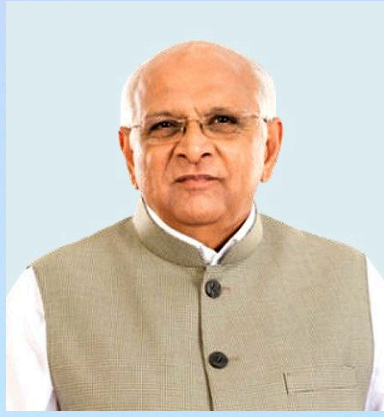
सत्यमेव जयते

Government of Gujarat



AI CONTENT FOR

Energy Efficiency & Audit

Diploma Engineering- Electrical

Subject Code: DI04009021

Semester: 4

Directorate of Technical Education

Gujarat

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◆ UNIT–1: ENERGY MANAGEMENT & AUDIT

Subject: Energy Efficiency & Audit
Branch: Diploma Electrical Engineering
Semester: 4 (GTU)

● PHASE 1: UNIT-1: UNIT–WISE STUDY PLAN

Topic No.	Topic Name	Nature	Hours	Exam Importance	Practical Relevance
1.1	India's Energy Demand & Per Capita Consumption (2024)	Core	1	Medium	High
1.2	Basic Energy Terminology & PAT Scheme	Core	1	High	Medium
1.3	First & Second Law of Thermodynamics	Core	1	High	Medium
1.4	BEE Schemes, Energy Intensive Industries & NMEEE	Supporting	0.5	Medium	Medium
1.5	Energy Audit: Types, Phases & ENCON Measures	Core	1.5	Very High	Very High
1.6	Energy Performance Indicators	Supporting	0.5	Medium	High
1.7	Electrical Measuring Instruments	Application	1	High	Very High
1.8	Sankey Diagram of 3-Phase Induction Motor	Core	0.5	High	Medium
1.9	Financial Analysis & Payback Period Case Study	Core	1	Very High	Very High

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⬤ PHASE 2: DETAILED LECTURE NOTES

Lecture 1 - Topic 1.1: India's Energy Demand & Per Cap Capita Consumption (2024)

(Unit–1: Energy Management & Audit / 60-minute session)

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1. Hook / Introduction (≈ 5 minutes)

Let me start with a simple question: **How many electrical appliances did you use today before coming to college?**
Fan, mobile charger, lights, maybe a water pump at home, or even an electric vehicle passing by on the road. All these consume **energy**, and when millions of people do the same every day, the total demand becomes enormous.

India is a fast-developing country. As our **population grows, cities expand, industries increase, and lifestyles improve**, our need for electrical energy increases rapidly. Understanding **India's energy demand and per capita consumption** is the **first step for an electrical engineer** who wants to design efficient systems and reduce wastage.

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2. Core Concepts (≈ 40 minutes)

What is Energy Demand?

Energy demand means the **total amount of energy required by a country** to run homes, industries, agriculture, transport, and services over a period of time.

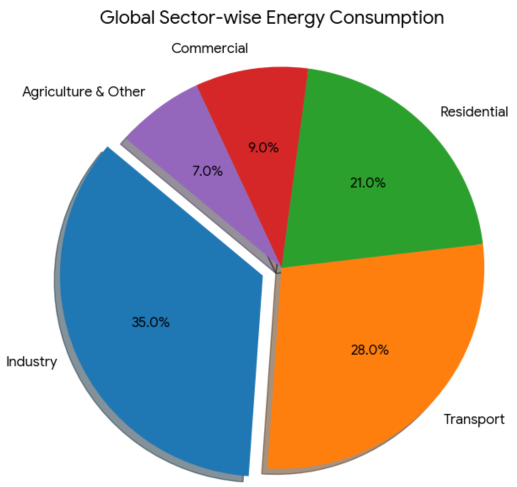

Fig. 1.1 - Sector-wise energy consumption (Industry – largest share).

In India, energy demand comes mainly from:

- **Industry** (motors, furnaces, compressors)
- **Residential sector** (fans, ACs, refrigerators)
- **Agriculture** (pumps)
- **Commercial sector** (shops, offices)
- **Transport** (railways, EVs)

India's Energy Demand Scenario (2024)

- India is among the **top 3 energy-consuming countries** in the world.
- Electricity demand is increasing due to:
    - Urbanization
    - Industrial growth
    - Air conditioners and cooling load
    - Electric vehicles
    - Digital infrastructure (data centers)

However, increasing generation alone is **not enough**. This is why **energy efficiency and audit** are critical.

What is Per Capita Energy Consumption?

Per capita energy consumption means:

Average energy consumed by one person in a year.

$$\text{Per Capita Consumption} = \frac{\text{Total Energy Consumption}}{\text{Population}}$$

📌 *Important Concept:*

- India's per capita energy consumption is **much lower than developed countries**.
- This does **not mean waste**—it means **huge future growth is expected**.

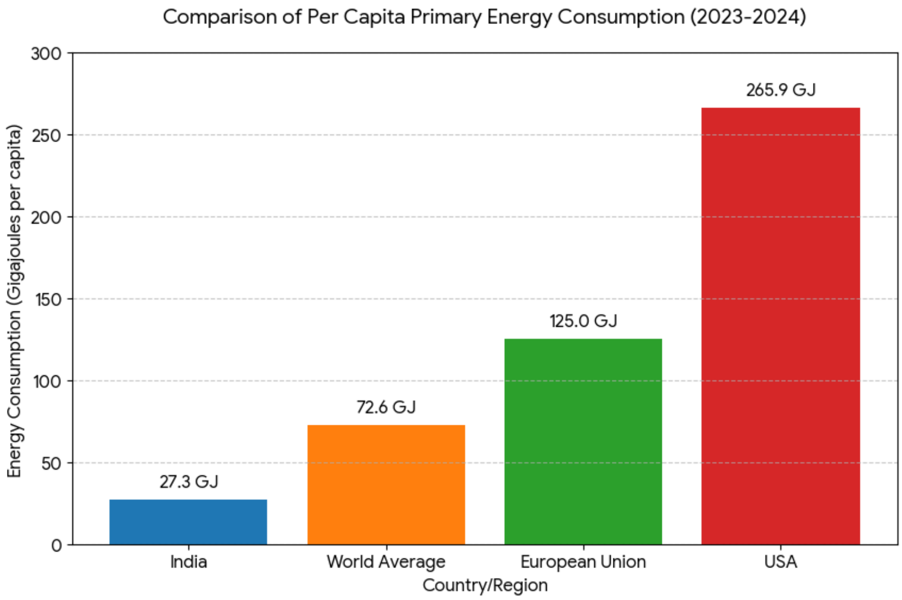

Fig. 1.2 - Comparing per capita energy consumption of: India, World average, Developed countries (USA, Europe)

Why is India's Per Capita Consumption Low?

- Large population
- Energy access inequality
- Rural areas with limited usage
- Cost sensitivity

As more people buy appliances and industries expand, **demand will rise sharply**.

Key Challenge

If demand increases **without efficiency**, it leads to:

- Power shortages
- Higher electricity bills
- Environmental pollution
- Stress on power plants and grid

That is why **energy management and energy audit** are required.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Utilities** use demand data to plan generation and transmission.

- **Industries** analyze demand to reduce peak load and electricity cost.
- **Energy auditors** study per capita consumption trends to design **DSM (Demand Side Management)** programs.
- **Government policies** like star labeling and PAT scheme are based on energy demand patterns.
- Engineers use this data to decide:
    - Transformer sizing
    - Substation planning
    - Renewable energy integration

📌 *Practical Example:*
If per capita consumption increases, **distribution transformers must be energy-efficient** to avoid losses.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Energy demand is continuously increasing in India.
- Per capita energy consumption indicates development level.
- India's low per capita consumption means **future demand growth is inevitable**.
- Energy efficiency is more important than only increasing generation.
- Electrical engineers play a key role in managing this demand.

Lecture 2 - Topic 1.2: Basic Energy Terminology & PAT Scheme

(Unit–1: Energy Management & Audit | 60-minute session)

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1. Hook / Introduction (≈ 5 minutes)

Let us begin with a small real-life situation. When your home electricity bill arrives, you often hear people say: *"This month units are more"* or *"Power consumption is high."*
But have you ever thought—**what is the difference between power and energy?** Why do industries talk about **power factor, demand, and efficiency**, while the government talks about **energy conservation schemes**?

As electrical engineers, we must speak the **language of energy** correctly. Today's lecture introduces the **basic energy terminology** used in textbooks, exams, industries, and audits, and then connects it to an important national initiative called the **PAT Scheme**.

---

2. Core Concepts (≈ 40 minutes)

Power

Power is the **rate at which electrical energy is consumed or converted into useful work**.

- Unit: **Watt (W), kilowatt (kW)**
- Example: A 1 kW motor means it consumes energy at the rate of 1 kW.

Energy

Energy is the **total electrical work done over time**.

- Unit: **kilowatt-hour (kWh)**
- Energy = Power × Time

📌 *Example:*
If a 1 kW heater runs for 2 hours, energy consumed = **2 kWh**.

Energy Audit

An **energy audit** is a **systematic study of energy use** in a system to identify **energy wastage and saving opportunities**.

Objectives:

- Reduce energy cost
- Improve efficiency
- Reduce losses

Demand Side Management (DSM)

DSM means **managing energy demand instead of increasing generation**.

Examples:

- Using energy-efficient motors
- Shifting load from peak hours to off-peak hours
- Replacing old lighting with LEDs

📌 *Fun Fact:*
Saving 1 unit of energy is **cheaper than generating 1 unit**.

Energy Intensity

Energy intensity shows **how efficiently energy is used in economic activity**.

$$\text{Energy Intensity} = \frac{\text{Energy Consumption}}{\text{GDP}}$$

Lower energy intensity = **better efficiency**.

PAT Scheme (Perform, Achieve & Trade)

The **PAT Scheme** is a flagship program launched by the **Bureau of Energy Efficiency (BEE)** under the **Energy Conservation Act**.

Purpose:

- Improve energy efficiency in **energy-intensive industries**
- Set **specific energy reduction targets**

How PAT Works:

1. Government identifies **Designated Consumers (DCs)**
2. Energy reduction targets are assigned

3. Industries that **save more** can **trade energy saving certificates**

Designated Consumers

Industries like:

- Power plants
- Cement
- Steel
- Fertilizer
- Aluminum

---

3. Real-World / Industry Applications (≈ 10 minutes)

- Industries use **power and energy concepts** to calculate electricity bills.
- **Energy audits** help industries reduce operating cost.
- DSM is applied by utilities to reduce peak load.
- PAT Scheme encourages industries to:
  - Upgrade motors
  - Improve processes
  - Reduce wastage

📌 *Example:*
A cement plant improving motor efficiency can **earn incentives** under PAT.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Power is rate, energy is total consumption.
- Energy audit identifies saving opportunities.
- DSM manages demand efficiently.
- Energy intensity measures efficiency of energy use.
- PAT Scheme promotes energy efficiency in industries.

Lecture 3 - Topic 1.3: Laws of Thermodynamics

(Unit–1: Energy Management & Audit / 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Let me start with a simple question: **Can we design a machine that gives output energy without any input?**
Or can we make a motor, transformer, or power plant that works with **100% efficiency**?

At first glance, it may sound attractive—but nature does not allow it. These limitations are explained by the **laws of thermodynamics**, which form the **foundation of energy management, efficiency analysis, and energy audit**. Every electrical system you study—motors, generators, transformers, HVAC—follows these laws.

Understanding these laws helps engineers answer one key question:
☞ *Where does the energy go, and why can't we save all of it?*

---

2. Core Concepts (≈ 40 minutes)

What is Thermodynamics?

Thermodynamics is the **science of energy, heat, and work**, and their conversion from one form to another.

In energy management, thermodynamics helps us:

- Understand **energy conversion**
- Identify **losses**
- Improve **efficiency**

First Law of Thermodynamics (Law of Energy Conservation)

Statement:

Energy can neither be created nor destroyed; it can only be converted from one form to another.

This means the **total energy remains constant**.

📌 **Mathematical form:**

$$\text{Energy Input} = \text{Useful Output} + \text{Losses}$$

Practical Electrical Example

- In an **electric motor**:
  - Electrical energy (input)
  - Mechanical energy (output)
  - Losses (heat, sound)

No energy disappears—it only **changes form**.

Importance of First Law in Energy Audit

- Helps in **energy balance calculation**
- Used to track where energy is going
- Identifies **avoidable and unavoidable losses**

📌 *Key Exam Point:*

First law talks about **quantity of energy**, not quality.

Second Law of Thermodynamics (Law of Energy Degradation)

Statement:

It is impossible to convert all the input energy into useful work. Some energy is always lost.

In simple words:

- **100% efficiency is impossible**
- Energy quality degrades in every process

Concept of Efficiency

$$\text{Efficiency} = \frac{\text{Useful Output}}{\text{Input Energy}}$$

Efficiency is always **less than 1 (or 100%)**.

Practical Electrical Example

- In a **transformer**:
  - Some energy is lost as heat (core loss, copper loss)
- In a **power plant**:
  - Huge losses occur during generation and transmission

Why Second Law is Important in Energy Management

- Explains **why losses occur**
- Helps engineers focus on **loss minimization**
- Basis for:
  - Energy-efficient design
  - Equipment replacement
  - Performance improvement

📌 *Fun Fact:*
Even the best power plants operate at **35–45% efficiency only**.

Difference between First and Second Law

First Law	Second Law
Energy conserved	Energy quality degrades
Quantity focus	Quality focus
No limit on efficiency	Efficiency always < 100%

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Energy auditors** apply these laws to calculate losses.
- **Industries** use them to:
  - Replace inefficient motors
  - Improve transformer efficiency
- **Utilities** plan systems knowing losses are unavoidable.
- **HVAC systems** are designed considering thermodynamic limits.

📌 *Real-Life Example:*
Replacing an old motor does not eliminate losses—but it **reduces losses**, improving efficiency.

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- First law: Energy is conserved.
- Second law: Losses are unavoidable.
- Efficiency can be improved but never reach 100%.
- These laws form the base of energy audit and management.
- Engineers aim to **minimize losses**, not eliminate them.

Lecture – 4 & 5: Topic 1.4 – BEE Schemes & NMEEE & Topic 1.5 – Energy Audit: Types, Phases & ENCON Measures

(Unit–1: Energy Management & Audit/ 120-minute Lecture Session)

◆ Topic 1.4 – BEE Schemes & NMEEE (≈ 50–55 minutes)

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1. Hook / Introduction (≈ 5 minutes)

Think about this question:
If electricity is so precious, who ensures that industries and consumers do not waste it?

Just like traffic rules are needed to manage vehicles, **energy rules and schemes are required to manage electricity consumption**. In India, this responsibility is handled by the **Bureau of Energy Efficiency (BEE)** through various national programs. These schemes are not only important for the country but are also **directly relevant to electrical engineers**, especially those working in industries, utilities, and energy auditing.

---

2. Core Concepts – BEE Schemes & NMEEE (≈ 40 minutes)

2.1 Bureau of Energy Efficiency (BEE)

The **Bureau of Energy Efficiency (BEE)** was established under the **Energy Conservation Act, 2001**.

Main Objectives of BEE:

- Promote efficient use of energy
- Reduce energy intensity of the Indian economy
- Develop standards, policies, and awareness programs

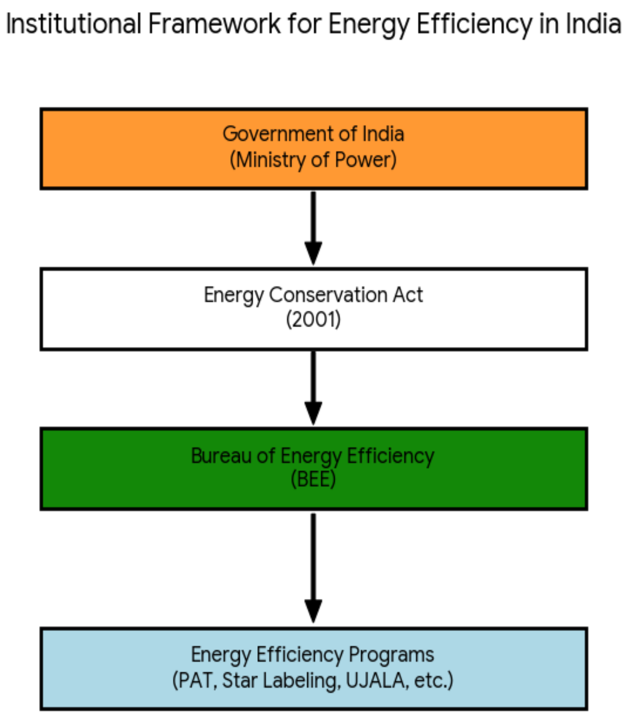

Fig. 1.3 Block diagram for Institutional Framework

2.2 Important BEE Schemes (Only Names with Purpose – Exam Focus)

As per GTU syllabus, students must **remember scheme names and basic objectives**.

