CODE	COURSE NAME	CATEGORY	L	T	P	CREDIT
EET444	ELECTRICAL MACHINE DESIGN	PEC	2	1	0	3

Preamble: This course provides an introduction to the design of DC and AC machines and gives a general idea to the computer aided design of electrical machines.

Prerequisite: 1. EET202 DC Machines and Transformers

2. EET307 Synchronous and Induction Machines

Course Outcomes: After the completion of the course the student will be able to:

CO1	Identify the general design considerations of electrical machines.
CO2	Design armature and field system of DC machines.
CO3	Design core, yoke, windings and cooling systems of transformers.
CO4	Design stator and rotor of induction machines.
CO5	Design stator and rotor of synchronous machines.
CO6	Apply software tools in electrical machine design.

Mapping of course outcomes with program outcomes

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	2	1	-	-	-	-	-	-	-	-	-	-
CO2	3	2	2	-	-	-	-	-	-	-	-	-
CO3	3	2	2	-	-	-	-	-	-	-	-	-
CO4	3	2	2	-	-	-	-	-	-	-	-	-
CO5	3	2	2	-	-	-	-	-	-	-	-	-
CO6	3	2	1	1	1	-	-	-	-	-	-	-

Assessment Pattern

Bloom's Category	Continuous Assessment Tests		End Semester Examination
	1	2	
Remember (K1)	10	10	20
Understand(K2)	10	10	20
Apply (K3)	30	30	60
Analyse (K4)			
Evaluate(K5)			
Create(K6)			

Mark distribution

Total Marks	CIE	ESE	ESE Duration
150	50	100	3 hours

Continuous Internal Evaluation Pattern:

Attendance : 10 marks
Continuous Assessment Test (2 numbers) : 25 marks
Assignment/Quiz/Course project : 15 marks

End Semester Examination Pattern: There will be two parts; Part A and Part B. Part A contain 10 questions with 2 questions from each module, having 3 marks for each question. Students should answer all questions. Part B contains 2 questions from each module of which student should answer any one. Each question can have maximum 2 sub-divisions and carry 14 marks.

Part A: 10 Questions x 3 marks=30 marks; **Part B:** 5 Questions x 14 marks =70 marks.

Course Level Assessment Questions

Course Outcome 1 (CO1)

1. List five types of enclosures used in electrical machines. (K1,PO2)
2. Explain the various insulation classes and the modern insulating materials. (K1,PO1)
3. Problems based on temperature rise calculations. (K2,PO2)

Course Outcome 2 (CO2)

1. Derive the output equation of a DC machine. (K2, PO1)
2. Discuss the factors that influence the choice of number of poles in a DC machine. (K1,PO2)
3. Problems based on the design of main dimensions and armature of a DC machine. (K3,PO3)
4. Problems based on the design of field system of a DC machine. (K3,PO3)

Course Outcome 3 (CO3)

1. Define window space factor in transformer design. (K1,PO2)
2. Derive output equation of transformers. (K2,PO1)
3. Problems based on the dimensions of transformers. (K3,PO3)

Course Outcome 4 (CO4)

1. Derive the expression for end ring current of a squirrel cage induction motor. (K2,PO1)
2. Write a short note on selection of current density in an induction motor in consideration to the insulation system. (K2,PO2)
3. Problems based on the design of an induction motor. (K3,PO3)

Course Outcome 5 (CO5)

1. Briefly explain the factors affecting the choice of specific electric and magnetic loadings in a synchronous machine. (K2,PO2)

2. Problems based on the design of synchronous machines. (K3,PO3)
3. Briefly explain the features of a brushless alternator. (K1,PO1)

Course Outcome 6 (CO6)

1. Explain how the finite element method is used for the analysis of electrical machines. (K2,PO1)
2. Explain various methods for the computer aided design of electrical machines. (K1,PO2)
3. Explain the analysis method with flow chart for computer aided design of electrical machines. (K1,PO2)

Note: *Design, simulation and optimization using electromagnetic field simulation software can be achieved* ***through assignments****. (PO3, PO4 and PO5)*

Model Question Paper

QP CODE:

