Lecture 1.1

Indian Energy Scenario

Agenda

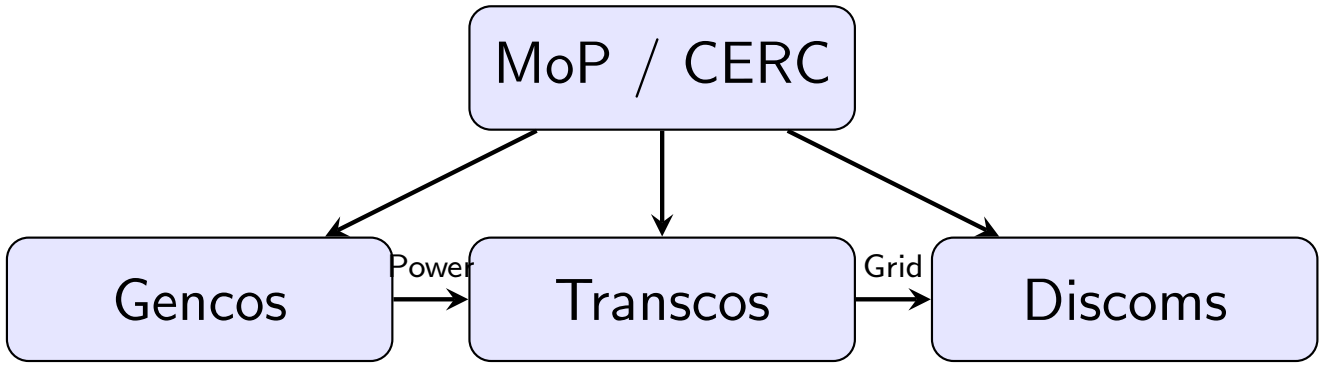
Topics to Cover

- Overview of India's Power Sector Structure
- Installed Generation Capacity and Energy Mix
- Thermal Power Dominance and Coal Dependency
- Renewable Energy Expansion and Integration
- Transmission Infrastructure and Sector Challenges
- Government Initiatives and Future Outlook

Overview of the Indian Power Sector

Key Points

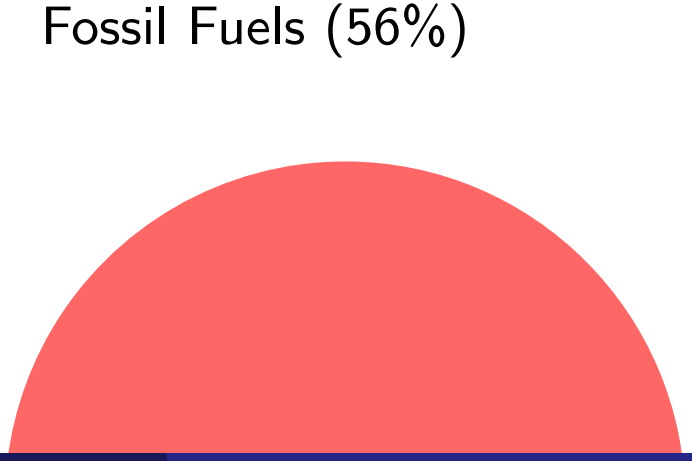
- India is the third-largest producer and consumer of electricity globally.
- Electricity is a concurrent subject under the Indian Constitution, implying shared jurisdiction between Central and State governments.
- The sector is functionally unbundled into Generation (Gencos), Transmission (Transcos), and Distribution (Discoms).
- Grid stability and dispatch are managed by the Power System Operation Corporation (POSOCO) via National and Regional Load Despatch Centres (NLDC/RLDCs).



Installed Generation Capacity Mix

Capacity Overview

- Total installed capacity exceeds 400 GW.
- Fossil Fuels ($\sim$56%): Dominated by coal-fired thermal plants.
- Renewable Energy ($\sim$30%): Rapidly growing solar and wind capacity.
- Hydroelectric ($\sim$11%): Provides essential peaking capabilities.
- Nuclear ($\sim$2%): Small but strategic base-load contributor.
- Private sector participation now accounts for nearly 50% of total installed capacity.



Thermal Power Dominance

Coal Characteristics & Challenges

- Base load generation is overwhelmingly supplied by coal-fired subcritical and supercritical thermal power plants.
- Domestic Indian coal has extremely high ash content (35-45%) and low calorific value, requiring specialized boiler and ash-handling designs.
- Challenges include declining Plant Load Factor (PLF) for older units due to merit order dispatch favoring cheaper renewables.
- Stricter environmental emission norms for SOx, NOx, and Particulate Matter mandate the retrofitting of Flue Gas Desulfurization (FGD) systems.

