage may be high. This type of connection is more suitable for core type transformers.

Application

This Type of Transformer is rarely used due to problems with unbalanced loads.

It is economical for small high voltage transformers as the number of turns per phase and the amount of insulation required is less.

4.2.3 Star/Delta connection(Yd1/Yd11)

There is a +30 Degree or -30 Degree Phase Shift between Secondary Phase Voltage to Primary Phase Voltage. The connection of Yd1 is shown in fig. 4.14 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle difference between the phase voltage of high voltage side and low voltage side is -30°.

Difficulty in coordination of Ground Protection: In Y-Y Transformer, a low-side ground fault causes

primary ground fault current, making coordination more difficult.

The delta connected winding carries third harmonic current due to which potential of neutral point is stabilized. Some saving in cost of insulation is achieved if HV side is star connected. But in practice the HV side is normally connected in delta so that the three phase loads like motors and single phase loads like lighting loads can be supplied by LV side using three phase

four wire system.

As Grounding Transformer: In Power System Mostly grounded Y- Δ transformer is used for no other purpose than to provide a good ground source in ungrounded Delta system.

Disadvantages

In this type of connection, the secondary voltage is not in phase with the primary. Hence it is not possible to operate this connection in parallel with star-star or delta-delta connected transformer.

One problem associated with this connection is that the secondary voltage is shifted by

30^0 with respect to the primary voltage. This can cause problems when paralleling 3-phase transformers since transformers secondary voltages must be in-phase to be paralleled. Therefore, we must pay attention to these shifts.

If secondary of this transformer should be paralleled with secondary of another transformer without phase shift, there would be a problem

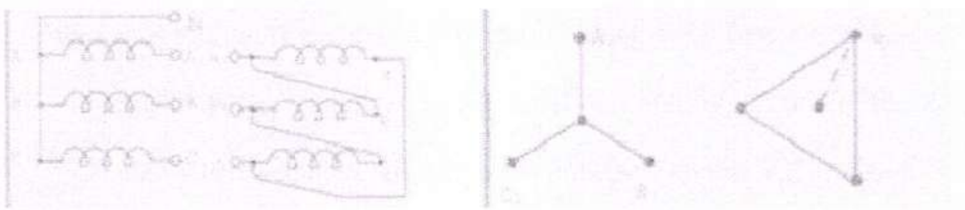


Fig 4.14. Yd1 connection and phasor diagram

The connection of Yd11 is shown in fig. 4.15 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle difference between the phase voltage of high voltage side and low voltage side is 30°.

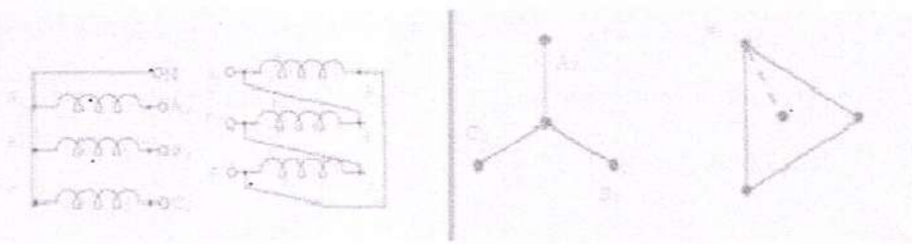


Fig 4.15. Yd11 connection and phasor diagram

Advantages

The primary side is star connected. Hence fewer numbers of turns are required. This makes the connection economical for large high voltage step down power transformers.

The neutral available on the primary can be earthed to avoid distortion.

The neutral point allows both types of loads (single phase or three phases) to be met.

Large unbalanced loads can be handled satisfactory.

The Y-D connection has no problem with third harmonic components due to circulating currents inD. It is also more stable to unbalanced loads since the D partially redistributes any imbalance that occurs.

This type of connection is commonly employed at the substation end of the transmission line. The main use with this connection is to step down the voltage. The neutral available on the primary side is grounded. It can be seen that there is phase difference of 30° between primary and secondary line voltages.

Commonly used in a step-down transformer, Y connection on the HV side reduces insulation costs the neutral point on the HV side can be grounded, stable with respect to unbalanced loads. As for example, at the end of a transmission line. The neutral of the primary winding is eart~~hed. In this system, line voltage ratio is 1~~/√3 Times of transformer turn-ratio and secondary voltage lags behind primary voltage by 30°. Also third harmonic currents flows in

4.2.4 <u>Delta-star connection (Dy1/Dy11)</u>

In this type of connection, the primary connected in delta fashion while the secondary current is connected in star. There is s +30 Degree or -30 Degree Phase Shift between Secondary Phase Voltage to Primary Phase Voltage.

The connection of Dy1 is shown in fig. 4.16 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle difference between the phase voltage of high voltage side and low voltage side is -30°.

Application

It is commonly employed for power supply transformers.

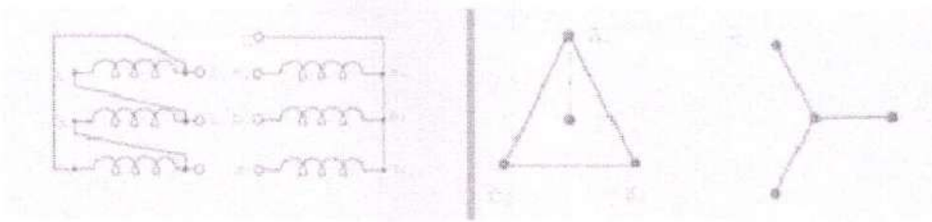


Fig 4.17. Dy11 connection and phasor diagram

Advantages

Cross section area of winding is less at Primary side: On primary side due to delta connection winding cross-section required is less.

Used at Three phase four wire System: On secondary side, neutral is available, due to which it can be used for 3-phase, 4 wire supply system.

No distortion of Secondary Voltage: No distortion due to third harmonic components.

Handled large unbalanced Load: Large unbalanced loads can be handled without any difficulty.

Grounding Isolation between Primary and Secondary: Assuming that the neutral of the Y-connected secondary circuit is grounded, a load connected phase- to-neutral or a phase-to-ground fault produces two equal and opposite currents in two phases in the primary circuit without any neutral ground current in the primary circuit. Therefore, in contrast with the Y-Y connection, phase-to-ground faults or current unbalance in the secondary circuit will not affect ground protective relaying applied to the primary circuit. This feature enables proper coordination of protective devices and is a very important design consideration.

The neutral of the Y grounded is sometimes referred to as a grounding bank, because it provides a local source of ground current at the secondary that is isolated from the primary circuit.

Fig 4.16. Dy1 connection and phasor diagram

The connection of Dy11 is shown in fig. 4.17 and the voltages on primary and secondary sides is also shown on the phasor diagram. The phase angle difference between the phase voltage of high voltage side and low voltage side is 30°.

Therefore, we must pay attention to these shifts.

Harmonic Suppression: The magnetizing current must contain odd harmonics for the induced voltages to be sinusoidal and the third harmonic is the dominant harmonic component. In a three-phase system the third harmonic currents of all three phases are in phase with each other because they are zero-sequence currents. In the Y-Y connection, the only path for third harmonic current is through the neutral. In the Δ - Y connection, however, the third harmonic currents, being equal in amplitude and in phase with each other, are able to circulate around the path formed by the Δ connected winding. The same thing is true for the other zero- sequence harmonics.

Grounding Bank: It provides a local source of ground current at the secondary that is isolated from the primary circuit. For suppose an ungrounded generator supplies a simple radial system through Δ-Y transformer with grounded Neutral at secondary as shown Figure. The generator can supply a single-phase-to-neutral load through the -grounded Y transformer.

Disadvantages

In this type of connection, the secondary voltage is not in phase with the primary. Hence it is not possible to operate this connection in parallel with star-star or delta-delta connected transformer.

One problem associated with this connection is that the secondary voltage is shifted by

30^{0} with respect to the primary voltage. This can cause problems when paralleling 3-phase transformers since transformers secondary voltages must be in-phase to be paralleled.

Figure 19: The approximate equivalent circuit

This circuit, called the approximate equivalent circuit, is simple to use for quick calcula-tions. With this equation the equivalent circuit can be modified as shown in fig. 20.

Dividing the equation for the rotor current by s and merging the two sides of the trans-former is not just a mathematical jugglery. The power dissipated in the rotor resistance (per phase) is obviously $I_2'^2R_r'$. From the equivalent circuit of fig. 20 one can see that the rotor current (referred to stator of course) flows through a resistance R_r'/s which has a component $R_r'(1 - s)/s$ in addition to R_r' , which also dissipates power. What does this represent?

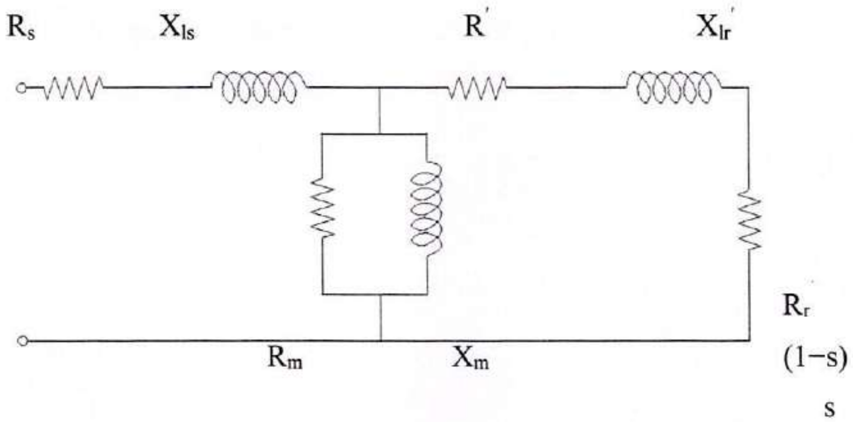


Figure 20: The exact equivalent circuit - separation of rotor resistance

From the equivalent circuit, one can see that the dissipation in R_s represents the stator loss, and dissipation in R_m represents the iron loss. Therefore, the power absorption indicated by the rotor part of the circuit must represent all other means of power consumption - the actual mechanical output, friction and windage loss components and the rotor copper loss components. Since the dissipation in R_r' is rotor copper loss, the power dissipation in $R_r'(1 - s)/s$ is the sum total of the remaining. In standard terminology, dissipation in

- R_r'/s is called the air gap power.
- R_r' is the rotor copper loss.

This expression can be modified as follows (dividing numerator and denominator by s)

Equation 7 tells us that the rotor current is the same as the current flowing in a circuit with a load impedance consisting of a resistance R_r'/s and inductive reactance X_{lr}'. This current would also now be at the frequency of E_1 (stator frequency). Note that the slip no longer multiplies the leakage reactance. Further this current is now caused by a voltage of E_1 itself (no multiplying factor of s). Hence the transformer in fig. 17 can also be removed.

Since, with this, the conversion to slip frequency is no longer there, the equivalent circuit can be represented as in fig. 18.

This is then the per-phase equivalent circuit of the induction machine, also called as exact equivalent circuit. Note that the voltage coming across the magnetizing branch is the applied stator voltage, reduced by the stator impedance drop. Generally the stator impedance drop is only a small fraction of the applied voltage. This fact is taken to advantage and the magnetizing branch is shifted to be directly across the input terminals and is shown in fig. 19.

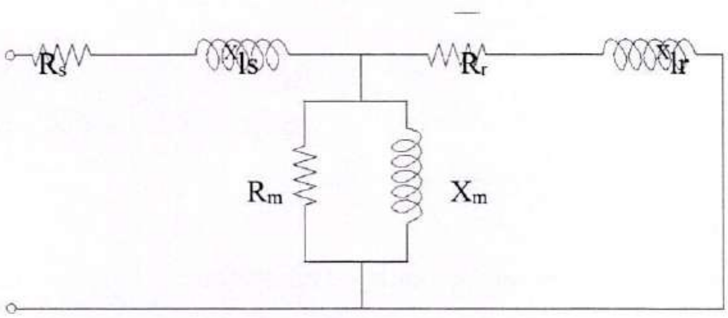
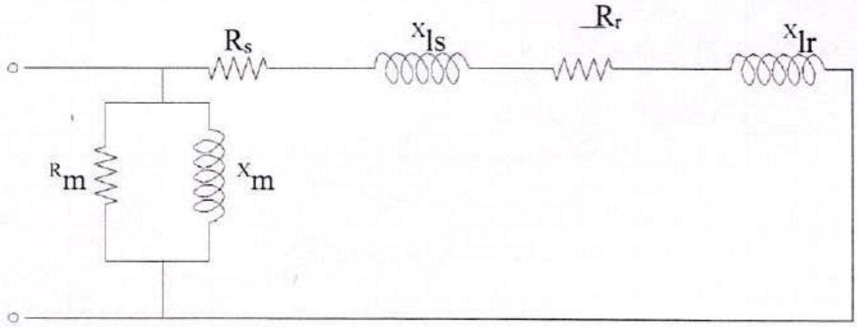
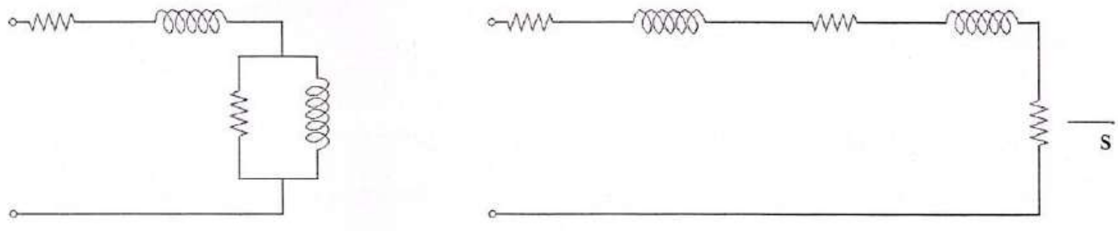


Figure 18: The Exact equivalent circuit





(a) No-load equivalent (b) Blocked rotor equivalent

Figure 21: Reduced equivalent circuits

These two observations and the reduced equivalent circuits are used as the basis for the two most commonly used tests to find out the equivalent circuit parameters — the blocked rotor test and no load test. They are also referred to as the short circuit test and open circuit test respectively in conceptual analogy to the transformer.

The no-load test

The behaviour of the machine may be judged from the equivalent circuit of fig. 21(a). The current drawn by the machine causes a stator-impedance drop and the balance voltage is applied across the magnetizing branch. However, since the magnetizing branch impedance is large, the current drawn is small and hence the stator impedance drop is small compared to the applied voltage (rated value). This drop and the power dissipated in the stator resistance are therefore neglected and the total power drawn is assumed to be consumed entirely as core loss. This can also be seen from the approximate equivalent circuit, the use of which is justified by the foregoing arguments. This test therefore enables us to compute the resistance and inductance of the magnetizing branch in the following manner.

Let applied voltage = V_s. Then current drawn is given by

$$I_s = \frac{V_s}{R_m} + \frac{V_s}{jX_m} \qquad (9)$$

The power drawn is given by

- $R_r'(1 - s)/s$ is the mechanical output.

In an ideal case where there are no mechanical losses, the last term would represent the actual output available at the shaft. Out of the power P_g Transferred at the air gap, a fraction s is dissipated in the rotor and $(1 - s)$ is delivered as output at the shaft. If there are no mechanical losses like friction and windage, this represents the power available to the load.

Determination of Circuit Parameters

In order to find values for the various elements of the equivalent circuit, tests must be conducted on a particular machine, which is to be represented by the equivalent circuit. In order to do this, we note the following.

1. When the machine is run on no-load, there is very little torque developed by it. In an ideal case where there is no mechanical losses, there is no mechanical power deveoped at no-load. Recalling the explanations in the section on torque production, the flow of current in the rotor is indicative of the torque that is produced. If no torque is produced, one may conclude that no current would be flowing in the rotor either. The rotor branch acts like an open circuit. This conclusion may also be reached by reasoning that when there is no load, an ideal machine will run up to its synchronous speed where the slip is zero resulting in an infinite impedance in the rotor branch.

2. When the machine is prevented from rotation, and supply is given, the slip remains at unity. The elements representing the magnetizing branch R_m &X_m are high impedances much larger than R_r' & X_{lr}' in series. Thus, in the exact equivalent circuit of the induction machine, the magnetizing branch may be neglected.

From these considerations, we may reduce the induction machine exact equivalent circuit of fig.18 to those shown in fig. 21

differences. If more accurate estimates are required IEEE guidelines may be followed which depend on the size of the machine.

Note that these two tests determine the equivalent circuit parameters in a 'Stator-referred' sense, i.e., the rotor resistance and leakage inductance are not the actual values but what they 'appear to be' when looked at from the stator. This is sufficient for most purposes as interconnections to the external world are generally done at the stator terminals.

Deducing the machine performance

From the equivalent circuit, many aspects of the steady state behavior of the machine can be deduced. We will begin by looking at the speed-torque characteristic of the machine. We will consider the approximate equivalent circuit of the machine. We have reasoned earlier that the power consumed by the 'rotor-portion' of the equivalent circuit is the power transferred across the air-gap. Out of that quantity the amount dissipated in R_r' is the rotor copper loss and the quantity consumed by $R_r'\,(1 - s)/s$ is the mechanical power developed. Neglecting mechanical losses, this is the power available at the shaft. The torque available can be obtained by dividing this number by the shaft speed.