PAGES: 3

Reg. No: ________________
Name : ________________

APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY
EIGHTH SEMESTER B.TECH DEGREE EXAMINATION, MONTH & YEAR
Course Code: EET444
Course Name: ELECTRICAL MACHINE DESIGN

Max. Marks: 100
Duration: 3 Hours

PART A (3 x 10 = 30 Marks)
Answer all questions. Each question carries 3 marks

1. List any four types of enclosures used in electrical machines.
2. Derive the gap contraction factor for slots.
3. Derive the output equation of a DC machine.
4. Explain the importance of proper pole proportions while separating the values of D and L in a DC machine.
5. Derive the output equation of a single phase transformer.
6. Briefly explain the cast resin transformer.
7. Discuss the choice of specific magnetic loading and specific electric loading in induction machines.
8. Derive the expression for end ring current in a squirrel cage induction motor.
9. Explain the synthesis method for computer aided design with a flow chart.
10. Briefly explain the features of a brushless alternator.

PART B (14 x 5 = 70 Marks)

Answer any one full question from each module. Each question carries 14 marks.

Module 1

11. a) Discuss the thermal and dielectric properties of the following insulating materials used in electrical machines. i) Nomex and ii) Polyamide films. (4 marks)

    b) The temperature rise of a transformer is 25°C after one hour and 37.5°C after 2 hours starting from cold conditions. Calculate its final steady temperature rise and the heating time constant. If its temperature falls from the final steady value to 40°C in 2.5 hours when disconnected, calculate its cooling time constant. The ambient temperature is 30°C. (10 marks)

12. a) What is Carter's coefficient and how does it help in the estimation of mmf of a machine with slotted armature? (6 marks)

    b)Derive the expression for the temperature rise in a machine. Is heating time constant greater than cooling time constant? Justify your answer. (8 marks)

Module 2

13. a) Discuss the factors that influence the choice of number of poles in DC machines. (4 marks)

    b) Find out the main dimensions of a 50kW, 4 pole, 600rpm DC shunt generator to give a square pole face. The full load terminal voltage being 220 V. The maximum gap density is 0.83Wb/m^2 and the ampere conductors per meter is 30000. Assume that full load armature voltage drop is 3 percent of rated terminal voltage and that the field current is 1 percent of rated full load current. Ratio of pole arc to pole pitch is 0.67. (10 marks)

14. a) Explain the design procedure of brushes and commutators for a DC machine. (4 marks)

    b) The following particulars refer to the shunt field coil for a 440V, 6pole, DC generator: mmf per pole = 7000A; depth of winding = 50mm; length of inner turn = 1.1m; length of outer turn = 1.4m; loss radiated from outer surface excluding ends = 1400 W/m2; space factor = 0.62; resistivity = 0.02 Ω/m and mm^2. Calculate a) the diameter of wire b) length of coil c) no. of turns and d) exciting current. Assume a voltage drop of 20% of terminal voltage across the field regulator. (10 marks)

Module 3

15. a) Compare distribution and power transformers. (4 marks)

    b) Determine the dimensions of core and window of a 5kVA, 50 Hz, single phase core type transformer. A rectangular core is used with long side twice as long as short side. The window height is 3 times the width. Voltage per turn is 1.8 V, space factor is 0.2, current density is 1.8A/mm^2 and flux density is 1Wb/m^2. (10 marks)

16. a) Define window space factor in transformer design. (4 marks)

    b) A 300kVA, 11000/400V, 3 phase, core type transformer has a total loss of 5000W at full load. The transformer tank is 1.25m in height and 1m x 0.75 m in plan. Design a suitable design for tubes if average temperature rise is to be limited to 360C. The diameter of the tube is 50mm and is placed 75mm apart. Average height of tubes is 1.05m, specific heat dissipation due to radiation = $6W/m^2$ ^oC and specific heat dissipation due to convection = $6.5W/m^2$ ^oC. Assume that convection is improved by 35 percent due to provision of tubes. (10 marks)