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1. Standards & Labeling (S&L) Program

- Introduces **star labels** on appliances
- Helps consumers select **energy-efficient products**
- Reduces household and commercial electricity demand

---

2. Perform, Achieve and Trade (PAT) Scheme

- Targets **energy-intensive industries**
- Fixes **specific energy consumption targets**
- Allows industries to **trade energy saving certificates**

📌 *Reminder:* PAT works on the principle **"Save more → Earn more."**

---

3. Market Transformation for Energy Efficiency (MTEE)

- Promotes **super-efficient appliances**
- Reduces high initial cost through incentives
- Encourages adoption of advanced technologies

---

4. Energy Efficiency Financing Platform (EEFP)

- Provides **financial support** for energy efficiency projects
- Links industries with banks and investors

---

5. Framework for Energy Efficient Economic Development (FEEED)

- Supports **large-scale efficiency projects**
- Encourages innovative financing mechanisms

2.3 Energy Intensive Industries (Designated Consumers)

These industries consume **large amounts of energy per unit output**.

Examples:

- Thermal power plants
- Cement
- Steel
- Aluminum
- Fertilizer
- Paper & pulp

Such industries are called **Designated Consumers (DCs)** and are closely monitored by BEE.

2.4 National Mission for Enhanced Energy Efficiency (NMEEE)

NMEEE is one of the missions under **India's National Action Plan on Climate Change (NAPCC)**.

Objectives of NMEEE:

- Promote large-scale energy efficiency
- Strengthen market-based mechanisms
- Reduce greenhouse gas emissions

Four Components of NMEEE:

1. PAT
2. MTEE
3. EEFP
4. FEEED

---

3. Real-World Applications (≈ 10 minutes)

- Appliance manufacturers design products as per **BEE standards**
- Industries upgrade motors, transformers to meet **PAT targets**
- Energy auditors verify compliance with BEE norms
- Government uses NMEEE data for **policy and planning**

📌 *Fun Fact:*
Energy saved through efficiency is called a **"Negawatt"**—the cleanest form of energy.

🔷 Topic 1.5 – Energy Audit: Types, Phases & ENCON Measures (≈ 65–70 minutes)

---

4. Hook / Introduction (≈ 5 minutes)

Imagine running a factory without checking where electricity is being wasted.
This is like driving a vehicle **without a speedometer or fuel gauge**.

An **energy audit** acts as a **medical check-up of an electrical system**, identifying where energy is lost and how it can be saved.

---

5. Core Concepts – Energy Audit (≈ 50 minutes)

5.1 What is Energy Audit?

An **energy audit** is a **systematic inspection, measurement, and analysis of energy use** in a system to reduce energy consumption without affecting output.

Objectives:

- Reduce energy cost
- Improve efficiency
- Reduce losses
- Improve reliability

5.2 Need of Energy Audit

- Rising electricity bills
- Inefficient equipment
- Overloading or underloading
- Environmental concerns
- Compliance with BEE norms

5.3 Types of Energy Audit

1. Preliminary Energy Audit

- Quick assessment
- Uses past bills and basic data
- Identifies major wastage areas

2. Targeted Energy Audit

- Focuses on specific equipment or section
- Used when a problem area is known

3. Detailed Energy Audit

- Complete and in-depth analysis
- Measurements, data logging, calculations
- Provides cost–benefit analysis.

Table comparing **Preliminary vs Detailed Audit**.

Feature	**Preliminary Energy Audit (Level 1)**	**Detailed Energy Audit (Level 2/3)**
Alternative Names	Walk-through audit, Screening audit	Comprehensive audit, Investment-grade audit
Duration	Very short (typically 1–2 days)	Long (weeks to several months)
Methodology	Uses existing data and simple "walk-through" visual inspections.	Uses sophisticated portable instruments for on-site measurements.
Data Source	Readily available utility bills and historical records.	New data collection via logging, material & energy balances.
Level of Accuracy	Low; provides a "rough estimate" of potential savings.	High; provides specific, actionable technical and financial data.
Scope	Focuses on major "glaring" areas of waste and easy no-cost/low-cost fixes.	Evaluates all major energy-consuming systems and their interactions.
Instruments	Minimal (e.g., lux meter, thermometer).	Advanced (e.g., power analyzers, thermal imagers, ultrasonic flow meters).

Feature	Preliminary Energy Audit (Level 1)	Detailed Energy Audit (Level 2/3)
Outcome	Identifies potential for further study; lists simple improvements.	Provides a detailed implementation plan with precise ROI/Payback periods.
Cost	Low cost	High cost

5.4 Phases of Energy Audit

1. Pre-Audit Phase

- Data collection
- Electricity bills
- Load details
- Process understanding

2. Audit Phase

- Measurements using instruments
- Observation of operating conditions
- Identification of losses

3. Post-Audit Phase

- Analysis of data
- Identification of energy-saving measures
- Payback period calculation
- Report submission

5.5 ENCON Measures (Energy Conservation Measures)

ENCON measures are classified as:

1. No-Cost Measures

- Switching off idle equipment
- Load scheduling
- Maintenance improvement

2. Low-Cost Measures

- Lighting replacement

- Capacitor installation
- Control adjustments

3. Investment-Based Measures

- Motor replacement
- Transformer upgrade
- Automation systems

---

6. Real-World / Industry Applications (≈ 10 minutes)

- Industries conduct regular audits to reduce bills
- Colleges perform energy audits for accreditation
- Utilities recommend ENCON measures to consumers
- Audits are compulsory for PAT industries

📌 *Example:*
Replacing fluorescent lamps with LEDs is a **low-cost ENCON measure** with quick payback.

---

7. Summary & Q&A (≈ 10 minutes)

Key Takeaways

- BEE guides national energy efficiency efforts
- NMEEE integrates major efficiency programs
- Energy audit identifies energy losses
- Audits follow systematic phases
- ENCON measures convert audit findings into savings

Lecture – 6 & 7: Topic 1.6 – Energy Performance Indicators (EPIs) & Topic 1.7 – Electrical Measuring Instruments & Topic 1.8 – Sankey Diagram of Three-Phase Induction Motor

(Unit–1: Energy Management & Audit / 120-Minute Lecture Session)

🔷 Topic 1.6 – Energy Performance Indicators (≈ 35–40 minutes)

---

1. Hook / Introduction (≈ 5 minutes)

Suppose two factories produce the **same number of products**, but one consumes **more electricity** than the other.
Which factory is better?

To answer this, we need a **measuring parameter**. Just like fuel efficiency (km/l) tells us how good a vehicle is, **Energy Performance Indicators (EPIs)** tell us how efficiently energy is being used.

---

2. Core Concepts (≈ 25 minutes)

What are Energy Performance Indicators (EPIs)?

Energy Performance Indicators are **numerical values used to measure and compare energy efficiency** of a plant, process, or equipment.

They help answer:

- How efficiently is energy used?
- Is energy performance improving or worsening?
- Where are losses occurring?

Plant Energy Performance Indicator

$$\text{Plant Energy Performance} = \frac{\text{Total Energy Consumed}}{\text{Total Production}}$$

- Unit: kWh per unit of product
- Lower value = **better efficiency**

Production Factor

Production factor indicates **how much output is obtained for a given energy input**.

$$\text{Production Factor} = \frac{\text{Production}}{\text{Energy Consumed}}$$

- Higher value = **better performance**

Why EPIs are Important

- Compare performance of:
  - Same plant (before & after improvements)
  - Two similar plants
- Track impact of energy-saving measures
- Required for **energy audit reports**

---

3. Real-World Applications (≈ 5–10 minutes)

- Industries use EPIs to:
  - Identify inefficient processes
  - Justify motor or equipment replacement
- Energy auditors use EPIs to:
  - Recommend ENCON measures
  - Calculate savings
- Management uses EPIs for decision-making

📌 *Example:*
After installing energy-efficient motors, **kWh/ton of production reduces**.

🔷 Topic 1.7 – Electrical Measuring Instruments (≈ 45 minutes)

---

4. Hook / Introduction (≈ 5 minutes)

An energy audit without measuring instruments is like a **doctor diagnosing a patient without instruments**.

To measure temperature, speed, light level, and energy accurately, **specialized electrical measuring instruments** are required.

---

5. Core Concepts – Measuring Instruments (≈ 35 minutes)

---

1. Non-Contact Infrared Thermometer

- Measures **surface temperature without contact**
- Used to detect:
    - Hot spots
    - Loose electrical connections
    - Overloaded equipment

Fig. 1.4 - Handheld thermometer pointing at a motor panel.

---

2. Stroboscope

- Used to measure **rotational speed** without stopping the machine
- Works on flashing light principle

📌 *Application:*
Speed measurement of motors, fans, and shafts.

---

3. Lux Meter

- Measures **illuminance**
- Unit: **Lux (lumens/m^2)**

Used in:

- Lighting audits
- Classroom and office lighting design

---

4. Smart Energy Meter

- Measures:
  - Voltage
  - Current
  - Power
  - Energy (kWh)
- Can store and transmit data

📌 *Key Point:*
Used for **load profiling and DSM studies**.

---

5. Thermography (Thermal Imaging Camera)

- Converts temperature into color images
- Identifies:
  - Overheating cables
  - Transformer hot spots
  - Motor bearing problems

---

6. Practical Importance (≈ 5 minutes)

- These instruments are used during:
  - Energy audits
  - Maintenance inspections
  - Safety checks
- Help detect problems **before failure occurs**

📌 *Fun Fact:*
Thermography is called **"seeing heat with eyes."**

🔷 Topic 1.8 – Sankey Diagram of Three-Phase Induction Motor (≈ 35–40 minutes)

---

7. Hook / Introduction (≈ 5 minutes)

When we supply 100 units of energy to a motor, do we get all 100 units as mechanical output?

The answer is **NO**, and to visualize where energy goes, we use a **Sankey diagram**.

---

8. Core Concepts – Sankey Diagram (≈ 25 minutes)

What is a Sankey Diagram?

A Sankey diagram is a **graphical representation of energy flow**, showing:

- Input energy
- Useful output
- Losses

Width of arrows represents **quantity of energy**.

Sankey Diagram of 3-Phase Induction Motor

Energy Flow:

1. Electrical input energy
2. Stator losses

3. Rotor losses
4. Mechanical losses
5. Useful mechanical output

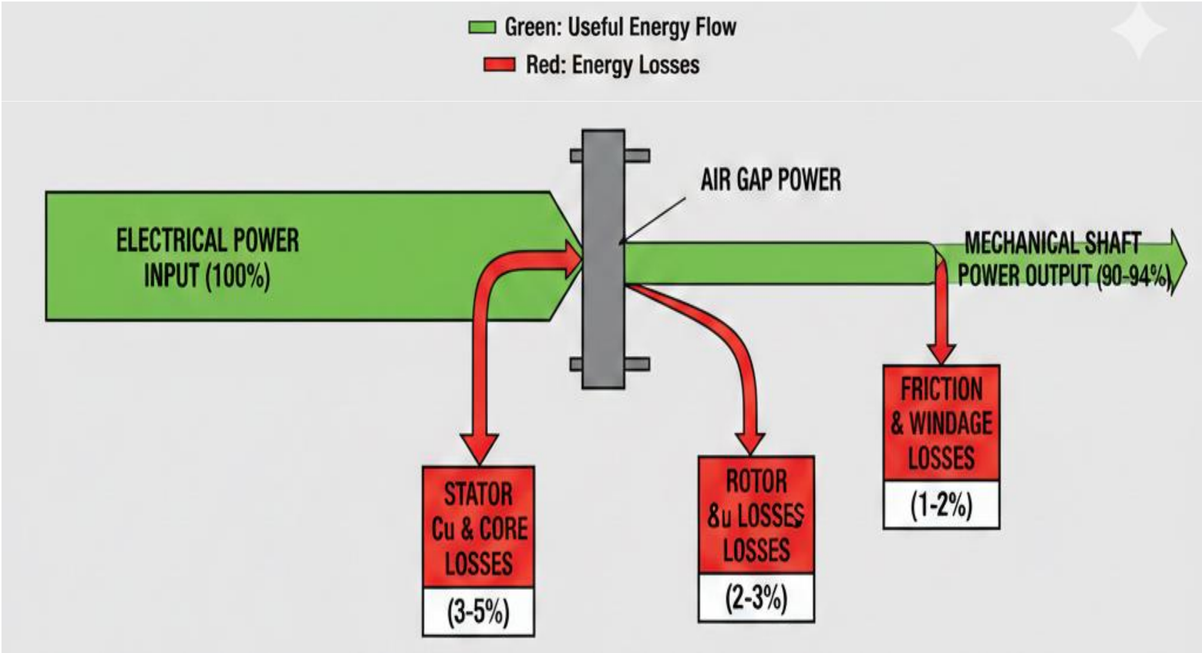

Fig. 1.5 - Sankey Diagram of 3-Phase Induction Motor with Percentage losses

---

Importance of Sankey Diagram

- Easy understanding of losses
- Helps identify improvement areas
- Used in energy audit reports

---

9. Real-World Applications (≈ 5–10 minutes)

- Used by energy auditors
- Helps justify motor replacement
- Used in teaching efficiency concepts
- Helps management understand losses visually

📌 *Example:*
IE3 motor Sankey diagram shows **lower loss arrows** than standard motor.

🔷 10. Summary & Q&A (≈ 10 minutes)

Key Takeaways

- EPIs measure energy efficiency numerically
- Measuring instruments are essential for audits
- Sankey diagrams visually represent energy losses
- All three topics are strongly interconnected

Lecture – 8: Topic 1.9: Financial Management & Payback Period

(Unit–1: Energy Management & Audit | 60 minute detailed lecture)

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1. Hook / Introduction (≈ 5 minutes)

Let us start with a very practical question:
If an industry spends extra money today to save electricity tomorrow, how do we know whether the decision is good or bad?

Engineers often focus only on **technical efficiency**, but in real life, **management asks one simple question – "How much money will we save and in how much time?"**
This is where **financial management tools** like **payback period, NPV, ROI, and IRR** become extremely important in **energy management and audit**.

---

2. Core Concepts (≈ 40 minutes)

What is Financial Management in Energy Audit?

Financial management in energy auditing means **evaluating energy-saving projects based on cost and monetary benefits**.
It helps in:

- Selecting best energy-saving option
- Justifying investment
- Decision-making by management

---

1. Simple Payback Period (MOST IMPORTANT)

Definition:
Payback period is the **time required to recover the initial investment** from annual savings.

$$\text{Payback Period (years)} = \frac{\text{Initial Investment}}{\text{Annual Energy Cost Saving}}$$

📌 **Key Points:**

- Simple to calculate
- Most commonly used in exams and industry
- Does not consider time value of money

Example – Payback Period (Exam-Oriented)

Case:

- Cost of LED replacement = ₹1,00,000
- Annual energy saving = ₹25,000

$$\text{Payback Period} = \frac{1,00,000}{25,000} = 4 \text{ years}$$

📌 *Conclusion:*
After 4 years, the project starts generating **net profit**.

---

2. Net Present Value (NPV)

Concept:
Money today is **more valuable** than money in the future due to inflation and interest.

