Module Outline

ENERGY STORAGE AND CONTROL DEVICES

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Relevance and Background

In some countries, solar PV systems have progressed from rural and remote off-grid applications to on-grid industrial and urban applications of GW-scale grid-feeding power plants. However, for many countries off-grid applications are still a necessity and for this purpose the two components that are essential are energy storage and the related solar charge controller (or regulator as it is called sometimes). Storage is mostly in the form of batteries because these can be used from a miniscule scale in the residential sector, up to larger requirements.

For several years, the batteries remained the weakest component in the solar power pack because of their shorter life and frequent maintenance. Recently there have been developments in battery technology with newer chemistries being proven more reliable and long lasting. The battery bank design can be done locally for the necessary application if the requirement is clearly understood.

The charge controllers are comparatively smaller in size and have a simple operation principle. Over the years different types of controllers have emerged, which can charge and also protect batteries with appropriate charging protocols.

Theme – Technical
Competency – Electronics
Code of the Module – T02C02M06

Learning Outcomes

By the end of this module, participants will be able to:

- Understand the significance of batteries in solar PV systems.
- Identify the types and characteristics of batteries used in solar PV applications.
- Comprehend the performance metrics and factors affecting battery selection.
- Explain the interconnection methods and considerations for battery integration.
- Explain the functions and importance of charge controllers in solar PV systems.
- Identify and describe different types of charge controllers.
- Understand the selection criteria for charge controllers based on system requirements.

Method of Delivery

Duration	Resource Code	Resource Delivery
60 min.	M06 L01	Lecture on Energy Storage and Control Devices

M06 L01: Lecture Presentation

The lecture will provide a comprehensive overview of batteries in solar PV applications, including the battery types, characteristics, performance metrics, interconnection methods, safety considerations, and their impact on system performance and economics. It will also discuss compliance with safety practices and regulations related to batteries.

The second section covers an overview of charge controllers and their function in regulating the charging of batteries in off-grid and hybrid systems, followed by a discussion of MPPT (Maximum Power Point Tracking), PWM (Pulse Width Modulation) and other technology in charge controllers for optimizing energy production.

The presentation will also describe the selection criteria for charge controllers based on system size, voltage requirements, and application, along with the standards for batteries and charge controllers.

Key Topics to be Covered

1. Storage and Control Devices
2. Energy Storage System - Battery
3. Solar Charge Controllers

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1 Storage and Control Devices

For many countries off-grid solar applications are still a necessity, in which the two components that are essential are energy storage (batteries, most commonly used) and the related solar charge controller (or regulator).

2 Energy Storage System - Battery

Batteries are essential components in solar PV systems, allowing for the storage of excess energy generated by solar panels. The technical description below provides detailed insights into batteries and storage in solar PV systems, focusing on the types of batteries, their characteristics, performance, interconnection methods, combination of different battery technologies, energy grid-level storage methods, and relevant standards and certifications.

2.1 Types of Batteries:

Batteries can be classified into two main categories based on their operational characteristics:

- **Primary Batteries:** Also known as non-rechargeable batteries, these are designed for single-use and cannot be recharged. Once depleted, they must be replaced. Examples include alkaline batteries, lithium primary batteries, and zinc-carbon batteries.
- **Secondary Batteries:** Also known as rechargeable batteries, these can be recharged multiple times and offer a sustainable and cost-effective solution for energy storage. Examples include lead-acid (LA) batteries, lithium-ion (Li-ion) batteries, nickel-cadmium batteries, and nickel-metal hydride batteries.

2.2 Battery Characteristics:

- **Depth of Discharge (DOD):** The depth to which a battery is discharged relative to its total capacity is expressed as a percentage and influences the usable energy of the battery.
- **State of Charge (SOC):** The current level of charge in the battery is expressed as a percentage of its total capacity.
- **Voltage:** This is the electrical potential difference between the positive and negative terminals of the battery, determining the electrical output and compatibility with the system.
- **Storage Capacity:** The amount of energy a battery can store, typically measured in kilowatt-hours (kWh) or ampere-hours (Ah) is its capacity.

