Lecture 3.27

Configuration of Hydroelectric Power Plants: General Layout and Working

Agenda

- Introduction to Hydroelectric Plant Configuration
- General Layout: The Hydraulic Circuit
- Key Components: Dam and Reservoir
- Water Conveyance: Penstocks and Surge Tanks
- Safety and Control: Spillways and Gates
- The Powerhouse Structure
- Energy Conversion Process
- Working Principle Walkthrough

Overview of Hydroelectric Plant Configuration

- A hydroelectric power plant requires a specific configuration of civil, mechanical, and electrical structures.
- The primary goal is to safely store water, convey it to the turbine under pressure, extract kinetic and pressure energy, and discharge it back.
- The layout is highly site-specific, depending on head (high, medium, low) and flow rate.
- Essential subsystems: Water Storage & Diversion, Conveyance System, Generation Unit, and Discharge System.

The General Layout: Hydraulic Circuit

- The hydraulic circuit traces the path of water from the catchment to the downstream river.
- Sequence: Catchment Area -¿ Reservoir -¿ Trash Rack -¿ Intake Gate -¿ Penstock -¿ (Surge Tank) -¿ Turbine / Scroll Casing -¿ Draft Tube -¿ Tailrace.
- The total gross head (H_g) is the difference between reservoir water level and tailrace water level.
- Net head (H_n) available at the turbine is $H_g - h_f$ (head loss in penstock).

Key Components: Dam and Reservoir

- **Reservoir:** The artificial lake created by the dam. Stores water during high runoff for use during low flow. Provides the necessary potential energy (head).
- **Dam:** A massive barrier constructed across a river. Types include gravity, arch, earth-fill, and rock-fill dams.
- The dam withstands immense hydrostatic pressure forces ($F = \rho g H_c A$).
- Storage capacity is categorized into 'live storage' (usable for power) and 'dead storage' (below intake level, accumulates silt).

Water Intake Structures and Trash Racks

- **Intake Structure:** The entry point for water into the conveyance system. Located well below the minimum drawdown level to prevent vortex formation and air entrainment.
- **Trash Rack:** A screen of parallel metal bars placed at the intake.
- Prevents floating debris, logs, and ice from entering the penstock.
- Debris in the turbine can cause catastrophic mechanical failure to the runner blades.
- Design considerations: Velocity through racks is kept low (0.6 to 1.5 m/s) to minimize head loss.

Water Conveyance: Penstocks

- **Penstock:** A large-diameter conduit that carries water under high pressure from the reservoir to the turbine.
- Materials: Usually steel, reinforced concrete, or fiberglass depending on the head.
- Designed to withstand static pressure and severe dynamic pressure surges (water hammer).
- Head loss in penstock ($h_f = \frac{fLV^2}{2gD}$) must be minimized for maximum efficiency.
- Anchor blocks are required at bends to resist enormous hydraulic thrust forces.

Protection Against Water Hammer: Surge Tanks

- **Water Hammer:** A severe pressure wave caused by the sudden closure of turbine wicket gates during load rejection.
- **Surge Tank:** An open cylindrical tank connected to the penstock as close to the powerhouse as possible.
- Absorbs the sudden rise in pressure by allowing water to surge upwards into the tank.
- Provides extra water during sudden load increases before the water in the long penstock can accelerate.
- Types: Simple, restricted orifice, and differential surge tanks.

Flow Control and Safety: Spillways

- **Spillway:** A safety structure designed to safely discharge floodwaters over or around the dam.
- Prevents water from overtopping and eroding the dam, which could lead to failure.
- Acts as the 'safety valve' of the reservoir.
- Spillway design capacity is based on Probable Maximum Flood (PMF) calculations.
- Includes energy dissipators (like hydraulic jump basins or ski-jump buckets) at the bottom to prevent scouring of the river bed.

The Powerhouse Structure

- The powerhouse contains the electro-mechanical equipment: turbines, generators, governors, and control systems.
- **Substructure:** Heavily reinforced concrete containing the spiral casing and draft tube.
- **Superstructure:** Houses the generator, exciter, overhead cranes, and control room.
- Typically features a vertical shaft arrangement for large units to save floor space.
- Transformers are usually located in an adjacent switchyard to step up voltage for transmission.

Discharge System: Draft Tube and Tailrace

- **Draft Tube:** A gradually expanding pipe that connects the turbine exit to the tailrace (specifically for reaction turbines).
- Function 1: Allows the turbine to be set above the tailwater level without losing head.
- Function 2: Recovers kinetic energy from the exiting water by converting velocity head into pressure head.
- **Tailrace:** The channel that carries the discharged water back into the natural river course.
- Tailwater level fluctuates with river flow and affects the net head available.

Working Principle: Energy Conversion

- Hydroelectric power generation relies on successive energy transformations.
- **Potential Energy:** Water stored at height in the reservoir ($E_p = mgh$).
- **Kinetic Energy:** As water flows down the penstock, potential energy converts to kinetic energy ($E_k = \frac{1}{2}mv^2$) and pressure energy.
- **Mechanical Energy:** The high-velocity/high-pressure water strikes the turbine blades, causing the runner to rotate.
- **Electrical Energy:** The rotating turbine shaft spins the rotor of the synchronous generator, inducing alternating current via electromagnetic induction.

Summary

- The general layout consists of storage (reservoir/dam), conveyance (intake, penstock), generation (powerhouse), and discharge (tailrace).
- Surge tanks protect penstocks from water hammer during rapid load changes.
- Spillways are critical safety structures for flood management.
- The entire system is designed to maximize net head and safely handle massive hydraulic forces.
- Energy conversion flows seamlessly from potential to kinetic to mechanical, and finally to electrical energy.

Next Lecture Preview

- Topic: Classification of Hydroelectric Power Plants
- We will categorize plants based on head (low, medium, high).
- Classification based on plant capacity and load type (base load vs. peak load).
- Introduction to Pumped Storage Plants and their role in grid stabilization.