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**SECOND SEMESTER 2023-2024**

# Course Handout Part II

Date: 09-01-2024

In addition to part-I (General Handout for all courses appended to the time table) this portion gives further specific details regarding the course.

*Course No.* : EEE/ECE/INSTR F428

## Course Title : **Energy Storage Systems**

## Instructor-in-Charge : **Dr. Ankur Bhattacharjee**

**Scope and Objective of the Course:**

Familiarization with various energy storage technologies, their working principle, design and applications in renewable energy domain, electric vehicles and other power supply systems.

**Textbooks:**

1. Energy Storage and Conversion: Materials and Devices, [Ashok Kumar](https://www.google.co.in/search?tbo=p&tbm=bks&q=inauthor:%22Ashok+Kumar%22), [Shyamal Kumar Das](https://www.google.co.in/search?tbo=p&tbm=bks&q=inauthor:%22Shyamal+Kumar+Das%22), Narosa Publishing House.
2. Energy Storage: Systems and Components, Alfres Rufer, CRC Press.
3. Energy Storage: Fundamentals, Materials and Applications, **Huggins**, Robert, Springer.
4. Linden’s Handbook of Batteries, Kirby W. Beard, The Mcgraw Hill publisher*.*

**Reference books**

1. Energy Storage Devices for Electronic Systems, Nihal Kularatna, Elsevier.

2. Advances in Batteries for Medium and Large-Scale Energy Storage, C Menictas M Skyllas-

Kazacos T M Lim, Woodhead Publishers.

