CODE	COURSE NAME	CATEGORY	L	T	P	CREDIT
EET438	ENERGY STORAGE SYSTEMS	PEC	2	1	0	3

Preamble: This course aims to introduce the importance and application of energy storage systems and to familiarize with different energy storage technologies.

Prerequisite: Nil

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

CO 1	Identify the role of energy storage in power systems
CO 2	Classify thermal, kinetic and potential storage technologies and their applications
CO 3	Compare Electrochemical, Electrostatic and Electromagnetic storage technologies
CO 4	Illustrate energy storage technology in renewable energy integration
CO 5	Summarise energy storage technology applications for smart grids)

Mapping of course outcomes with program outcomes

	PO 1	PO 2	PO 3	PO 4	PO 5	PO 6	PO 7	PO 8	PO 9	PO 10	PO 11	PO 12
CO 1	3	2										
CO 2	3											
CO 3	3	2	1				1					
CO 4	3	2	1			1	1					1
CO 5	3	1	1			1	1					1

Assessment Pattern

Bloom's Category	Continuous Assessment Tests		End Semester Examination
	1	2	
Remember (K1)	15	15	30
Understand (K2)	20	20	40
Apply (K3)	15	15	30
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.

Course Level Assessment Questions

Course Outcome 1 (CO1)

1. What are the different parts of a complete energy storage unit? (K1, PO1)
2. Explain the Dynamic Duty of storage plant. (K2, PO1,PO2)
3. What are the different types of central store? (K2, PO1)

Course Outcome 2 (CO2)

1. List the applications of thermal energy storage systems. (K1, PO1)
2. Explain hydrogen-based power utility concept.(K2,PO1)
3. What are the different storage containments of hydrogen? (K1, PO1)

Course Outcome 3(CO3)

1. Explain the working of fuel cell along with schematic diagram. (K2, PO1,PO2,PO7)
2. Write short notes on supercapacitors. (K2, PO1)
3. Explain the arrangement of a control and protection system for Super Conducting Magnetic Energy Storage.(K2 , PO1,PO3)

Course Outcome 4 (CO4)

1. Explain small-scale hydroelectric energy. (K2,PO1,PO3,PO6,PO7,PO12)
2. Write short notes on wave energy and its storage system. (K2, PO1, PO7,PO12)
3. What are the different types of renewable power sources? (K1, PO1, PO7,PO12)

Course Outcome 5 (CO5)

1. Explain distributed energy storage system. (K2, PO1, PO3,PO6,PO7,PO12)
2. What are the characteristics of smart grid system? (K1, PO1, PO6,PO7,PO12)
3. What is demand response? (K1, PO1, PO2)

Model Question Paper

QP CODE: Pages:

Reg No.:_____

Name:_____

APJ ABDUL KALAM TECHNOLOGICAL UNIVERSITY EIGHTH SEMESTER

B.TECH DEGREE EXAMINATION,

MONTH & YEAR

Course Code: EET438

Course Name: ENERGY STORAGE SYSTEMS

Max. Marks: 100 Duration: 3 hours

PART A

Answer all questions; each question carries 3 marks.

1.	Discuss the power transformation of energy storage system.	(3)
2.	Explain the different components of energy storage system with schematic structure.	(3)
3.	Define Flow equation related to thermal energy storage system.	(3)
4.	Write the difference between hybrid and combined energy storage in power system.	(3)
5.	Explain the chemical reaction of lead acid batteries.	(3)
6.	Write down the basic principle of capacitor bank storage system.	(3)
7.	Classify hydro power plants based on their rated capacity.	(3)
8.	Briefly discuss small-scale hydroelectric energy system.	(3)

9.		What is distributed energy storage system?	(3)
10		List the various layers of smart grid.	(3)

PART B

Answer any one complete question from each section; each question carries 14 marks

11	(a)	Explain static duty of energy storage plant.	(8)
	(b)	With neat diagram explain energy and power balance in a storage unit.	(6)
		OR	
12	(a)	Explain the econometric model of energy storage. Derive the expression for annual cost of the system.	(10)
	(b)	What are the key parameters considered for the comparison of energy storage in power system?	(4)
13	(a)	Discuss the working principle of compressed air energy storage system.	(7)
	(b)	Write short note on flywheel energy storage system.	(7)
		OR	
14	(a)	Write any three industrial methods to produce hydrogen.	(9)
	(b)	Explain 'power to gas' concept.	(5)
15	(a)	Explain the working of Li-ion batteries.	(7)
	(b)	Describe the typical voltage–discharge profile for a battery cell.	(7)
		OR	
16	(a)	Describe basic principle and working of superconducting magnetic energy storage system.	(7)
	(b)	With the help of a block diagram, explain the arrangement of control and	(7)

protection system for superconducting magnetic energy storage system.

