INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad -500 043

ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE DESCRIPTOR

Course Title	**POWER SYSTEM OPERATION AND CONTROL**				
Course Code	**AEE016**				
Programme	**B.Tech**				
Semester	**SEVEN**				
Course Type	**Professional Core**				
Regulation	**IARE - R16**				
Course Structure	**Theory**			**Practical**	
	Lectures	**Tutorials**	**Credits**	**Laboratory**	**Credits**
	3	1	4	-	-
Chief Coordinator	Dr. P Sridhar, Professor				

I. COURSE OVERVIEW:

The objective of the control strategy is to generate and distribute power in an interconnected system as economically and reliably as possible while maintaining the frequency and voltage within permissible limits. The factors influencing power generation at minimal cost are operating efficiencies, fuel cost and transmission losses. In order to keep any power system in steady state the flow of active and reactive power must be checked. Successful achievement of these operational targets entailed the development of optimal dispatch solutions to find the optimal dispatch of generation for an interconnected power system.

II. COURSE PRE-REQUISITES:

Level	Course Code	Semester	Prerequisites	Credits
UG	AEE011	V	Transmission and Distribution Systems	4
UG	AEE012	VI	Power System Analysis	4

III. MARKS DISTRIBUTION:

Subject	SEE Examination	CIA Examination	Total Marks
Power System Operation and Control	70 Marks	30 Marks	100

IV. DELIVERY / INSTRUCTIONAL METHODOLOGIES:

✔	Chalk & Talk	✔	Quiz	✔	Assignments	✘	MOOCs
✔	PPT	✔	Seminars	✘	Mini Project	✔	Videos
✘	Open Ended Experiments						

V. EVALUATIONMETHODOLOGY:

The course will be evaluated for a total of 100 marks, with 30 marks for Continuous Internal Assessment (CIA) and 70 marks for Semester End Examination (SEE). Out of 30 marks allotted for CIA during the semester, marks are awarded by taking average of two CIA examinations or the marks scored in the make-up examination.

Semester End Examination (SEE): The SEE is conducted for 70 marks of 3 hours duration. The syllabus for the theory courses is divided into five units and each unit carries equal weightage in terms of marks distribution. The question paper pattern is as follows. Two full questions with "either" or "choice" will be drawn from each unit. Each question carries 14 marks. There could be a maximum of two subdivisions in a question.

Table 1: The expected percentage of cognitive level of questions in SEE

Percentage of Cognitive Level	Blooms Taxonomy Level
10 %	Remember
50 %	Understand
25 %	Apply
15 %	Analyze
0 %	Evaluate
0 %	Create

Continuous Internal Assessment (CIA):

CIA is conducted for a total of 30 marks (Table 2), with 25 marks for Continuous Internal Examination (CIE), 05 marks for Quiz/ Alternative Assessment Tool (AAT).

Table 2: Assessment pattern for CIA

Component	**Theory**		**Total Marks**
Type of Assessment	**CIE Exam**	**Quiz / AAT**	
CIA Marks	25	05	30

Continuous Internal Examination (CIE):

Two CIE exams shall be conducted at the end of the 8th and 16th week of the semester respectively. The CIE exam is conducted for 25 marks of 2 hours duration consisting of two parts. Part A shall have five compulsory questions of one mark each. In part B, four out of five questions have to be answered where, each question carries 5 marks. Marks are awarded by taking average of marks scored in two CIE exams.