NPV calculates the **present value of future cash flows**.

$$\text{NPV} = \text{Present Value of Savings} - \text{Initial Investment}$$

📌 **Decision Rule:**

- NPV > 0 → Project acceptable
- NPV < 0 → Project rejected

---

3. Cash Flow

Cash Flow represents:

- **Outflow:** Initial investment
- **Inflow:** Annual savings

---

4. Return on Investment (ROI)

$$\text{ROI} = \frac{\text{Annual Net Saving}}{\text{Investment}} \times 100$$

- Higher ROI = Better project

📌 *Used by management to compare projects.*

---

5. Internal Rate of Return (IRR)

- IRR is the **rate of interest at which NPV becomes zero**
- Used for long-term projects
- Indicates profitability

---

3. Case Study: Payback Period (≈ 10 minutes)

Case: Energy-Efficient Motor Replacement

- Old motor efficiency = 85%
- New motor efficiency = 92%
- Investment = ₹1,50,000
- Annual energy saving = ₹50,000

$$\text{Payback Period} = \frac{1,50,000}{50,000} = 3 \text{ years}$$

📌 **Interpretation:**
After 3 years, energy savings are pure profit.
This justifies replacing old motors during energy audit.

---

4. Real-World / Industry Applications (≈ 10 minutes)

- Used in:
  - LED replacement projects
  - Motor efficiency upgrades
  - Transformer replacement
  - HVAC efficiency improvement
- Energy auditors **must present payback period** to management.
- Shorter payback projects are **approved faster**.

📌 *Industry Rule:*
Most industries prefer projects with **payback ≤ 2–3 years**.

---

5. Summary & Q&A (≈ 5–10 minutes)

Key Takeaways

- Financial analysis is essential in energy audit.
- Payback period is the simplest and most important tool.
- NPV, ROI, and IRR help in better decision-making.
- Case studies help justify energy-saving investments.
- Technical + financial analysis = successful energy project.

🔵 PHASE 3: STUDENT AI TOOLKIT (25 PROMPTS)

A. Low-Level Prompts (Remember & Understand) – 10 Prompts

1. *"Explain the difference between power and energy in very simple words with daily-life examples."*
2. *"Define energy management and energy audit in one paragraph suitable for diploma exams."*
3. *"List and explain basic energy terminology such as power, energy, power factor, and energy intensity."*
4. *"Explain the need and objectives of energy management in industries."*
5. *"Describe the First Law of Thermodynamics with a simple electrical example."*
6. *"Explain the Second Law of Thermodynamics in simple language with one practical example."*
7. *"What is Demand Side Management (DSM)? Explain it for a beginner."*
8. *"Explain the PAT scheme and its purpose in simple exam-oriented points."*
9. *"List the schemes of BEE under the Energy Conservation Act (only names) with brief meaning."*
10. *"Summarize Unit-1: Energy Management & Audit in 10 easy revision points."*

B. Moderate-Level Prompts (Apply & Analyze) – 10 Prompts

11. *"Compare preliminary, targeted, and detailed energy audit in a table with examples."*
12. *"Explain the steps involved in pre-audit and post-audit phases of an energy audit."*
13. *"How does improving power factor help in energy saving? Explain with numerical illustration."*
14. *"Explain the role of energy audit in reducing electricity bills of an industry."*
15. *"Analyze the importance of energy-intensive industries in India with respect to energy management."*
16. *"Explain plant energy performance and production factor with a simple case study."*
17. *"Describe the working and application of non-contact infrared thermometer, lux meter, and thermography in energy audit."*
18. *"Explain Sankey diagram of a three-phase induction motor showing energy losses."*
19. *"Differentiate between simple payback period, ROI, and NPV with suitable examples."*
20. *"Explain classification of ENCON (Energy Conservation) measures with practical examples."*

C. High-Level Prompts (Design & Create) – 5 Prompts

21. *"Design a basic energy audit plan for a small industrial workshop including audit type, instruments used, and expected savings."*
22. *"Create a step-by-step workflow of conducting a detailed energy audit from data collection to implementation."*
23. *"Develop a simple Sankey diagram explanation for an induction motor and suggest methods to reduce losses."*
24. *"Prepare a case study to calculate annual energy savings and payback period for replacing old equipment with energy-efficient equipment."*
25. *"Create an exam-oriented concept map connecting energy management, energy audit, DSM, BEE, PAT scheme, and financial analysis."*

● PHASE 4: MASTERY CHECK

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1. Key Definitions / Glossary (Top 15 Terms)

1. **Energy Management** – Systematic planning, monitoring, and control of energy use to reduce cost and wastage without affecting output.
2. **Energy Audit** – A systematic inspection and analysis of energy use in a system to identify opportunities for energy saving.
3. **Power** – The rate at which electrical energy is consumed or produced, measured in watts (W).
4. **Energy** – The total electrical work done over time, measured in kilowatt-hour (kWh).
5. **Demand Side Management (DSM)** – Techniques used to control and optimize electricity consumption at the consumer end.
6. **Power Factor (PF)** – Ratio of active power to apparent power in an AC circuit.
7. **Reactive Power** – Power that oscillates between source and load and does no useful work, measured in kVAR.
8. **Energy Intensity** – Amount of energy consumed per unit of output or GDP.
9. **PAT Scheme** – Perform, Achieve and Trade scheme to improve energy efficiency in energy-intensive industries.
10. **Bureau of Energy Efficiency (BEE)** – Statutory body under the Energy Conservation Act for promoting energy efficiency in India.
11. **NMEEE** – National Mission for Enhanced Energy Efficiency to strengthen market-based energy efficiency mechanisms.
12. **Preliminary Energy Audit** – Initial assessment to identify major energy consumption areas and saving potential.
13. **Detailed Energy Audit** – Comprehensive analysis involving detailed measurements and economic evaluation.
14. **ENCON Measures** – Energy Conservation measures taken to reduce energy consumption and losses.

15. **Payback Period** – Time required to recover the initial investment of an energy-saving project.

---

2. FAQ & Assessment Section

A. Multiple Choice Questions (MCQs)

Q1. Energy is measured in:
A) kW
B) kVA
C) kWh
D) kVAR

Q2. Which organization implements the PAT scheme in India?
A) CEA
B) BEE
C) MNRE
D) NTPC

Q3. Power factor is the ratio of:
A) kW/kVAR
B) kVA/kW
C) kW/kVA
D) kVAR/kVA

Q4. Which energy audit identifies quick and low-cost savings?
A) Detailed audit
B) Targeted audit
C) Preliminary audit
D) Investment audit

Q5. Which law of thermodynamics deals with energy conservation?
A) Zeroth law
B) First law
C) Second law
D) Third law

Q6. Reactive power is measured in:
A) kWh
B) kVA
C) kVAR
D) kW

Q7. Energy intensity indicates:
A) Total power consumption
B) Energy efficiency level
C) Cost of electricity
D) Voltage level

Q8. Which instrument measures illumination level?
A) Lux meter
B) Thermometer
C) Stroboscope
D) Tachometer

Q9. Which industry is energy intensive?
A) Textile
B) Cement
C) IT services
D) Education

Q10. Sankey diagram represents:
A) Voltage variation
B) Energy flow and losses
C) Power factor
D) Tariff structure

Q11. Which audit phase involves data collection?
A) Post-audit
B) Pre-audit
C) Implementation
D) Reporting

Q12. Which measuring device is used for temperature without contact?
A) RTD
B) Thermocouple
C) Infrared thermometer
D) Mercury thermometer

Q13. Energy conservation mainly aims to:
A) Increase power generation
B) Reduce energy wastage
C) Increase load
D) Increase tariff

Q14. Simple payback period is expressed in:
A) ₹
B) kWh
C) Years
D) Percentage

Q15. Production factor is related to:
A) Tariff
B) Plant performance
C) Transformer rating
D) Lighting efficiency

Q16. Second law of thermodynamics states that:
A) Energy can be created
B) Energy can be destroyed
C) Heat flows naturally from hot to cold body
D) Efficiency is 100%

Q17. Which scheme promotes star labeling of appliances?
A) NMEEE
B) BEE
C) PAT
D) DSM

Q18. Which phase of audit checks achieved savings?
A) Pre-audit
B) Audit
C) Post-audit
D) Planning

Q19. Energy audit is compulsory for:
A) Domestic users
B) Commercial shops
C) Energy intensive industries
D) Educational institutes

Q20. Which financial parameter considers time value of money?
A) Payback period
B) ROI
C) Net Present Value
D) Simple interest

Answer Key (MCQs)

1. C
2. B
3. C
4. C
5. B
6. C
7. B
8. A
9. B

10. B
11. B
12. C
13. B
14. C
15. B
16. C
17. B
18. C
19. C
20. C

B. Short Answer / Viva Questions (10 Questions)

1. Define energy management and explain its importance.
2. What is the difference between power and energy?
3. Explain the need for energy audit.
4. Differentiate between preliminary and detailed energy audit.
5. What is power factor and why should it be improved?
6. List any four energy-intensive industries.
7. Explain the role of BEE in energy conservation.
8. What is the significance of Sankey diagram in energy audit?
9. Define payback period with its importance.
10. Explain ENCON measures with suitable examples.

● PHASE 5: DIGITAL RESOURCE LIBRARY

AI & Digital Tools

- RETScreen – Energy audit & savings analysis
- OpenEnergyMonitor – Real-time monitoring
- ChatGPT / Gemini – Concept clarification
- Excel – Financial calculations

Video Learning (Search Keywords)

Topic	Channel	Keywords
Energy Audit Basics	NPTEL	"Energy audit diploma NPTEL"
Thermodynamics	Khan Academy	"First second law thermodynamics"
Sankey Diagram	Electrical4U	"Sankey diagram induction motor"

🔵 PHASE 6: EXTERNAL EXPOSURE

- **Emerging Tech:** Smart energy meters, IoT-based audits
- **MOOCs:**
    - NPTEL – Energy Management
    - SWAYAM – Energy Conservation
- **Industry Visits:**
    - Power utility
    - Manufacturing plant
    - Energy audit firm
- **Conferences:** IEEE EnergyCon, BEE workshops

🔵 PHASE 7: PREDICTED QUESTION BANK

Most Repeated Questions

- Explain energy audit and its types.
- Draw and explain Sankey diagram.
- Explain PAT scheme.
- Explain laws of thermodynamics.
- Explain payback period with example.

Application Questions

1. Calculate payback period for LED replacement.
2. Explain ENCON measures for motors.
3. Analyze energy losses using Sankey diagram.
4. Explain use of lux meter in audit.
5. Prepare simple audit report outline.

◆ UNIT–2: STAR LEVEL & ENERGY SAVING

Subject: Energy Efficiency & Audit
Branch: Diploma Electrical Engineering
Semester: 4 (GTU)

● PHASE 1: UNIT–2: UNIT–WISE STUDY PLAN

Topic No.	Topic Name	Nature	Hours	Exam Importance	Practical Relevance
2.1	Standards & Labeling Program – Technical Details	Core	1	High	Medium
2.2	Mandatory & Voluntary Star Labeled Appliances	Core	1	Very High	Medium
2.3	Significance of 1–5 Star Rating for Appliances	Core	2	Very High	High
2.4	Case Study: Energy Efficient Pump & Transformer	Application	1	Very High	Very High
2.5	Air Conditioner: Working Principle	Core	1	High	Medium
2.6	Types of RAC – Window & Split AC	Core	0.5	Medium	Medium
2.7	EER & ISEER – Definition & Comparison	Core	1	Very High	High
2.8	ISEER Evaluation Methods & Significance	Core	1	High	Medium
2.9	VFD Compressors & Star Rating of RAC	Supporting	0.5	Medium	High
2.10	RAC Efficiency Improvement Techniques	Core	1	High	Medium
2.11	IoT-Based RAC & Super-Efficient AC	Advanced	0.5	Medium	High

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⬤ PHASE 2: DETAILED LECTURE SERIES

Lecture 1 - Topic 2.1: Standards & Labeling Program

(Unit–2: Star Level & Energy Saving | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Let us begin with a familiar situation. When your family plans to buy a new refrigerator or air conditioner, the shopkeeper usually says, *"Sir, this is a 5-Star model, it will save electricity."* But what does **5-Star** actually mean? Who decides these stars, and on what technical basis?

The answer lies in the **Standards & Labeling (S&L) Program**, one of India's most important energy efficiency initiatives. For an electrical engineer, understanding this program is essential because it directly affects **appliance design, selection, energy saving, and electricity bills**.

---

2. Core Concepts (≈ 40 minutes)

What is the Standards & Labeling Program?

The **Standards & Labeling (S&L) Program** is implemented by the **Bureau of Energy Efficiency (BEE)** under the **Energy Conservation Act, 2001**.
Its main aim is to **reduce electricity consumption by promoting energy-efficient appliances**.

Under this program, electrical appliances are given **star ratings from 1 to 5**, based on their **energy performance**.

📌 *Fun Fact:*
A **5-Star appliance** can save up to **30–40% energy** compared to a 1-Star appliance.

Objectives of the S&L Program

- Provide **clear information** to consumers
- Encourage manufacturers to improve efficiency
- Reduce peak electricity demand
- Lower electricity bills and carbon emissions

Understanding the Star Label (Technical Details)

A typical BEE star label contains:

1. **Star Rating (1–5 stars)** – efficiency level
2. **Appliance Name & Category**
3. **Brand and Model**
4. **Rated Capacity** (e.g., litres, tons, watts)
5. **Annual Energy Consumption** (kWh/year)
6. **Label Validity Period**

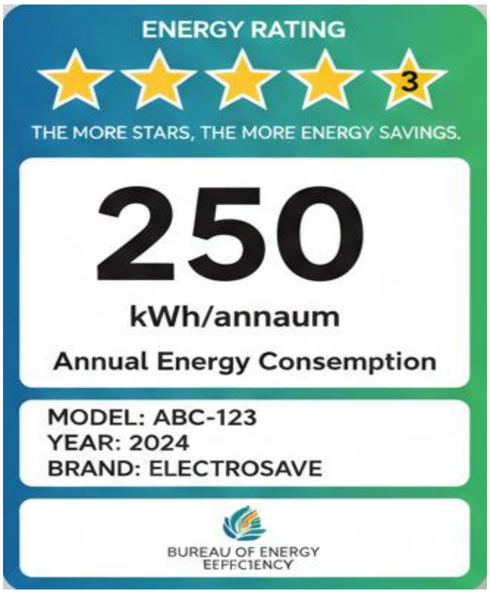

Fig. 2.1 - A rectangular star label diagram showing stars at the top and energy data.

Technical Basis of Star Rating

Star rating is decided based on:

- **Specific Energy Consumption (SEC)**
- **Energy Efficiency Ratio (EER) or ISEER** (for ACs)
- **Losses** (for motors, transformers)
- **Test conditions defined by BEE**

Lower energy consumption for the same output → **Higher star rating**.

Mandatory vs Voluntary Labeling

- **Mandatory Labeling:**
  Appliances must display star labels (e.g., refrigerators, ACs).

- **Voluntary Labeling:**
  Manufacturers may choose to label appliances (e.g., motors, pumps).

Label Validity and Revision

Star rating criteria are **revised every few years**.
This ensures:

- Continuous improvement in technology
- Older models become less competitive
- Consumers always get better efficiency

📌 *Example:*
Today's 3-Star AC may be equivalent to yesterday's 5-Star AC.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Consumers** use star labels to choose energy-saving appliances.
- **Industries** use labeled motors and transformers to reduce operating cost.
- **Energy auditors** recommend high star-rated equipment during audits.
- **Manufacturers** design products to meet higher star standards.
- **Utilities** use star data for demand forecasting.

📌 *Practical Example:*
Replacing a 1-Star fan with a 5-Star fan significantly reduces monthly electricity bills.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- S&L Program promotes energy efficiency.
- Star ratings indicate energy performance.
- Technical parameters decide star levels.
- Higher stars mean lower energy consumption.
- Labels are revised periodically for improvement.

Lecture 2 - Topic 2.2: Mandatory & Voluntary Star-Labeled Appliances

(Unit–2: Star Level & Energy Saving | Diploma Electrical Engineering | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Think about this situation: you visit an appliance showroom and notice that **some appliances must carry a star label**, while others may or may not have it.
Why is it **compulsory for certain appliances** and optional for others?