17	(a)	What are the main features of renewable energy systems?	(4)
	(b)	Explain the role of storage systems in an integrated power system with grid-connected renewable power sources.	(10)

OR

18	(a)	Explain photovoltaics system.	(4)
	(b)	Discuss the role of storage in an isolated power system with renewable power sources.	(10)
19	(a)	Describe the distributed energy storage system.	(6)
	(b)	"HEV act as a distributed energy generator and storage", justify your answer.	(8)

OR

20	(a)	What is demand response?	(5)
	(b)	Draw and explain the battery SCADA system.	(9)

Syllabus

Module 1

Introduction to energy storage in power systems (6)

Need and role of energy storage systems in power system, General considerations, Energy and power balance in a storage unit, Mathematical model of storage system: modelling of power transformation system (PTS)-Central store (CS) and charge–discharge control system (CDCS), Econometric model of storage system.

Module 2

Overview on Energy storage technologies (7)

Thermal energy: General considerations -Storage media- Containment- Thermal energy storage in a power plant, Potential energy: Pumped hydro-Compressed Air, Kinetic energy: Mechanical- Flywheel , Power to Gas : Hydrogen - Synthetic methane

Module 3

Overview on Energy storage technologies (8)

Electrochemical energy : Batteries- Battery parameters: C-rating -SoC- DoD- Specific Energy-Specific power (numerical examples), Fuel cells, Electrostatic energy (Super Capacitors), Electromagnetic energy (Super conducting Magnetic Energy Storage), Comparative analysis, Environmental impacts of different technologies.

Module 4

Energy storage and renewable power sources (6)

Types of renewable energy sources: Wave - Wind – Tidal – Hydroelectric - Solar thermal technologies and Photovoltaics, Storage role in isolated power systems with renewable power sources, Storage role in an integrated power system with grid-connected renewable power sources

Module 5

Energy storage Applications (7)

Smart grid, Smart microgrid, Smart house, Mobile storage system: Electric vehicles – Grid to Vehicle (G2V)-Vehicle to Grid (V2G), Management and control hierarchy of storage systems - Aggregating energy storage systems and distributed generation (Virtual Power Plant Energy Management with storage systems), Battery SCADA, Hybrid energy storage systems: configurations and applications.

Text Books

1. A.G.Ter-Gazarian, "Energy Storage for Power Systems", Second Edition, The Institution of Engineering and Technology (IET) Publication, UK, (ISBN - 978-1-84919-219-4),2011.

2. Francisco Díaz-González, Andreas Sumper, Oriol Gomis-Bellmunt," Energy Storage in Power Systems" Wiley Publication, ISBN: 978-1-118-97130-7, Mar 2016.

Reference Books

1. Electric Power Research Institute (USA), "Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits" (1020676), December 2010.

2. Paul Denholm, Erik Ela, Brendan Kirby and Michael Milligan, "The Role of Energy Storage with Renewable Electricity Generation", National Renewable Energy Laboratory (NREL) -a National Laboratory of the U.S. Department of Energy.

3. P. Nezamabadi and G. B. Gharehpetian, "Electrical energy management of virtual power plants in distribution networks with renewable energy resources and energy storage systems", IEEE *Power Distribution Conference*, 2011.

Course Contents and Lecture Schedule

No	Topic	No. of Lectures
1	**Introduction to energy storage for power systems: (6)**	
1.1	General considerations- different parts of energy storage unit- static duty of storage plant- dynamic duty of storage plant	2
1.2	Energy and power balance in a storage unit- schematic structure of energy storage	1
1.3	Mathematical model of storage system	1
1.4	Econometric model of storage- capital cost of energy storage- annual cost of storage facility	2
2	**Overview on Energy storage technologies: (7)**	
2.1	Principle of thermal energy storage- sensible heat storage – latent heat storage- containment- thermal energy storage in power plant application	2
2.2	Principle and operation of pumped hydroelectric storage (PHS)- general considerations- schematic diagram	1
2.3	Principle and operation of Compressed Air Energy Storage (CAES)- general considerations- basic principle-industrial application	1
2.4	Principle and operation of Flywheel Energy storage System (FESS)-general considerations -applications	1
2.5	General considerations- synthetic storage media-Hydrogen production-Hydrogen based power utility concept- storage containment for hydrogen-Methods of extraction of methane-	2

	Block diagram Power to gas concept	
3	**Overview on Energy storage technologies (8)**	
3.1	Basic concepts of conventional batteries and flow batteries- Battery parameters- C-rating-SoC- DoD- Specific Energy-Specific power (numerical examples), Fuel cell- Schematic diagram of an electrochemical fuel cell	2
23.2	Super conducting Magnetic Energy Storage (SMES)- basic circuit-principle-advantages	2
3.3	The Supercapacitor Energy Storage System- topology-principle-advantages	2
3.4	Comparative study of different energy storage system based on specific energy, specific power, cycling capability and life in years	2
4	**Energy storage and renewable power sources (6)**	
4.1	Types of renewable power sources- brief description	2
4.2	Storage role in isolated power system with renewable power sources	1
4.3	Storage role in an integrated power system with grid-connected renewable power sources	1
4.4	Small scale hydroelectric energy	1
4.5	Solar thermal technologies and photovoltaics	1
5	**Energy storage Applications (7)**	
5.1	Smart grid-concepts- characteristics- Smart metering	2
5.2	Field of Electromobility- thyristor based battery charger and DC power supply	1
5.3	Vehicle to grid and grid to vehicle charging point topology	1
5.4	Distributed energy storage	1
5.5	Battery SCADA- overview	1
5.6	Hybrid energy storage systems: configurations and applications	1