The complete torque-speed characteristics

In order to estimate the speed torque characteristic let us suppose that a sinusoidal voltage is impressed on the machine. Recalling that the equivalent circuit is the per-

$$I_s = \frac{V_s}{\left(R_s + \frac{R_r'}{s}\right) + j(X_{ls} + X_{lr}')} \tag{14}$$

where V_s is the phase voltage phasor and I_s is the current phasor. The magnetizing phase represen-tation of the machine, the current drawn by the circuit is given by

current is neglected. Since this current is flowing through $\frac{R_r'}{s}$, the air-gap power is given by The mechanical power output was shown to be $(1 - s)P_g$ (power dissipated in R_r'/s).

The torque is obtained by dividing this by the shaft speed ω_m. Thus we have,

$$P_s = \frac{V_s^2}{R_m} \Rightarrow R_m = \frac{V_s^2}{P_s} \tag{10}$$

V_s, I_s and P_s are measured with appropriate meters. With R_m known from eqn. 10, X_m can be found from eqn. 9. The current drawn is at low power factor and hence a suitable wattmeter should be used.

Blocked-rotor Test

In this test the rotor is prevented from rotation by mechanical means and hence the name. Since there is no rotation, slip of operation is unity, s = 1. The equivalent circuit valid under these conditions is shown in fig. 21(b). Since the current drawn is decided by the resistance and leakage impedances alone, the magnitude can be very high when rated voltage is applied. Therefore in this test, only small voltages are applied — just enough to cause rated current to flow. While the current magnitude depends on the resistance and the reactance, the power drawn depends on the resistances.

The parameters may then be determined as follows. The source current and power drawn may be written as

$$I_s = \frac{V_s}{(R_s + R'_r) + j(X_s + X'_r)} \tag{11}$$

$$P_s = |I_s|^2(R_s + R'_r) \tag{12}$$

In the test V_s, I_s and P_s are measured with appropriate meters. Equation 12 enables us to compute$(R_s + R_r')$. Once this is known, $(X_s + X_r')$ may be computed from the eqn. 11.

Note that this test only enables us to determine the series combination of the resistance and the reactance only and not the individual values. Generally, the individual values are assumed to be equal; the assumption $R_s = R_r'$, and$X_s = X_r'$suffices for most purposes. In practice, there are

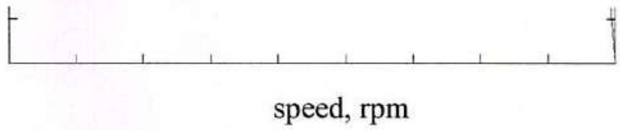


Figure 22: Induction machine speed-torque characteristic

We must note that the approximate equivalent circuit was used in deriving this relation. Readers with access to MATLAB or suitable equivalents (octave, scilab available free under GNU at the time of this writing) may find out the difference caused by using the 'exact' equivalent circuit by using the script found here. A comparison between the two is found in the plot of fig. 23. The plots correspond to a 3 kW, 4 pole, 50 Hz machine, with a rated speed of 1440 rpm. It can be seen that the approximate equivalent circuit is a good approximation in the operating speed range of the machine. Comparing fig. 22 with fig. 23, we can see that the slope and shape of the characteristics are dependent intimately on the machine parameters.

Further, this curve is obtained by varying slip with the applied voltage being held constant. Coupled with the fact that this is an equivalent circuit valid under steady state, it implies that if this characteristic is to be measured experimentally, we need to look at the torque for a given speed after all transients have died down. One cannot, for example, try to obtain this curve by directly starting the motor with full voltage applied to the terminals

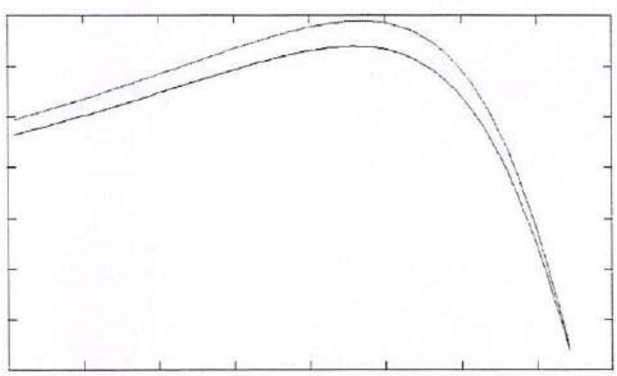


Figure 23: Comparison of exact and approximate circuit predictions

and measuring the torque and speed dynamically as it runs up to steady speed.
Another point to note is that the equivalent circuit and the values of torque predicted is

$$\frac{P_g(1-s)}{\omega_m} = \frac{P_g(1-s)}{\omega_s(1-s)} = |I_s|^2 \frac{R_r}{s\omega_s} \tag{16}$$

where ω_s is the synchronous speed in radians per second and s is the slip. Further, this is the torque produced per phase. Hence the overall torque is given by

$$T_e = \frac{3}{\omega_s} \cdot \frac{V_s^2}{\left(R_s + \frac{R_2}{s}\right)^2 + \left(X_{ls} + X'_{lr}\right)} \cdot \frac{R'_r}{s}$$

The torque may be plotted as a function of 's' and is called the torque-slip (or torque-speed, since slip indicates speed) characteristic — a very important characteristic of the induction machine. Eqn. 17 is valid for a two-pole (one pole pair) machine. In general, this expression should be multiplied by p, the number of pole-pairs. A typical torque-speed characteristic is shown in fig. 22. This plot corresponds to a 3 kW, 4 pole, 60 Hz machine. The rated operating speed is 1780 rpm.

Torque

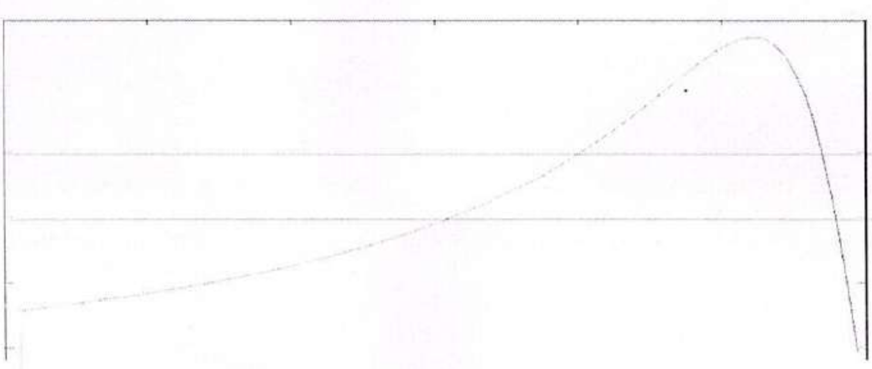
remaining constant all the while. But this is a subject to be discussed later. While considering the negative slip range, (generator mode) we note that the maximum torque is higher than in the positive slip region (motoring mode)

Operating Point

Consider a speed torque characteristic shown in fig. 25 for an induction machine, having the load characteristic also superimposed on it. The load is a constant torque load i.e.,the torque required for operation is fixed irrespective of speed.

The system consisting of the motor and load will operate at a point where the two characteristics meet. From the above plot, we note that there are two such points. We therefore need to find out which of these is the actual operating point.

To answer this we must note that, in practice, the characteristics are never fixed; they change slightly with time. It would be appropriate to consider a small band around the curve drawn where the actual points of the characteristic will lie. This being the case let us considers that the system is operating at point 1, and the load torque demand increases slightly. This is shown in fig. 26, where the change is exaggerated for clarity. This would shift the point of operation to a point 1′ at which the slip would be less and the developed torque higher.



valid when the applied voltage waveform is sinusoidal. With non-sinusoidal voltage wave-forms, the procedure is not as straightforward.

With respect to the direction of rotation of the air-gap flux, the rotor maybe driven to higher speeds by a prime mover or may also be rotated in the reverse direction. The torque-speed relation for the machine under the entire speed range is called the complete speed-torque characteristic. A typical curve is shown in fig. 7.1 for a four-pole machine, the synchronous speed being 1500 rpm. Note that negative speeds correspond to slip values greater than 1, and speeds greater than 1500 rpm correspond to negative slip. The plot also shows the operating modes of the induction machine in various regions. The slip axis is also shown for convenience.

Restricting ourselves to positive values of slip, we see that the curve has a peak point. This is the maximum torque that the machine can produce, and is called as stalling torque. If the load torque is more than this value, the machine stops rotating or stalls. It occurs at a slip $\hat{s}$, which for the machine of fig. 7.1 is 0.38. At values of slip lower than $\hat{s}$, the curve falls steeply down to zero at $s = 0$. The torque at synchronous speed is therefore zero. At values of slip higher than $s = \hat{s}$, the curve falls slowly to a minimum value at $s = 1$. The torque at $s = 1$ (speed = 0) is called the starting torque.

The value of the stalling torque may be obtained by differentiating the expression for torque with respect to zero and setting it to zero to find the value of $\hat{s}$. Using this method

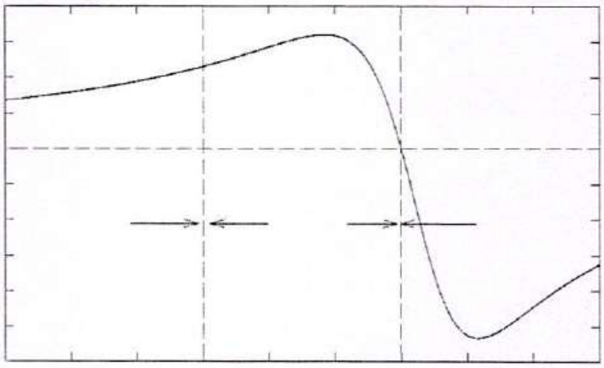


Figure 24: Complete speed-torque characteristic

This fact can be made use of conveniently to alter $\hat{s}$. If it is possible to change R_r', then we can get a whole series of torque-speed characteristics, the maximum torque presence of the non-zero slip that causes a torque to be developed. Thus the region of the curve between $s = 0$ and $s = 1$ is the region where the machine produces torque to rotate a passive load and hence is called the motoring region. Note further that the direction of rotation of the rotor is the same as that of the air gap flux.

Suppose when the rotor is rotating, we change the phase sequence of excitation to the machine. This would cause the rotating stator field to reverse its direction — the rotating stator mmf and the rotor are now moving in opposite directions. If we adopt the convention that positive direction is the direction of the air gap flux, the rotor speed would then be a negative quantity. The slip would be a number greater than unity. Further, the rotor as we know should be "dragged along" by the stator field. Since the rotor is rotating in the opposite direction to that of the field, it would now tend to slow down, and reach zero speed. Therefore this region ($s > 1$) is called the braking region. (What would happen if the supply is not cut-off when the speed reaches zero?)

There is yet another situation. Consider a situation where the induction machine is operating from mains and is driving an active load (a load capable of producing rotation by itself). A typical example is that of a windmill, where the fan like blades of the wind mill are connected to the shaft of the induction machine. Rotation of the blades may be caused by the motoring action of the machine, or by wind blowing. Further suppose that both acting independently cause rotation in the same direction. Now when both grid and wind act, a strong wind may cause the rotor to rotate faster than the mmf produced by the stator excitation. A little reflection shows that slip is then negative. Further, the wind is rotating the rotor to a speed higher than what the electrical supply alone would cause. In order to do this it has to contend with an opposing torque generated by the machine preventing the speed build up. The torque generated is therefore negative. It is this action of the wind against the torque of the machine that enables wind-energy generation. The region of slip $s > 1$ is the generating mode of operation. Indeed this is at present the most commonly used approach in wind-energy generation. It may be noted from the torque expression of eqn. 17 that torque is negative for negative values of slip.

Speed control of Induction Machines

We have seen the speed torque characteristic of the machine. In the stable region of operation in

speed, rpm

Figure 26: Stability of operating point

The difference in torque developed ΔT_e, being positive will accelerate the machine. Any overshoot in speed as it approaches the point $1'$ will cause it to further accelerate since the developed torque is increasing. Similar arguments may be used to show that if for some reason the developed torque becomes smaller the speed would drop and the effect is cumulative. Therefore we may conclude that 1 is not a stable operating point.

Let us consider the point 2. If this point shifts to $2'$, the slip is now higher (speed is lower) and the positive difference in torque will accelerate the machine. This behavior will tend to bring the operating point towards 2 once again. In other words, disturbances at point 2 will not cause a runaway effect. Similar arguments may be given for the case where the load characteristic shifts down. Therefore we conclude that point 2 is a stable operating point.

From the foregoing discussions, we can say that the entire region of the speed-torque characteristic from $s = 0$ to $s = \hat{s}$ is an unstable region, while the region from $s = \hat{s}$ to $s = 0$ is a stable region. Therefore the machine will always operate between $s = 0$ and $s = \hat{s}$

Modes of Operation

The reader is referred to fig. 7.1 which shows the complete speed-torque characteristic of the induction machine along with the various regions of operation.

Let us consider a situation where the machine has just been excited with three phase supply and the rotor has not yet started moving. A little reflection on the definition of the slip indicates that we are at the point $s = 1$. When the rotating magnetic field is set up due to stator currents, it is the induced emf that causes current in the rotor, and the interaction between the two causes torque. It has already been pointed out that it is the

UNIT-IV

Performance Characteristics of Three phase Induction Motor

Speed control by changing applied voltage

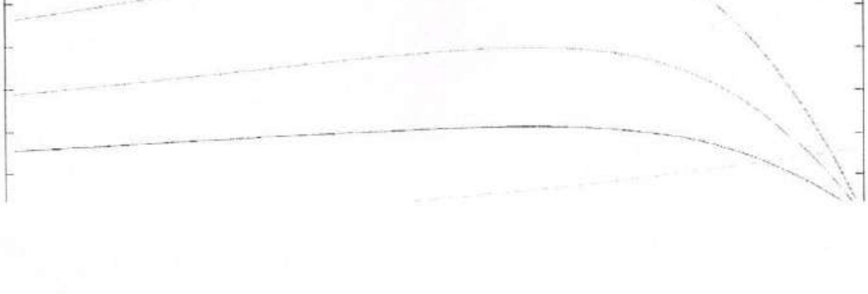
From the torque equation of the induction machine given in eqn.17, we can see that the torque depends on the square of the applied voltage. The variation of speed torque curves with respect to the applied voltage is shown in fig. 27. These curves show that the slip at maximum torque $\hat{s}$ remains same, while the value of stall torque comes down with decrease in applied voltage. The speed range for stable operation remains the same.

Further, we also note that the starting torque is also lower at lower voltages. Thus, even if a given voltage level is sufficient for achieving the running torque, the machine may not start. This method of trying to control the speed is best suited for loads that require very little starting torque, but their torque requirement may increase with speed.

Figure 27 also shows a load torque characteristic — one that is typical of a fan type of load. In a fan (blower) type of load,the variation of torque with speed is such that $T \propto \omega^2$. Here one can see that it may be possible to run the motor to lower speeds within the range n_s to $(1 - \hat{s})n_s$. Further, since the load torque at zero speed is zero, the machine can start even at reduced voltages. This will not be possible with constant torque type of loads.

One may note that if the applied voltage is reduced, the voltage across the magnetising branch also comes down. This in turn means that the magnetizing current and hence flux level are reduced. Reduction in the flux level in the machine impairs torque production

Stator voltage variation



the motoring mode, the curve is rather steep and goes from zero torque at synchronous speed to the stall torque at a value of slip $s = \hat{s}$. Normally $\hat{s}$ may be such that stall torque is about three times that of the rated operating torque of the machine, and hence may be about 0.3 or less. This means that in the entire loading range of the machine, the speed change is quite small. The machine speed is quite stiff with respect to load changes. The entire speed variation is only in the range n_s to $(1 - \hat{s})n_s$, n_s being dependent on supply frequency and number of poles.

The foregoing discussion shows that the induction machine, when operating from mains is essentially a constant speed machine. Many industrial drives, typically for fan or pump applications, have typically constant speed requirements and hence the induction machine is ideally suited for these. However,the induction machine, especially the squirrel cage type, is quite rugged and has a simple construction. Therefore it is good candidate for variable speed applications if it can be achieved.

speed, rpm

Figure 28: Speed-torque curves : rotor resistance variation

Note that while the maximum torque and synchronous speed remain constant, the slip at which maximum torque occurs increases with increase in rotor resistance, and so does the starting torque. whether the load is of constant torque type or fan-type, it is evident that the speed control range is more with this method. Further, rotor resistance control could also be used as a means of generating high starting torque.

For all its advantages, the scheme has two serious drawbacks. Firstly, in order to vary the rotor resistance, it is necessary to connect external variable resistors (winding resistance itself cannot be changed). This, therefore necessitates a slip-ring machine, since only in that case rotor terminals are available outside. For cage rotor machines, there are no rotor terminals. Secondly, the method is not very efficient since the additional resistance and operation at high slips entails dissipation.