Quiz / Alternative Assessment Tool (AAT):

Two Quiz exams shall be online examination consisting of 25 multiple choice questions and are be answered by choosing the correct answer from a given set of choices (commonly four). Marks shall be awarded considering the average of two quizzes for every course. The AAT may include seminars, assignments, term paper, open ended experiments, five minutes video and MOOCs. The AAT chosen for this course is given in Table 3**.**

Table 3: Assessment pattern for AAT

5 Minutes Video	Assignment	Tech-talk	Seminar
30%	30%	30%	10%

VI. COURSE OBJECTIVES:

The students will try to learn:	
I	The economic operation through optimal generation - load dispatch, hydro -thermal and pumped storage plant scheduling and their implementation through various classical methods.
II	The required mathematical and engineering fundamentals for controlling the governing system, turbine, excitation models and automatic, load frequency controllers in the power system.
III	The necessity and effective management of generation, transmission and distribution of electrical power for optimal operation of the system.
IV	The concepts of load frequency control in interconnected systems, its operation, reactive power control, compensation techniques in transmission line and types of loads with characteristics for real-world engineering problems and applications.
V	The control actions required on the system to meet the minute-to-minute variation of system demand and its significance in power system operation and control by maintaining the frequency and voltage as constant.

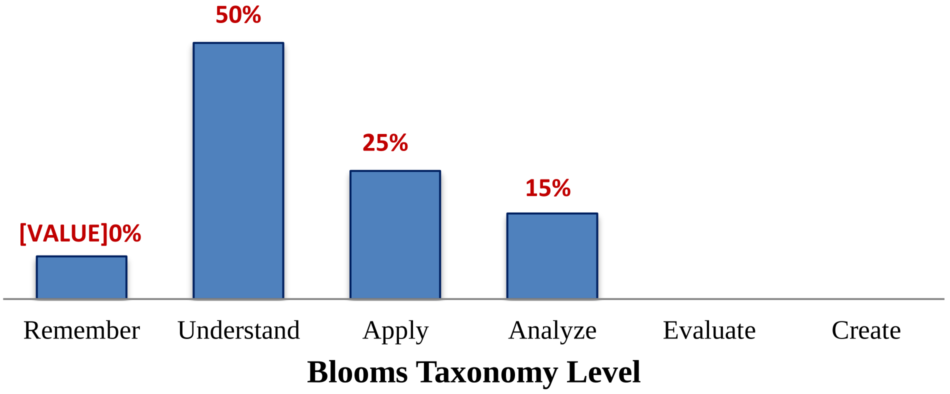
VII. COURSE OUTCOMES:

Upon the successful completion of this course, the students will be able to:

CO No	Course Outcomes	Knowledge Level (Bloom's Taxonomy)
CO1	**Recall** the knowledge of engineering science including electrical circuits, control systems and electrical machines in power system operation and control.	Remember
CO2	**Determine** economic scheduling of generation in a power system to supply specific amount of demand.	Understand
CO3	**Outline** the problems related to the economic dispatch of power, plant scheduling, strategies for minimizing transmission line losses and penalties imbibed.	Understand
CO4	**Calculate** the cost of generation, economic dispatch of power among ‘n’ thermal units using incremental cost curves and coordinate equation using iteration method.	Understand
CO5	**Develop** the mathematical models of the mechanical and electrical components involved in the operation of power systems under steady and dynamic conditions.	Analyze
CO6	**Model** excitation system using the fundamental characteristics and transfer function method.	Apply
CO7	**Analyze** the static performance of the system with automatic generation control, excitation voltage and reactive power control in an interconnected power system.	Analyze
CO8	**Design** a compensation scheme in a transmission line for imparting knowledge of various controllers with its evolution, principle of operation and applications.	Apply
CO9	**Determine** the optimal location of power capacitors for power factor improvement with economic justification.	Understand
CO10	**Demonstrate** the importance of load compensation in symmetrical as well as unsymmetrical loads with its characteristics.	Understand

CO11	**Solve** different numerical problems related to Economic Load Dispatch, Load Frequency Control and reactive power control.	Apply

COURSE KNOWLEDGE COMPETENCY LEVELS



VIII. HOW PROGRAM OUTCOMES ARE ASSESSED:

Program Outcomes		Strength	Proficiency assessed by
PO1	**Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.	3	CIE/Quiz/AAT
PO2	**Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences	3	CIE/Quiz/AAT
PO3	**Design / development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.	2	CIE/Quiz/AAT