Renewable Energy Expansion Targets

Growth & Integration

- India has set aggressive targets: 500 GW of non-fossil fuel capacity by 2030 (Panchamrit declaration).
- Solar PV (utility-scale parks and decentralized rooftop) leads the capacity additions due to steep drops in Levelized Cost of Energy (LCOE).
- Wind energy is concentrated in southern and western states, offering generation profiles that often complement solar output.
- Major technical challenge: Integrating intermittent renewables requires increasing grid flexibility and grid-forming inverters.

Hydro and Nuclear Contributions

Role in Grid Stability

- Large Hydroelectric projects provide crucial ramping capabilities, peaking power, and black start facilities during grid collapses.
- Renewed focus on Pumped Storage Hydro (PSH) for large-scale, long-duration energy storage to balance solar intermittency.
- Nuclear capacity relies on indigenous Pressurized Heavy Water Reactors (PHWRs) and the strategic Three-Stage Nuclear Power Programme.
- Nuclear provides reliable, zero-carbon base-load power, though capital costs and gestation periods remain high.

Transmission Infrastructure: The National Grid

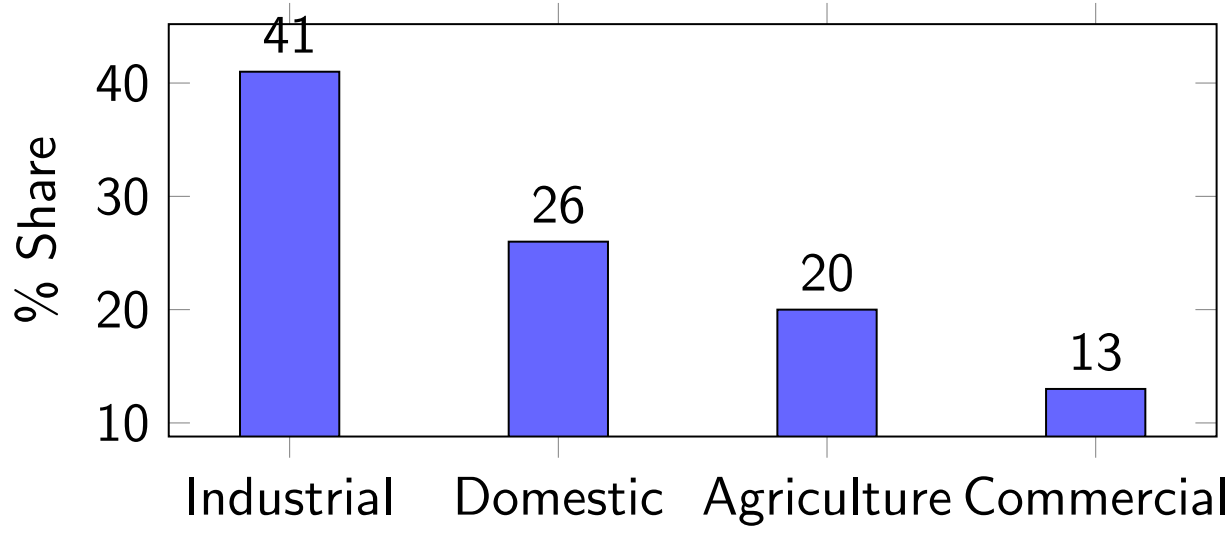
One Nation, One Grid

- The 'One Nation, One Grid, One Frequency' initiative successfully synchronized all regional grids.
- Extensive deployment of High Voltage Direct Current (HVDC) and 765 kV Ultra High Voltage AC (UHVAC) corridors.
- These corridors minimize transmission losses when wheeling power from generation-rich regions (e.g., Eastern coalfields) to load centers.
- Implementation of Wide Area Measurement Systems (WAMS) and Phasor Measurement Units (PMUs) for real-time dynamic stability monitoring.

Energy Consumption Patterns

Sector-wise Consumption

- Industrial Sector: Largest consumer, requires high reliability, heavily cross-subsidizes other sectors.
- Agricultural Sector: High seasonal demand (irrigation pumps), characterized by highly subsidized or free power, causing financial strain.
- Domestic Sector: Rapidly rising demand driven by rural electrification schemes (Saubhagya) and increased appliance penetration.
- Commercial Sector: High tariff paying, driving demand for rooftop solar and open access.