The resistors connected to the slip-ring brushes should have good power dissipation ca-pability. Water based rheostats may be used for this. A 'solid-state' alternative to a rheostat is a chopper controlled resistance where the duty ratio control of of the chopper presents a variable resistance load to the rotor of the induction machine.

Cascade control

The power drawn from the rotor terminals could be spent more usefully. Apart from using the heat generated in meaning full ways, the slip ring output could be connected to another induction machine. The stator of the second machine would carry slip frequency currents of the first machine which would generate some useful mechanical power. A still better option would be to mechanically couple the shafts of the two machines together. This sort of a connection is called cascade connection and it gives some measure of speed control as shown below.

Let the frequency of supply given to the first machine be f_1 , its number poles be p_1, and its slip of operation be s_1 . Let f_2, p_2 and s_2 be the corresponding quantities for the second machine. The

speed, rpm

Figure 27: Speed-torque curves: voltage variation

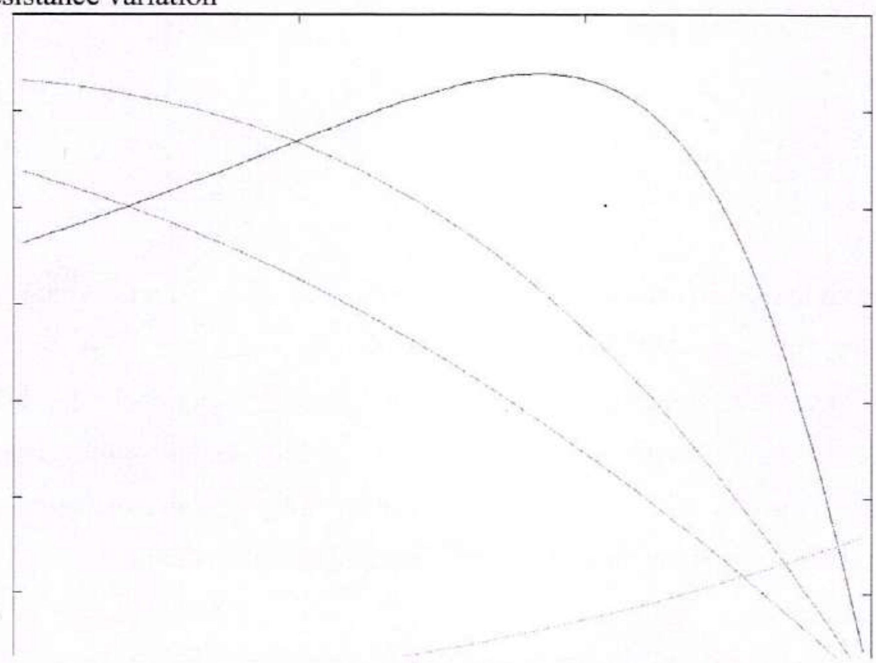
(recall explantions on torque production), which is primarily the explanation for fig. 27. If, however, the machine is running under lightly loaded conditions, then operating under rated flux levels is not required. Under such conditions, reduction in magnetizing current improves the power factor of operation. Some amount of energy saving may also be achieved.

Voltage control may be achieved by adding series resistors (a lossy, inefficient proposition), or a series inductor / autotransformer (a bulky solution) or a more modern solution using semiconductor devices. A typical solid state circuit used for this purpose is the AC voltage controller or AC chopper. Another use of voltage control is in the so-called 'soft-start' of the machine. This is discussed in the section on starting methods.

Rotor resistance control

The reader may recall from eqn.17 the expression for the torque of the induction machine. Clearly, it is dependent on the rotor resistance. Further, eqn.19 shows that the maximum value is independent of the rotor resistance. The slip at maximum torque eqn.18 is dependent on the rotor resistance. Therefore, we may expect that if the rotor resistance is changed, the maximum torque point shifts to higher slip values, while retaining a constant torque. Figure 28 shows a family of torque-speed characteristic obtained by changing the rotor resistance.

Rotor resistance variation



per phase

$$sE_1I_2' \cos \varphi_2 = I_2' R_2' + P_r . \qquad (22)$$

Clearly now, the value of s can be changed by the value of P_r . For $P_r = 0$, the machine is like a normal machine with a short circuited rotor. As P_r becomes positive, for all other circuit conditions remaining constant, s increases or in the other words, speed reduces. As P_r becomes negative,the right hand side of the equation and hence the slip decreases. The physical interpretation is that we now have an active source connected on the rotor side which is able to supply part of the rotor copper losses. When $P_r = -I_2'^2R_2$ the entire copper loss is supplied by the external source. The RHS and hence the slip is zero. This corresponds to operation at synchronous speed. In general the circuitry connected to the rotor may not be a simple resistor or a machine but a power electronic circuit which can process this power requirement. This circuit may drive a machine or recover power back to the mains. Such circuits are called static kramer drives.

Pole changing schemes

Sometimes induction machines have a special stator winding capable of being externally connected to form two diff erent number of pole numbers. Since the synchronous speed of the induction machine is given by $n_s = f_s/p$ (in rev./s) where p is the number of pole pairs, this would correspond to changing the synchronous speed. With the slip now corresponding to the new synchronous speed, the operating speed is changed. This method of speed control is a stepped variation and generally restricted to two steps.

If the changes in stator winding connections are made so that the air gap flux remains constant, then at any winding connection, the same maximum torque is achievable. Such winding arrangements are therefore referred to as constant-torque connections. If however such connection changes result in air gap flux changes that are inversely proportional to the synchronous speeds, then such connections are called constant-horsepower type.

The following figure serves to illustrate the basic principle. Consider a magnetic pole structure consisting of four pole faces A, B, C, D as shown in fig. 30.

frequency of currents flowing in the rotor of the first machine and hence in the stator of the second machine is $s_1 f_1$. Therefore $f_2 = s_1 f_1$. Since the machines are coupled at the shaft, the speed of the rotor is common for both. Hence, if n is the speed of the rotor

in radians,

$$n = \frac{f_1}{p_1}(1 - s_1) = \pm \frac{s_1 f_1}{p_2}(1 - s_2). \tag{20}$$

Note that while giving the rotor output of the first machine to the stator of the second, the resultant stator mmf of the second machine may set up an air-gap flux which rotates in the same direction as that of the rotor, or opposes it. this results in values for speed as

$$n = \frac{f_1}{p_1 + p_2} \quad \text{or } n = \frac{f_1}{p_1 - p_2} \quad (s_2 \text{ negligible}) \tag{21}$$

The latter expression is for the case where the second machine is connected in opposite phase sequence to the first. The cascade connected system can therefore run at two possible speeds

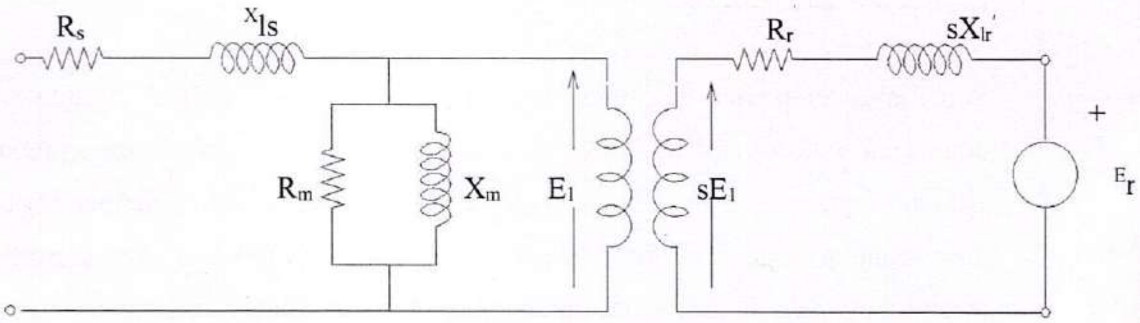


Figure 29: Generalized rotor control

Speed control through rotor terminals can be considered in a much more general way. Consider the induction machine equivalent circuit of fig. 29, where the rotor circuit has been terminated with a voltage source E_r .

If the rotor terminals are shorted, it behaves like a normal induction machine. This is equivalent to saying that across the rotor terminals a voltage source of zero magnitude is connected. Diff erent situations could then be considered if this voltage source E_r had a non-zero magnitude. Let the power consumed by that source be P_r . Then considering the rotor side circuit power dissipation

Thus the expressions for v_Y and v_B would be

$$v_Y = V_{1m}\sin(\omega_1 t + \varphi_1 - \frac{2\pi}{3}) + V_{3m}\sin(3\omega_1 t + \varphi_3 - 3.\frac{2\pi}{3})$$

$$+V_{5m}\sin(5\omega_1 t + \varphi_5 - 5.\frac{2\pi}{3}) + V_{7m}\sin(7\omega_1 t + \varphi_7 - 7.\frac{2\pi}{3}) + - - - \qquad (26)$$

$$v_B = V_{1m}\sin(\omega_1 t + \varphi_1 - \frac{4\pi}{3}) + V_{3m}\sin(3\omega_1 t + \varphi_3 - 3.\frac{4\pi}{3})$$

4π 4π

shifted from v_R respectively. It is further well known that if a waveform is shifted by φ degrees, its harmonics are shifted by $n\varphi$ degrees, where n is the order of the harmonic.

If we consider the third harmonic components of the three phase waveforms, and if $v_{x3}(t)$ is the third harmonic of phase x, we can see that

$$v_{R3} = V_{3m}\sin(3\omega_1 t + \varphi_3)$$

$$v_{Y3} = V_{3m}\sin(3\omega_1 t + \varphi_3)$$

$$v_{B3} = V_{3m}\sin(3\omega_1 t + \varphi_3) \qquad (28)$$

Therefore, all the three third harmonics are in phase. In a STAR connected system with isolated neutral, these voltages cannot cause any current flow since all three terminals are equal in potential. If the neutral point is connected to some point, then then current can flow through the neutral connection. Such a connection is however rare in induction machines. The machine is therefore an open circuit to third harmonics. In fact, one can see that any harmonic whose order is a multiple of three, i.e., the triplen harmonics, as they are called, will face an identical situation. Since the machine is an open circuit to triplen harmonics in the excitation voltage, these do not have eff ect on the machine.

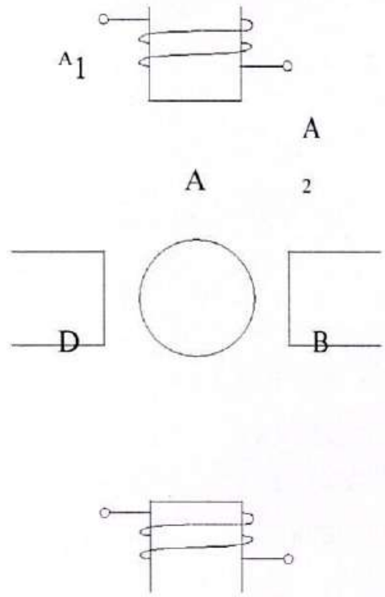


Figure 30: Pole arrangement

Harmonics in Induction Machines

In attempting to understand the performance of an induction machine, we consider that the air-gap flux wave is purely sinusoidal. It is from that assumption the analysis of induced emf, sinusoidal currents, the expressions for generated torque etc. proceed. In practice, there are deviations from this idealistic picture.

Time Harmonic

The first non-ideality is the presence of harmonics in the input supply given to the three phase machine. The source may contain 3rd, 5th, 7th. . . harmonics. Note that due to the symmetry of the waveform ($f(t) = -f(t + T/2)$, where T is the period of the supply sine waveform, even ordered harmonics cannot exist. Let the R phase supply voltage be given by the expression

$$v_R = V_{1m}\sin(\omega_1 t + \varphi_1) + V_{3m}\sin(3\omega_1 t + \varphi_3) + V_{5m}\sin(5\omega_1 t + \varphi_5) + V_{7m}\sin(7\omega_1 t + \varphi_7) + --- \quad (25)$$

Being a balanced three phase supply, we know that the waveforms of v_Y and v_B are 120° and 240°

Let us now consider the fifth harmonic. From the equations above, one can see that

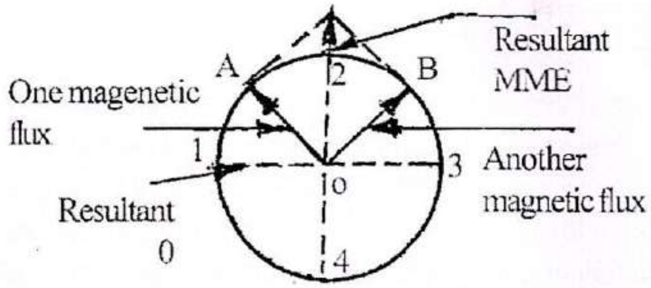
$$v_{RS} = V_{5m} \sin(5\omega_1 t + \varphi_5)$$

$$v_{YS} = V_{5m} \sin\left(5\omega_1 t + \varphi_5 - 5.\frac{2\pi}{3}\right)$$

$$= V_{5m} \sin\left(5\omega_1 t + \varphi_5 \ \frac{4\pi}{3}\right)$$

$$v_{BS} = V_{5m} \sin\left(5\omega_1 t + \varphi_5 - 5.\frac{4\pi}{3}\right)$$

$$= V_{5m} \sin\left(5\omega_1 t + \varphi_5 \ \frac{2\pi}{3}\right) \qquad (29)$$



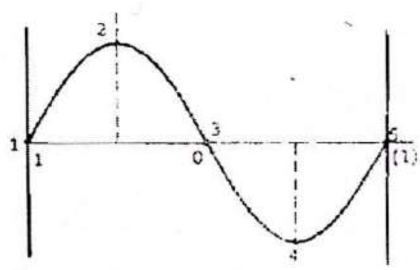


Fig: 4.2 (b)

The resultant of the two fields of equal magnitude rotating in opposite directions is alternating. Therefore an alternating current can be considered as having two components which are of equal in magnitude and rotating in opposite directions.

From the above, it is clear that when a single phase alternating current is supplied to the stator of a single phase motor, the field produced will be of alternating in nature which can be divided into two components of equal magnitude one revolving in clockwise and other in counter clockwise direction.

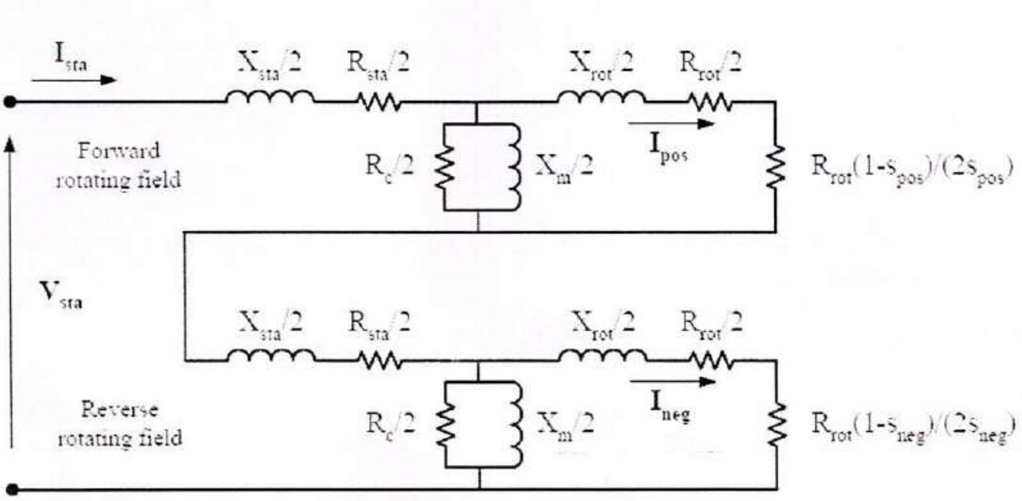
If a stationary squirrel cage rotor is kept in such a field equal forces in opposite direction will act and the rotor will simply vibrate and there will be no rotation.

But if the rotor is given a small jerk in any direction in this condition, it will go on revolving and will develop torque in that particular direction. It is clear from the above that a single phase induction motor when having only one winding is not a self-starting. To make it a self-starting anyone of the following can be adopted.

(i) Split phase starting.
(ii) Repulsion starting.
(iii) Shaded pole starting.

EQUVALENT CIRCUIT OF SINGLE PHASE INDUCTION MOTOR

The equivalent circuit of single phase induction motor is shown below (Fig: 4.3)



Unit-V
Single Phase Induction Motors

Single phase Induction motors perform a great variety of useful services at home, office, farm, factory and in business establishments. Single phase motors are generally manufactured in fractional HP ratings below 1 HP for economic reasons. Hence, those motors are generally referred to as fractional horsepower motors with a rating of less than 1 HP. Most single phase motors fall into this category. Single phase Induction motors are also manufactured in the range of 1.5, 2, 3 and up to 10 HP as a special requirement.