The answer lies in how **frequently an appliance is used**, **how much power it consumes**, and **its impact on national electricity demand**. In this lecture, we will clearly understand **mandatory and voluntary star-labeled appliances**, a very important and **high-scoring topic for exams** as well as real-life engineering decisions.

---

2. Core Concepts (≈ 40 minutes)

What is Mandatory and Voluntary Labeling?

Under the **BEE Standards & Labeling Program**, appliances are divided into two categories:

- **Mandatory Star Labeling:**
  Appliances **must** display a star label by law.
- **Voluntary Star Labeling:**
  Appliances **may** display a star label if the manufacturer chooses.

📌 *Key Idea:*
Mandatory appliances have **high energy consumption and large national impact**.

Mandatory Star-Labeled Appliances

The following appliances **must carry a BEE star label**:

1. **Frost-Free Refrigerator**
   - Operates **24×7**
   - Large contribution to household energy consumption
2. **Room Air Conditioner (Window & Split)**
   - High power rating
   - Major contributor to peak load

3. **Ceiling Fan**
    - Used for long hours
    - High cumulative energy consumption
4. **Color Television**
    - Widely used appliance
    - Increasing screen size increases energy use
5. **Distribution Transformer**
    - Operates continuously
    - Losses affect entire power system

Appliance	Reason for Mandatory Labeling
Air Conditioners	High energy consumption; significant impact on peak power demand.
Refrigerators	Continuous operation; large contribution to household electricity use.
Water Heaters	High power usage; potential for standby losses.

Table - Appliance – Reason for Mandatory Labeling.

Why Mandatory Labeling is Important

- Forces manufacturers to improve efficiency
- Helps consumers make informed choices
- Reduces national electricity demand
- Improves grid reliability

Voluntary Star-Labeled Appliances

These appliances **may carry star labels**, but it is not compulsory.

Common Voluntary Appliances (As per syllabus)

1. **Washing Machine**
2. **Induction Motor**
3. **Agricultural Pump Sets**
4. **Electronic / Magnetic Ballast**
5. **Solid State Inverter**
6. **EV Charger**

📌 *Reason for Voluntary Category:*

- Specialized usage
- Industrial or limited application
- Technology still evolving

Importance of Voluntary Labeling

- Encourages manufacturers to adopt efficiency voluntarily
- Helps industries select energy-efficient equipment
- Prepares appliances for future mandatory inclusion

📌 *Fun Fact:*
Many appliances start as **voluntary** and later become **mandatory**.

Technical & Energy Perspective

- Mandatory appliances generally:
    - Run for long hours
    - Consume high power
    - Affect peak demand
- Voluntary appliances:
    - Used in specific sectors
    - Often selected by technical professionals

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Households:** Choose higher star refrigerators, fans, ACs to reduce bills.
- **Industries:** Prefer star-rated motors and transformers for energy savings.
- **Energy Auditors:** Recommend mandatory & voluntary star appliances in audit reports.
- **Utilities:** Use data from mandatory appliances for load forecasting.

📌 *Example:*
Replacing an old non-star pump with a star-rated pump reduces energy cost significantly.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Mandatory labeling is compulsory for high-energy appliances.
- Voluntary labeling is optional but beneficial.
- Both categories help reduce energy consumption.
- Engineers must understand appliance classification for audits and design.

Lecture 3 - Topic 2.3: Significance of 1–5 Star Ratings (Appliance-wise)

(Unit–2: Star Level & Energy Saving | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Let me ask you a practical question: **If two appliances do the same job, why does one have a higher electricity bill than the other?**
The answer is not always power rating alone—it is **energy efficiency**, which is clearly communicated through **star ratings**.

The **1–5 Star Rating system** is a simple but powerful tool that helps consumers and engineers understand **how efficiently an appliance uses electrical energy**. In today's lecture, we will study the **significance of star ratings for different appliances**, which is a **high-scoring and application-oriented topic** in exams as well as in real life.

---

2. Core Concepts (≈ 40 minutes)

What Does a Star Rating Indicate?

A **star rating** indicates the **energy efficiency level** of an appliance when tested under standard conditions defined by BEE.

- **1-Star:** Lowest efficiency, highest energy consumption
- **5-Star:** Highest efficiency, lowest energy consumption

📌 *Important Point:*
Star rating **does not indicate quality or performance**, only **energy efficiency**.

General Significance of Higher Star Rating

- Lower electricity consumption
- Reduced electricity bill
- Lower carbon emissions
- Reduced load on power system
- Higher initial cost but **lower life-cycle cost**

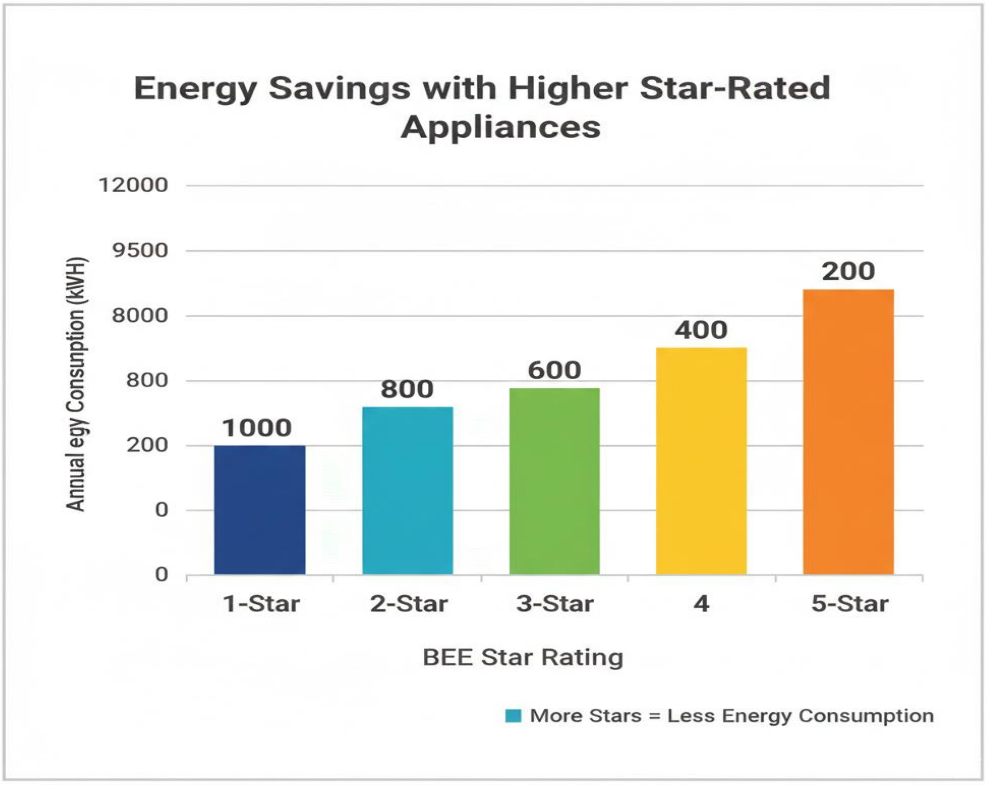

Fig. 2.2 A bar graph showing decreasing energy consumption from 1-Star to 5-Star.

Appliance-wise Significance of Star Ratings

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1. Frost-Free Refrigerator

- Operates **24×7**, all year
- Higher star rating gives **continuous energy saving**
- 5-Star refrigerator can save **30–40% energy** compared to 1-Star

📌 *Key Reason:* Long operating hours → high cumulative savings.

---

2. Room Air Conditioner (Window & Split)

- High power consumption
- Major contributor to **peak demand**
- 5-Star AC consumes much less energy for same cooling

📌 *Important Parameter:*
ISEER is used for star rating of ACs.

3. Ceiling Fan

- Used for **long hours daily**
- Star-rated fans use **BLDC motors**
- 5-Star fan consumes nearly **50% less power**

📌 *Example:*
Old fan ≈ 75 W, 5-Star fan ≈ 30–35 W.

---

4. Color Television

- Increasing screen size increases power consumption
- Higher star rating reduces long-term electricity usage
- Significant saving for daily viewing

---

5. Washing Machine

- Energy saving depends on:
    - Motor efficiency
    - Water heating
- Higher star rating reduces total energy and water consumption

---

6. Tubular Fluorescent Lamp (TFL)

- Higher star rating indicates:
    - Better luminous efficacy
    - Lower power consumption
- 5-Star TFL gives same light with less power

---

7. Electronic / Magnetic Ballast

- Electronic ballast has higher efficiency
- Lower losses and flicker
- Higher star rating → lower energy consumption

---

8. Distribution Transformer

- Operates **24×7**
- 5-Star transformer has:
    - Lower core loss
    - Lower copper loss
- Saves energy continuously throughout life

📌 *Exam Favorite:*
"Explain significance of star rating of distribution transformer."

---

9. Induction Motor

- Motors consume major share of industrial energy
- Higher star rating means:
    - Higher efficiency
    - Lower losses
- Important for **continuous industrial operation**

---

10. Agricultural Pump Sets

- Used for long hours in irrigation
- Star-rated pumps reduce:
    - Energy consumption
    - Operating cost for farmers

---

11. Solid-State Inverter & EV Charger

- Higher star rating improves:
    - Conversion efficiency
    - Reduced losses
- Supports national energy efficiency goals

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Households:** Select appliances with higher stars for long-term savings.
- **Industries:** Choose star-rated motors and transformers to reduce energy cost.
- **Energy Auditors:** Recommend appliance upgrades based on star rating.
- **Utilities:** Use star rating data for demand forecasting and DSM planning.

📌 *Practical Example:*
Replacing 100 old fans with 5-Star fans can reduce connected load significantly.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Star rating indicates energy efficiency, not quality.
- Higher stars mean lower energy consumption.
- Appliance-wise significance depends on usage hours and power rating.
- Star ratings help reduce electricity bills and environmental impact.

Lecture 4 - Topic 2.4: Case Study of Energy Saving (Pump & Distribution Transformer) Considering Star Rating

(Unit–2: Star Level & Energy Saving | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Let us start with a very practical question:
If two pumps deliver the same amount of water, or two transformers supply the same load, why does one consume more electricity than the other?

The answer lies in **energy efficiency and star rating**. Star rating is not just a label—it represents **real, measurable energy savings**. In today's lecture, we will understand this through **two important case studies**:

1. **Energy-efficient water pump**
2. **Star-rated distribution transformer**

These case studies clearly show how **higher star rating leads to lower energy consumption and quick financial payback**, which is extremely important for exams and real-life engineering decisions.

2. Core Concepts (≈ 40 minutes)

Case Study–1: Energy Saving in Water Pump Using Star Rating

Background

Agricultural and industrial pumps operate for **long hours**, making them one of the **largest energy consumers**. Older or non-star-rated pumps usually have **low efficiency**.

Given Data (Typical Case)

- Existing pump efficiency = **55%** (Non-star)
- Star-rated pump efficiency = **75%** (5-Star)
- Motor rating = **7.5 HP (≈ 5.6 kW)**
- Operating hours = **2000 hours/year**
- Electricity cost = **₹6 per kWh**

Energy Consumption Comparison

Before Replacement (Non-Star Pump):
$$\text{Energy} = 5.6 \times 2000 = 11200\ \text{kWh/year}$$

After Replacement (5-Star Pump):
Due to higher efficiency, power input reduces.
$$\text{Energy} \approx 8500\ \text{kWh/year}$$

Annual Energy Saving:
$$11200 - 8500 = 2700\ \text{kWh/year}$$

Cost Saving

$$2700 \times 6 = ₹16,200 \text{ per year}$$

📌 **Conclusion:**
Higher star-rated pump reduces energy consumption significantly without affecting output.

Payback Insight

If the additional cost of star-rated pump = ₹35,000,

$$\text{Payback Period} = \frac{35000}{16200} \approx 2.2 \text{ years}$$

Case Study–2: Energy Saving in Distribution Transformer Using Star Rating

Background

Distribution transformers operate **24×7**, so even small loss reduction results in **huge lifetime energy savings**.

Star Rating Basis

- Based on **no-load loss** and **load loss**
- 5-Star transformer has **lower core and copper losses**

Given Data (Typical Case)

- Rating = **100 kVA transformer**
- Operating hours = **8760 hours/year**
- Loss reduction in 5-Star transformer = **500 W**
- Electricity cost = **₹6 per kWh**

Annual Energy Saving

$$\text{Energy Saving} = 0.5 \times 8760 = 4380 \text{ kWh/year}$$

Annual Cost Saving

$$4380 \times 6 = ₹26,280 \text{ per year}$$

📌 *Key Observation:*
Transformer saves energy **continuously**, unlike pumps which operate intermittently.

Life-Cycle Benefit

- Transformer life ≈ **25 years**
- Total energy saving ≈ **1,09,500 kWh**
- Huge reduction in operating cost

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Agriculture:** Star-rated pumps reduce subsidy burden and power demand.
- **Utilities:** Use 5-Star transformers to reduce technical losses.
- **Industries:** Select star-rated equipment to reduce operating expenses.
- **Energy Auditors:** Use such case studies to justify investments.

📌 *Practical Insight:*
Star rating is more beneficial for **continuous-operation equipment** like transformers.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Star-rated pumps and transformers significantly reduce energy consumption.
- Pumps save energy during operation hours; transformers save energy 24×7.
- Higher initial cost is recovered quickly through savings.
- Star rating is a practical and financial decision tool.

Lecture 5 - Topic 2.5: Working Principle of Air Conditioner (Evaporation – Compression – Condensation – Expansion)

(Unit–2: Star Level & Energy Saving | 60-minute detailed classroom session)

---

1. Hook / Introduction (≈ 5 minutes)

Have you ever wondered how an air conditioner throws **cool air inside a room**, even when the outside temperature is very high?
Does the AC *create cold*?

The truth is—**an air conditioner does not create cold; it removes heat** from the room and throws it outside. This heat-transfer process follows the **basic laws of thermodynamics** and works on a well-defined cycle called the **Vapour Compression Refrigeration Cycle**.

Understanding this working principle is very important for **energy efficiency, star rating, and proper selection of air conditioners**, which is why this topic is frequently asked in exams.

---

2. Core Concepts (≈ 40 minutes)

Basic Principle of Air Conditioning

An air conditioner works on the principle of:

Heat transfer from a low-temperature region to a high-temperature region using external work.

Main working medium: **Refrigerant**
Examples: R-32, R-410A (low GWP refrigerants)

Main Components of an Air Conditioner

1. **Evaporator**
2. **Compressor**
3. **Condenser**
4. **Expansion Device** (Capillary tube / Expansion valve)

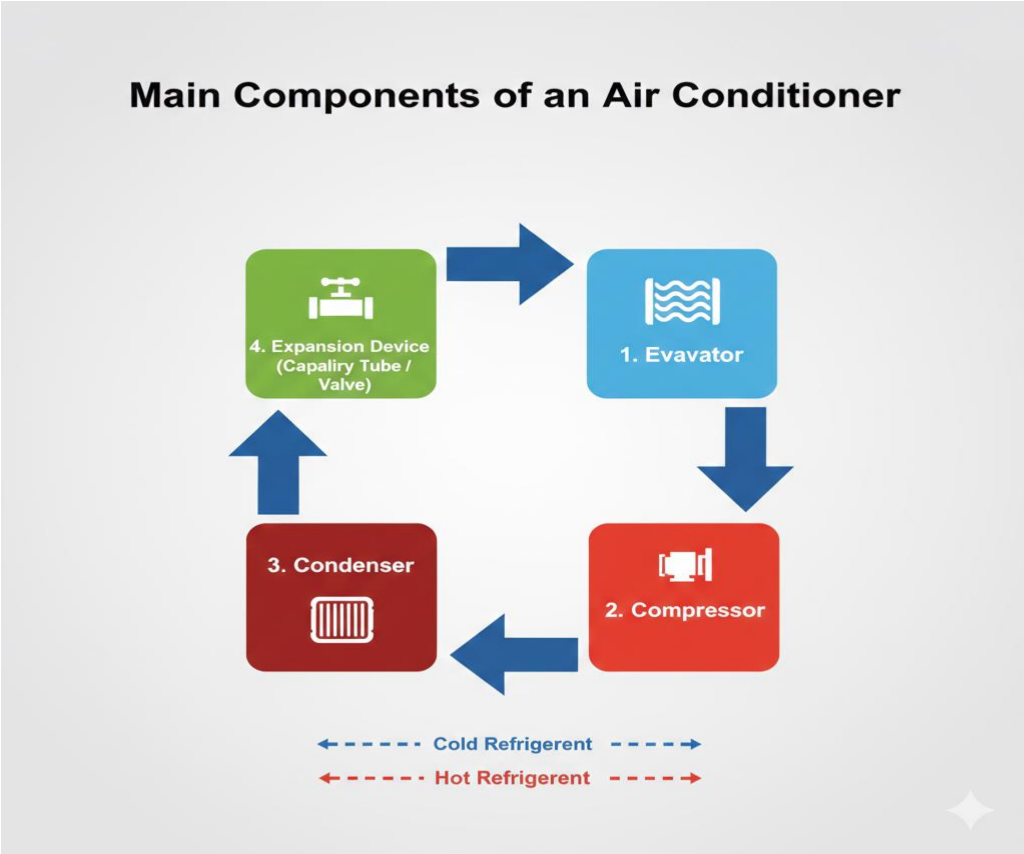

Fig. 2.3 Closed loop diagram showing four components of Air conditioner

---

Step-by-Step Working of Air Conditioner

---

1. Evaporation (Cooling Process)

- Low-pressure liquid refrigerant enters the **evaporator**
- It absorbs heat from room air
- Refrigerant **evaporates into low-pressure vapour**
- Room air becomes cool and is circulated by fan

📌 *Key Point:*
Cooling occurs due to **heat absorption**, not cold generation.