Key Sector Challenges: AT&C Losses

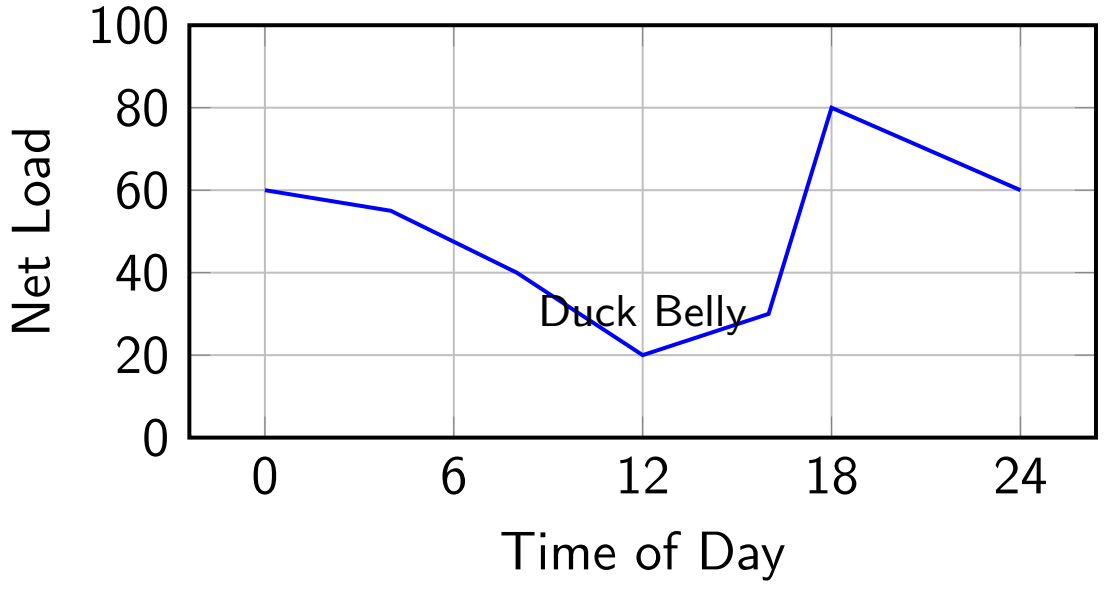
Financial Bottlenecks

- Aggregate Technical and Commercial (AT&C) losses represent the gap between energy supplied and revenue realized.
- Technical losses stem from inadequate distribution infrastructure and overloaded transformers.
- Commercial losses are driven by power theft, unmetered agricultural supply, and inefficient billing/collection cycles.
- High AT&C losses severely impact the financial viability of state-owned DISCOMs, creating a bottleneck for upstream payments to Gencos.

Fuel Supply and Grid Integration Challenges

Operational Risks

- Fuel Supply Risks: Periodic domestic coal shortages force reliance on expensive imported coal, exposing the sector to global price volatility.
- Renewable Integration: The 'Duck Curve' phenomenon where high daytime solar generation forces thermal plants to ramp down rapidly, followed by steep ramping requirements during the evening peak.
- Grid Inertia: Displacement of synchronous thermal generators by inverter-based renewables reduces overall system inertia, increasing vulnerability to frequency deviations.



Government Initiatives & Policy Framework

Key Policies

- Revamped Distribution Sector Scheme (RDSS): Capital outlay for infrastructure upgradation and mandatory transition to prepaid smart metering.
- Green Energy Corridors: Dedicated transmission infrastructure for evacuating power from large renewable energy parks.
- Electricity (Amendment) Rules: Promoting competition, enabling open access for green energy, and strictly enforcing Renewable Purchase Obligations (RPOs).
- Production Linked Incentive (PLI) schemes for domestic manufacturing of high-efficiency solar PV modules and advanced chemistry cells (batteries).

Future Outlook and Grid Modernization

The Path Ahead

- Decarbonization trajectory aligned with India's Net Zero by 2070 commitment.
- Transition towards intelligent, bi-directional smart grids capable of handling distributed energy resources (DERs).
- Emergence of Green Hydrogen as a storage medium and a pathway to decarbonize heavy industries and transportation.
- Integration of Electric Vehicles (EVs) not just as load, but as dynamic grid assets using Vehicle-to-Grid (V2G) capabilities.

Summary

Key Takeaways

- India's energy landscape is fundamentally transitioning from high-ash domestic coal dominance to a diverse, renewable-heavy portfolio.
- The national grid is unified and highly robust, but distribution sector financial health remains a critical vulnerability.
- Technical challenges have shifted from simply adding capacity to managing grid flexibility, integrating intermittency, and modernizing legacy assets.
- Policy frameworks are aggressively pushing smart metering, domestic manufacturing, and green energy evacuation infrastructure.

Next Lecture Preview

Topic: Load Curves and Load Factors

- Understanding how and why consumer electrical demand fluctuates over a 24-hour cycle.
- Analyzing Chronological Load Curves, Load Duration Curves, and Mass Curves.
- Calculating crucial metrics: Base Load, Peak Load, Average Load, and Plant Use Factor.
- Determining generation capacity requirements based on load profiling.