3 = High; 2 = Medium; 1 = Low

IX. HOW PROGRAM SPECIFIC OUTCOMES ARE ASSESSED:

Program Specific Outcomes		Strength	Proficiency assessed by
PSO2	Focus on the components of power system, its analysis, operation, control and protection: electrical drives with its converter topology for energy conversion, management and auditing specific applications of industry and academia.	2	CIE / Quiz / AAT

3 = High; 2 = Medium; 1 = Low

X. MAPPING OF EACH CO WITH POs / PSOs:

Course Outcomes	Program Outcomes												Program Specific Outcomes		
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
CO1	√														
CO2	√	√												√	
CO3		√	√											√	
CO4	√		√											√	
CO5	√	√												√	
CO6	√	√												√	
CO7	√	√													
CO8	√	√													
CO9	√	√												√	
CO10	√		√												
CO11	√		√											√	

XI. JUSTIFICATIONS FOR CO – PO / PSO MAPPING

Course Outcomes	POs / PSOs	Justification for mapping (Students will be able to)	No. of key competencies
CO1	PO1	Understand **the principles of mathematics, science and engineering** for solving problems related to power system operation and control.	2
CO2	PO1	Determine at all times the optimum combination of generating units connected to the systems so as to supply the load **demand** at minimum cost **using principles of mathematics, science, and engineering fundamentals.**	2
	PO2	Identify the optimum combinations of generating units for economics load dispatch there by using the analysis to solve complex engineering problems with **basic mathematics and engineering sciences.**	6
	PSO2	Design the economic scheduling of generation to meet demand **Focusing on the components of power system, its analysis, operation, control and protection.**	1
CO3	PO2	Analyze the equality and inequality problems arises during power plant scheduling, strategies for reducing line losses and penalties using **principles of mathematics, science and engineering**	7
	PO3	**Design the solutions for the problems** that arises during operation and control of power system.	4
	PSO2	Structuring the economic dispatch of power, plant scheduling, strategies for minimizing transmission line losses in **power system operation and control.**	1

CO4	**PO1**	Calculated the additional expenses involved in the production process, such as raw material, for one additional generating unit using **fundamentals of mathematics, science, and engineering fundamentals.**	2
	PO3	**Design the specifications of components** required in incrementing units of thermal power plant to meet the requirements economically.	5
	PSO2	Find the number of thermal power plant units required for **optimal operation of power system.**	1
CO5	**PO1**	Calculate the values of mechanical and electrical components of power system effected under steady state and transient states using principles **mathematics, science and engineering fundamentals.**	2
	PO2	Analyze the electrical and mechanical components affected during steady state and transient state study of power system to solve complex problems in operation and control of power system using **basics of mathematics and engineering.**	6
	PSO2	Design the mechanical and electrical components **to improve power system operation** under steady state and transient conditions.	1
CO6	**PO1**	Determine the excitation system to provide continuous supply to the system with the **knowledge of mathematics, science and engineering fundamentals.**	2
	PO2	**Design the solution** related to excitation system in power system using different approaches with basics of mathematics and engineering	7
	PSO2	Study the performance of excitation system in **power system operation and control**	1
CO7	**PO1**	Understand the behavior of power system under static conditions with automatic generation control, excitation voltage and reactive power control using **knowledge of mathematics, science and engineering fundamentals.**	2
	PO2	Determine the solution for the power system operation and control under static conditions with various schemes using **basics of mathematics and engineering.**	6
CO8	**PO1**	Demonstrate the voltage magnitude, improve the voltage quality, and enhance the system stability using **fundamentals of mathematics, science, and engineering fundamentals.**	2
	PO2	Design the compensation schemes for power quality improvement under various conditions and implement the same with **basics of mathematics and engineering.**	7
CO9	**PO1**	Calculate the position where capacitor must be placed for power factor improvement **using the principles of mathematics and engineering fundamentals.**	2
	PO2	Provide the expressions used for optimal location of power system to improve its performance under typical conditions **with help of basic mathematics and engineering sciences.**	7
	PSO2	Identify the location of capacitor in **power system for optimal operation and control.**	1
CO10	**PO1**	Illustrate the management of reactive power to improve power quality i.e. V profile and power factor **using the principles of mathematics and engineering fundamentals.**	2