---

2. Compression (Pressure Increase)

- Low-pressure vapour enters the **compressor**
- Compressor increases:
    - Pressure

    - Temperature
- Refrigerant becomes **high-pressure, high-temperature vapour**

📌 *Energy Aspect:*
Compressor consumes **maximum electrical power** in AC.

---

3. Condensation (Heat Rejection)

- Hot refrigerant vapour enters the **condenser**
- Heat is released to outside air
- Refrigerant **condenses into high-pressure liquid**

📌 *Important:*
This is why **hot air blows out** from outdoor unit.

---

4. Expansion (Pressure Reduction)

- High-pressure liquid passes through **expansion device**
- Pressure and temperature drop suddenly
- Refrigerant becomes **low-pressure, low-temperature mixture**
- Ready to enter evaporator again

📌 *Key Point:*
Expansion device controls refrigerant flow.

Complete Cycle Summary

Evaporation → Compression → Condensation → Expansion → Repeat

---

3. Temperature–Pressure Relationship (Conceptual)

- Evaporator: Low pressure, low temperature
- Compressor outlet: High pressure, high temperature
- Condenser: High pressure, moderate temperature
- Expansion valve outlet: Low pressure, low temperature

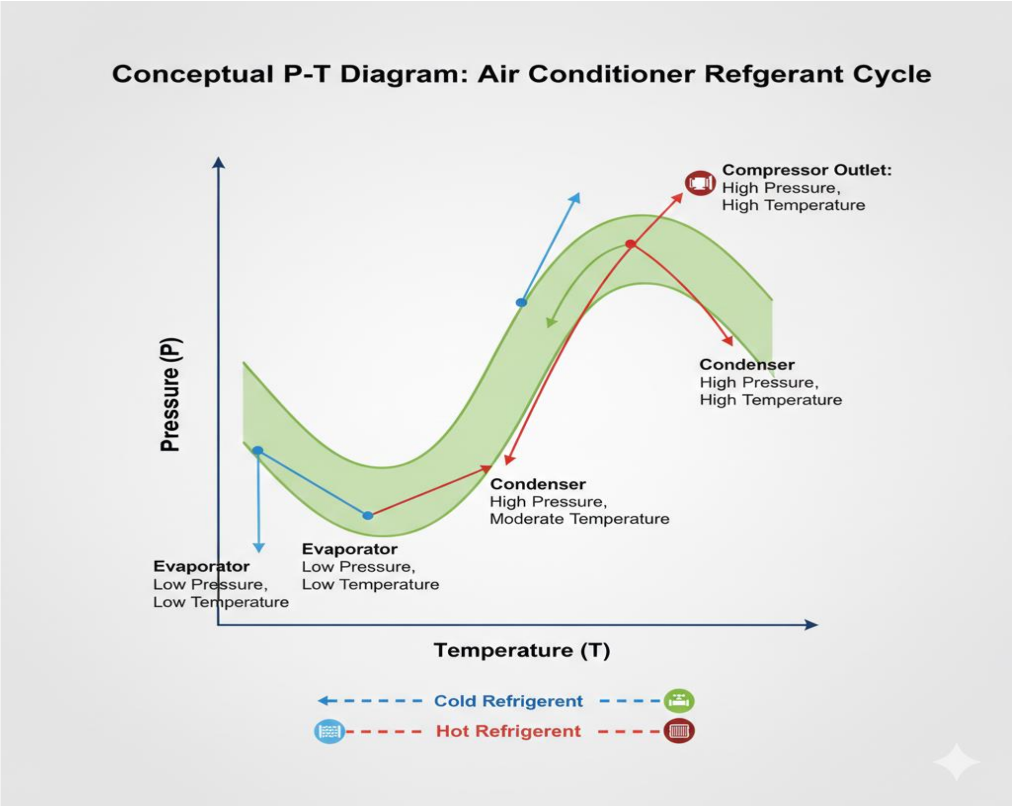

Fig. 2.4 P-T chart representation of Air conditioner

---

4. Importance in Energy Efficiency

- Efficient heat transfer → Higher star rating
- Better compressor → Lower power consumption
- Advanced expansion valves → Improved cooling control

📌 *Link to Unit-2:*
Higher efficiency in these processes increases **EER and ISEER**.

---

5. Real-World / Industry Applications (≈ 10 minutes)

- **Window AC & Split AC** use same basic cycle
- **Inverter ACs** vary compressor speed for efficiency
- **HVAC engineers** optimize each stage for energy saving
- **Energy auditors** analyze AC performance using cycle behavior

📌 *Practical Example:*
Dirty condenser coils reduce heat rejection → higher power consumption.

---

6. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- AC works on vapour compression cycle
- Cooling occurs due to heat removal
- Four main processes: evaporation, compression, condensation, expansion
- Compressor consumes most power
- Proper cycle operation improves energy efficiency

Lecture 6 - Topic 2.6: Types of Room Air Conditioners (Window AC & Split AC)

(Unit–2: Star Level & Energy Saving | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

When you walk through a city street, you will notice **window ACs** installed in older buildings and **split ACs** in modern homes, offices, and malls.
Both cool the room—but **why is split AC preferred today?**
Is it only for looks, or is there an **engineering reason behind it**?

In this lecture, we will clearly understand the **types of room air conditioners—Window AC and Split AC**, their construction, working, advantages, disadvantages, and **energy efficiency aspects**, which are frequently asked in exams.

---

2. Core Concepts (≈ 40 minutes)

Classification of Room Air Conditioners (RAC)

Room Air Conditioners are mainly classified into:

1. **Window Air Conditioner**
2. **Split Air Conditioner**

Both types work on the **vapour compression refrigeration cycle**, but their **construction and performance differ**.

---

1. Window Air Conditioner

Construction & Components

A **window AC** is a **single compact unit** installed in a window or wall opening.

Main components housed in one cabinet:

- Compressor
- Condenser
- Expansion device
- Evaporator
- Blower and fan

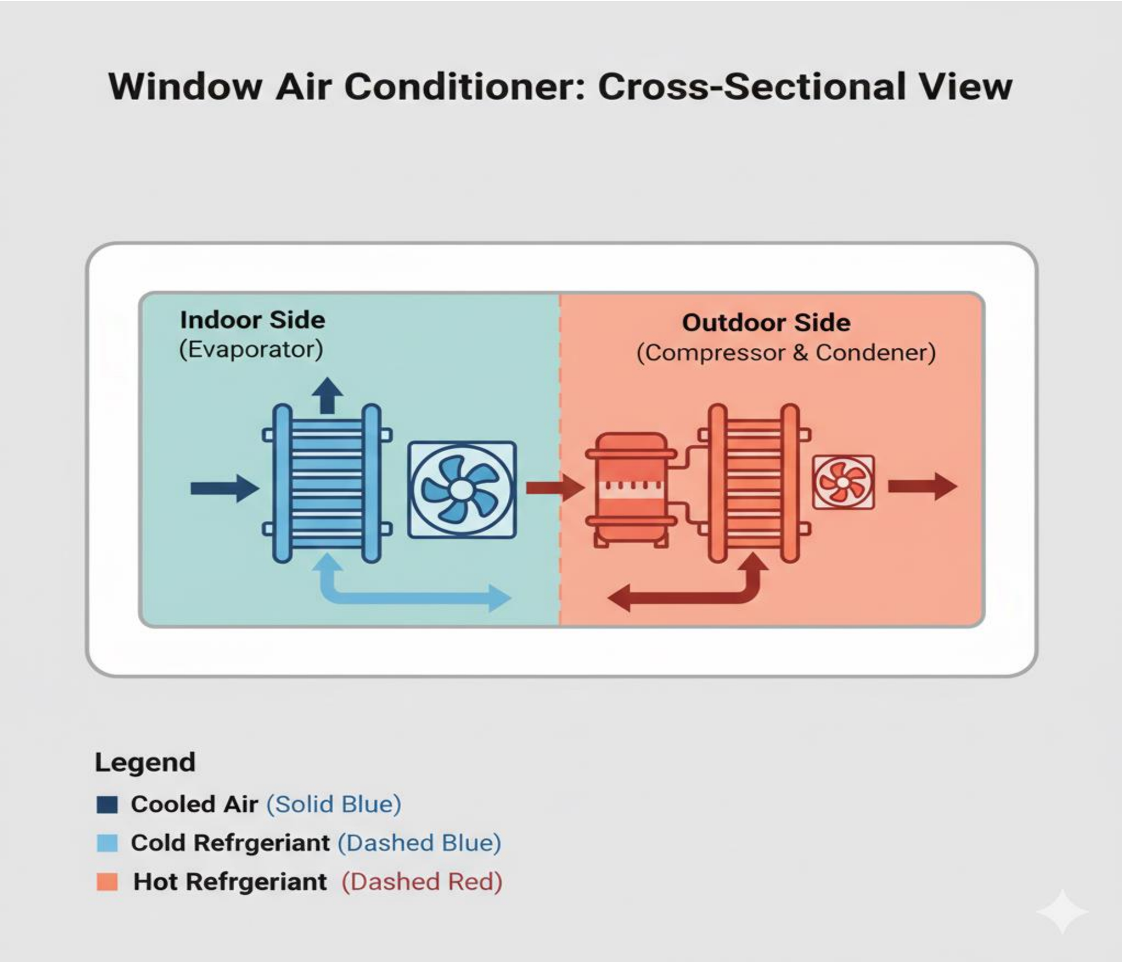

Fig. 2.5 Rectangular box divided into: Indoor side (evaporator) & Outdoor side (compressor & condenser)

Working Principle (Brief)

- Indoor side absorbs heat from room air.
- Outdoor side rejects heat to atmosphere.
- Same unit performs both functions.

Advantages of Window AC

- Lower initial cost
- Simple installation
- Easy maintenance
- Suitable for small rooms

Disadvantages of Window AC

- Noisy operation
- Lower energy efficiency
- Limited cooling capacity
- Occupies window space

📌 *Energy Aspect:*
Window ACs generally have **lower ISEER** compared to split ACs.

---

2. Split Air Conditioner

Construction & Components

A **split AC** has **two separate units**:

1. **Indoor Unit**
   - Evaporator
   - Blower
   - Air filter
2. **Outdoor Unit**
   - Compressor
   - Condenser
   - Cooling fan

Working Principle (Brief)

- Indoor unit absorbs heat.
- Refrigerant carries heat to outdoor unit.
- Outdoor unit rejects heat.

Advantages of Split AC

- Quieter operation
- Higher energy efficiency
- Better cooling performance
- Aesthetic appearance
- Suitable for larger rooms

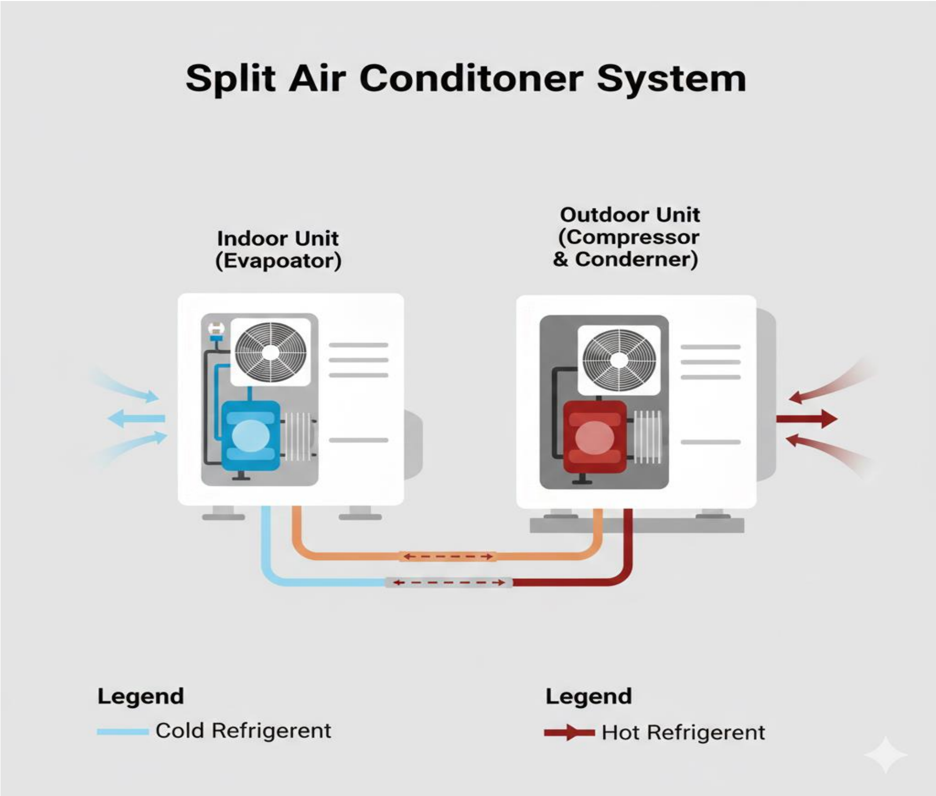

Fig. 2.6 Two separate boxes connected by copper refrigerant pipes of Split AC System

---

Disadvantages of Split AC

- Higher initial cost
- Installation complexity
- Requires skilled installation

Energy Efficiency Comparison

Parameter	Window AC	Split AC
Noise	High	Low
Efficiency	Lower	Higher
Installation	Simple	Complex
ISEER	Lower	Higher
Cost	Lower	Higher

3. Real-World / Industry Applications (≈ 10 minutes)

- **Homes:** Split ACs preferred for comfort and efficiency.
- **Shops & small rooms:** Window ACs still used.
- **Commercial buildings:** Split ACs with inverter technology.
- **Energy auditors:** Recommend split ACs for long operating hours.

📌 *Example:*
Replacing window AC with split inverter AC reduces electricity bill significantly.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Window AC is a single-unit system.
- Split AC has separate indoor and outdoor units.
- Split AC offers higher efficiency and comfort.
- Selection depends on room size, budget, and usage hours.

Lecture 7 - Topic 2.7: Energy Efficiency Ratio (EER) & Indian Seasonal Energy Efficiency Ratio (ISEER)

(Unit–2: Star Level & Energy Saving | 60-minute detailed classroom session)

---

1. Hook / Introduction (≈ 5 minutes)

You may have heard statements like:
"This AC has higher ISEER, so it consumes less electricity."
But what exactly is **ISEER**, and how is it different from **EER**?

Earlier, air conditioners were selected mainly based on **power rating**. Today, engineers and consumers focus on **efficiency ratios** like EER and ISEER, which tell us **how effectively an AC converts electrical power into cooling**. This lecture explains both concepts clearly, with **simple numericals**, making it very important for **exams, appliance selection, and energy auditing**.