2.3 C Rating & Cranking of Automobile Batteries:

The battery models available in the market display their C rating in case of stationary batteries or their Cranking amps in case of automobile batteries. The C rating represents the battery's discharge and charge rates relative to its capacity. In the context of automobile batteries, it is commonly referred to as cranking amps (CA) or cold cranking amps (CCA). These ratings indicate the battery's ability to deliver high currents for engine starting, particularly in cold temperatures.

2.4 Performance Characteristics of Batteries (LA & Li-ion):

- Micro Cycling is the process of frequent shallow cycling of a battery, which may reduce its overall cycle life and capacity over time.
- Cycle Life is the number of charge-discharge cycles a battery can undergo before its capacity significantly degrades, affecting its useful lifespan.
- Memory Effect is a phenomenon where a battery's capacity is reduced due to incomplete discharge and recharge cycles, more common in some older battery chemistries.

Lead Acid batteries are specifically designed for deep cycling applications and have thicker plates compared to automotive batteries.

2.5 Interconnection of Batteries:

Batteries can be interconnected in series or parallel configurations to increase voltage or capacity, respectively. Alternatively, bus bar systems offer a modular and flexible approach to interconnection, enabling efficient connection of multiple batteries.

2.6 Levelized Cost of Stored Energy (Battery):

The levelized cost of stored energy (LCOS) measures the lifetime cost of storing energy in batteries, including the initial investment, operational costs, and lifetime performance. It provides an assessment of the economic viability of energy storage solutions.

2.7 Batteries in Solar PV Applications (Residential to Grid Level):

Batteries find applications in various solar PV systems, ranging from residential installations to Mini grids and grid-connected mega-watt hour (MWh) projects. They enable increased self-consumption, peak shaving, load shifting, and grid stabilization.

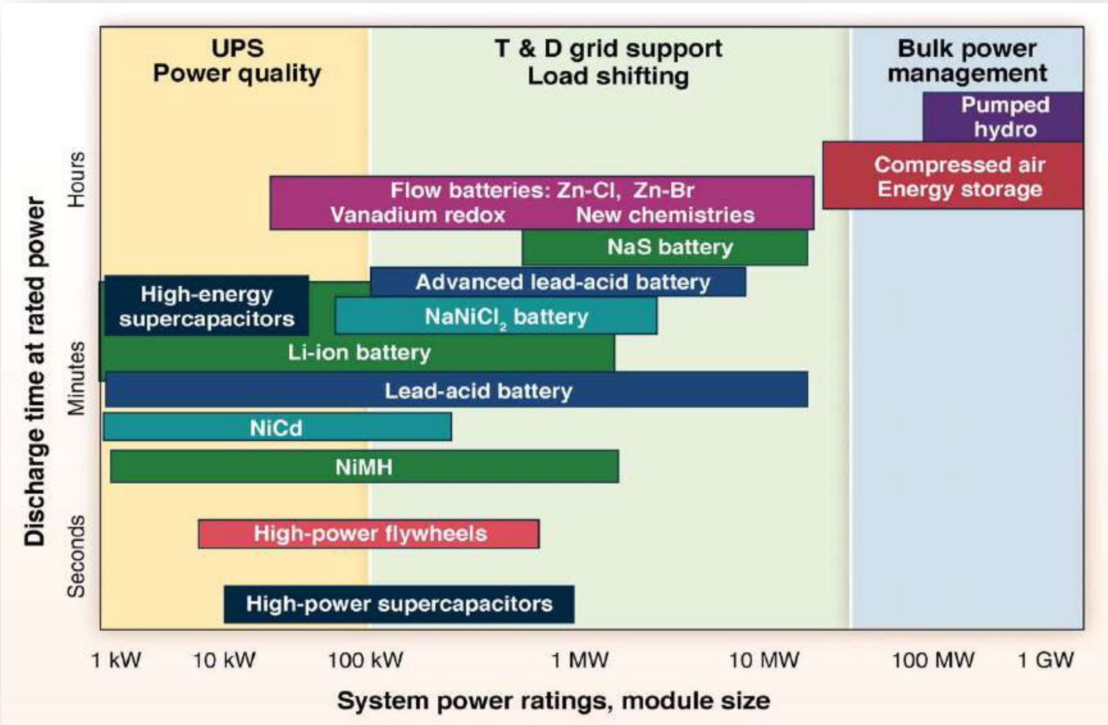
2.8 Some important differences between LA and Li-ion batteries are:

- **Construction:** LA batteries consist of lead plates, an electrolyte solution of sulfuric acid, and separators, while Li-ion batteries consist of electrodes (anode and cathode), an electrolyte, and a separator.
- **Chemical Reaction:** LA batteries involve lead and sulfuric acid reactions, while Li-ion batteries rely on the movement of lithium ions between the electrodes.
- **Storage Capacity:** Li-ion batteries typically offer higher storage capacity and energy density compared to LA batteries.
- **Specific Energy Density:** This is the energy stored per unit mass of the battery, where Li-ion batteries generally exhibit a higher specific energy density compared to LA batteries.
- **Cycle Life:** Li-ion batteries generally have a longer cycle life than LA batteries, enabling more charge-discharge cycles over their lifetime.
- **Effect of Rate Charging and Discharging:** The performance of both LA and Li-ion batteries can be influenced by the rate at which they are charged and discharged.
- **Effect of Temperature:** Extreme temperatures can impact the performance and lifespan of both LA and Li-ion batteries.

2.9 Combining LA and Li-ion Batteries with Solar PV:

Combining different battery technologies in a hybrid energy storage system can offer advantages in terms of energy efficiency, performance, and cost-effectiveness, by leveraging the strengths of each technology.

There are many other methods of storing energy in addition to the batteries, extensively discussed here. Grid-level energy storage methods include pumped hydro storage, compressed air energy storage, flywheel energy storage, flow batteries, and hydrogen-based storage systems. Each method has unique characteristics and suitability for specific applications. In each of these cases the energy generation can be through solar technology and then stored by these different technologies.



2.10 Standards & Certifications:

Standards and certifications, such as UL 1973, UL 9540, IEC 61427, and IEC 62133, ensure the quality, safety, and performance of solar LA and Li-ion batteries. Compliance with these standards is essential for reliable and safe battery operation in solar PV systems.

3 Solar Charge Controllers

Charge controllers play a crucial role in solar systems and regulate the charging process for batteries, ensuring that they are charged efficiently and safely. They prevent overcharging by regulating the charging current and voltage from the power source to the battery bank. Charge controllers also protect batteries from over-discharging and can incorporate various charging algorithms to optimize the charging process and extend battery life.

3.1 Types of Solar Charge Controllers:

Solar charge controllers can be categorized into different types based on their functionality and charging methods. Two common types are single-stage and multistage charging controllers.

- Single-stage charge controllers are relatively simple and provide a fixed charging voltage to the battery. They offer a constant charging current until the battery reaches a specific voltage level, after which they reduce the current to a trickle charge to maintain battery capacity. Single-stage controllers are cost-effective but may not provide the most efficient charging profile.
- Multistage charge controllers employ different charging stages to optimize the charging process and maximize battery life. These stages typically include bulk, absorption, and float charging. In the bulk stage, the controller delivers a higher charging current to rapidly charge the battery. The absorption stage maintains a constant voltage to fully charge the battery, while the float stage provides a lower voltage to maintain the battery's charge level without overcharging.

3.2 Comparison of MPPT and PWM Chargers:

MPPT and PWM are two commonly used charging technologies in solar charge controllers.

- MPPT chargers are designed to extract maximum power from solar panels by continuously tracking the panel's maximum power point. This is achieved by dynamically adjusting the operating voltage of the solar panel to match the battery's optimal charging voltage. MPPT chargers are more efficient in converting solar energy to usable power, especially in situations where the panel's voltage does not match the battery voltage.
- PWM chargers regulate the charging voltage by periodically interrupting the current flow from the solar panel to the battery. They maintain a constant charging voltage, which may not be the most efficient when the panel voltage is significantly higher than the battery voltage. PWM chargers are generally less expensive than MPPT chargers but may result in slightly lower charging efficiency.

Reading Material

1. *Handbook for Rooftop Solar Development in Asia by Asian Development Bank* (https://www.adb.org/sites/default/files/publication/153201/rooftop-solar-development-handbook.pdf)
2. *Best Practices for Operation and Maintenance of Photovoltaic and Energy Storage Systems; 3rd Edition by National Renewable Energy Laboratory* *(https://www.nrel.gov/docs/fy18osti/68469.pdf)*