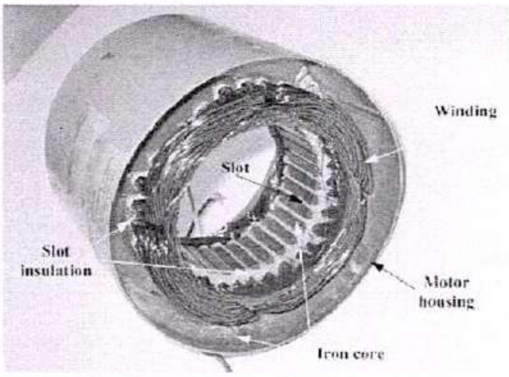


Fig: 4.1(a) Stator

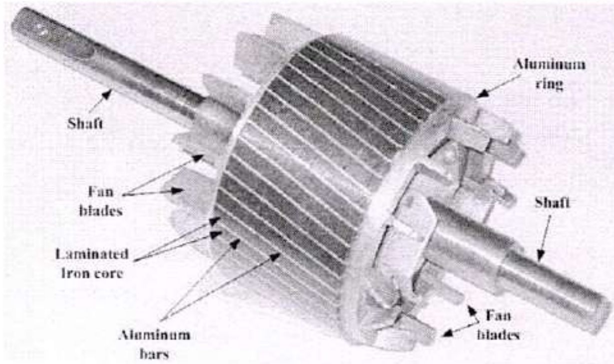


Fig: 4.1(b) Squirrel cage rotor

Theory of Operation

A single phase induction motor is similar in construction to that of a polyphase induction motor with difference that its stator has only one winding. If such a stator is supplied with single phase alternating current, the field produced by it changes in magnitude and direction sinusoidally. Thus the magnetic field produced in the air gap is alternating one but not rotating as a result these kind of motors are *NOT SELF STARTING*. Fig: 4.2 (a) shows the torque-speed characteristic of single phase induction motor.

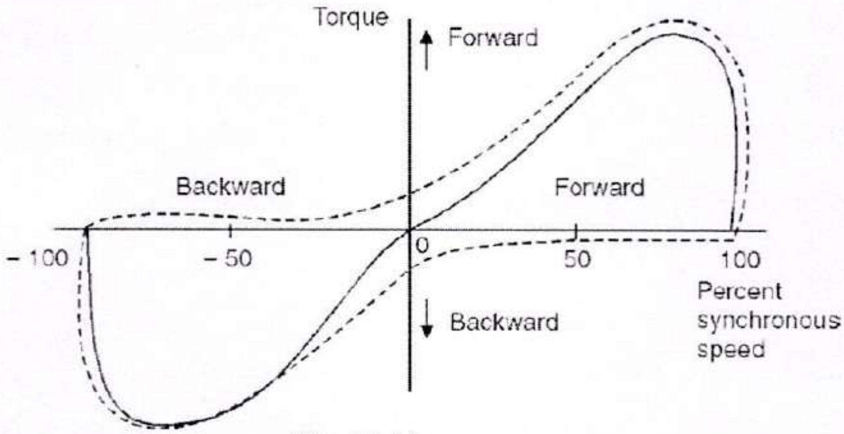


Fig: 4.2 (a)

Such an alternating filed is equivalent to two fields of equal magnitude rotating in opposite directions at equal speed as explained below:

Double Revolving Field Theory of Single Phase Induction Motor

Consider two magnetic fields represented by quantities OA and OB of equal magnitude revolving in opposite directions as shown in fig: 4.1.

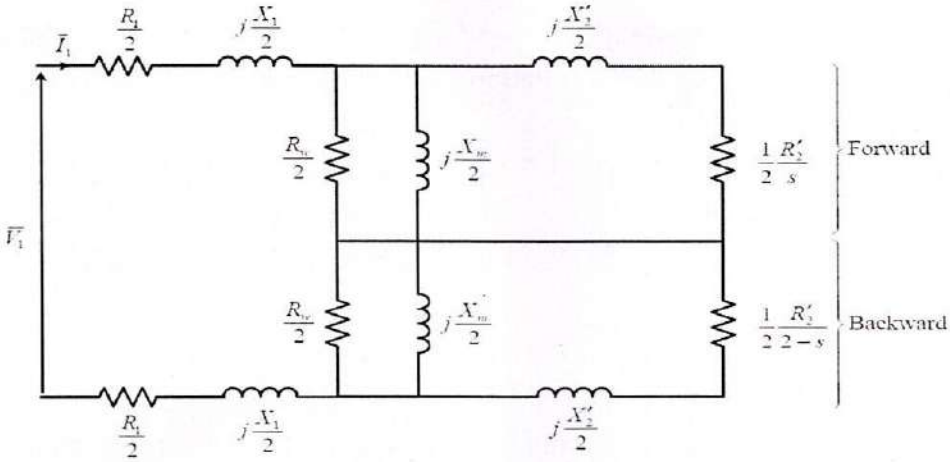


Fig: 4.4 Equivalent circuit of single phase induction motor.

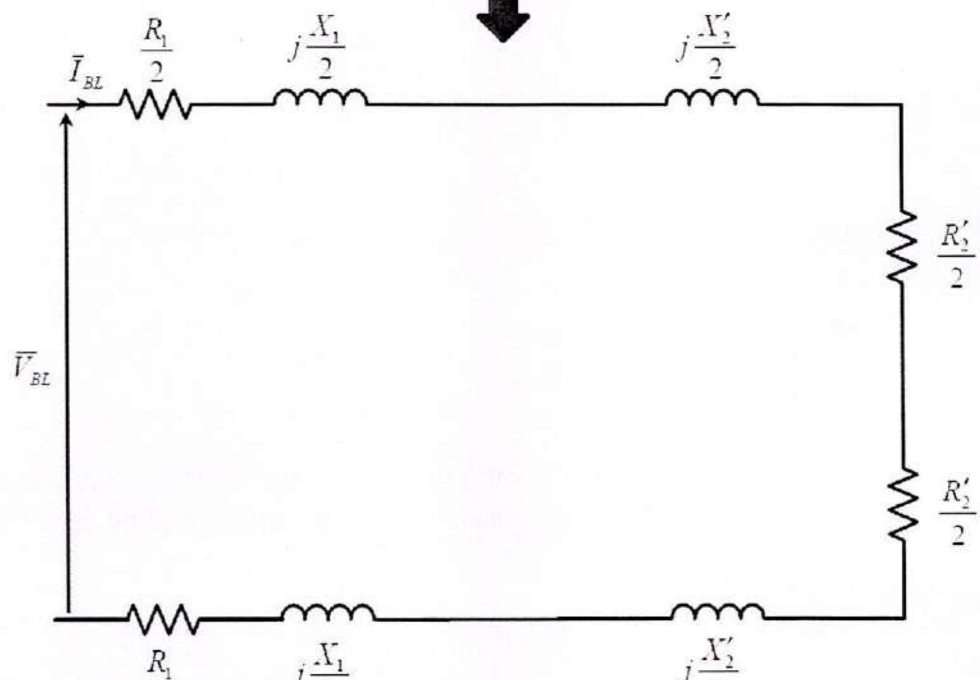


Fig: 4.5(a) Approximate equivalent circuit of the single phase induction motor at standstill.

Determination of Equivalent Circuit Parameters of Single Phase Induction motor

It is possible to find the parameters of the equivalent circuit of the single phase induction motor experimentally as shown in Fig.4.4. For this purpose, three tests should be conducted:

1- The DC Test:

The DC resistance of the stator can be measured by applying DC current to the terminals of the main winding and taking the reading of the voltage and the current (or using ohmmeter) and determine the DC resistance as follows:

$$R_{DC} = \frac{V_{DC}}{I_{DC}}$$

Then, the AC resistance is given by:

$$R_{AC} = 1.25\ R_{DC}$$

2-The Blocked Rotor Test:

When the rotor is locked (i.e. prevented from running), $\mathbf{S_b = S_f = 1}$. The secondary impedances become much less than the magnetizing branches and the corresponding equivalent circuit becomes that of Fig: 4.5.

1-The No Load Test:

When the induction motor is allowed to run freely at no load, the forward slip S_f approaches zero and the backward slip S_b approaches 2 ($S_f = s$, $S_b = 2-s$). The secondary forward impedance becomes very large with respect to the magnetizing branch, while the secondary backward impedance becomes very small if compared with the magnetizing branch. Accordingly, the equivalent circuit corresponding to these operating conditions can be approximated by that of Fig: 4.6.

The readings to be obtained from this test are:

d) Single phase power P_{NL}

e) Phase voltage V_{NL}

f) Phase current I_{NL}

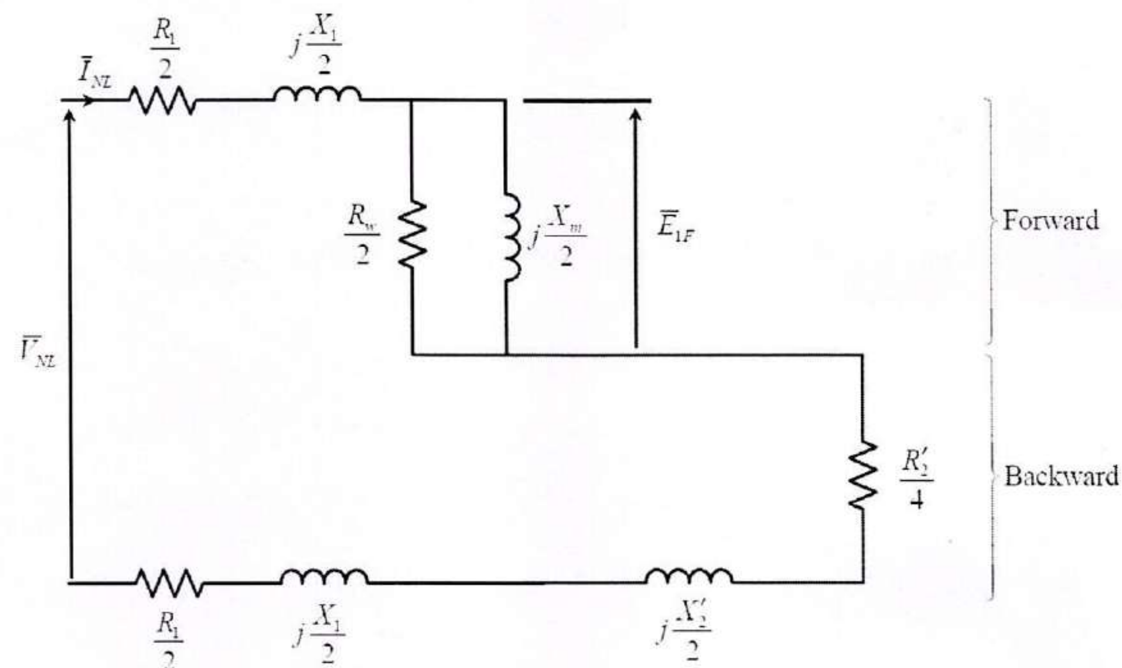


Fig: 4.6 (a) Approximate equivalent circuit of the single phase induction motor at no load.

The circuit in Fig: 4.5 (a) can be rearranged to the equivalent circuit that is shown in Fig: 4.5(b).

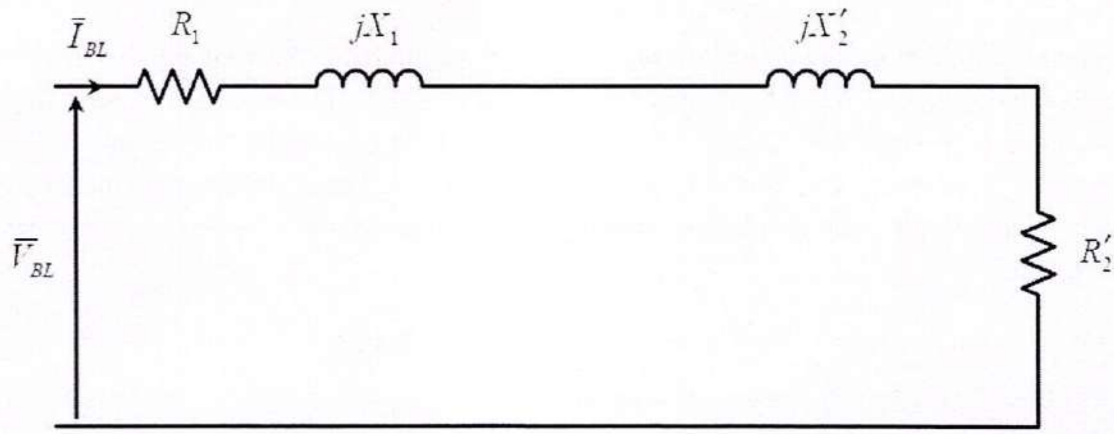


Fig: 4.5(b) Rearranged approximate equivalent circuit of the single phase induction motor at standstill.

The readings to be obtained from this test are:

a) Single phase power P_{BL}

b) Phase voltage V_{BL}

c) Phase current I_{BL}

Then. R_{eq}, Z_{eq}, and X_{eq} can be obtained using the following equations:

$$R_{eq} = \frac{P_{BL}}{I_{BL}^2}$$

$$Z_{eq} = \frac{V_{BL}}{I_{BL}}$$

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

Separation of X_1, X_2', R_1, and R_2' can be done as follows:

$$X_1 = X_2' = \frac{1}{2} X_{eq}$$

$$R_2' = R_{eq} - R_1$$

Methods of Starting

It is clear from previous discussion that a single phase induction motor when having only one winding and it is not self-starting. To make it a self-starting anyone of the following can be adopted.

(1) Split phase starting.

(2) Repulsion starting.

(3) Shaded pole starting.

PRINCIPLE OF SPLIT PHASE INDUCTION MOTOR

The basic principle of operation of a split phase induction motor is similar to that of a polyphase induction motor. The main difference is that the single phase motor does not produce a rotating magnetic field but produces only a pulsating filed.

Hence, to produce the rotating magnetic field for self-starting, phase splitting is to be done to make the motor to work as a two phase motor for starting.

Working of Split Phase Motor

In split phase motor two windings named as main winding and starting winding are provided. At the time of starting, both the main and starting windings should be connected across the supply to produce the rotating magnetic field.

The rotor is of a squirrel cage type and the revolving magnetic field sweeps part the stationary rotor, inducing emf in the rotor. As the rotor bars are short-circuited, a current flows through them producing a magnetic field.

This magnetic field opposes the revolving magnetic field and will combine with the main filed to produce a revolving filed. By this action, the rotor starts revolving in the same direction of the rotating magnetic field as in the case of a squirrel cage induction motor.

Hence, once the rotor starts rotating, the starting winding can be disconnected from the supply by some mechanical means as the rotor and stator fields from a revolving magnetic field. There are several types of split phase motors.

TYPES OF SPLIT-PHASE INDUCTION MOTORS

1. Resistance-start, induction-run motors
2. Capacitor-start, induction-run motors
3. Capacitor-start, capacitor-run motors
4. Shaded pole motors.