---

2. Core Concepts (≈ 40 minutes)

2.1 Energy Efficiency Ratio (EER)

Definition

EER is the ratio of **cooling capacity** of an air conditioner to the **electrical power input** at **fixed test conditions**.

$$\text{EER} = \frac{\text{Cooling Capacity (W)}}{\text{Power Input (W)}}$$

📌 **Units:** W/W (dimensionless)

Meaning of EER

- Higher EER → Better energy efficiency
- Lower EER → More power consumption

📌 *Simple analogy:*
EER is like **km/litre** of a vehicle.

Numerical Example – EER

Given:

- Cooling capacity = 3500 W
- Power input = 1200 W

$$\text{EER} = \frac{3500}{1200} = 2.92$$

📌 **Interpretation:**
For every 1 W of electrical power, the AC provides 2.92 W of cooling.

Limitation of EER

- Measured at **one fixed condition**
- Does not represent real Indian climate
- Not accurate for variable load operation

☞ This limitation led to the development of **ISEER**.

2.2 Indian Seasonal Energy Efficiency Ratio (ISEER)

Definition

ISEER is the ratio of **total annual cooling output** to **total annual energy consumption**, considering **Indian climatic conditions**.

$$\boxed{\text{ISEER} = \frac{\text{Annual Cooling Output (Wh)}}{\text{Annual Energy Consumption (Wh)}}}$$

Why ISEER is Better Than EER

- Considers **seasonal temperature variation**
- Represents **actual usage conditions**

- Suitable for Indian weather
- Basis for **BEE star rating of ACs**

📌 *Key Point:*
Higher ISEER = Higher star rating = Lower electricity bill.

Operating Conditions Considered in ISEER

ISEER Load Conditions:

ISEER is a more realistic measure of an AC's efficiency because it doesn't just test the unit at maximum capacity. Instead, it calculates a weighted average of performance across different typical operating states:

- **100% Load:** Full capacity operation.
- **75% Load:** High-partial load.
- **50% Load:** Half-capacity (common for inverter ACs).
- **25% Load:** Low-partial load operation.

By measuring performance at these varying stages, the ISEER rating better reflects how an AC will actually consume power over an entire cooling season in Indian climatic conditions.

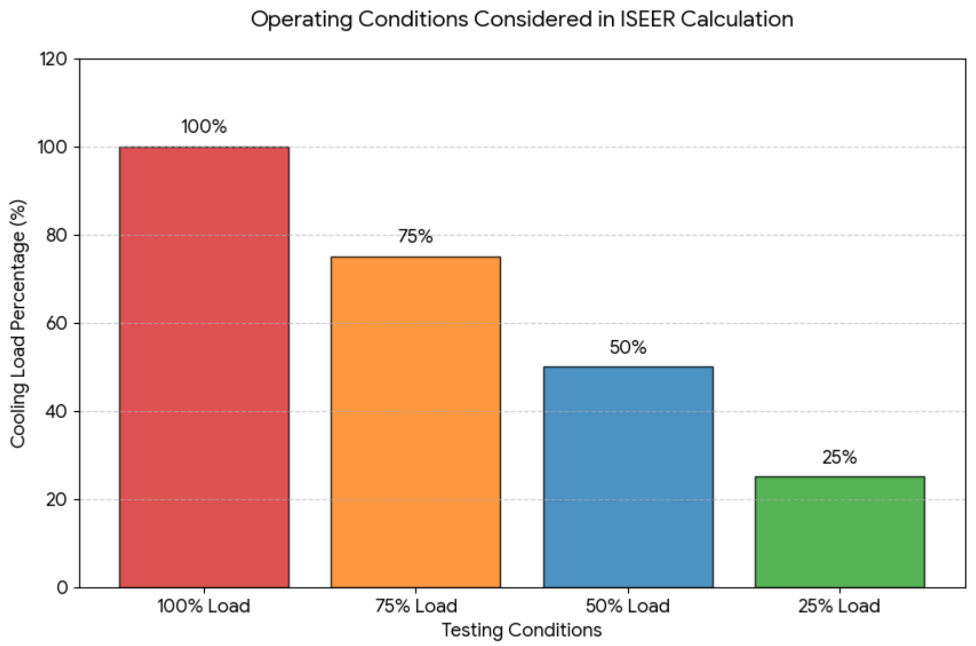

Fig. 2.7 A bar diagram showing AC operation at different load percentages.

This bar diagram represents the four specific cooling load conditions used to calculate the **ISEER (Indian Seasonal Energy Efficiency Ratio)** for air conditioners in India.

Numerical Example – ISEER (Simplified for Diploma)

Given:

- Annual cooling output = 12,000 kWh
- Annual energy consumption = 3,000 kWh

$$\text{ISEER} = \frac{12,000}{3,000} = 4.0$$

📌 **Interpretation:**
The AC delivers 4 units of cooling for every 1 unit of electricity consumed annually.

2.3 Relationship between EER, ISEER & Star Rating

Parameter	EER	ISEER
Test condition	Fixed	Seasonal
Accuracy	Less	More
Used for	Older ACs	Modern ACs
Star rating	Not used now	Used by BEE

2.4 Energy Saving Perspective

- AC with higher ISEER:
  - Consumes less energy
  - Reduces peak demand
  - Gives long-term savings
- Inverter ACs have **higher ISEER** due to variable speed compressors.

📌 *Fun Fact:*
Two 1.5-ton ACs may consume **very different energy** based on ISEER.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Consumers:** Compare ACs using ISEER instead of wattage.
- **Energy Auditors:** Estimate annual energy consumption using ISEER.
- **Utilities:** Forecast demand and promote high-ISEER appliances.

- **Manufacturers:** Design inverter ACs to achieve higher ISEER.

📌 *Practical Example:*
Replacing a low-ISEER AC with a high-ISEER inverter AC can save **20–30% energy annually**.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- EER measures efficiency at fixed conditions.
- ISEER measures efficiency over a season.
- Higher EER/ISEER means better efficiency.
- ISEER is used for star rating of ACs.
- Numerical are simple and scoring.

Lecture 8 - Topic 2.8: Methods of Evaluation of ISEER & Its Significance

(Unit–2: Star Level & Energy Saving | 60-minute detailed classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Suppose two air conditioners both claim to be **5-Star rated**, but one gives a much lower electricity bill in real use.
Why does this happen?

The answer lies in **how the efficiency is evaluated**. Earlier, AC efficiency was measured at **one fixed condition**, which did not represent real-life usage. To overcome this, **ISEER (Indian Seasonal Energy Efficiency Ratio)** was introduced.

In this lecture, we will understand **how ISEER is evaluated step by step** and why it is so important for **energy saving, star rating, and real-world AC performance**.

---

2. Core Concepts (≈ 40 minutes)

2.1 What is ISEER Evaluation?

ISEER evaluation is a **standardized method** defined by **BEE** to measure the **seasonal energy efficiency** of room air conditioners under **Indian climatic conditions**.

📌 *Key Idea:*
ISEER reflects **actual annual performance**, not just laboratory performance.

2.2 Why a Special Evaluation Method is Needed?

- India has **wide temperature variations**
- ACs do not operate at full load all the time
- Fixed-condition testing (EER) is unrealistic
- Modern ACs use **variable speed compressors**

📌 *Conclusion:*
Efficiency must be measured at **different load conditions**.

2.3 Load Conditions Used in ISEER Evaluation

ISEER considers **four operating conditions** based on **percentage load**:

Load Condition	Cooling Load
Full Load	100%
Medium Load	75%
Low Load	50%
Very Low Load	25%

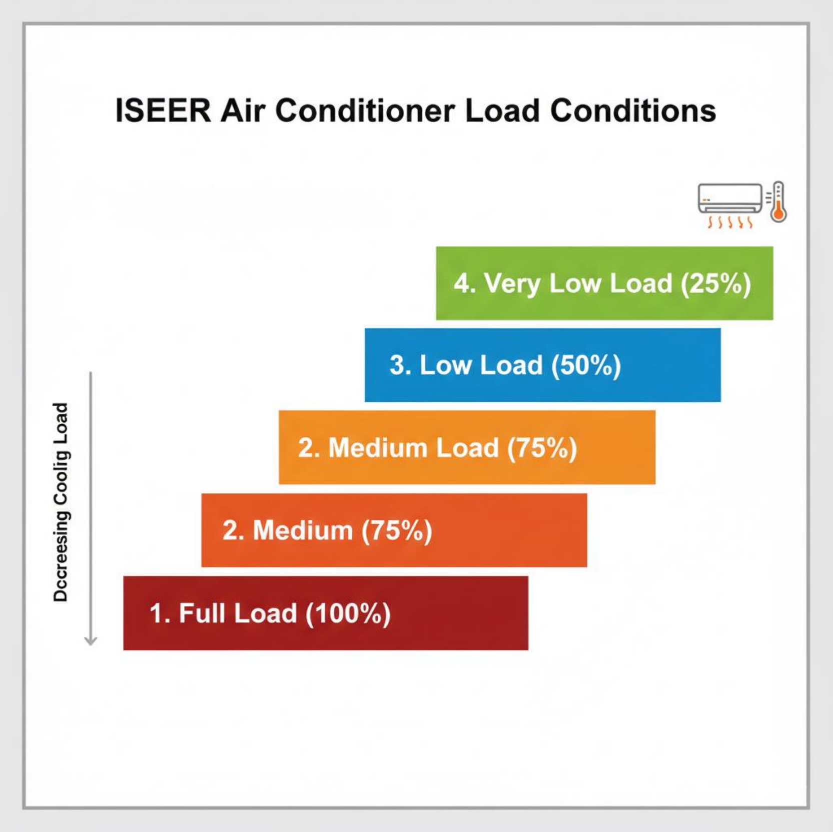

Fig. 2.8 A step bar diagram showing AC operation at 100%, 75%, 50%, and 25% load.

2.4 Temperature Conditions in ISEER Evaluation

- Different **outdoor temperatures** are considered
- Represents seasonal operation (summer, moderate, mild)
- Indoor conditions are maintained constant

📌 *Key Concept:*
AC efficiency changes with outdoor temperature.

2.5 Weightage Factor in ISEER Calculation

Each load condition is assigned a **weightage factor**, representing **how long an AC operates at that load** during a year.

📌 *Simple Explanation:*
AC operates **more hours at partial load** than at full load.

2.6 Step-by-Step Method of ISEER Evaluation

Step 1: Measure Cooling Capacity at Each Load

- Cooling output measured in **Watts**

Step 2: Measure Power Consumption

- Electrical input power measured at each load

Step 3: Calculate Seasonal Cooling Output

- Cooling output × operating hours

Step 4: Calculate Seasonal Energy Consumption

- Power input × operating hours

Step 5: Calculate ISEER

$$\text{ISEER} = \frac{\text{Total Seasonal Cooling Output}}{\text{Total Seasonal Energy Consumption}}$$

2.7 Simplified Numerical Example (Diploma Level)

Given (simplified):

- Total seasonal cooling output = 10,000 kWh
- Total seasonal energy consumption = 2,500 kWh

$$\text{ISEER} = \frac{10,000}{2,500} = 4.0$$

📌 **Interpretation:**
The AC provides **4 units of cooling for every 1 unit of electricity consumed** over a season.

2.8 Significance of ISEER

For Consumers

- Accurate estimate of annual electricity consumption
- Helps compare ACs realistically
- Reduces electricity bills

For Manufacturers

- Encourages efficient compressor and heat exchanger design
- Promotes inverter technology
- Drives innovation

For Utilities

- Helps demand forecasting
- Reduces peak load
- Supports DSM programs

For Energy Auditors

- Basis for AC energy saving calculations
- Helps recommend equipment replacement
- Improves audit accuracy

2.9 ISEER and Star Rating

- BEE uses **ISEER ranges** to assign star ratings
- Higher ISEER → Higher star rating
- Star rating criteria are revised periodically

3. Real-World / Industry Applications (≈ 10 minutes)

- Used in **energy audits** for HVAC systems
- Helps in **selection of ACs** for buildings
- Applied in **green building certification**
- Influences government energy efficiency policies

📌 *Practical Example:*
An inverter AC shows higher ISEER due to better part-load efficiency.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- ISEER measures seasonal efficiency
- Evaluation is done at multiple load conditions
- Weightage factors represent actual usage
- Higher ISEER means better energy saving
- ISEER is more realistic than EER

(Unit–2: Star Level & Energy Saving | Diploma Electrical Engineering | 60-minute detailed classroom session)

---

1. Hook / Introduction (≈ 5 minutes)

Think about how you drive a vehicle in traffic. You don't keep the accelerator fully pressed all the time—you **vary the speed as per road condition**.
Now imagine if an air conditioner worked only at **full speed or completely off**. Would that be efficient?

Traditional air conditioners work like this—**ON–OFF control**. In contrast, modern **inverter air conditioners** use **Variable Frequency Drive (VFD) compressors**, which adjust speed continuously as per cooling demand. This is why inverter ACs are **quieter, more efficient, and more energy-saving**.

---

2. Core Concepts (≈ 40 minutes)

2.1 What is a VFD (Inverter) Compressor?

A **Variable Frequency Drive (VFD) compressor** is a compressor whose **speed can be varied** by changing the **supply frequency** using an **inverter circuit**.

📌 *Basic idea:*

$$\text{Speed of Motor} \propto \text{Supply Frequency}$$

By controlling frequency, the compressor speed and cooling capacity are controlled.

2.2 Conventional (Non-Inverter) vs Inverter AC

Conventional AC (Fixed Speed)

- Compressor operates at full speed
- Frequent ON–OFF cycling
- High starting current
- Poor part-load efficiency

Inverter AC

- Compressor speed varies
- No frequent ON–OFF
- Smooth operation
- High energy efficiency

2.3 Construction of Inverter Compressor System

Main components:

1. **Rectifier** – Converts AC to DC
2. **DC Link** – Smooth DC supply
3. **Inverter** – Converts DC to variable frequency AC
4. **Compressor Motor** – Usually BLDC or PMSM

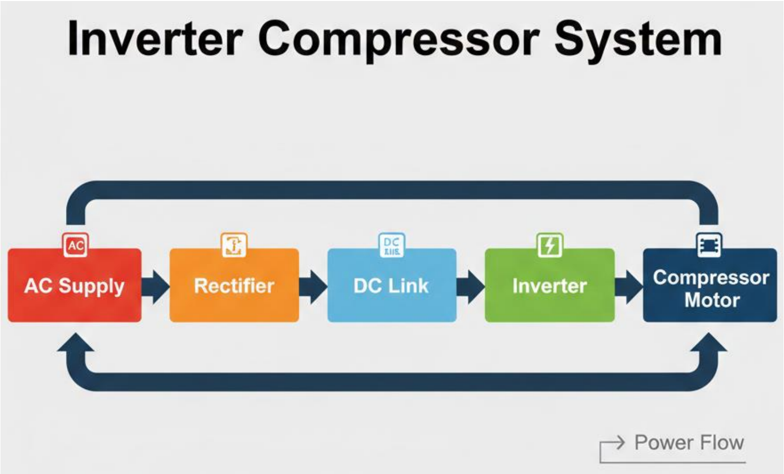

Fig. 2.9 Block diagram of Inverter Compressor System

2.4 Working Principle of VFD Compressor

1. AC power is converted to DC
2. DC is converted to variable frequency AC
3. Compressor motor speed varies as per frequency
4. Cooling output adjusts as per room load

📌 *Important:*
Lower cooling demand → Lower speed → Lower power consumption

2.5 Energy Saving Mechanism

Energy saving occurs due to:

- Reduced starting current
- Elimination of ON–OFF losses
- Better part-load operation
- Reduced compressor cycling

📌 *Key Point:*
Most ACs operate at **partial load**, where inverter ACs are most efficient.

2.6 Effect on EER, ISEER & Star Rating

- Inverter ACs have **higher ISEER**
- Better seasonal efficiency
- Higher star rating achievable

📌 *Link to previous topic:*
VFD compressors improve performance at **25%, 50%, 75% loads** used in ISEER calculation.

