# Lecture 3.26

Fundamentals of Hydropower and Classification

# Agenda

- 1. Fundamentals of Hydropower Generation
- 2. The Hydrological Cycle and Energy Conversion
- 3. Classification by Available Head
- 4. Classification by Capacity
- 5. Classification by Facility Type (Run-of-River, Storage, Pumped)
- 6. Various Purposes of Hydroelectric Plants
- 7. Summary and Preview

# Fundamentals of Hydropower: Basic Physics

- Hydropower converts the potential energy of water into mechanical energy, and then into electrical energy.
- Potential Energy (PE) = m * g * h, where m is mass of water, g is gravitational acceleration, and h is the effective head.
- Hydraulic Power (P) = \ensuremath{\rho} * Q * g * h * \ensuremath{\eta}, where \ensuremath{\rho} is water density (1000 kg/m\ensuremath{^3}), Q is volumetric flow rate (m\ensuremath{^3}/s), h is net head (m), and \ensuremath{\eta} is overall efficiency.
- Net Head is the gross head minus the hydraulic losses (friction in penstock, turbulence).

# The Hydrological Cycle and Hydropower

- Hydropower is ultimately a form of solar energy, driven by the hydrological cycle.
- Solar radiation evaporates water, which precipitates over higher elevations, creating potential energy.
- Catchment area dictates the total water volume available, while topography dictates the available head.
- Firm Power: Power continuously available regardless of seasonal flow variations.
- Secondary Power: Power generated above the firm power level during high flow periods.

# Classification of Hydroelectric Power Plants

- Hydroelectric plants can be classified based on several distinct criteria:
- 1. Available Head (Low, Medium, High)
- 2. Plant Capacity (Micro, Mini, Small, Large)
- 3. Facility Type / Hydraulic Characteristics (Run-of-river, Storage, Pumped-storage)
- 4. Load Characteristics (Base load, Peak load)
- The selection of turbine type (Pelton, Francis, Kaplan) heavily depends on this classification, specifically the available head and flow.

# Classification by Available Head

- High Head Plants: Head ¿ 100 meters. Often utilize Pelton wheels (impulse turbines). Require small flow rate for given power. Usually situated in mountainous regions.
- Medium Head Plants: Head between 30 and 100 meters. Typically utilize Francis turbines (reaction turbines). Forebay is often used.
- Low Head Plants: Head ¡ 30 meters. Utilize Kaplan or Propeller turbines (reaction turbines with adjustable blades). Require very large flow rates to generate significant power. Often built across wide rivers.

# Classification by Capacity

- Micro-hydro: Up to 100 kW. Provides power to a small community or rural industry. Usually run-of-river.
- Mini-hydro: 100 kW to 1 MW. Can power larger facilities or feed into a local grid.
- Small-hydro: 1 MW to 10 MW (definitions vary by country, up to 25 MW in India). Minimal environmental impact.
- Large-hydro: ¿ 10 MW (or ¿ 25 MW). Involves major civil structures, large dams, and significant environmental and social considerations.

# Classification by Facility Type: Run-of-River

- Run-of-River (RoR) plants have little or no water storage (pondage).
- Subject to seasonal river flows; power generation fluctuates with rainfall and snowmelt.
- Often serve as base load plants during high flow seasons.
- Lower environmental impact compared to large storage dams since the natural flow of the river is mostly maintained.
- May include a small weir to direct flow into a penstock, but no massive reservoir.

# Classification by Facility Type: Storage Plants

- Storage hydropower uses a large dam to store water in a reservoir.
- Decouples power generation from the immediate natural inflow of water.
- Can store water during wet seasons for use during dry seasons (seasonal or multi-year storage).
- Provides firm capacity and can rapidly adjust output to meet peak grid demands.
- Significant environmental footprint: valley flooding, displacement of communities, altered downstream ecology.

# Classification by Facility Type: Pumped-Storage

- Pumped-storage involves two reservoirs at different elevations.
- During off-peak hours (low electricity demand/price), excess grid power is used to pump water from the lower to the upper reservoir.
- During peak hours, water is released back down through turbines to generate electricity.
- Net consumer of energy (due to pump/turbine inefficiencies, \ensuremath{\eta} \ensuremath{\approx} 70-80%), but highly valuable for grid balancing and frequency regulation.
- Crucial for integrating intermittent renewable sources like solar and wind.

# Various Purposes of Hydroelectric Plants

- Hydroelectric plants, particularly storage types, are rarely built solely for power generation. They are often Multi-Purpose Projects.
- Primary Purposes:
- - Base Load Generation: Continuous power supply (RoR or large storage).
- - Peak Load Generation: Rapid ramping to meet high daily demand peaks.
- - Grid Ancillary Services: Frequency regulation, voltage control, and black-start capability.

# Secondary Non-Power Purposes

- Large reservoirs serve critical non-power functions, often subsidizing the cost of the dam:
- - Irrigation: Storing monsoon water for year-round agricultural use.
- - Flood Control: Buffering extreme rainfall events to protect downstream settlements.
- - Municipal Water Supply: Providing reliable drinking water to nearby cities.
- - Navigation: Regulating river depth to allow barge transport year-round.
- - Recreation and Fisheries: Creating new economic opportunities around the reservoir.

# Summary

- Hydropower converts potential energy to electrical energy (P = \ensuremath{\rho}*Q*g*h*\ensuremath{\eta}).
- Classification is vital: Head (Low, Med, High) dictates turbine choice, while Capacity dictates grid role.
- Facility types include Run-of-River (flow dependent), Storage (dispatchable), and Pumped-Storage (energy storage).
- Hydroelectric projects are largely multi-purpose, balancing grid demands with irrigation, flood control, and water supply needs.

# Next Lecture Preview

- Topic 3.2: Hydrology and Site Selection
- Understanding hydrographs and flow duration curves.
- Mass curve analysis for determining reservoir capacity.
- Geological, topographical, and environmental criteria for selecting a dam site.