1. RESISTANCE-START, INDUCTION-RUN MOTORS

As the starting torque of this type of motor is relatively small and its starting current is high, these motors are most commonly used for rating up to 0.5 HP where the load could be started

The circuit in Fig: 4.6 (a) can be rearranged to the equivalent circuit that is shown in Fig: 4.6 (b)

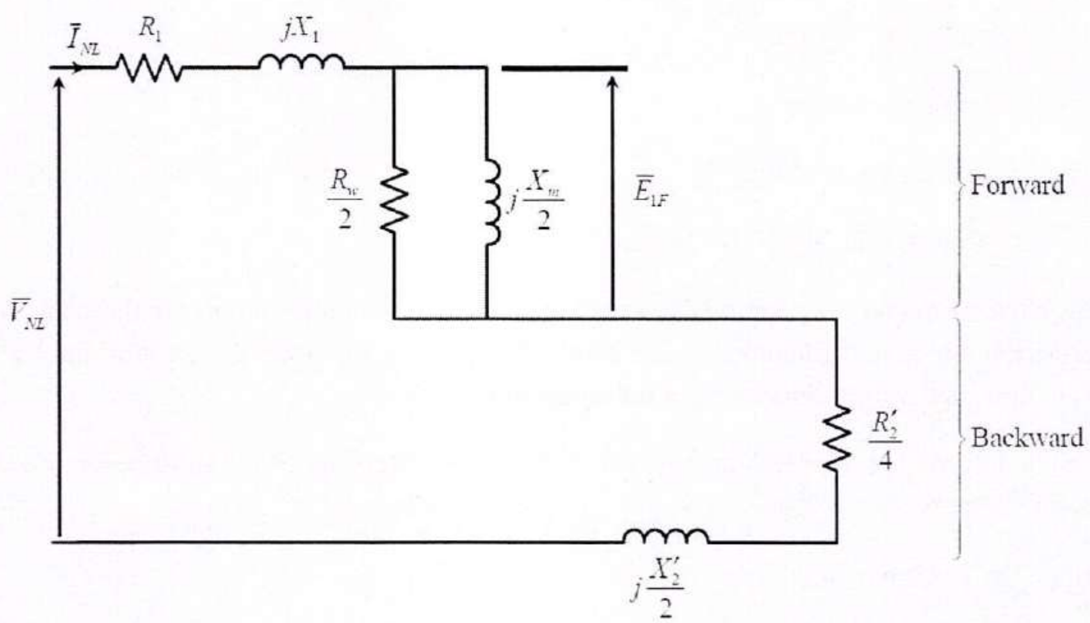


Fig: 4.6 (b) Rearranged approximate equivalent circuit of the single phase induction motor at no load

Then, R_w, and X_m, can be obtained as fallows:

$$P_{core+mechanical} = P_{NL} - I_{NL}^2\left(R_1 + \frac{R_2'}{4}\right)$$

$$\bar{E}_{1F} = \bar{V}_{NL} - \bar{I}_{NL}\left(\left(R_1 + \frac{R_2'}{4}\right) + j\left(X_1 + \frac{X_2'}{2}\right)\right)$$

Note: $(\bar{I}_{NL} = I_{NL}\angle -\theta,\quad \theta = \cos^{-1}\frac{P_{NL}}{V_{NL}\ I_{NL}})$

$$R_w = 2\frac{|E_{1F}|^2}{P_{core+mechanical}}$$

$$I_w = \frac{|E_{1F}|}{\left(\frac{R_w}{2}\right)} = 2\frac{|E_{1F}|}{R_w}$$

$$I_m = \sqrt{I_{NL}^2 - I_w^2}$$

$$X_m = 2\frac{|E_{1F}|}{I_m}$$

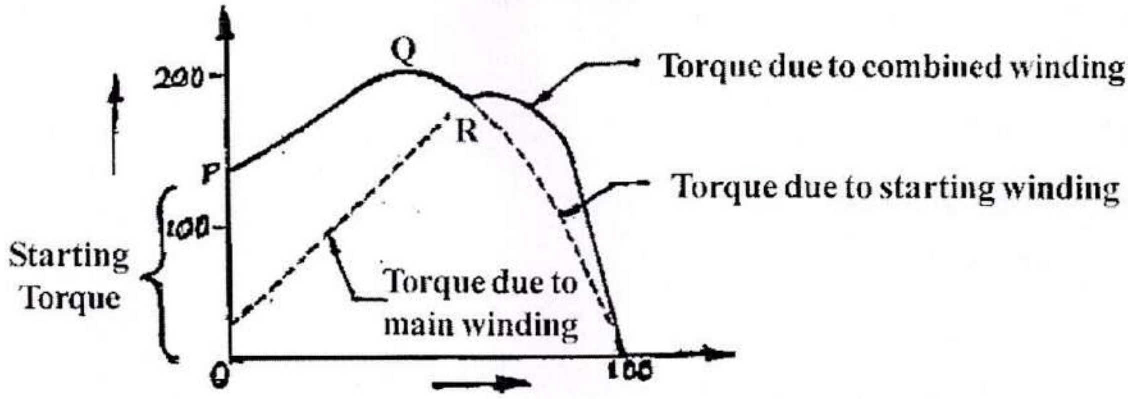


Fig: 4.8

The direction of rotating of a split-phase motor is determined by the way the main and auxiliary windings are connected. Hence, either by changing the main winding terminals or by changing the starting winding terminals, the reversal of direction of rotating could be obtained.

APPLICATIONS

These motors are used for driving fans, grinders, washing machines.

2. <u>CAPACITOR-START, INDUCTION-RUN MOTOR</u>

A drive which requires a large starting torque may be fitted with a capacitor-start, induction-run motor as it has excellence starting torque as compared to the resistance-start, induction-run motor.

CONSTRUCTION AND WORKING

Fig: 4.9(a) shows the schematic diagram of a capacitor-start, induction-run motor. As shown, the main winding is directly connected across the main supply whereas the starting winding is connected across the main supply through a capacitor and centrifugal switch.

Both these windings are placed in a stator slot at 90 degree electrical apart, and a squirrel cage type rotor is used.

As shown in Fig: 4.9(b), at the time of starting the current in the main winding lags the supply voltages by 90 degrees, depending upon its inductance and resistance. On the other hand, the current in the starting winding due to its capacitor will lead the applied voltage, by say 20 degrees.

Hence, the phase difference between the main and starting winding becomes near to 90 degrees. This in turn makes the line current to be more or less in phase with its applied voltage, making the power factor to be high, thereby creating an excellent starting torque.

However, after attaining 75% of the rated speed, the centrifugal switch operates opening the starting winding and the motor then operates as an induction motor, with only the main winding connected to the supply.

easily. The essential parts are shown in Fig: 4.7.

- Main winding or running winding.
- Auxiliary winding or starting winding
- Squirrel cage type rotor.
- Centrifugal switch.

CONSTRUCTION AND WORKING

The starting winding is designed to have a higher resistance and lower reactance than the main winding. This is achieved by using small conductors in the auxiliary winding than in the main winding. The main winding will have higher inductance when surrounded by more iron, which could be made possible by placing it deeper into the stator slots, it is obvious that the current would split as shown in Fig: 4.7(b).

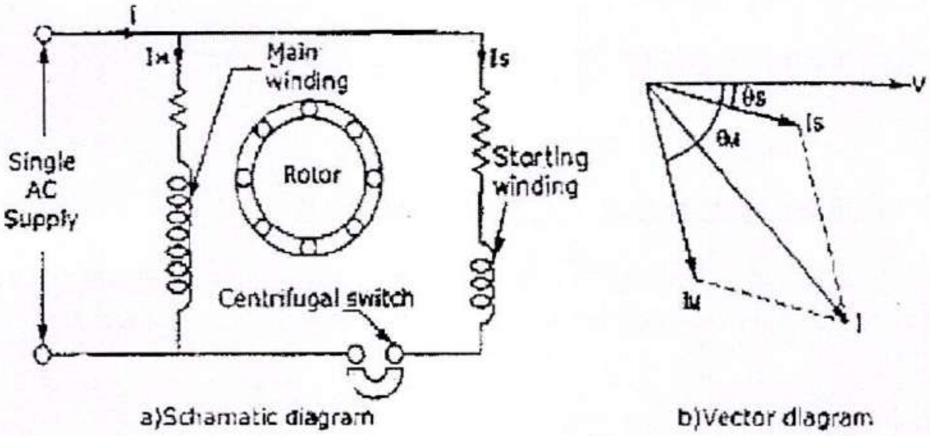


Fig: 4.7

The starting current "I" start will lag the main supply voltage "V" line by 15 degree and the main winding current. "I" main lags the main voltage by about 80 degree. Therefore, these currents will differ in time phase and their magnetic fields will combine to produce a rotating magnetic field.

When the motor has come upto about 75 to 80% of synchronous speed, the starting winding is opened by a centrifugal switch and the motor will continue to operate as a single phase motor.

CHARACTERISTICS

At the point where the starting winding is disconnected, the motor develops nearly as much torque with the main winding alone as with both windings connected. This can be observed from, the typical torque-speed characteristics of this motor, as shown in Fig: 4.8.

As discussed earlier, one capacitor-start, induction-run motors have excellent starting torque, say about 300% of the full load torque and their power factor during starting in high.

However, their running torque is not good, and their power factor, while running is low. They also have lesser efficiency and cannot take overloads.

CONSTRUCTION AND WORKING

The aforementioned problems are eliminated by the use of a two valve capacitor motor in which one large capacitor of electrolytic (short duty) type is used for starting whereas a smaller capacitor of oil filled (continuous duty) type is used for running, by connecting them with the starting winding as shown in Fig:4.11. A general view of such a two valve capacitor motor is shown in Fig: 4.11.

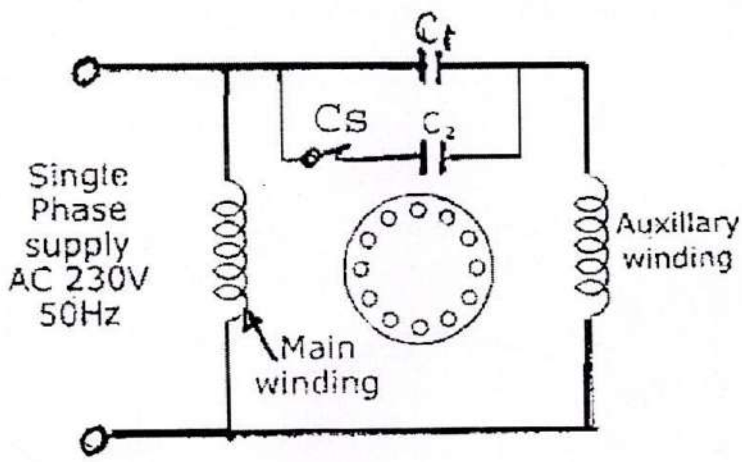


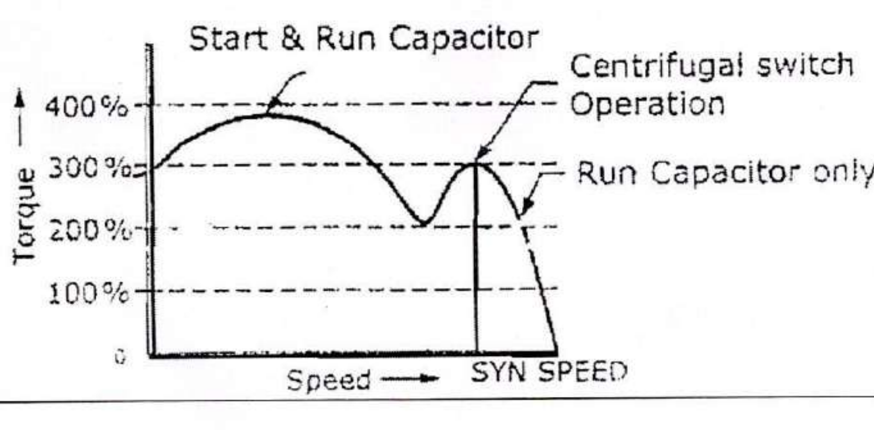
Fig: 4.11

This motor also works in the same way as a capacitor-start, induction-run motor, with exception, that the capacitor C1 is always in the circuit, altering the running performance to a great extent.

The starting capacitor which is of short duty rating will be disconnected from the starting winding with the help of a centrifugal switch, when the starting speed attains about 75% of the rated speed.

CHARACTERISTICS

The torque-speed characteristics of this motor is shown in Fig: 4.12.



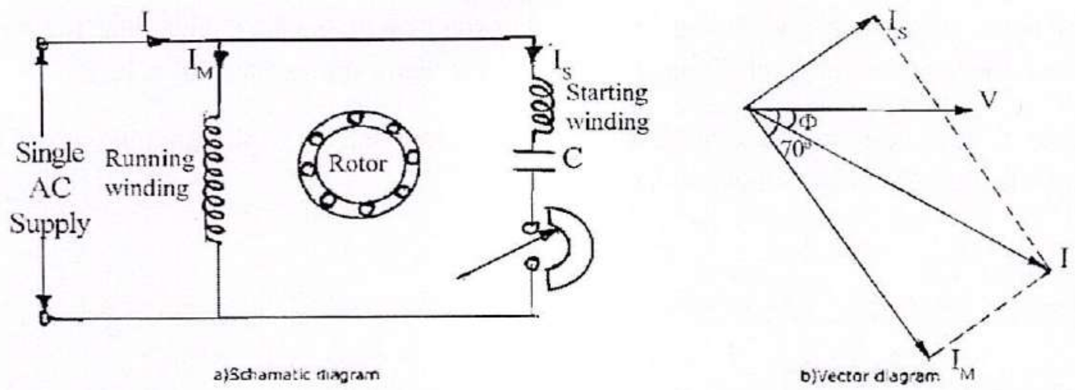


Fig: 4.9

As shown in Fig: 4.9(b), the displacement of current in the main and starting winding is about 80/90 degrees, and the power factor angle between the applied voltage and line current is very small. This results in producing a high power factor and an excellent starting torque, several times higher than the normal running torque as shown in Fig: 4.10.

CHARACTERISTICS

The torque-speed characteristics of this motor is shown in Fig: 4.10.

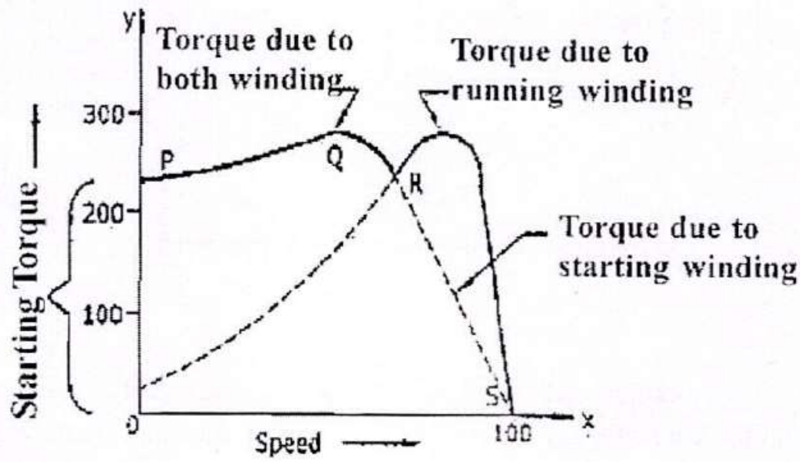


Fig: 4.10

In order to reverse the direction of rotation of the capacitor-start, induction-run motor, either the starting or the main winding terminals should be changed.

This is due to the fact that the direction of rotation depends upon the instantaneous polarities of the main field flux and the flux produced by the starting winding. Therefore, reversing the polarity of one of the field will reverse the torque.

APPLICATIONS

Due to the excellent starting torque and easy direction-reversal characteristics,

- Used in belted fans,
- Used in blowers dryers,
- Used in washing machines,
- Used in pumps and compressors.

3. CAPACITOR-START, CAPACITOR-RUN MOTORS

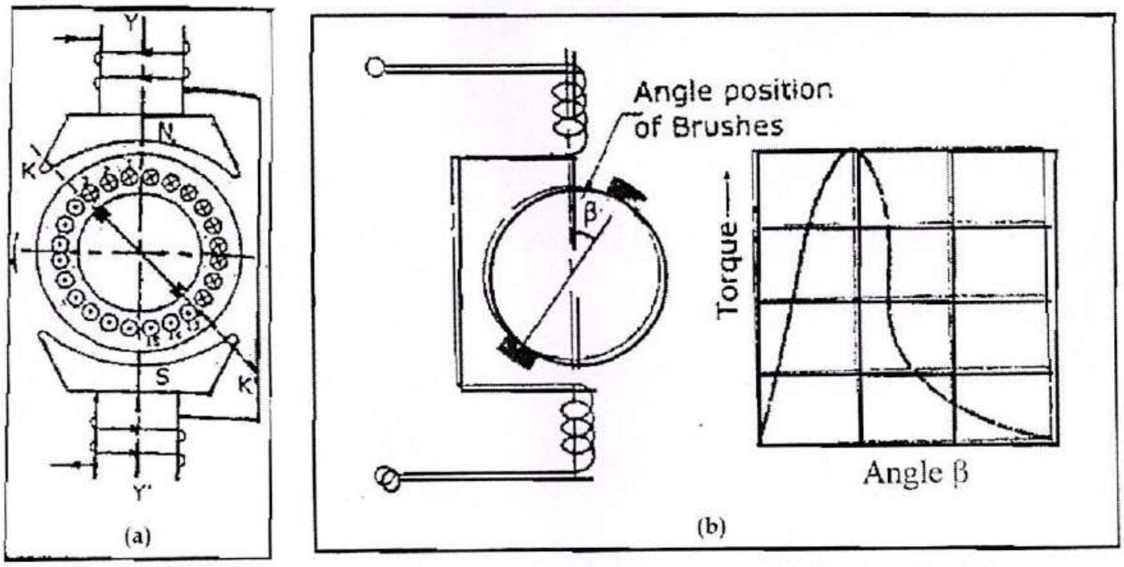


Fig: 4.13

To change the direction of rotation of this motor, the brush axis needs to be shifted from the right side as shown in Fig:4.13(b) to the left side of the main axis in a counter clockwise direction as shown in Fig:4.13(b).

CHARACTERISTICS

The torque developed in a repulsion motor will depend upon the amount of brush shaft as shown in Fig: 4.13 (b), whereas the direction of shift decides the direction of rotation.

Further, the speed depends upon the amount of brush shift and the magnitude of the load also on the relationship between the torque and brush-position angle.

Though the starting torque from 250 to 400% of the full load torque, the speed will be dangerously high during light loads. This is due to the fact that the speed of the repulsion motor start does not depend on frequency or number of poles but depends upon the repulsion principle.

Further, there is a tendency of sparking in the brushes at heavy loads, and the PF will be poor at low speeds. Hence the conventional repulsion motor start is not much popular.

SHAPED POLE STARTING

The motor consists of a yoke to which salient poles are fitted as shown in Fig: 4.14(a) and it has a squirrel cage type rotor.

Fig: 4.12

This motor has the following advantages:

- The starting torque is 300% of the full load torque
- The starting current is low, say 2 to 3 times of the running current.
- Starting and running power factor are good.
- Highly efficient running.
- Extremely noiseless operation.
- Can be loaded upto 125% of the full load capacity.

APPLICATIONS

- Used for compressors, refrigerators, air-conditioners, etc.
- Higher starting torque.
- High efficiency, higher power factor and overloading.
- Costlier than the capacitor-start — Induction run motors of the same capacity.

