GUJARAT TECHNOLOGICAL UNIVERSITY

Program Name: Engineering

Level: Diploma

Branch: Renewable Energy

Course / Subject Code: 4366405

Course / Subject Name: Energy Storage

w. e. f. Academic Year:	July-2024
Semester:	6th
Category of the Course:	Program Core

Prerequisite:	Basic knowledge related to non-conventional sources of Energy, Renewable Energy, Physics and Chemistry. Brief knowledge of Electrical Energy Storage systems.
Rationale:	The course on Energy Storage is designed to provide students with a comprehensive understanding of the fundamental principles governing the Energy Storage systems and to emphasize the role of Energy Storage technology and its potential. This course aims to provide final-year diploma students in Renewable Energy Engineering with a fundamental understanding of various energy storage technologies, their applications in modern power systems, and hands-on experience with practical exercises to build competency in operating energy storage systems. By studying these topics, students will develop a solid foundation in Energy Storage systems and gain practical knowledge necessary for their future careers in renewable and electrical engineering.

Course Outcome:

After Completion of the Course, Student will able to:

No	Course Outcomes	RBT Level
01	Gain knowledge about types and importance of Energy Storage	**R**
02	Understand Electrochemical Energy Storage Systems	**U**
03	Understand Mechanical and Thermal Energy Storage Systems	**U**
04	Comprehend Grid Integration of Energy Storage Systems	**A**

**Revised Bloom's Taxonomy (RBT)*

Teaching and Examination Scheme:

Teaching Scheme (in Hours)			Total Credits L+T+ (PR/2)	Assessment Pattern and Marks				Total Marks
				Theory		Practical		
L	T	PR	C	ESE (E)	PA/CA (M)	PA/CA (I)	ESE (V)	
3	0	2	4	70	30	25	25	150

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Course Content:

Unit No.	Content	No. of Hours	% of Weightage
1.	Introduction to Energy Storage Systems (ESS)	08	20
2.	Electrochemical Energy Storage (Batteries)	12	28
3.	Mechanical and Thermal Energy Storage	12	28
4.	Energy Storage for Grid Applications	10	24
	Total	**42**	**100**

Unit	Unit Outcomes (UOs)	Topics and Sub-topics
Unit I Introduction to Energy Storage Systems (ESS)	**1a.** Understand the fundamentals of Energy Storage and its types **1b.** Compare different types of Energy Storage	**1.1** Definition and Importance of Energy Storage **1.2** Different Types of Energy Storage • Mechanical • Electrochemical • Electrical • Thermal **1.3** Comparison of Energy Storage Technologies
Unit II Electrochemical Energy Storage (Batteries)	**2a.** Explain the working principle of Batteries **2b.** Comprehend construction and working of different types Batteries **2c.** Understand the ratings of a Battery	**2.1** Working Principles of Batteries **2.2** Types of Batteries: • Lead-Acid Batteries • Lithium-Ion Batteries • Flow Batteries (Vanadium Redox, Zinc-Bromine) **2.3** Battery Ratings: • Voltage • Capacity (Ah) • C-Rate (Discharge Rate) • Temperature Range • Internal Resistance

Unit III Mechanical and Thermal Energy Storage	**3a.** Understand various types of Mechanical Energy Storage systems **3b.** Understand various types of Thermal Energy Storage systems	**3.1** Mechanical Energy Storage • Pumped Hydro Storage (PHS) • Compressed Air Energy Storage (CAES) • Flywheel Energy Storage **3.2** Thermal Energy Storage • Molten Salt Storage in Solar Power Plants • Ice Storage Systems • Sensible and Latent Heat Storage
Unit IV Energy Storage for Grid Applications	**4a.** Describe the benefits of Grid-Scale Energy Storage and Integrate Energy storage with Renewable Energy **4b.** Comprehend Frequency Regulation and Load Balancing using Energy Storage Systems **4c.** Understand Future Trends in Energy Storage Technologies	**4.1** Grid-Scale Energy Storage and its Benefits **4.2** Energy Storage and Renewable Integration (Solar, Wind) **4.3** Energy Storage for Frequency Regulation and Load Balancing **4.4** Future Trends in Energy Storage Technologies • Solid-State Batteries • Hybrid Energy Storage Systems • Smart Grid and Energy Storage Integration

Suggested Specification Table with Marks (Theory):

Distribution of Theory Marks (in %)					
R Level	**U Level**	**A Level**	**N Level**	**E Level**	**C Level**
50%	**35%**	**10%**	**3%**	**1%**	**1%**

Where R: Remember; U: Understanding; A: Application, N: Analyze and E: Evaluate C: Create (as per Revised Bloom's Taxonomy)

References/Suggested Learning Resources:

(a) Books:

1. "Energy Storage Systems: A Technology Overview" by S. K. Ghosh
2. "Introduction to Energy Storage Systems" by Daniel Cohn
3. "Renewable Energy Systems: A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions" by Henrik L.
4. "Energy Storage for Power Systems" by Ibrahim Dincer and Marc A. Rosen
5. "Handbook of Energy Storage" by Michael R. Tinker
6. "Fundamentals of Energy Storage" by J. M. St. John