2.7 Advantages of Inverter AC

- 20–40% energy saving
- Lower noise
- Better temperature control
- Longer compressor life
- Reduced voltage fluctuation impact

2.8 Limitations / Disadvantages

- Higher initial cost
- Sensitive electronics
- Repair requires skilled technicians

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Residential buildings:** Energy-efficient cooling
- **Commercial spaces:** Variable load conditions
- **Green buildings:** Higher star ratings
- **Energy audits:** Recommended replacement option

📌 *Practical Example:*
Replacing fixed-speed AC with inverter AC gives **short payback period** due to energy savings.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- VFD compressor varies speed using frequency control
- Eliminates frequent ON–OFF operation
- Improves EER and ISEER
- Saves significant energy at part load
- Key technology behind modern inverter ACs

Lecture 10 - Topic 2.10: Window & Split Air Conditioner Star Rating

(Unit–2: Star Level & Energy Saving | 60-minute classroom session)

---

1. Hook / Introduction (≈ 5 minutes)

You may have noticed that when buying an air conditioner, the salesperson highlights two things: **tonnage** and **star rating**.
Two ACs of the same capacity (say 1.5 ton) may have **very different electricity consumption**. Why?

The answer lies in the **BEE star rating system**, which is based on **energy efficiency (ISEER)** and differs slightly in application for **Window ACs and Split ACs**.
Understanding this topic helps you **select the right AC**, **estimate energy consumption**, and **score well in exams**.

---

2. Core Concepts (≈ 40 minutes)

2.1 What is AC Star Rating?

The **star rating of an air conditioner** indicates its **energy efficiency**, decided by the **Bureau of Energy Efficiency (BEE)**.

- Star rating ranges from **1-Star to 5-Star**
- Based on **ISEER (Indian Seasonal Energy Efficiency Ratio)**
- Higher star rating → Higher efficiency → Lower energy consumption

📌 **Important Note:**
Star rating is **not related to cooling capacity** (tonnage), but to **energy efficiency**.

2.2 Basis of Star Rating for Room Air Conditioners

BEE assigns star ratings based on:

- **ISEER value**
- Performance at **partial load conditions**
- Standard test conditions for Indian climate
- Annual energy consumption

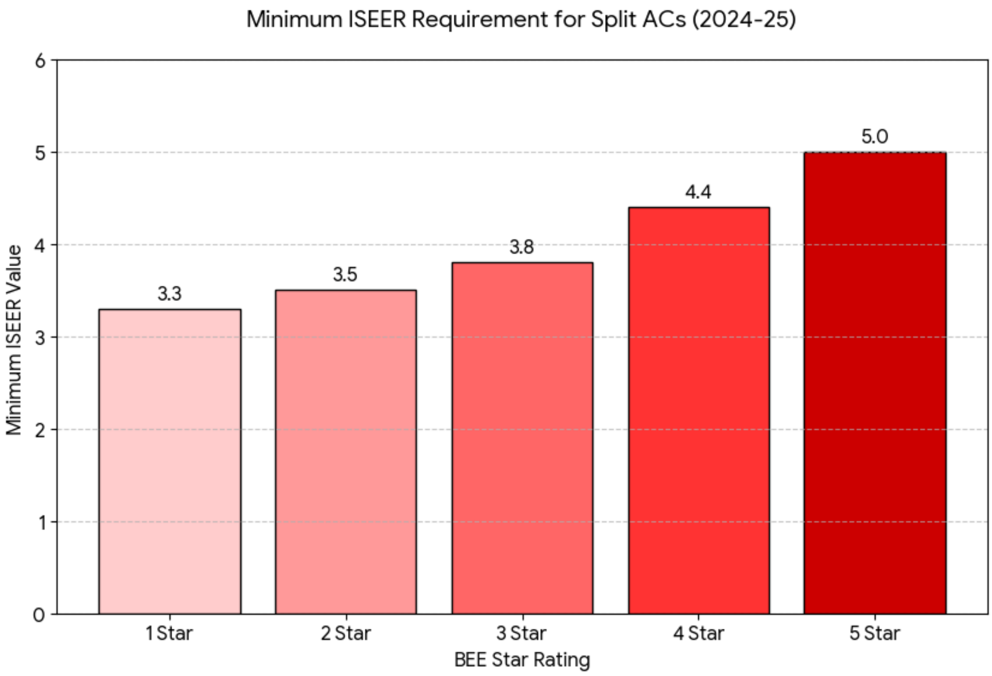

Fig. 2.10 A bar graph showing increasing ISEER from 1-Star to 5-Star.

2.3 Window AC Star Rating

Characteristics

- Fixed-speed compressor (mostly)
- Single unit (indoor + outdoor together)
- Generally lower efficiency compared to split AC

Star Rating Criteria

- Based on **ISEER**
- Lower ISEER range compared to split AC
- Limited maximum star rating due to design constraints

📌 **Energy Aspect:**
Window ACs have:

- Higher heat loss
- Less flexibility in part-load operation
- Lower seasonal efficiency

2.4 Split AC Star Rating

Characteristics

- Separate indoor and outdoor units
- Better heat exchange
- Can be fixed-speed or inverter type

Star Rating Criteria

- Based on **ISEER**
- Inverter split ACs achieve **higher ISEER**
- Better performance at partial load

📌 **Key Reason for Higher Star Rating:**

- Variable speed compressor
- Advanced heat exchangers
- Better airflow and control

2.5 Comparison: Window AC vs Split AC Star Rating

Parameter	Window AC	Split AC
Compressor	Mostly fixed-speed	Fixed / Inverter
ISEER	Lower	Higher
Max Star Rating	Limited	Higher
Part-load efficiency	Poor	Excellent
Energy saving	Lower	Higher

2.6 Star Rating Label – Information Provided

A BEE star label on AC includes:

- Star rating (1–5)
- ISEER value
- Cooling capacity (tonnage)
- Annual energy consumption
- Brand and model
- Year of validity

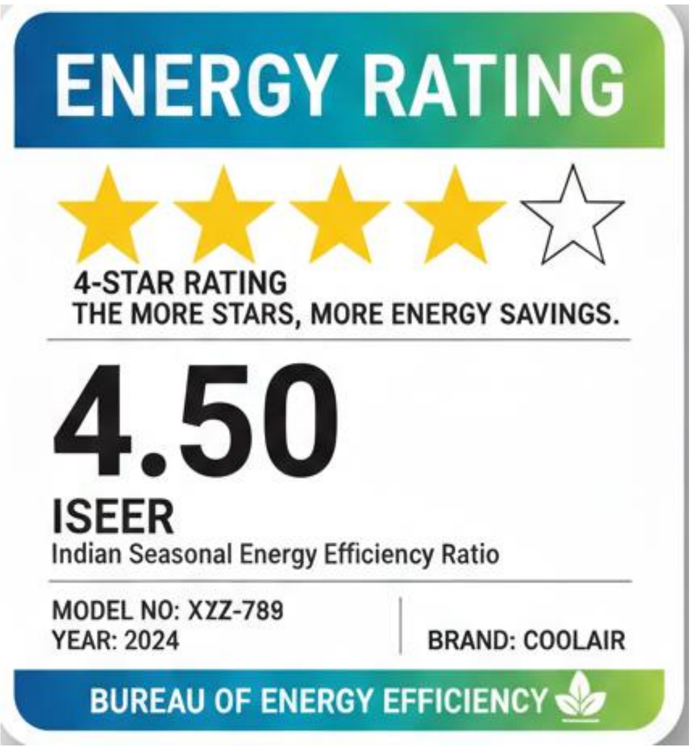

Fig. 2.11 A rectangular BEE label showing stars and energy details.

2.7 Star Rating Revision & Validity

- BEE **revises star rating bands periodically**
- Makes efficiency norms stricter
- Encourages technological improvement

📌 *Fun Fact:*
A 5-Star AC today may become a **3-Star AC** after revision.

2.8 Energy Saving Perspective

- Higher star AC:
  - Consumes less electricity
  - Reduces peak load
  - Saves money in long run
- Best suited for **long operating hours**

📌 **Rule of Thumb:**
If AC runs more than **6–8 hours/day**, higher star rating is always economical.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Households:** Prefer split inverter ACs for better savings
- **Commercial buildings:** High-star split ACs reduce operating cost
- **Energy Auditors:** Recommend AC replacement based on star rating
- **Utilities:** Promote high-star ACs to reduce peak demand

📌 *Practical Example:*
Replacing a 1-Star window AC with a 5-Star split AC can reduce energy consumption by **25–35%**.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- AC star rating is based on ISEER
- Window ACs have lower star rating potential
- Split ACs, especially inverter type, achieve higher star ratings
- Higher star rating means lower annual energy consumption
- Star rating is periodically revised

Lecture 11 - Topic 2.11: Methods to Improve Room Air Conditioner (RAC) Efficiency

(Unit–2: Star Level & Energy Saving | 60-minute detailed classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Have you noticed that two air conditioners of the same capacity and star rating sometimes give **different electricity bills**?
This happens because **efficiency is not only decided by star rating**, but also by **technology, installation, operation, and maintenance**.

As electrical engineers, it is important to understand **how RAC efficiency can be improved** at the design level, installation level, and user level. This topic directly links to **energy saving, star rating improvement, and reduction of peak electricity demand**.

---

2. Core Concepts (≈ 40 minutes)

Methods to improve Room Air Conditioner efficiency can be classified into:

1. **Design & Technology-Based Improvements**
2. **Component-Level Improvements**
3. **Installation & Operational Improvements**

2.1 Advanced Heat Exchangers

Role of Heat Exchangers

- Evaporator absorbs heat from room
- Condenser rejects heat to atmosphere
- Efficiency depends on heat transfer rate

Efficiency Improvement Methods

- Larger heat exchanger surface area
- Fins with better thermal conductivity
- Improved airflow design

📌 *Result:*
Better heat transfer → Lower compressor workload → Energy saving

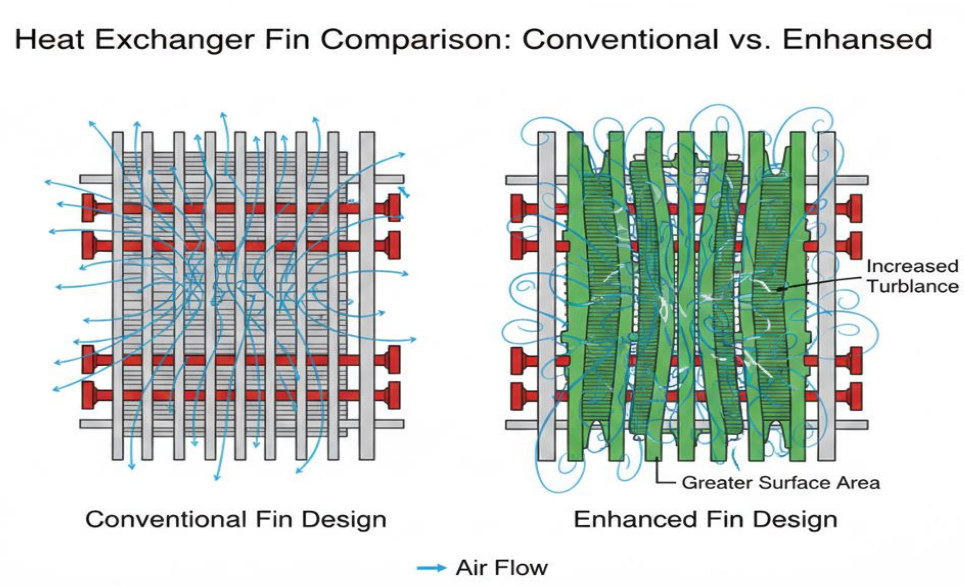

Fig. 2.12 Comparison of conventional vs enhanced fin design.

2.2 Advanced Compressor Technology

- Use of **high-efficiency compressors**
- Improved mechanical design
- Reduced internal leakage
- Lower friction losses

📌 *Example:*
Scroll compressors provide better efficiency than conventional types.

2.3 Variable Frequency Drive (Inverter) Compressors

- Compressor speed varies with load
- Avoids frequent ON–OFF operation
- Reduces starting current and losses

📌 *Link to previous topic:*
VFD compressors significantly improve **ISEER**.

2.4 Electronic Expansion Valves (EEV)

- Precisely control refrigerant flow
- Adjust flow as per cooling load
- Improve evaporator utilization

📌 *Energy Benefit:*
Better control → Higher cooling efficiency → Lower power consumption

---

2.5 High-Efficiency Motors

- Use of **BLDC motors** for indoor fans
- Higher efficiency than induction motors
- Lower heat generation

📌 *Application:*
Used in modern inverter AC indoor units.

2.6 Dual Barrier Technology

- Special coatings on heat exchanger coils
- Protect against:
  - Corrosion
  - Dust
  - Moisture

📌 *Result:*
Maintains efficiency over long time.

2.7 Power Plasma / Air Purification Technologies

- Improve indoor air quality
- Reduce load on evaporator
- Indirectly help maintain efficiency

2.8 Use of Low GWP Refrigerants

- Use of environmentally friendly refrigerants
- Examples: R-32
- Better heat transfer properties

📌 *Benefits:*
Improves efficiency + reduces environmental impact

2.9 Proper Installation Practices

- Correct refrigerant charge
- Proper insulation of piping
- Correct placement of indoor & outdoor units

📌 *Practical Insight:*
Poor installation can reduce efficiency by **10–15%**.

2.10 Regular Maintenance

- Cleaning filters
- Cleaning condenser coils
- Checking refrigerant pressure

📌 *Fun Fact:*
A dirty filter can increase energy consumption by **5–10%**.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Manufacturers:** Use advanced components to achieve higher star rating
- **Energy Auditors:** Recommend operational improvements
- **HVAC Engineers:** Design systems for maximum seasonal efficiency
- **Consumers:** Save electricity through correct usage

📌 *Example:*
Upgrading to inverter AC + regular maintenance gives maximum energy saving.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- RAC efficiency can be improved at multiple levels
- Advanced heat exchangers and compressors play key role
- Inverter technology significantly improves efficiency
- Installation and maintenance are equally important
- Efficiency improvement leads to lower bills and higher star rating

[Lecture 12 - Topic 2.12: IoT-Based Applications in Room Air Conditioners (RAC) & Super-Efficient ACs]

(Unit–2: Star Level & Energy Saving | 60-minute detailed classroom session)

---

1. Hook / Introduction (≈ 5 minutes)

Think about this situation: you are on the way home from college on a hot summer day. Wouldn't it be convenient if your AC could **switch ON automatically**, cool the room to the right temperature, and **consume minimum electricity**—all without you touching a switch?

This is no longer imagination. With **IoT (Internet of Things)** and **super-efficient air conditioners**, cooling systems have become **smart, connected, and energy-optimized**. For electrical engineers, this topic is important because it combines **energy efficiency, automation, control, and modern technology**, which is the future of HVAC systems.

---

2. Core Concepts (≈ 40 minutes)

2.1 What is IoT in Room Air Conditioners?

IoT-based RAC means an air conditioner that can:

- Communicate through the internet
- Be monitored and controlled remotely
- Automatically optimize energy consumption

📌 *Simple definition:*

IoT connects ACs with sensors, controllers, and cloud platforms to make them **smart and energy efficient**.