REPULSION STARTING

This type of starting need a wound rotor with brush and commutator arrangement like a dc armature Fig 4.13(a). The starting operation is based on the principle of repulsion and hence the name.

CONSTRUCTION AND WORKING

Repulsion starting, though complicated in construction and higher in cost, are still used in certain industries due to their excellent starting torque, low starting current, ability to withstand long spell of starting currents to drive heavy loads and their easy method of reversal of direction.

Now there is a condition that the rotor north pole will be repelled by the main north pole and the rotor south pole is repelled by the main south pole, so that a torque could be developed in the rotor. Now due to the repulsion action between the stator and the rotor poles, the rotor will start rotating in a clockwise direction. As the motor torque is due to repulsion action, this starting method is named as repulsion starting.

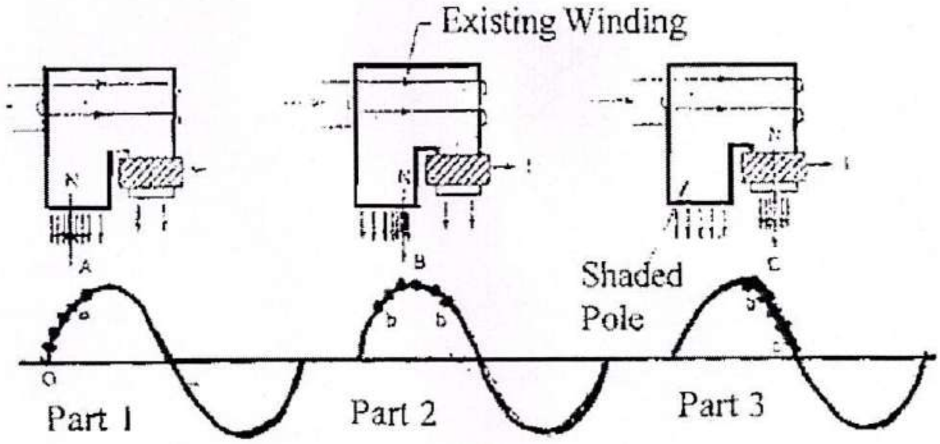


Fig: Shifting of magnetic flux

When the current raises from "Zero" Value of point "0" to a point "a" the change in current is very rapid (Fast). Hence, it reduces an emf in the shaded coil on the basis of Faraday's law of electromagnetic induction.

The induced emf in the shaded coil produces a current which, in turn, produces a flux in accordance with Lenz Law. This induced flux opposes the main flux in the shaded portion and reduces the main flux in that area to a minimum value as shown in Fig: 4.15.

This makes the magnetic axis to be in the centre of the unshaded portion as shown by the arrow in part of Fig: 4.15. On the other hand as shown in part 2 of 3 when the current raises from point "a" to point "b" the change in current is slow the induced emf and resulting current in the shading coil is minimum and the main flux is able to pass through the shade portion.

This makes the magnetic axis to be shifted to the centre of the whole pole as shown in by the arrow in part 2 of Fig: 4.15.

In the next instant, as shown in part 3 of Fig: 4.15. When the current falls from "b" to "c" the change in current is fast but the change of current is from maximum to minimum.

Hence a large current is induced in the shading ring which opposes the diminishing main flux, thereby increasing the flux density in the area of the shaded part. This makes the magnetic axis to shift to the right portion of the shaded part as shown by the arrow in part.

From the above explanation it is clear the magnetic axis shifts from the unshaded part to the shaded part which is more or less a physical rotary movement of the poles.

Simple motors of this type cannot be reversed. Specially designed shaded pole motors have been constructed for reversing operations. Two such types:

a. The double set of shading coils method

b. The double set of exciting winding method.

Shaded pole motors are built commercially in very small sizes, varying approximately from 1/250 HP to 1/6 HP. Although such motors are simple in construction and cheap, there are certain disadvantages with these motor as stated below:

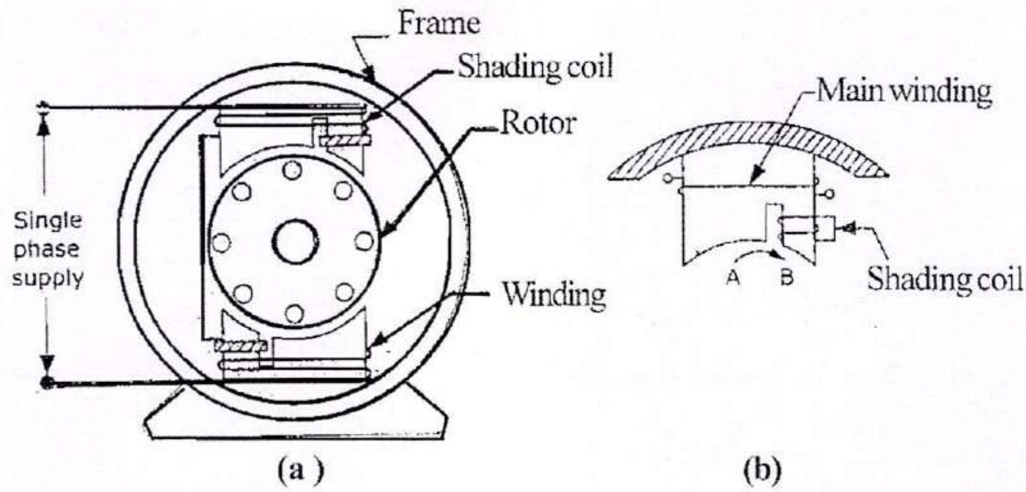


Fig: 4.14

A shaded pole made of laminated sheets has a slot cut across the lamination at about one third the distance from the edge of the pole.

Around the smaller portion of the pole, a short-circuited copper ring is placed which is called the shading coil, and this part of the pole is known as the shaded part of the pole. The remaining part of the pole is called the unshaded part which is clearly shown in Fig: 4.14(b).

Around the poles, exciting coils are placed to which an AC supply is connected. When AC supply is effected to the exciting coil, the magnetic axis shifts from the unshaded part of the pole to the shaded part as will be explained in details in the next paragraph. This shifting of axis is equivalent to the physical movement of the pole.

This magnetic axis, which is moving, cuts the rotor conductors and hence, a rotational torque is developed in the rotor.

By this torque the rotor starts rotating in the direction of the shifting of the magnetic axis that is from the unshaded part to the shaded part.

THE MAGNETIC FLUX SHIFTING

As the shaded coil is of thick copper, it will have very low resistance but as it is embedded in the iron case, it will have high inductance. When the exciting winding is connected to an AC supply, a sine wave current passes through it.

Let us consider the positive half cycle of the AC current as shown in Fig: 4.15.

4. In order to reduce the effect of armature reaction, thereby improving commutation and reducing armature reactance, a compensating winding is used.

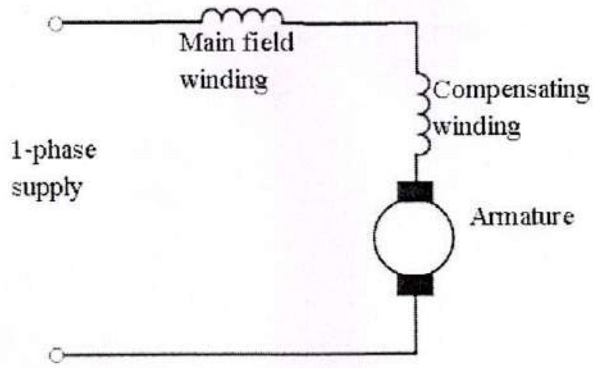


Fig: 4.16

The compensating winding is put in the stator slots. The axis of the compensating winding is 90 (electrical) with the main field axis. It may be connected in series with both the armature and field as shown in Fig: 4.16. In such a case the motor is conductively compensated.

The compensating winding may be short circuited on itself, in which case the motor is said to be inductively compensated shown in Fig: 4.17.

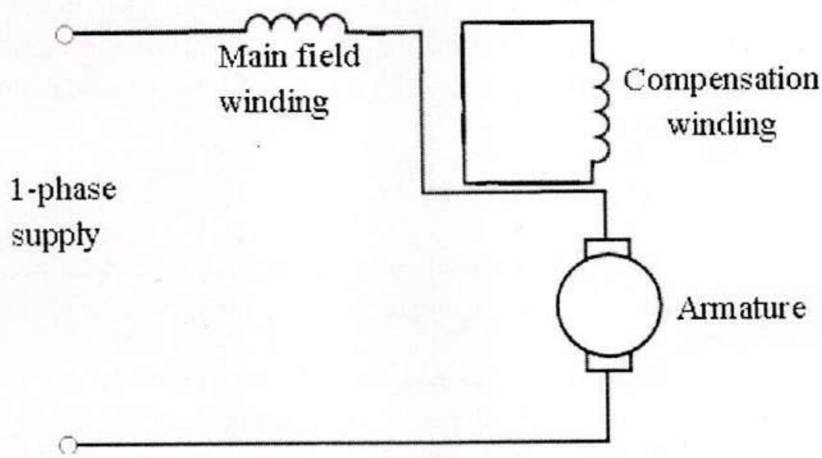


Fig: 4.17

The characteristics of single-phase series motor are very much similar to those of D.C. series motors, but the series motor develops less torque when operating from an a.c. supply than when working from an equivalent D.C. supply [Fig: 4.18]. The direction of rotation can be changed by interchanging connections to the field with respect to the armature as in D.C. series motor.

- Low starting torque.
- Very little overload capacity.
- Low efficiency.

APPLICATIONS

- Record players
- Fans
- Hair driers.

Single Phase Series Motor

The single-phase series motor is a commutator-type motor. If the polarity of the line terminals of a dc series motor is reversed, the motor will continue to run in the same direction. Thus, it might be expected that a dc series motor would operate on alternating current also. The direction of the torque developed in a dc series motor is determined by both filed polarity and the direction of current through the armature$[TT \propto \phi\phi II_{aa}]$.

Operation

Let a dc series motor be connected across a single-phase ac supply. Since the same current flows through the field winding and the armature, it follows that ac reversals from positive to negative, or from negative to positive, will simultaneously affect both the field flux polarity and the current direction through the armature. This means that the direction of the developed torque will remain positive, and rotation will continue in the same direction. Thus, a series motor can run both on dc and ac.

However, a series motor which is specifically designed for dc operation suffers from the following drawbacks when it is used on single-phase ac supply:

1. Its efficiency is low due to hysteresis and eddy-current losses.
2. The power factor is low due to the large reactance of the field and the armature winding.
3. The sparking at the brushes is excessive.

In order to overcome these difficulties, the following modifications are made in a D.C. series motor that is to operate satisfactorily on alternating current:

1. The field core is constructed of a material having low hysteresis loss. It is laminated to reduce eddy-current loss.
2. The field winding is provided with small number of turns. The field-pole areas is increased so that the flux density is reduced. This reduces the iron loss and the reactive voltage drop.
3. The number of armature conductors is increased in order to get the required torque with the low flux.

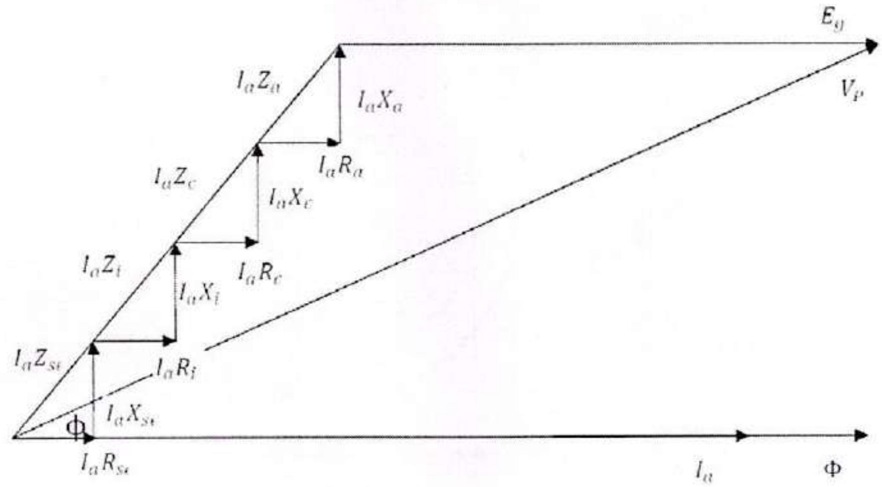


Fig: 4.20

The resistance I_aR_{se}, I_aR_i, I_aR_c and I_aR_a drops are due to resistances of series field, interpole winding, compensating winding and of armature respectively are in phase with armature current I_a. The reactance drops I_aX_{se}, I_aX_i, I_aX_c and I_aX_a are due to reactance of series field, interpole winding, compensating winding and of armature respectively lead current I_a by 90^0. The generated armature counter emf is E_g. The terminal phase voltage V_P is equal to the phasor sum of E_g and all the impedance drops in series.

$$V_p = E_g + I_aZ_{se} + I_aZ_i + I_aZ_c + I_aZ_a$$

The power factor angle between V_P and I_a is .

Applications

There are numerous applications where single-phase ac series motors are used, such as hair dryers, grinders, table-fans, blowers, polishers, kitchen appliances etc. They are also used for many other purposes where speed control and high values of speed are necessary.

Schrage Motor

Schrage motor is basically an inverted polyphase induction motor, with primary winding on the rotor and secondary winding on the stator. The primary winding on the rotor is fed through three slip rings and brushes at line frequency; secondary winding on the stator has slip frequency voltages induced in it.

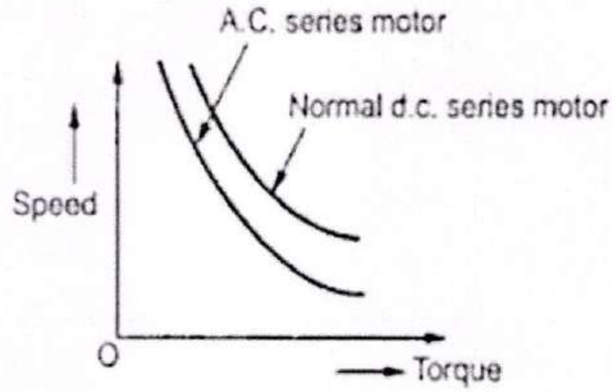


Fig: 4.18

Speed control of universal motors is best obtained by solid-state devices. Since the speed of these is not limited by the supply frequency and may be as high as 20,000 r.p.m. (greater than the maximum synchronous speed of 3000 r.p.m. at 50 Hz), they are most suitable for applications requiring high speeds.

Phasor Diagram of A.C Series Motor

The schematic diagram and phasor diagram for the conductively coupled single-phase ac series motor are shown in Fig: 4.19 and Fig: 4.20 respectively.

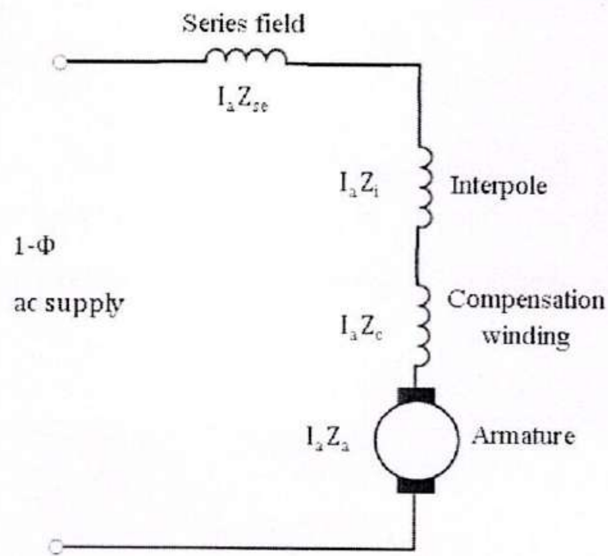


Fig: 4.19

stator.

Voltage across the brush pairs A_1 - A_2, B_1 - B_2 & C_1 - C_2 increases as brushes are separated.

Magnitude of voltage injected into the secondary winding depends on the angle of separation 'θ' of the brushes A_1 & A_2, B_1 & B_2, C_1 & C_2. ('θ' – Brush separation angle).

When primary is energized synchronously rotating field in clockwise direction is set up in the rotor core. Assume that the brushes are short circuited through commutator segment i.e. the secondary is short circuited. Rotor still at rest, the rotating field cuts the stationary secondary winding, induces an e.m.f. The stator current produce its own field. This stator field reacts with the rotor field thus a clockwise torque produced in the stator. Since the stator cannot rotate, as a reaction, it makes the rotor rotate in the counter clockwise direction.

Suppose that the rotor speed is N_r rpm. Rotor flux is rotating with N_S relative to primary & regulating winding. Thus the rotor flux will rotate at slip speed (N_S - N_r) relative to secondary winding in stator with reference to space.

Speed Control

Speed of Schrage Motor can be obtained above and below Synchronous speed by changing the Brush position i.e. changing "θ" ('θ' – Brush separation angle).

In Fig: 4.22 (a) Brush pair on the same commutator segment.i.e. the secondary winding short circuited. Thus the Injected voltage Ej = 0 and the machine operates as an Inverted Induction Motor so here $N_r < N_S$.