	PO3	Determine **the specifications of components** involved in symmetrical and asymmetrical load compensation for management of reactive power control.	4
CO11	**PO1**	Demonstrate the factors involved in Economic Load Dispatch, Load Frequency Control and reactive power control **using knowledge of mathematics, science and engineering fundamentals.**	2
	PO3	**Calculate the specifications of components** used for increasing number of units economically, maintain uniform frequency and reactive power generation and consumption.	5
	PSO2	Solve the number of generating units, operation frequency under synchronism and reactive **power for economic operation and control of power system.**	1

XII. NUMBER OF KEY COMPETENCIES FOR CO – PO/PSO MAPPING:

Course Outcomes	**Program Outcomes / Number of Vital Features**												**PSO/No. of Vital Features**		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
	3	**10**	**10**	**11**	**1**	**5**	**3**	**3**	**12**	**5**	**12**	**12**	**2**	**2**	**2**
CO1	2														
CO2	2	6												1	
CO3		7	4											1	
CO4	2		5											1	
CO5	2	6												1	
CO6	2	7												1	
CO7	2	6													
CO8	2	7													
CO9	2	7												1	
CO10	2		4												
CO11	2		5											1	

XIII. PERCENTAGE OF KEY COMPETENCIES FOR CO – PO/PSO MAPPING:

Course Outcomes	**Program Outcomes / Number of Vital Features**												**Program Specific Outcomes / No. of Vital Features**		
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3
	3	**10**	**10**	**11**	**1**	**5**	**3**	**3**	**12**	**5**	**12**	**12**	**2**	**2**	**2**
CO1	66.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

CO2	66.6	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0
CO3	0.0	70.0	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0
CO4	66.6	0.0	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0
CO5	66.6	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0
CO6	66.6	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0
CO7	66.6	60.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO8	66.6	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO9	66.6	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0
CO10	66.6	0.0	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
CO11	66.6	0.0	50.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0

XIV. COURSE ARTICULATION MATRIX (CO - PO / PSO MAPPING):

COs and POs and COs and PSOs on the scale of 0 to 3, **0** being **no correlation**, **1** being the **low correlation**, **2** being **medium correlation** and **3** being **high correlation**.

0 – **0**≤ C≤ 5%- No correlation;
1 – 5 <C≤ 40%- Low/ Slight;
2 − 40 % <C< 60% - Moderate.
3 – 60% ≤ C< 100% -Substantial /High

Course Outcomes	**Program Outcomes**												**Program Specific Outcomes**		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**
CO1	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CO2	3	3	-	-	-	-	-	-	-	-	-	-	-	2	-
CO3	-	3	2	-	-	-	-	-	-	-	-	-	-	2	-
CO4	3	-	2	-	-	-	-	-	-	-	-	-	-	2	-
CO5	3	3	-	-	-	-	-	-	-	-	-	-	-	2	-
CO6	3	3	-	-	-	-	-	-	-	-	-	-	-	2	-
CO7	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-
CO8	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-
CO9	3	3	-	-	-	-	-	-	-	-	-	-	-	2	-
CO10	3	-	2	-	-	-	-	-	-	-	-	-	-	-	-
CO11	3	-	2	-	-	-	-	-	-	-	-	-	-	2	-
TOTAL	30	21	8											14	
AVERAGE	**3.0**	**3.0**	**2.0**											**2.0**	

XV. ASSESSMENT METHODOLOGIES - DIRECT:

CIE Exams	PO 1,PO 2, PO 3,PSO 2	SEE Exams	PO 1, PO 2, PO 3,PSO 2	Assignments	PO 1, PO 2, PO 3, PSO 2	Seminars	PO 1, PO 2, PO 3, PSO 2
Laboratory Practices	-	Student Viva	-	Mini Project	-	Term Paper	PO 1, PO 2, PO 3, PSO 2
Certification							