Module 4

17. Find the main dimensions, number of radial ducts, number of stator slots and number of turns per phase of a 3.7kW, 4 pole, 50 Hz, squirrel cage induction motor to be started by star-delta starter. Work out the winding details. The average flux density in the air gap = 0.45 T, ampere conductors per meter = 23000, efficiency = 0.85, power factor = 0.84. Choose main dimensions to achieve cheap design. Winding factor = 0.955, Iron stacking factor = 0.9. (14 marks)

18. a) What is cogging in an induction motor? (4 marks)

    b) Determine approximate values for the stator bore and the effective core length of a 55kW, 415V, 3-phase, star connected, 50Hz, four pole induction motor, Efficiency = 90%, power factor= 0.91, winding factor = 0.955, Assume suitable data wherever necessary with proper justification. (10 marks)

Module 5

19. a) What is short circuit ratio? How does the value of SCR affect the design of a synchronous generator? (4 marks)

    b) Determine the main dimensions of a 2500 kVA, 187.5rpm, 50Hz, 3 phase, 3 kV, salient pole alternator. The generator is to be a vertical, water wheel type. The specific magnetic loading is $0.6Wb/m^2$ and the specific electric loading is 34000A/m. Use circular poles with ratio of core length to pole pitch= 0.65. Specify the type of pole construction used if the run-away speed is about 2 times the normal speed. (10 marks)

20. a) Explain the design procedure for a synchronous generator using finite element software technique. (4 marks)

    b) Determine the diameter, core length, size, no. of conductors and no. of slots for stator of a 15MVA, 11kV, 50Hz, 2 pole, star connected turbo-alternator with 60^0 phase spread. Assume specific magnetic loading = 0.55 Tesla, specific electric loading = 36,000, current density = $5A/mm^2$, peripheral speed = 160m/s. The winding should be arranged to eliminate 5^{th} harmonic. (10 marks)

Syllabus

Module 1 (7 hours)

Principles of electrical machine design: General design considerations, types of enclosures - types of ventilation. Heating - cooling and temperature rise calculation – numerical problems. Continuous, short time and intermittent ratings. Insulation classes – Introduction to modern insulating materials, such as Nomex, Polyamide films and Silicone. Types of cooling in transformers and rotating electrical machines.

Magnetic system - Carter's coefficient – real and apparent flux density. Unbalanced magnetic pull and its practical aspects.

Module 2 (7 hours)

DC Machines: Output equation - main dimensions - choice of specific electric and magnetic loadings corresponding to the insulating materials, magnetic material and type of cooling considered - choice of speed and number of poles - design of armature conductors, slots and winding - design problems. Design of air-gap - design of field system – design problems. Fundamental design aspects of interpoles, compensating winding, commutator and brushes.

Module 3 (7 hours)

Transformers: Design of transformers - single phase and three phase transformers - distribution and power transformers - output equation - core design with due consideration to percentage impedance required - window area - window space factor - overall dimensions of core – design problems. Windings - no. of turns - current density in consideration to the insulation scheme - conductor section. Design of cooling tank with tubes – design problems. Essential design features of cast resin dry type transformers. Fundamentals of K-factor rated transformer, ECBC standards for transformers, BEE Star rating of transformers.

Module 4 (7 hours)

Induction machines: Output equation - main dimensions - choice of specific electric and magnetic loadings corresponding to the insulating materials, magnetic material and type of cooling considered - design of stator and rotor windings - round conductor or rectangular conductor - design of stator and rotor slots, air-gap of slip ring and squirrel cage motors - calculation of rotor bar and end ring currents in cage rotor - design of slip ring rotor winding - design problems. Design aspects of induction motor for drive applications (basic principles only).

Module 5 (8 hours)

Synchronous Machines: Output equation - salient pole and turbo alternators - main dimensions - choice of specific electric and magnetic loadings corresponding to the insulating materials, magnetic material and type of cooling considered - significance of short circuit ratio - choice of speed and number of poles - design of armature conductors, slots and winding - round conductor or rectangular conductor - design of air-gap - design problems.

Fundamental design aspects of the field system and damper winding. Features of brushless alternators.

Introduction to computer aided design: Analysis and synthesis methods - hybrid techniques. Introduction to machine design softwares using Finite Element Method.

Design, simulation and optimization using electromagnetic field simulation software (Assignment only).

