

ENERGY STORAGE SYSTEMS

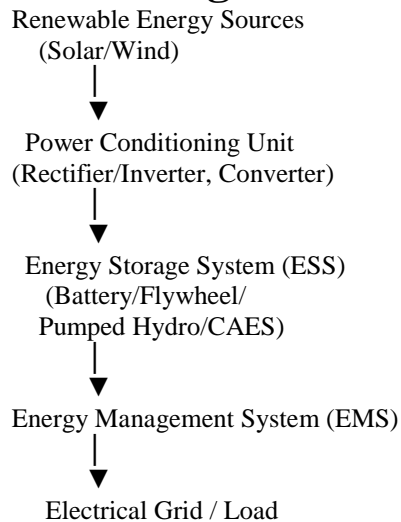
Definition

Energy Storage System (ESS) is a technology that stores electrical energy in another form (chemical, mechanical, thermal, or electrical) and releases it when required. ESS improves the **reliability, stability, efficiency, and flexibility** of modern power systems, especially those integrating renewable energy sources.

Need for Energy Storage in Power Systems

- Balances generation and load demand.
- Integrates intermittent renewable energy sources.
- Improves power quality.
- Provides backup power during outages.
- Enhances frequency and voltage stability.
- Reduces peak demand and transmission congestion.
- Increases overall grid efficiency.

Block Diagram of Energy Storage System



Types of Energy Storage Systems

1. Battery Energy Storage System (BESS)

- Stores energy chemically.
- Most common battery: Lithium-ion.

Advantages

- Fast response time
- High efficiency (90–95%)
- Modular design
- Low maintenance

Applications

- Renewable integration
- Microgrids
- Electric vehicles
- Peak load management

2. Pumped Hydro Storage (PHS)

Working Principle

- Water is pumped from a lower reservoir to an upper reservoir during off-peak hours.
- During peak demand, water flows through turbines to generate electricity.

Advantages

- Very large storage capacity
- Long service life
- Low operating cost

Disadvantages

- High initial investment
- Requires suitable geographical location

3. Compressed Air Energy Storage (CAES)

Working

- Electricity compresses air and stores it in underground caverns.
- During demand, compressed air drives a turbine to produce electricity.

Advantages

- Large capacity
- Suitable for long-duration storage

Disadvantages

- Lower efficiency
- Site dependent

4. Flywheel Energy Storage

Working

Stores energy as rotational kinetic energy in a rapidly spinning rotor.

Advantages

- Very fast response
- Long cycle life
- High reliability

Applications

- Frequency regulation
- UPS systems
- Power quality improvement

5. Thermal Energy Storage

Stores energy in the form of heat or cold.

Applications

- Solar thermal plants
- District heating
- Industrial processes

6. Hydrogen Energy Storage

Working

- Excess electricity performs electrolysis of water.
- Hydrogen is stored.
- Fuel cells convert hydrogen back into electricity.

Advantages

- Long-term storage
- Zero carbon emissions during electricity generation

Applications in Power System Analysis

- Renewable energy integration
- Load leveling
- Peak shaving
- Frequency regulation
- Voltage support
- Spinning reserve
- Black start capability
- Microgrid operation
- Power quality improvement
- Transmission congestion management

Advantages

- Improves grid reliability
- Enhances power quality
- Reduces operating costs
- Supports renewable energy
- Reduces greenhouse gas emissions
- Increases system flexibility
- Provides uninterrupted power supply
- Defers transmission and distribution upgrades

Limitations

- High initial investment
- Battery degradation with age
- Environmental concerns for battery disposal
- Site constraints for pumped hydro and CAES
- Complex control and energy management systems