1. Handbook on Battery Energy Storage System, Asian Development Bank (ADB).

**Course Plan:**

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| **Lecture No.** | **Learning objectives** | **Topics to be covered** | **Chapter in the Text Book** |
| 1 | To familiarize with the need of energy storage and different energy storage technologies | Need of Energy Storage. Broad Classification of Energy Storage Systems, Primary and Secondary Energy Storages and their applications. | **TB1,TB2** |
| 2 | To know the electrochemical properties and principles | Electrochemical principles: Electrochemical Redox, Oxidation-reduction half cells | **TB1,TB2** |
| 3 | To know about different types of electrochemical cells | Galvanic Cells, Simple Voltaic Cell, Reversible and Irreversible Cells | **TB1,TB2** |
| 4 | To learn about the parameters related to electrode | Electrode potential, Factors affecting electrode potentials, Reversible electrode (standard electrodes) | **TB1,TB2** |
| 5 | To get familiarized with electrode chemistry | Nernst Potential Equation, Electrode reactions and Cell Chemistry | **TB1,TB2** |
| 6 | To learn about the electrode reactions | Nature of the electrode reaction, Electron Transfer, Mass transport, Fick’s Law, Impedance spectroscopy. | **TB1,TB2** |
| 7 | To know battery energy storage | Batteries: Primary and secondary batteries: Pb-Acid, Li-ion, NiCd, NaS, Redox Flow (RFBs), Advanced batteries, Operation of a battery cell | **TB1,TB3** |
| 8 | To learn about the operating parameters of the batteries | Theoretical cell voltage, capacity and energy, specific energy and energy density of a battery | **TB1,TB3** |
| 9 | To know the charging and discharging of batteries | Mode of battery charge and discharge, electrical characteristic under different rate of charge-discharge operations, Round-Trip efficiency of battery | **TB3,RB3** |
| 10 | To learn about the operational features of the batteries | Thermal behavior of batteries during charge and discharge, Battery service life, Battery Aging, Operation and maintenance, Battery safety issues, Recycling | **TB1,TB3, RB3** |
| 11 | To familiarize with the Battery Standards | Battery Standards: International Standards, Concept of Standardization, IEC and ANSI nomenclature | **TB1,TB3, RB3** |
| 12 | To know about the performance of Battery storage | Rechargeable battery, Electrical performance, Regulatory and Safety standards. | **TB1,TB3** |
| 13 | To design battery stack | Battery stack design, its engineering aspects | **TB3, RB3** |
| 14 | To design battery Charge Controller | Charge controller design: different charging algorithms | **TB3, RB3** |
| 15 | To know about the stationary and portable applications of battery storage | Off-Grid and On-Grid applications of battery storage, Application oriented choice of batteries | **TB3, RB3** |
| 16 | To know the Power Electronic Components associated with Battery storage interfacing | Power Electronic Converters for interfacing Batteries with power systems, Integration with renewable energy sources | **TB3, RB3** |
| 17 | To design and control the battery performance parameters | Battery Management Systems (BMS) | **TB3, RB3** |
| 18 | To learn battery performance for small, medium and large-scale applications | Battery sizing calculations, Utility Scale Battery Storage System, Batteries for Electric Vehicles | **TB1,TB3, RB3** |
| 19 | To familiar with the techno-commercial aspects of BESS design and its field scale implementation | Techno-commercial aspects of BESS design and applications. | **TB3, RB3** |
| 20 | To know about Fuel cells working principle and different types of fuel cells | Fuel Cells: Principle - working thermodynamics, Comparison on battery Vs fuel cell, Types of fuel cells – AFC, PAFC, SOFC, MCFC, DMFC, PEMFC, microbial fuel cells, relative merits and demerits. | **TB1,TB2** |
| 21 | To know about the hydrogen fuel cells | Hydrogen production for fuel cell feeding, fuel flexibility in fuel cells | **TB1,TB2** |
| 22 | To acquire knowledge about the fuel cell Applications | Polymer electrolyte membrane fuel cell, Portable and stationary application of fuel cells | **TB1,TB2** |
| 23 | To design electrical equivalent model of fuel cells | Electrical analysis of fuel cell with equivalent circuit and small fuel cell power plants | **TB1,TB2** |
| 24 | To integrate fuel cells in power systems | Fuel cell usage for domestic power systems | **TB1,TB2** |
| 25 | To learn about the large-scale power generation | large scale power generation | **TB1,TB2** |
| 26 | To analyze the fuel cells | Automobile, Space, economic and environmental analysis on usage of hydrogen and fuel cell | **TB1,TB2** |
| 27 | To explore the applications of fuel cells | Future trends in fuel cells, portable fuel cells | **TB1,TB2** |
| 28 | To learn about the Hydrogen Energy Storage | Hydrogen energy storage: Electrochemical-Electrolysis, photo electro chemical | **TB1,TB2** |
| 29 | To know about Photo-catalytic process | PM based electrolyser, Photo-electrolysis, Photo-catalytic | **TB1,TB2** |
| 30 | To learn about the Biological processes | Biological-Anaerobic digestion reactions-oxidation and reduction | **TB1,TB2** |
| 31 | To know about the Thermal Processes | Thermal-Steam reformation, thermos-chemical water splitting | **TB1,TB2** |
| 32 | To familiarize with the Hydrogen Storage | Hydrogen storage: Zeolites, metal hydride storage | **TB1,TB2** |
| 33 | To utilize the Hydrogen Storage in Renewables | Hydrogen as a storage medium for renewable energy systems. | **TB1,TB2** |
| 34 | To learn about the Super-capacitors | Super-capacitor storage, working principle | **TB1,TB2** |
| 35 | To plot its electrical characteristics | Electrical characteristics, Charging-discharging, | **TB1,TB2** |
| 36 | To know the practical utilization of Super-Capacitors | Super-capacitor Interfacing, Applications. | **TB1,TB2** |
| 37 | To know the basics of Thermal Storage | Introduction to Thermal Storage, Heat and cold energy storage | **TB1,TB2** |
| 38 | To learn about the different Thermal Storage Techniques | Heat and cold energy storage, Different storage techniques: sensible, latent, thermochemical storage | **TB1,TB2,RB1** |
| 39 | To learn about the Phase Changing Materials (PCM) | Different materials and selection criteria, Phase Change Materials (PCMs) based Thermal Energy Storage | **TB1,TB2** |
| 40 | To enhance the understanding on Thermal Storage | Thermochemical Heat Storage Using Salt Hydrates, Cold Thermal Storage and Energy transport using Ice Slurry, their applications | **TB1,TB2** |
| 41 | To learn about the Compressed Air Energy Storage (CAES) | Compressed Air Energy Storage (CAES), Flywheel Energy storage, Applications | **TB1,TB2, RB1** |
| 42 | To know about the Pumped Hydro Energy Storage (PHES) | Pumped Hydro Energy Storage (PHES), Applications | **TB1,TB2, RB1** |

**Evaluation Scheme:**

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| **Component** | **Duration** | **Weightage (%)** | **Marks** | **Date & Time** | **Nature of Component** |
| Quiz (Best ‘one’ out of ‘two’) | - | 15% | 30 | To be announced | Closed Book |
| Mid-Semester examination | 90 Minutes | 30% | 60 | 15/03 - 11.00 - 12.30PM | Closed Book |
| Group Project | - | 20% | 40 | To be announced | Open Book |
| Comprehensive Examination | 180 Minutes | 35% | 70 | 16/05 AN | Closed Book |

**Chamber Consultation Hour:** To be announced at the beginning of the class

**Notices:** All the official notices related to this course will be uploaded on CMS

**Make-up Policy:** There will be make-up for the Mid-semester examination and Comprehensive examination subject to prior approval taken from the IC. No make-up is allowed for Quiz examination.

**Academic Honesty and Integrity Policy:** Academic honesty and integrity should be maintained by all the students throughout the semester and any type academic dishonesty is not acceptable.



**INSTRUCTOR-IN-CHARGE**