XVI. ASSESSMENT METHODOLOGIES -INDIRECT:

✔	Early Semester Feedback	✔	End Semester OBE Feedback
✘	Assessment of Mini Projects by Experts		

XVII. SYLLABUS

UNIT - I	**ECONOMIC OPERATION OF POWER SYSTEMS**
Optimal scheduling of thermal power system: Optimal operation of generators in thermal power stations, heat rate curve, cost curve, incremental fuel and production costs, input output characteristics, optimum generation allocation without and with transmission line losses coefficients, general transmission line loss formula, unit commitment; Optimal scheduling of hydrothermal system: Hydroelectric power plant models, scheduling problems, short term hydrothermal scheduling problem.	
UNIT - II	**MODELING OF GOVERNOR, TURBINE AND EXCITATION SYSTEMS**
Modeling of governor: Mathematical modeling of speed governing system, derivation of small signal transfer function; Modeling of turbine: First order turbine model, block diagram representation of steam turbines and approximate linear models; Modeling of excitation system: Fundamental characteristics of an excitation system, transfer function, block diagram representation of IEEE type-1 model.	
UNIT - III	**SINGLE AREA AND TWO AREA LOAD FREQUENCY CONTROL**
Load frequency control of single area system: Necessity of keeping frequency constant, definitions of control area, single area control, block diagram representation of an isolated power system, steady state analysis, dynamic response, uncontrolled case. Load frequency control of two area system: Uncontrolled case and controlled case, tie line bias control; Load frequency controllers: Proportional plus integral control of single area and its block diagram representation, steady state response, load frequency control and economic dispatch.	
UNIT - IV	**COMPENSATION FOR POWER FACTOR IMPROVEMENT AND REACTIVE POWER CONTROL**
Voltage control: Equipment for voltage control, effect of series capacitors, line drop compensation, effect of AVR, power factor control using different types of power capacitors, shunt and series capacitors, effect of shunt capacitors (fixed and switched), power factor correction, capacitor allocation, economic justification, procedure to determine the best capacitor location; Reactive power control: Reactive power compensation in transmission systems, advantages and disadvantages of different types of compensating equipment for transmission systems; Uncompensated and compensated transmission lines: Shunt and series compensation.	
UNIT - V	**LOAD COMPENSATION**
Load Compensation: characteristics of loads, factors associated with loads, relation between the load factor and loss factor; specifications of load compensator; Classification of loads: Residential, commercial, agricultural and industrial and their characteristics.	
Textbooks:	
1. Sivanagarju, “Power system operation and control”, Pearson Education India,2009 2. Turan Gonen, “Electric Power Distribution System Engineering”, Mc Graw-Hill Book Company 3. T J E Miller, “Reactive power control in Electrical system”, Wiley Inderscience Publication,1982. 4. V K Mehta and Rohit Mehta, “Principles of Power System”, S Chand, 3rd revised Edition,2015.	

Reference Books:
1. Singh S N, “Electric Power Generation, Transmission and Distribution”, Prentice Hall of India Pvt. Ltd., New Delhi, 2nd Edition, 2002. 2. Turan Gonen, “Electrical Power Distribution System Engineering”, CRC Press, 3rd Edition,2014. 3. V Kamaraju, “Electrical Power Distribution Systems”, TMH, Publication, 2nd Edition, 2009 4. O I Elgerd, “Electrical Energy Systems Theory”, Tata McGraw-Hill, 2nd Edition, 2007.

XVIII. COURSE PLAN:

The course plan is meant as a guideline. Probably there may be changes.