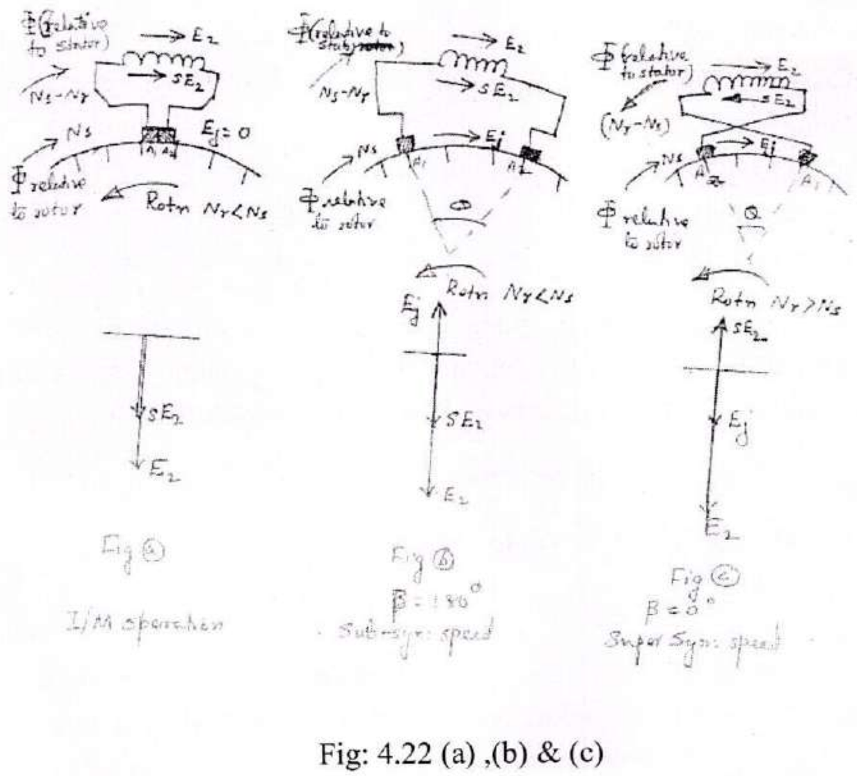


Fig: 4.22 (a) ,(b) & (c)

In Fig: 4.22 (b) Brushes parted in one direction which produces sub-synchronous speed.

The speed and power factor of slip ring induction motor can be controlled by injecting slip frequency voltage in the rotor circuit. If resultant rotor voltage increases, current increases, torque increases and speed increases. Depending on the phase angle of injected voltage, power factor can be improved. In 1911, K. H. Schrage of Sweden combined elegantly a SRIM (WRIM) and a frequency converter into a single unit.

Construction and Operation

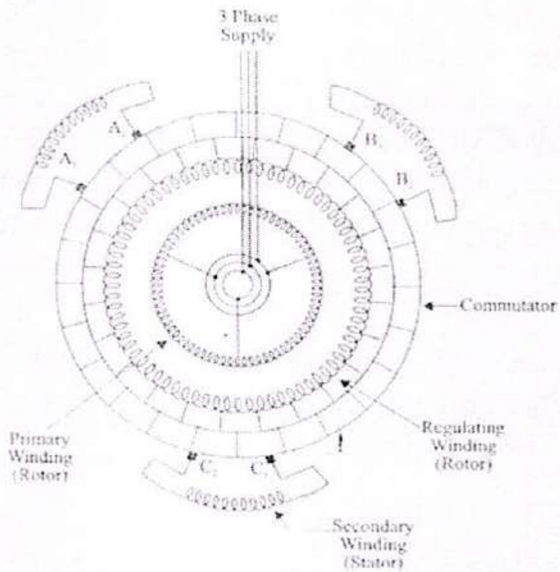


Fig: 4.21

Schrage motor has three windings- Two in Rotor and One in Stator.

Primary winding: Placed on the lower part of the slots of the Rotor. Three phase supply at line frequency is fed through slip rings and brushes which generates working flux in the machine.

Regulating winding: Placed on the upper part of the slots of the Rotor. These are connected to commutator segments in a manner similar to that of D.C. machine. Regulating windings are also known as *tertiary winding / auxiliary winding / commutator winding.*

Secondary winding: Same is phase wound & located on stator. Each winding is connected to a pair of brushes arranged on the commutator. Brushes are mounted on brush rockers. These are designed to move in opposite directions, relative to the centre line of its stator phase.

Brushes A_1, B_1 & C_1 move together and are 120^0 apart.

Brushes A_2, B_2 & C_2 also move together and are 120^0 apart.

Now the primary energized with line frequency voltage. Transformer action occurs between primary and regulating winding. Induction motor action occurs between primary and secondary windings. Commutator acting as a frequency converter converts line frequency voltage of regulating winding to slip frequency voltage and feeds the same to secondary winding on the

Both p.f. and speed can be controlled by varying 'θ' & 'ρ'.

Thus 'Ej Cos ρ' and 'Ej Sin ρ' effect the speed and p.f. respectively. Fig: 4.23 show Variation of no load speed with Brush Separation.

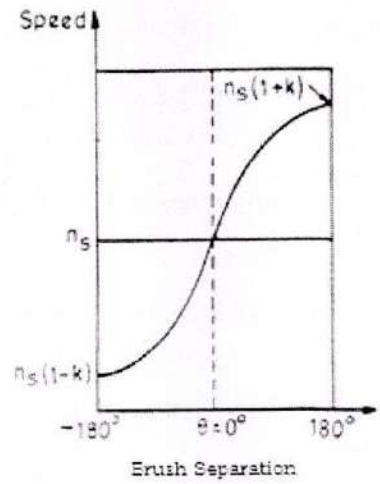


Fig: 4.23

Speed Torque Characteristics

Above discussion reveals that the Schrage Motor is almost a constant speed motor i.e. it has D.C Shunt motor characteristics. Figure 4.23 shows the typical speed-torque characteristics of Schrage motor.

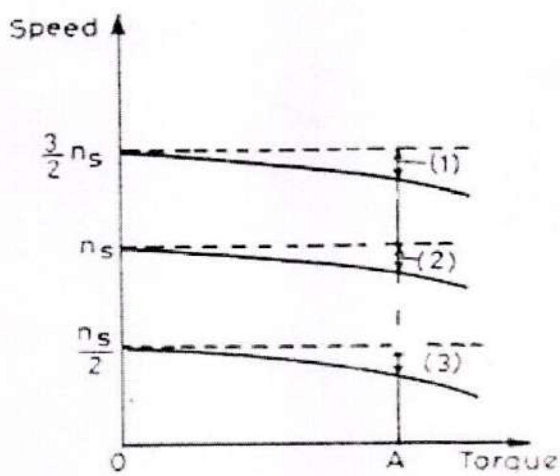


Fig: 4.23

Advantages & Shortcomings

Advantages:

(iv) Good Speed Regulation.

(v) High p.f. for high speed setting.

Injected voltage Ej, is obtained from the section of the regulating winding between them. If the centre line of this group of conductors is coincident with the centre line of the corresponding secondary phase, then E_2 and Ej are in phase opposition.

Neglecting impedance drop, sE_2 must be equal and opposite of Ej.

"β" is the angle between E_2 and Ej. $\beta=180^0$ and so here also $N_r < N_S$.

In Fig: 4.22 (c) Brushes parted in opposite direction which produces super-synchronous speed. Here Ej is reversed relative to E_2 i.e. $\beta=0^0$ & sE_2 must also be reversed.

This is occurring only because 's' becoming negative i.e. The speed is thus above synchronous speed so $N_r > N_S$.

The commutator provides maximum voltage when the brushes are separated by one pole pitch. i.e. 'θ' = 180^0.

Power Factor Improvement

This can be obtained by changing the phase angle of the injected voltage into the secondary winding. In this case one set of brushes is advanced more rapidly than the other set. Now the two centre lines do not coincide, have an angle 'ρ' between them. ("ρ" – Brush shift angle).

In Fig: 4.22 (d) Brush set is moved against the direction of rotation of rotor. In this case Speed decreases and the p.f. is improved.

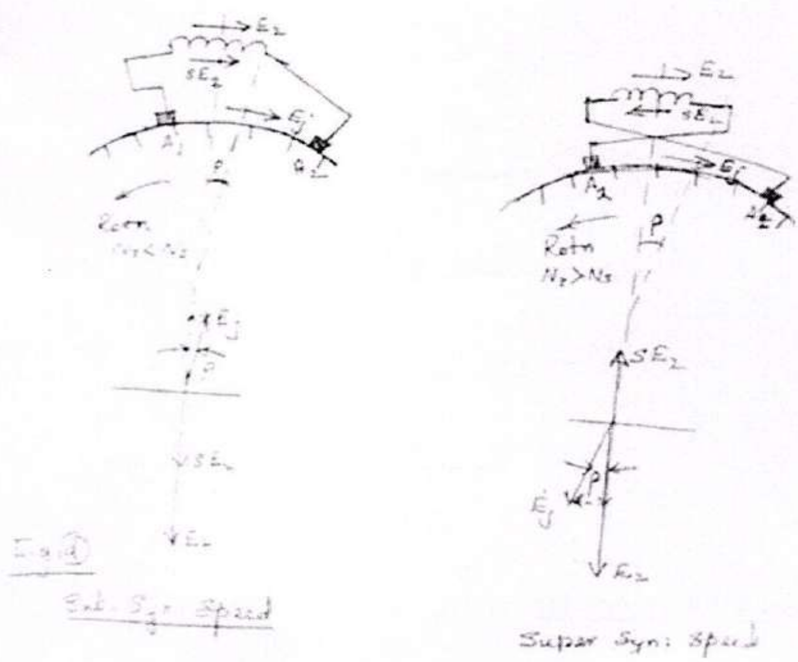


Fig: 4.22 (d) & (e)

In Fig: 4.22 (e) Brush set is moved in the same direction of rotation of rotor. In this case Speed increases, the p.f. is also improved.

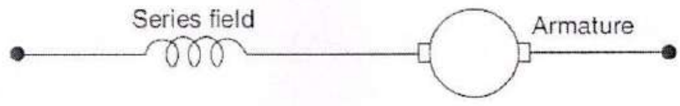
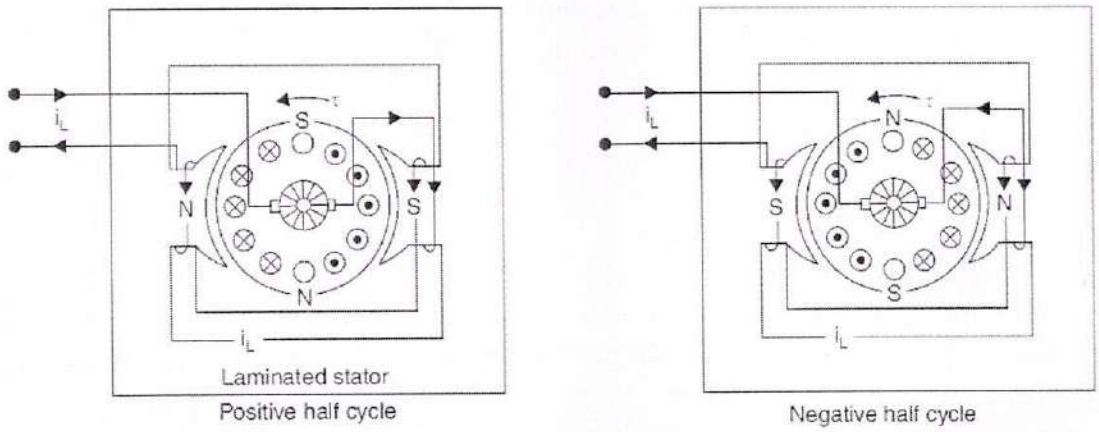


Fig: 4.24



(a) (b)

Fig: 4.25

The main parts of a universal motor are an armature, field winding, stator stampings, frame and plates and brushed. The increased sparking at the brush position in AC operation is reduced by the following means:

Providing commutating inter poles in the stator and connecting the interpole winding in series with the armature winding. Providing high contact resistance brushed to reduce sparking at brush positions.

Operation

A universal motor works on the same principles as a DC motor i.e. force is created on the armature conductors due to the interaction between the main field flux and the flux created by the current carrying armature conductors. A universal motor develops unidirectional torque regardless of whether it operated on AC or DC supply.

Fig: 4.25 (a),(b) & Fig: 4.26 shows the operation of a universal motor on

(vi) High efficiency at all speeds except N_S

Shortcomings:

(i) Operating voltage has to be limited to 700V because the power is to be supplied through slip rings.
(ii) Low p.f. at low speed settings.
(iii) Poor commutation.
(iv) High Cost.

Applications

Can be applied to any individual drive requiring variable speed, especially in knitting & Ring spinning applications, Cranes & Hoists Fans & Centrifugal Pumps, printing Machinery Conveyors, Packing machinery & Paper Mills etc.

Universal Motors

It is also commutator type motor. A universal motor is one which operates both on AC and DC supplies. It develops more horsepower per Kg. weight than any other AC motor mainly due to its high speed.

The principle of operation is the same as that of a DC motor. Though a universal motor resembles a DC series motor, it required suitable modification in the construction, winding and brush grade to achieve sparkles commutation and reduced heating when operated on AC supply, due to increased inductance and armature reaction.

A universal motor could therefore be defined as a series or a compensated series motor [Fig:
4.24 & Fig: 4.25 (a), (b)]designed to operate at approximately the same speed and output at either direct current or single phase alternating current of a frequency not greater than 50Hz, and of approximately the same RMS voltage. Universal motor is also named as AC single phase series motor.

AC supply. In AC operation, both field and armature currents change their polarities, at the same time resulting in unidirectional torque.

Fig: 4.26

Characteristic

The speed of a universal motor inversely proportional to the load i.e. speed is low at full load and high, on no load.

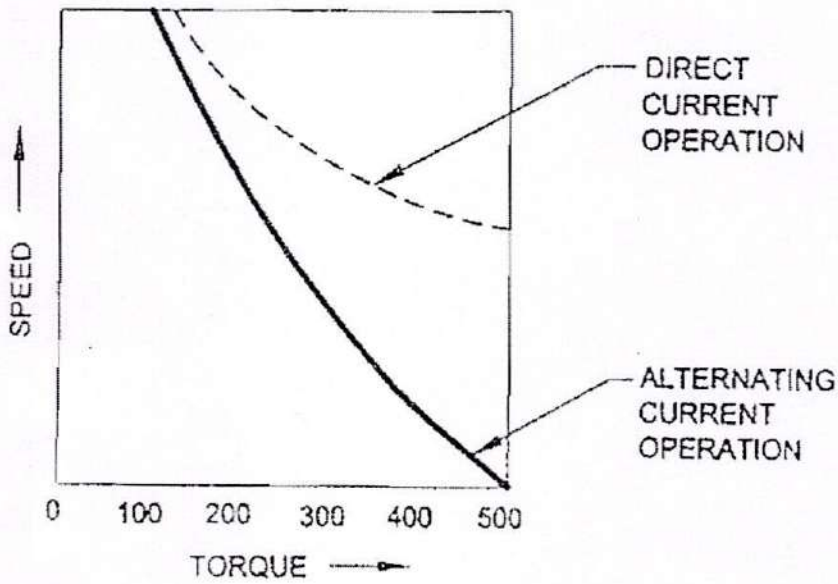


Fig: 4.27

The speed reaches a dangerously high value due to low field flux at no loads in fact the no load speed is limited only by its own friction and windage losses. As such these motors are connected with permanent loads or gear trains to avoid running at no load thereby avoiding high speeds.

Fig: 4.27 shows the typical torque-speed relation of a universal motor, both for AC and DC operations. This motor develops about 450 % of full load torque at starting, as such higher than any other type of single phase motor.

Applications

There are numerous applications where universal motors are used, such as hand drills, hair dryers, grinders, blowers, polishers, and kitchen appliances etc. They are also used for many other purposes where speed control and high values of speed are necessary like in vaccum cleaners, food mixers, portable drills and domestic sewage machines. Universal motors of a given horse power rating are significantly smaller than other kinds of a.c. motors operating at the same frequency.

- Because of these reasons, motors are comparatively small ratings (mostly in fractional kW ratings) are manufactured in large number to operate on 1-ϕ ac at standard frequencies.
- Single phase ac motors may be divided into three general categories namely i) induction motors, ii) commutator motors, and iii) synchronous motors.
- 1-Φ induction motors in very small sizes(1/400kW to 1/25 kW) are used in toys, hair dryers, vending machines etc.

Advantages:
- Simple in construction.
- Reliable.
- Easy to repair.
- Cheaper in cost.

Disadvantages:
- Low over load capacity
- Low efficiency
- Low power factor
- Low output as compared to that of a 3-phase motor of the given frame size.

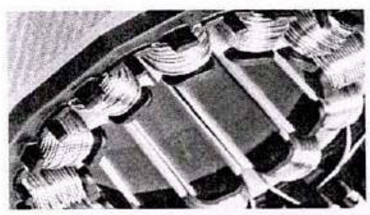
Constructional features

A 1- ϕ induction motor is similar to a 3−ϕ squirrel cage induction motor in physical appearance. The rotor of a 1− ϕ squirrel cage induction motor is essentially same as that employed in 3−ϕ squirrel cage induction motors and needs no further description.