(b) Open source software and website:

1. https://github.com/tobirohrer/building-energy-storage-simulation
2. https://www.pscad.com/knowledge-base/article/176

Suggested Course Practical List:

Sr. No.	Practical Outcomes (PrOs)	Unit No.	Approx. Hrs. Required
1	Lead-Acid Battery Testing, Measure and record the open-circuit voltage (OCV) and specific gravity of electrolyte	2	4
2	Lithium-Ion Battery Testing, Measure voltage, capacity, and internal resistance of a lithium-ion battery	2	2
3	Battery Charging System (Lead-Acid), Draw and label a battery charging circuit for a lead-acid battery	2	2
4	Prepare a report on the Vanadium Redox Flow Battery	2	2
5	Prepare a report on the Zinc Bromine Flow Battery	2	2
6	Draw and label a flywheel-based energy storage system and explain the same	3	2

7	Compressed Air Energy Storage (CAES) Simulation of operation and study using small scale model	3	4
8	Prepare a report on the operation of a pumped hydro system and simulate	3	2
9	Prepare a report on the challenges in the Grid connection of the Energy Storage systems	4	4
10	Draw and label a simple off-grid solar system with battery storage	4	4

List of Laboratory/Learning Resources Required:

Sr. No.	Equipment Name with Broad Specifications	Pr. No.
1	Lead Acid Battery	1, 3
2	Battery Electrolyte Gravity Tester	1
3	Electrical Multi-meter	1, 2
4	Lithium Ion Battery	2

Suggested Project List:

Only one micro-project is planned to be undertaken by a student that needs to be assigned to him/her in the beginning of the semester. In the first four semesters, the micro-projects are group-based (group of 4 to 5). However, **in the fifth and sixth semesters**, the number of students in the group should ***not exceed four.*** The micro-project could be industry application based, internet-based, workshop-based, laboratory-based or field-based. Each micro-project should encompass two or more COs which are in fact, an integration of PrOs, UOs and ADOs. Each student will have to maintain dated work diary consisting of individual contribution in the project work and give a seminar presentation of it before submission. The duration of the micro project should be about **14-16** ***(fourteen to sixteen) student engagement hours*** during the course. The students ought to submit micro-project by the end of the semester to develop the industry-oriented COs.

A suggestive list of micro-projects is given here. This has to match the competency and the COs. Similar micro-projects could be added by the concerned course teacher:

a) Design and create miniature Demo Mechanical Energy Storage system.
b) Design and create miniature Demo Electrochemical Energy Storage system.
c) Design and create miniature Demo Electrical Energy Storage system.
d) Explore the electrical components of a Grid Connected Energy Storage System.
e) Build a device to measure gravity of Lead-Acid Battery Electrolyte.
f) Create an educational presentation or workshop on Energy Storage system for local schools.
g) Design and Build a Simple Battery Charger.
h) Battery Voltage Monitoring System.
i) Solar-Powered Battery Charging Station.
j) Pumped Hydro Storage System Model.
k) Design a Hybrid Energy Storage System (HESS).

Suggested Activities for Students:

Other than the classroom and laboratory learning, following are the suggested student-related ***co-curricular*** activities which can be undertaken to accelerate the attainment of the various outcomes in this course. Students should perform following activities in group (or individual) and prepare reports of about 5 pages for each activity. They should also collect/record physical evidences for their (student's) portfolio which may be useful for their placement interviews:

a. Create a quiz to test students' understanding of fundamental concepts related to Energy Storage, including terminology, principles, and historical developments.
b. Ask students to create detailed diagrams or models illustrating the different parts of a Pumped Hydro Storage, explaining the function of each component.

c. Use online simulation tools or software to allow students to virtually design and test their own Energy Storage Systems.

d. Invite a professional from the Electric Vehicle industry to speak to the class. Allow students to ask questions and learn about current trends, challenges, and career opportunities.

e. Explore the impact on frequency due to integration of Energy Storage system with Power Grid.

CO- PO Mapping:

Semester 5th	Course Name (Course Code: 4356405)						
	POs						
Course Outcomes	PO 1 Basic & Discipline specific knowledge	PO 2 Problem Analysis	PO 3 Design/ development of solution	PO4 Engineering Tools, Experimentation Testing	PO 5 Engineering practices for society, sustainability & environment	PO 6 Project Management	PO 7 Life-long learning
CO1	2	-	-	-	1	-	-
CO2	2	-	-	-	-	-	-
CO3	2	-	-	-	-	-	-
CO4	-	2	-	-	1	-	-

*Legend: '**3**' for high, '**2**' for medium, '**1**' for low and '**-**' for no correlation of each CO with PO.*

No	Course Outcomes
CO1	Gain knowledge about types and importance of Energy Storage
CO2	Understand Electrochemical Energy Storage Systems
CO3	Understand Mechanical and Thermal Energy Storage Systems
CO4	Comprehend Grid Integration of Energy Storage Systems

GTU Resource Person

Sr. No.	Name and Designation	Institute	Contact No.	Email
1.	Chitrang Kamendu Vyas Lecturer, Electrical Engineering	AVPTI, Rajkot	7405744810	ckv.avp@gmail.com

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