Text Books

1. Sawhney A K, A Course in Electrical Machine Design, Dhanpat Rai & Co., 2016.
2. Say M G, The Performance and Design of AC Machines, CBS Publishers, New Delhi, 3rd edition, 2002.
3. Clayton A E & Hancock N N, Performance and Design of DC Machines, ELBS, 1971.

References

1. IS 1180 (Part 1):2014, Bureau of Indian Standards. https://bis.gov.in
2. S.O. No. 4062 (E) for Distribution Transformer dated 16th December, 2016, Bureau of Energy Efficiency, Govt. of India, Ministry of Power. https://www.beestarlabel.com
3. M. V. Deshpande, "Design and Testing of Electrical Machines", Wheeler Publishing.
4. R. K. Agarwal, "Principles of Electrical Machine Design", Essakay Publications, Delhi.
5. Ramamoorthy M, "Computer Aided Design of Electrical Equipment", East-West Press.
6. M. N. O. Sadiku, "Numerical techniques in Electromagnetics", CRC Press Edition-2001.

Course Contents and Lecture Schedule

No.	Topic	No. of Lectures
1	**Principles of electrical machine design (7 hours)**	
1.1	General design considerations, types of enclosures - types of ventilation.	1
1.2	Heating - cooling and temperature rise calculation – numerical problems.	1
1.3	Continuous, short time and intermittent ratings.	1
1.4	Insulation classes – Introduction to modern insulating materials,	1

	such as Nomex, Polyamide films and Silicone.	
1.5	Types of cooling in transformers and rotating electrical machines.	1
1.6	Magnetic system - Carter's coefficient – real and apparent flux density.	1
1.7	Unbalanced magnetic pull and its practical aspects.	1
2	**Design of DC Machines (7 hours)**	
2.1	Output equation - main dimensions	1
2.2	Choice of specific electric and magnetic loadings corresponding to the insulating materials, magnetic material and type of cooling considered	1
2.3	Choice of speed and number of poles	1
2.4	Design of armature conductors, slots and winding	1
2.5	Design problems and design of air-gap	1
2.6	Design of field system – design problems.	1
2.7	Fundamental design aspects of interpoles, compensating winding, commutator and brushes	1
3	**Design of Transformers (7 hours)**	
3.1	Single phase and three phase transformers - distribution and power transformers - output equation	1
3.2	Core design with due consideration to percentage impedance required	1
3.3	Window area - window space factor - overall dimensions of core – design problems.	1
3.4	Windings - no. of turns - current density in consideration to the insulation scheme - conductor section.	1
3.5	Design of cooling tank with tubes – design problems.	1
3.6	Essential design features of cast resin dry type transformers.	1
3.7	Fundamentals of K-factor rated transformer, ECBC standards for transformers, BEE Star rating of transformers.	1
4	**Design of Induction machines (7 hours)**	
4.1	Output equation - main dimensions	1
4.2	Choice of specific electric and magnetic loadings corresponding to the insulating materials, magnetic material and type of cooling considered	1
4.3	Design of stator and rotor windings - round conductor or rectangular conductor	1
4.4	Design of stator and rotor slots, air-gap of slip ring and squirrel cage motors - calculation of rotor bar and end ring currents in cage rotor	1
4.5	Design of slip ring rotor winding	1
4.6	Design problems	1
4.7	Design aspects of induction motor for drive applications (basic principles only).	1

5	**Design of Synchronous Machines and Introduction to computer aided design (8 hours)**	
5.1	Output equation - salient pole and turbo alternators - main dimensions	1
5.2	Choice of specific electric and magnetic loadings corresponding to the insulating materials, magnetic material and type of cooling considered	1
5.3	Significance of short circuit ratio - choice of speed and number of poles	1
5.4	Design of armature conductors, slots and winding - round conductor or rectangular conductor - design of air-gap	1
5.5	Design problems	1
5.6	Fundamental design aspects of field system and damper winding. Features of brushless alternators.	1
5.7	Analysis and synthesis methods - hybrid techniques.	1
5.8	Introduction to machine design softwares using Finite Element Method. Design, simulation and optimization using electromagnetic field simulation software (Assignment only).	1