There is a uniform air gap between stator and rotor, but no electrical connection between them. A single phase motor can be wound for any even number of poles two, four and six being most common. Like three phase machines, adjacent poles have opposite magnetic polarity and synchronous speed equation also applies.

In single phase induction motor, the stator windings are distinctly different in two aspects.

First single phase motors are usually provided with concentric coils. With concentric coils, the number of turns per coil can be adjusted to provide an approximately sinusoidal distribution of MMF along the air gap and this is one of the advantage.

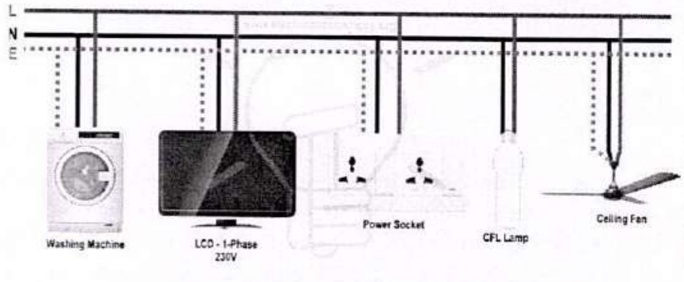


1-Φ Induction Motors

INTRODUCTION

- There are two basic reasons for the use of 1-ϕ rather than 3-ϕ motors.
- First for the reasons of economy. Most of the houses, offices and also rural areas are supplied with single phase AC supply. As power requirements of individual load items are rather small.

- The second factor is the economics of the motor.
- Fixed loads requiring not more than 0.5 kW can generally be served most economically with single phase power and a single phase motor.
- 1-Φ motors are simple in construction, reliable , easy to repair and comparatively cheaper in cost. Hence these are widely used in fans refrigerators, vacuum cleaners, washing machines, kitchen equipment, tools, blowers, centrifugal pumps and small farming appliances



Double revolving field theory

- 1-ϕ induction motor has single winding in the stator.
- Let supply voltage is applied to the stator winding.
- Current passes through the stator winding.
- The stator current establish the flux and the direction of flux can be find by using Fleming's right hand thumb rule.
- This flux transfers from stator to rotor through air gap.
- Emf is induced in the rotor windings through induction.
- Rotor conductors are shorted current flows through the conductors.

- Magnetic field produced due to stator current is
  $\Phi = \Phi m \sin\omega t \cos \alpha$
- Resultant flux varies sinusoidally in space.
- The above flux is divided into two components
- $\Phi = \Phi m/2 \sin(\omega t+\alpha) + \Phi m/2 \sin(\omega t-\alpha)$
- $\Phi_1 = \Phi m/2 \sin(\omega t+\alpha)$ & $\Phi_2 = \Phi m/2 \sin(\omega t-\alpha)$
- Φ_1 starts rotating in clockwise and Φ_2 rotating in anti clockwise direction.
- Because of these flux torque is produced in rotor and resultant torque is also divided into two components. O[illegible] is forward torque and the other is backward torque

- Slip of the rotor w.r.t rotor forward torque is
  $S_f = (Ns-N)/ Ns = s$

Slip of the rotor w.r.t rotor backward torque is

$S_b = (Ns-(-N))/ Ns$

$= (2Ns-(Ns-N))/ Ns$

$= 2-s.$

Power developed by a rotor $P_g = (1-s/s)\ I_2^2\ R_2.$

Torque developed by rotor $T_g = P_g / \omega$

$= ((1-s/s)\ I_2^2\ R_2) / 2\pi N$

where N is the speed of the rotor, $N= N_s(1-s)$.

$T_g = ((1-s/s)\ I_2^2\ R_2) / 2\pi N_s(1-s)$

$= (I_2^2\ R_2) / 2\pi\ s\ N_s$

$= K\ (I_2^2\ R_2)/s\ ,\ K= 1/2\pi N_s$

Hence the forward and backward torques are,

$T_f = K\ (I_2^2\ R_2)/s$ Synchronous Watts and

$T_b = -\ K\ (I_2^2\ R_2)/(2-s)$ Synchronous watts

Net Torque $T = T_f + T_b$

Second, single phase squirrel cage motors normally have two stator windings, but one of them have usually have few turns of much thin wire. Two windings are in space quadrature w.r.t each other.

In motors that operate with both windings are energized, the winding with heaviest wire is known as the main winding and the other is called the auxiliary winding.

A motor that runs with auxiliary winding open, uses a centrifugal switch to cut out the starting (or auxiliary) winding after starting. In most of the motors the main winding is placed at the bottom of the slots and the starting winding on the top but shifted to 90 degrees from the running winding.

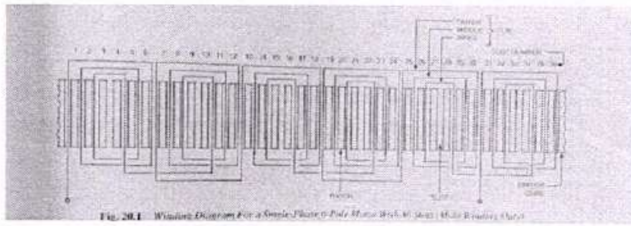


Fig. 20.1

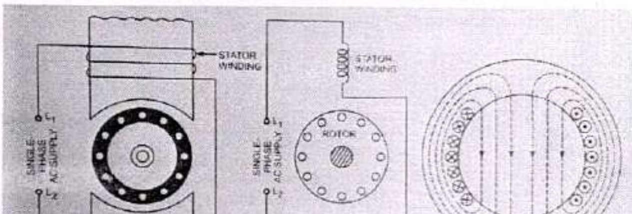


Fig. 20.3 *Elementary Single-Phase Induction Motor*

Single phase Induction motor operation is explained by two theories.

i) Double revolving field theory.

ii) Cross field theory.

- Now Fleming's left hand rule can be used to find the direction of the force experienced by the rotor conductors.
- It can be seen that when Φ_s acts in upward direction and increasing positively, the conductors on left experience force from left to right while conductors on right experience force from right to left.
- Thus overall, the force experienced by the rotor is zero. Hence no torque exists on the rotor and rotor can not start rotating.

Torque developed by the rotor,

$$T \propto \Phi_s \Phi_r \sin(\Phi_s \hat{} \Phi_r),$$

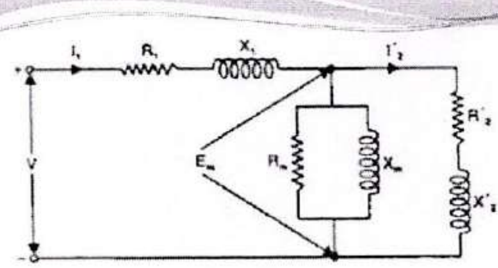
At standstill condition, Φ_s & Φ_r are opposite to each other.

Hence $T \propto \Phi_s \Phi_r \sin(\Phi_s \hat{} \Phi_r)$, $\Phi_s \hat{} \Phi_r = 180^\circ$

$T = 0.$

Equivalent Circuit

- The equivalent circuit of a single phase induction motor can be developed on the basis of two revolving field theory.
- To develop the equivalent circuit it is necessary to consider standstill or blocked rotor conditions.
- The motor with a blocked rotor merely acts like a transformer with its secondary short circuited and its equivalent circuit will be as shown in fig:

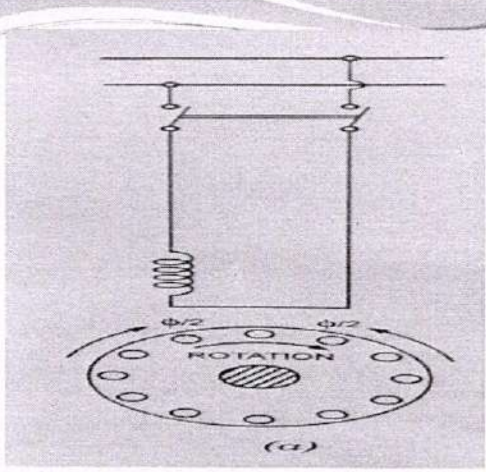


E_m is e.m.f. induced in the stator.

R_1 & X_1 are the resistance and reactances of the stator winding.

R_2' & X_2' are the resistance and reactances of the rotor winding referred to stator side.

I_2' is the rotor current referred to stator side.



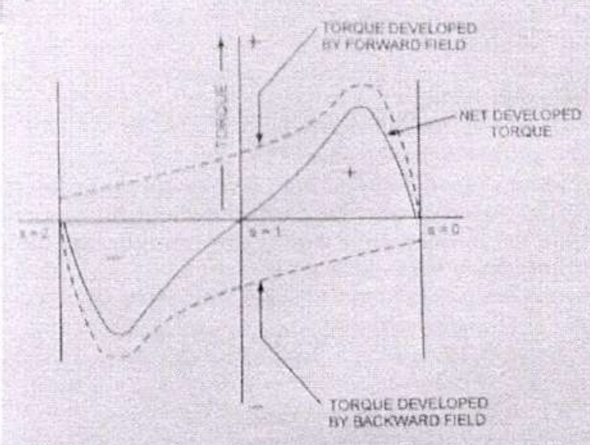
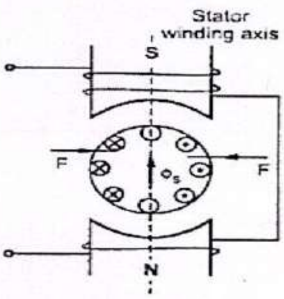


Fig. 20.5 *Torque-Slip Curves For a Single-Phase Induction Motor*

Cross Field Theory



- Consider a single phase induction motor with standstill rotor as shown in the Fig.
- The stator winding is excited by the single phase a.c. supply.
- This supply produces an alternating flux Φ_s which acts along the axis of the stator winding.
- Due to this flux, e.m.f., gets induced in the rotor conductors due to transformer action.
- As rotor is closed one, this e.m.f. circulates current through the rotor conductors.
- The direction of the rotor current is as shown in the Fig.
- The direction of rotor current is so as to oppose the cause producing it, which is stator flux Φ_s.

Starting Methods and Types of Induction Motors

As discussed earlier the single phase induction motor is not self starting and therefore it is necessary to employ some method to make it self starting.

i) Resistance Start Motor or Split – Phase Motor.

ii) Capacitor - Start, Capacitor - Run or Two Value Capacitor Motor.

The selection of a suitable induction motor and choice of its starting method, depend upon the following:

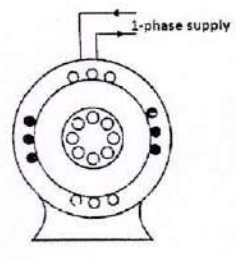
(i) Torque-speed characteristic of load from standstill to the normal operating speed.

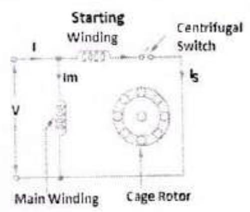
(ii) The duty cycle and

(iii)The starting and running line-current limitations as imposed by the supply authorities.

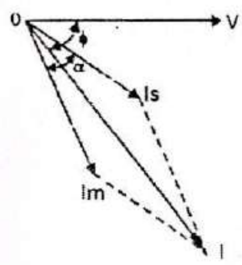
i) Resistance Start Motor or Split – Phase Motor.

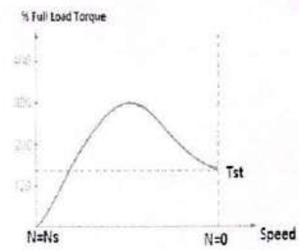
- The stator of a split-phase induction motor is provided with an auxiliary or starting winding S in addition to the main or running winding M. The starting winding is located 90° electrical from the main winding and operates only during the brief period when the motor starts up.
- The two windings are so designed that the starting winding S has a high resistance and relatively small reactance while the main winding M has relatively low resistance and large reactance as shown in the schematic connections in figure.
- Consequently, the currents flowing in the two windings have reasonable phase difference (25° to 30°) as shown in the phasor diagram in figure.



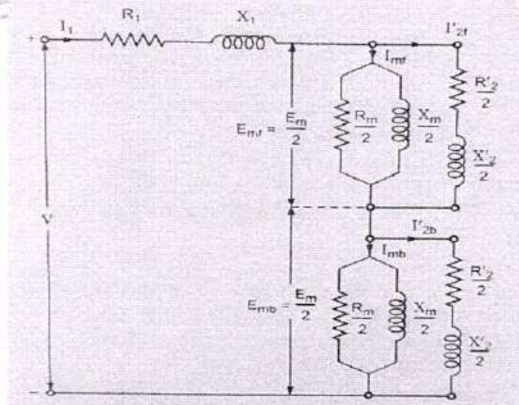


Schematic Diagram of Resistor-split phase motor



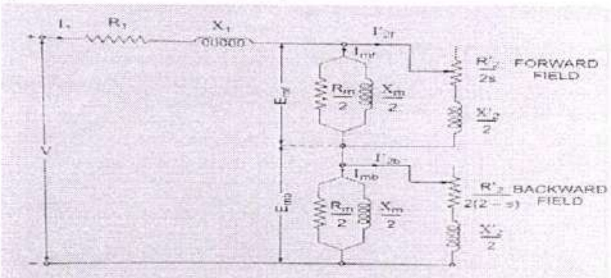


- The motor may now be viewed from the point of view of the two revolving field theory.
- The two flux components induce e.m.f. E_{mf} and E_{mb} in the respective stator winding.
- Since at standstill the two oppositely rotating fields are of same strength, the magnetizing and rotor impedances are divided into two equals halves connected in series as shown in figure.



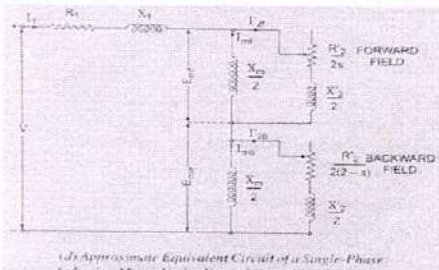
(b) Equivalent Circuit of a Single-Phase Induction Motor at Standstill on The Basis of Double Revolving Field Theory

- When the rotor runs at speed N with respect to forward field, the slip is S w.r.t. forward field and (2-S) w.r.t. backward field and the equivalent circuit is as shown in fig.



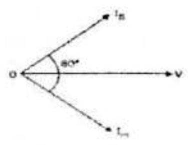
(c) Equivalent Circuit of a Single Phase Induction Motor Under Normal Operating Conditions

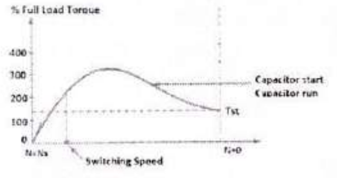
- If the core losses are neglected the equivalent circuit is modified as shown in fig



(d) Approximate Equivalent Circuit of a Single-Phase Induction Motor Under Normal Operating Conditions

- The core losses, here, are handled as rotational losses and subtracted from the power converted into mechanical power; the amount of error thus introduced is relatively small.





Applications:

a. Hospitals

b. Studios and

c. Other places where silence is important.

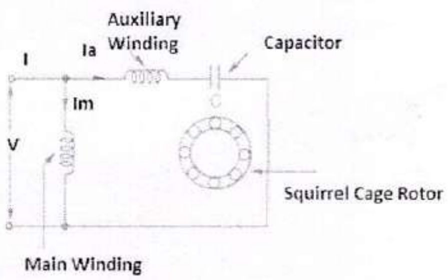
- **Applications:**
- These motors are suitable where a moderate starting torque is required and where starting periods are infrequent e.g., to drive:
  - a. Fans
  - b. washing machines
  - c. oil burners
  - d. Small machine tools etc.

  The power rating of such motors generally lies between 60 W and 250 W .

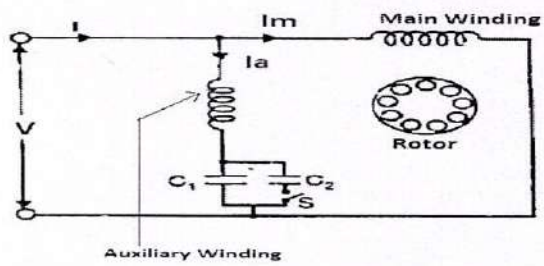
Capacitor-Start and Capacitor-Run motors

This motor is identical to a capacitor-start motor except that starting winding is not opened after starting so that both the windings remain connected to the supply when running as well as at starting.

Two designs are generally used.



In first design, a single capacitor C is used for both starting and running as shown in fig. This design eliminates the need of a centrifugal switch and at the same time improves the power factor and efficiency of the motor.



In the other design, two capacitors C_1 and C_2 are used in the starting winding as shown in fig. The smaller capacitor C_1 required for optimum running conditions is permanently connected in series with the starting winding. The much larger capacitor C_2 is connected in parallel with C_1 for optimum starting and remains in the circuit during starting. The starting capacitor C_1 is disconnected when the motor approaches about 75% of synchronous speed. The motor then runs as a single-phase induction motor.