Lecture No	Topics to be covered	Course Outcomes	Reference
1-2	Understand optimal operation of generators in thermal power stations and their characteristics	CO1	T1:5-6
3	Understand the heat rate curve, cost curve, incremental fuel and production costs, input output characteristic	CO2	T1: 25-26
4	Solve optimum generation allocation without transmission line losses coefficients, general transmission line loss formula	CO4	T1: 26-28
5	Solve optimum generation allocation with transmission line losses coefficients, general transmission line loss formula,	CO4	T1: 26-28 R1: 34 - 45
6	Solve the unit Commitment problem with various constraints using conventional optimization techniques and general transmission line loss formula	CO11	T1: 26-28 R4: 32- 51
7-9	Examine optimal scheduling of hydrothermal system, its performance characteristics and their economic operation	CO11	T1: 30-32
10-11	Design mathematical modeling of speed governing system and derive small signal transfer function	CO5	T3:312-318
13-14	Design block diagram representation of steam turbines and approximate linear models	CO5	T3:312-318
15	Design mathematical modeling of excitation system of steam turbine	CO6	T3:322-326
16	Understand the fundamental characteristics of an excitation system	CO6	T3:319
17	Understand the block diagram of an excitation system	CO6	T2:11.5 R2:17.5
18-19	Understand block diagram representation of IEEE type-1model.	CO6	T1: 84-85
20	Study the definitions of control area and single area control	CO7	T1: 327-330
21	Interpret the block diagram representation of an isolated power system for uncontrolled case	CO7	T1: 327-330
22	Describe the steady state analysis and dynamic response for uncontrolled case	CO7	T1: 327-330
23	Study the uncontrolled case and controlled case, tie line bias control for two area system	CO7	T1: 327-330
24	Study the controlled case, tie line bias control for two area system	CO7	T1: 58-59
25	Examine the proportional plus integral control of single area system	CO7	T1: 58-59
26-27	Study the Proportional plus integral control of single area and its block diagram representation	CO7	T1 :60-62
28-29	Study the steady state response, load frequency control and economic dispatch	CO7	T1 :65-68
30	Understand the significance of reactive power control in power systems to maintain quality of power	CO8	T1:296
31	Discuss equipment for voltage control, effect of series capacitors, line drop compensation, effect of AVR, power factor control using different types of power capacitors.	CO8	T2:383-385

32	Describe the effect of series capacitors, line drop compensation, effect of AVR, power factor control using different types of power capacitors	CO9	T2:383- 385 T3: 254 - 295
33	Study the effect of series capacitors, line drop compensation	CO9	T2:383
34	Learn the shunt and series capacitors, effect of shunt capacitors fixed and switched power factor correction,	CO9	T 1: 330-345
35	Analyze the capacitor location and Reactive power control	CO9	T2:337
36-37	Demonstrate the reactive power compensation in transmission systems	CO9	T2:342-345
38	Distinguish between advantages and disadvantages of different types of compensating equipment for transmission systems	CO10	T2:342-345
39	Describe the uncompensated and compensated transmission lines and shunt and series compensation.	CO10	T2:337
40-42	Understand the uncompensated and compensated transmission lines and shunt and series compensation	CO10	T2:325-327 R3: 114-154
43 - 44	Tutorial problems	CO11	T2:325-327
45	Tutorial problems	CO11	T2:325-327
46	Learn characteristics of loads and load compensation	CO10	T2:25
47	Understand the significance of distribution systems and their characteristics	CO10	T2:26-28
48 - 55	Illustrate the different types of loads and their characteristics	CO10	T2:29-35
56-58	Tutorial problems	CO11	T2:31-35
59-60	Revision	CO11	T2:31-35

XIX. GAPS IN THE SYLLABUS - TO MEET INDUSTRY / PROFESSION REQUIREMENTS:

S No	Description	Proposed Actions	Relevance with POs	Relevance with PSOs
1	Designing the turbine model, generator load modelling and load frequency loop with gains using digital simulation	MATLAB Demos /NPTEL	PO5	-
2	Optimum generation allocation with and without transmission line losses coefficients by using digital simulation	MATLAB Demos / NPTEL	PO5	-

Prepared by:
Dr. P Sridhar, Professor **HOD, EEE**