Lecture 3.28

Pump Storage and Micro Hydel Power Plants

Agenda

- Introduction to Pumped Storage Hydroelectric Power Plant
- Operating Principles (Generating and Pumping Modes)
- Key Components of Pumped Storage Systems
- Advantages and Limitations of Pumped Storage
- Introduction to Micro Hydel Power Plant
- Classification and Components of Micro Hydel Systems
- Applications and Benefits of Micro Hydel Plants

Introduction to Pumped Storage Hydroelectric Plants

- Pumped-storage hydroelectricity (PSH) is a type of hydroelectric energy storage used by electric power systems for load balancing.
- The method stores energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation.
- PSH acts essentially as a giant, grid-scale rechargeable battery.
- It provides spinning reserve, frequency regulation, and voltage control to the grid.
- Particularly vital for integrating intermittent renewable energy sources like wind and solar.

Principle of Operation: Dual Reservoirs

- The system relies on two water reservoirs situated at significantly different elevations.
- Upper Reservoir: Stores water during periods of low electrical demand (off-peak).
- Lower Reservoir: Collects water discharged from the upper reservoir during power generation.
- Reversible Pump-Turbine: A single machine acts as both a turbine (to generate power) and a pump (to push water up).
- Motor-Generator: The electrical machine operates as a generator when driven by the turbine, and as a motor when driving the pump.

Operating Modes: Generating vs. Pumping

- Generating Mode (Peak Hours):
- - High grid demand drives up electricity prices.
- - Water is released from the upper reservoir through the penstock.
- - The flow drives the turbine, which spins the generator to produce electricity.
- Pumping Mode (Off-Peak Hours):
- - Low grid demand and excess base-load/renewable power (lower electricity prices).
- - The generator acts as a motor, drawing power from the grid.
- - It drives the turbine in reverse, pumping water from the lower reservoir back to the upper reservoir.

Components of Pumped Storage Plant

- Upper and Lower Reservoirs: Must have sufficient storage volume to sustain generation for several hours.
- Penstock and Surge Tank: High-pressure conduits for bidirectional water flow; surge tanks mitigate water hammer during mode switching.
- Reversible Francis Pump-Turbine: The most common hydraulic machine used due to its efficiency in both directions.
- Synchronous Motor-Generator: Capable of smooth switching between motoring and generating modes.
- Phase Reversal Switchgear: Electrical equipment that reverses the phase sequence to change the direction of rotation for pumping.

Diagram: Pumped Storage Configuration

- Upper Reservoir (High Potential Energy)
- Intake Structure and Trash Racks
- Underground Penstock
- Underground Powerhouse (Pump-Turbine & Motor-Generator)
- Draft Tube / Suction Pipe
- Lower Reservoir (Tailrace)

Advantages and Challenges of Pumped Storage

- Advantages:
- - High efficiency (typically 70-80% round-trip efficiency).
- - Massive storage capacity compared to battery storage technologies.
- - Fast response time (can synchronize and generate within minutes).
- - Long lifespan (50+ years for civil structures).
- Challenges:
- - Highly site-specific (requires suitable topography and geology).
- - High initial capital cost and long construction times.
- - Environmental impact related to flooding and reservoir creation.

Introduction to Micro Hydel Power Plant

- Micro-hydel (or micro-hydro) power plants are small-scale hydroelectric systems designed for decentralized power generation.
- Typically defined as having an installed capacity up to 100 kW.
- Often operate as 'run-of-river' systems, requiring no massive dams or large reservoirs.
- Can provide reliable, clean electricity to remote, off-grid communities or isolated facilities.
- Utilize natural water flow in streams or small rivers with a suitable drop in elevation (head).

Classification and System Requirements

- Classification by Capacity:
- - Pico-hydro: Under 5 kW
- - Micro-hydro: 5 kW to 100 kW
- - Mini-hydro: 100 kW to 1 MW
- Hydrological Requirements:
- - Head (H): The vertical drop; determines the potential energy (Low head: ¡10m, High head: ¿50m).
- - Flow Rate (Q): The volume of water passing per second (m\ensuremath{ˆ3}/s).
- - Power Output Equation: P = \ensuremath{\eta} * \ensuremath{\rho} * g * Q * H
- - Continuous availability of water is critical for run-of-river operations.

Components of a Micro Hydel Plant

- Diversion Weir: Diverts a portion of the stream flow without blocking the entire river.
- Intake and Desilting Tank: Removes sediment to prevent turbine abrasion.
- Headrace Channel and Forebay: Conveys water to a stabilizing tank (forebay) before the penstock.
- Penstock: Pipe that carries water under pressure to the turbine.
- Turbine: Small-scale Pelton (high head), Cross-flow (medium head), or Kaplan/Propeller (low head).
- Generator & Electronic Load Controller (ELC): Maintains constant frequency by dumping excess power to a ballast load.

Applications and Benefits of Micro Hydel

- Applications:
- - Rural electrification in mountainous or hilly regions.
- - Powering isolated agricultural processing units (e.g., milling).
- - Supplying eco-tourism resorts and remote monitoring stations.
- Benefits:
- - Negligible environmental impact (no large flooding).
- - High reliability and predictable generation compared to wind/solar.
- - Low running and maintenance costs.
- - Empowers local communities through decentralized energy independence.

Summary

- Pumped Storage Hydroelectric Power Plants function as large-scale energy storage, pumping water during off-peak and generating during peak demand.
- They utilize a single reversible pump-turbine and motor-generator unit for high round-trip efficiency.
- Micro Hydel Power Plants (up to 100 kW) provide decentralized, run-of-river power generation.
- They rely on minimal civil structures, using natural stream head and flow to drive small turbines.
- Both systems serve critical but entirely different roles: Grid stabilization vs. Remote electrification.

Next Lecture Preview

- Unit 3 Wrap-up and Assessment
- Performance Evaluation of Hydroelectric Power Plants
- Introduction to Unit 4: Nuclear Power Plant
- Basic Principles of Nuclear Energy and Fission Reactions
- Key Components of a Nuclear Reactor