2.2 Basic Architecture of IoT-Based RAC

Main elements:

1. **Sensors** – temperature, humidity, occupancy, power
2. **Controller / Microcontroller**
3. **Communication module** (Wi-Fi)
4. **Cloud platform**

5. **User interface** (mobile app)

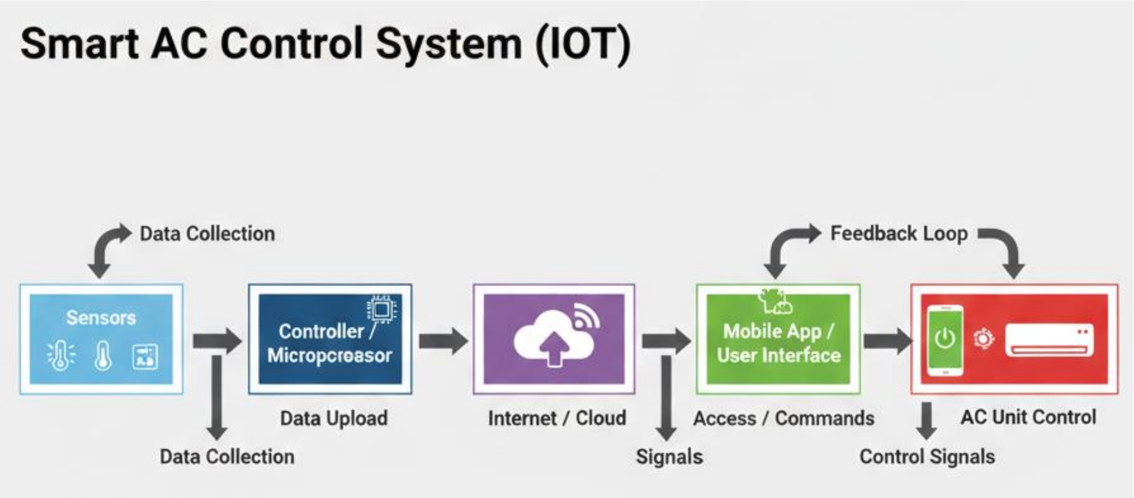

Fig. 2.13 Basic Elements & block diagram of IoT-Based RAC

2.3 Key IoT Features in RAC

1. Remote Monitoring & Control

- ON/OFF control via mobile
- Temperature and mode setting
- Timer scheduling

📌 *Energy benefit:*
Avoids unnecessary AC operation.

---

2. Smart Scheduling

- AC operates only during required hours
- Load shifting to non-peak hours

📌 *Link to DSM:*
Supports **Demand Side Management**.

---

3. Occupancy-Based Control

- AC reduces cooling when room is empty

- Uses motion or occupancy sensors

📌 *Result:*
Major energy saving in offices and classrooms.

---

4. Adaptive Cooling

- Adjusts compressor speed automatically
- Depends on room load, outdoor temperature

📌 *Technology used:*
Inverter compressors + smart algorithms.

---

5. Energy Monitoring

- Displays real-time power consumption
- Daily, monthly energy reports

📌 *Use in energy audit:*
Helps track AC energy usage accurately.

2.4 Super-Efficient Air Conditioners

Super-efficient ACs are advanced ACs that consume **much less electricity** compared to conventional ACs.

Key Technologies Used

- Inverter (VFD) compressors
- High-efficiency heat exchangers
- Electronic expansion valves
- BLDC motors
- Low GWP refrigerants (R-32)

📌 *Important:*
Super-efficient ACs usually have **very high ISEER values**.

2.5 Difference: Conventional AC vs IoT-Based Super-Efficient AC

Parameter	Conventional AC	IoT-Based Super-Efficient AC
Control	Manual	Smart & remote
Compressor	Fixed speed	Inverter
Energy monitoring	Not available	Available
Efficiency	Moderate	Very high
ISEER	Lower	Higher

2.6 Role of IoT in Improving RAC Efficiency

- Reduces idle operation
- Improves part-load efficiency
- Optimizes compressor speed
- Improves maintenance planning

📌 *Example:*
Automatic alert for dirty filters prevents efficiency loss.

2.7 Predictive Maintenance Using IoT

- Monitors temperature, current, vibration
- Detects faults early
- Prevents sudden breakdowns

📌 *Energy advantage:*
Fault-free AC operates closer to rated efficiency.

2.8 Environmental & National Benefits

- Reduced electricity demand
- Lower peak load
- Reduced carbon emissions
- Supports **energy conservation goals of India**

📌 *Fun Fact:*
Large-scale use of super-efficient ACs can save **thousands of MW** of power nationally.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Smart homes:** App-controlled inverter ACs
- **Commercial buildings:** Centralized monitoring of RACs
- **Hotels & hospitals:** Occupancy-based cooling
- **Energy audits:** Real-time data for efficiency analysis
- **Utilities:** Load forecasting and DSM programs

📌 *Practical Example:*
IoT-based ACs in offices automatically reduce cooling during lunch breaks, saving energy.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- IoT makes RACs smart and energy efficient
- Sensors, controllers, and cloud enable automation
- Super-efficient ACs use advanced technologies
- IoT improves ISEER and reduces energy wastage
- Future RACs will be intelligent and connected

● PHASE 3: STUDENT AI TOOLKIT (25 PROMPTS)

A. Low-Level Prompts (Remember & Understand) – 10 Prompts

1. *"Explain the Standards & Labeling (S&L) Program in simple words suitable for diploma students."*
2. *"What is a star label? Explain the meaning of 1-star to 5-star rating in simple terms."*
3. *"List mandatory and voluntary star-labeled appliances in India as per BEE."*
4. *"Define Energy Efficiency Ratio (EER) and Indian Seasonal Energy Efficiency Ratio (ISEER)."*
5. *"Explain why higher star-rated appliances consume less electricity."*
6. *"Explain the difference between window AC and split AC in simple points."*
7. *"What is an inverter (VFD-based) compressor? Explain in simple language."*
8. *"Explain the difference between electronic ballast and magnetic ballast."*
9. *"List the advantages of using energy-efficient appliances."*
10. *"Summarize Unit-2: Star Level & Energy Saving in 10 easy revision points."*

B. Moderate-Level Prompts (Apply & Analyze) – 10 Prompts

11. *"Compare mandatory and voluntary star labeling with examples in a table."*
12. *"Explain the significance of 1-star to 5-star ratings for refrigerators, ACs, and ceiling fans."*
13. *"Calculate and compare annual energy consumption of a 3-star and 5-star AC using assumed data."*
14. *"Explain why ISEER is a better performance indicator than EER for air conditioners."*
15. *"Analyze energy savings achieved by replacing a conventional water pump with a star-rated pump."*
16. *"Explain the working principle of an air conditioner using the four processes: evaporation, compression, condensation, and expansion."*
17. *"Explain how variable frequency drive (inverter) compressors reduce energy consumption."*
18. *"Analyze the impact of star-rated distribution transformers on energy losses."*
19. *"Explain the role of star labeling in national energy conservation programs."*
20. *"Prepare a short case study showing energy and cost savings due to star-rated appliances."*

C. High-Level Prompts (Design & Create) – 5 Prompts

21. *"Design a comparison chart showing energy consumption and cost savings for 1-star to 5-star appliances over one year."*
22. *"Create a decision-making guide to help a consumer select the most energy-efficient AC based on star rating and ISEER."*
23. *"Develop a case study for an institution upgrading to star-rated appliances and calculate payback period."*
24. *"Create a concept map connecting star labeling, energy efficiency, inverter technology, and national energy savings."*
25. *"Design an awareness poster or presentation outline explaining the benefits of star-rated appliances for energy conservation."*

● PHASE 4: MASTERY CHECK

---

1. Key Definitions / Glossary (Top 15 Terms)

1. **Standards & Labeling Program (S&L)** – A scheme by BEE to rate appliances based on their energy efficiency using star labels.
2. **Star Rating** – A rating from 1 to 5 stars indicating the energy efficiency of an appliance; higher stars mean higher efficiency.
3. **Mandatory Appliances** – Appliances for which star labeling is compulsory as per BEE regulations.
4. **Voluntary Appliances** – Appliances where star labeling is optional but encouraged.
5. **Energy Efficiency Ratio (EER)** – Ratio of cooling output to power input of an air conditioner under rated conditions.
6. **Indian Seasonal Energy Efficiency Ratio (ISEER)** – Seasonal efficiency index of air conditioners considering varying load conditions.
7. **Frost-Free Refrigerator** – Refrigerator that prevents ice formation automatically using electric heating.
8. **Distribution Transformer Star Level** – Efficiency classification of transformers based on loss levels.
9. **Variable Frequency Drive (VFD)** – Device used to control speed of motor or compressor by varying supply frequency.
10. **Inverter Air Conditioner** – AC using VFD-based compressor for variable speed operation.
11. **Energy Saving** – Reduction in energy consumption while maintaining same output or comfort.
12. **Electronic Ballast** – High-frequency electronic circuit used to operate fluorescent lamps efficiently.
13. **Magnetic Ballast** – Iron-core ballast operating at supply frequency with higher losses.

14. **Time-of-Use Efficiency** – Efficiency variation of appliances at different operating conditions.
15. **IoT-Based Control** – Use of internet-enabled sensors and controls to optimize appliance performance and energy use.

---

2. FAQ & Assessment Section

A. Multiple Choice Questions (MCQs)

Q1. Star labeling program in India is implemented by:
A) CEA
B) MNRE
C) BEE
D) DISCOM

Q2. Higher star rating indicates:
A) Higher power consumption
B) Lower efficiency
C) Higher energy efficiency
D) Higher voltage

Q3. Which appliance comes under mandatory star labeling?
A) Electric iron
B) Ceiling fan
C) Mixer grinder
D) Electric kettle

Q4. EER is the ratio of:
A) Input power to cooling capacity
B) Cooling capacity to input power
C) Energy consumed per hour
D) Voltage to current

Q5. ISEER differs from EER because it considers:
A) Only peak load
B) Seasonal load variations
C) Voltage variations
D) Power factor

Q6. Which star rating consumes the least energy?
A) 1-star
B) 2-star
C) 3-star
D) 5-star

Q7. Inverter AC saves energy mainly due to:
A) Higher voltage
B) Constant speed compressor
C) Variable speed compressor
D) Larger condenser

Q8. Which ballast has lower losses?
A) Magnetic ballast
B) Electronic ballast
C) Iron-core ballast
D) Reactor

Q9. Energy-efficient pump set gives savings due to:
A) Higher HP
B) Lower efficiency
C) Improved hydraulic and motor efficiency
D) Higher speed

Q10. Distribution transformer star rating is based on:
A) Output voltage
B) Temperature rise
C) Core and copper losses
D) Power factor

Q11. Window AC and Split AC differ mainly in:
A) Voltage rating
B) Installation and construction
C) Refrigerant type
D) Frequency

Q12. Which refrigerant is considered eco-friendly?
A) R-22
B) R-12
C) Low GWP refrigerants
D) CFCs

Q13. Energy saving from star-rated appliances results in:
A) Higher tariff
B) Reduced electricity bill
C) Increased demand
D) Voltage drop

Q14. Which appliance uses maximum electricity in a household?
A) Fan
B) LED lamp
C) Refrigerator / AC
D) Mobile charger

Q15. IoT in appliances helps in:
A) Increasing power consumption
B) Manual control
C) Monitoring and optimizing energy use
D) Reducing voltage

Q16. Magnetic ballast causes flicker due to:
A) DC operation
B) High frequency
C) Low frequency operation
D) High PF

Q17. Star label on appliances mainly helps consumers to:
A) Select cheaper appliance
B) Select stylish appliance
C) Compare energy efficiency
D) Increase power usage

Q18. Which motor generally has star labeling?
A) Universal motor
B) DC motor
C) Induction motor
D) Stepper motor

Q19. Energy saving case studies are used to:
A) Increase tariff
B) Calculate penalties
C) Demonstrate economic benefit
D) Increase load

Q20. Electronic ballast operates at frequency of:
A) 50 Hz
B) 100 Hz
C) 20–50 kHz
D) 1 MHz

Answer Key (MCQs)

1. C
2. C
3. B
4. B
5. B
6. D
7. C
8. B
9. C

10. C
11. B
12. C
13. B
14. C
15. C
16. C
17. C
18. C
19. C
20. C

B. Short Answer / Viva Questions (10 Questions)

1. What is the purpose of the star labeling program?
2. Differentiate between mandatory and voluntary star-labeled appliances.
3. Define EER and ISEER.
4. Why is ISEER more realistic than EER?
5. Explain how inverter AC saves energy.
6. List any four star-labeled appliances.
7. Compare electronic ballast and magnetic ballast.
8. What is the significance of star rating in distribution transformers?
9. Explain energy saving using energy-efficient pumps or transformers.
10. How do IoT-based appliances help in energy conservation?

● PHASE 5: DIGITAL RESOURCE LIBRARY

AI & Tools

- BEE Star Label Portal – Rating reference
- RETScreen – Energy saving estimation
- Excel – Payback calculation
- AI Chatbots – Concept clarification

Video Learning (Search Keywords)

Topic	Platform	Keywords
Star Labeling	NPTEL	"BEE star labeling diploma"
AC Working	Khan Academy	"Vapor compression cycle AC"
ISEER	BEE	"ISEER calculation RAC"

● PHASE 6: EXTERNAL EXPOSURE

- **Emerging Tech:** Inverter AC, IoT HVAC, EV chargers
- **MOOCs:**
  - NPTEL – Energy Efficiency
  - SWAYAM – HVAC basics
- **Industry Visit:**
  - HVAC manufacturing unit
  - Transformer factory
  - Pump testing lab
- **Events:** IEEE Energy Conferences, BEE workshops

● PHASE 7: PREDICTED QUESTION BANK

Most Repeated Questions

- Explain star labeling program.
- Differentiate EER and ISEER.
- Explain working principle of AC.
- Explain benefits of 5-star appliances.
- Case study on energy efficient pump.

Application Questions

1. Compare energy cost of 3-star and 5-star AC.
2. Explain energy saving using inverter AC.
3. Analyze transformer star rating benefits.
4. Calculate energy saving using star rating data.
5. Suggest AC efficiency improvement measures.

🔶 UNIT–3: REACTIVE POWER COMPENSATION

Subject: Energy Efficiency & Audit
Branch: Diploma Electrical Engineering
Semester: 4 (GTU)

● PHASE 1: UNIT–3: UNIT–WISE STUDY PLAN

Topic No.	Topic Name	Nature	Hours	Exam Importance	Practical Relevance
3.1	Concept of Reactive Power & Power Factor	Core	1	Very High	High
3.2	Causes of Low Power Factor	Core	0.5	High	High
3.3	Advantages of Reactive Power Compensation	Core	0.5	High	Very High
3.4	Methods of Compensation: Centralized, Group & Individual	Core	1	Very High	Very High
3.5	Capacitor Rating using Formula & Standard Table	Core	1	Very High	Very High
3.6	Effect of Power Factor on 3-Phase Line Current (Case Study)	Application	0.5	High	High
3.7	Effect of Power Factor on Copper Losses (Case Study)	Application	0.5	High	High
3.8	Capacitor Rating for Star & Delta Connection	Core	0.5	High	Very High
3.9	Effect of Power Factor on Cable Size & Energy Saving	Application	0.5	Medium	High

---

⬤ PHASE 2: DETAILED LECTURE SERIES

Lecture 1 - Topic 3.1: Concept of Reactive Power & Power Factor

(Unit–3: Reactive Power Compensation | 60-minute classroom session)

---

1. Hook / Introduction (≈ 5 minutes)

Let me start with a simple question: **Why does an industry get penalized even after paying for all the units (kWh) it consumes?**
Or why does a motor draw more current than expected, even though its output power is fixed?

The answer lies in **reactive power and power factor**—two concepts that do not appear directly on your electricity bill in units, but **strongly affect losses, equipment size, and cost**. For an electrical engineer, understanding reactive power is as important as understanding voltage and current, because it directly impacts **system efficiency and energy management**.

---

2. Core Concepts (≈ 40 minutes)

2.1 What is Reactive Power?

In an AC system, power is not just one quantity. It has **two components**:

1. **Active Power (P)**
   - Does useful work (rotation of motor, lighting, heating)
   - Unit: **kilowatt (kW)**
2. **Reactive Power (Q)**
   - Required to **establish magnetic and electric fields**
   - Does no useful mechanical work
   - Unit: **kilovolt-ampere reactive (kVAR)**

📌 *Simple analogy:*
Active power is like **milk you drink**, reactive power is like **foam on milk**—necessary, but not useful by itself.

2.2 Why Reactive Power is Needed?

Most electrical loads are **inductive**:

- Induction motors

- Transformers
- Fluorescent lamps
- Welding machines

These loads require **magnetizing current** to create a magnetic field. This magnetizing current consumes **reactive power**.

📌 *Important:*
Without reactive power, **motors cannot rotate and transformers cannot work**.

2.3 Apparent Power and Power Triangle

The combination of active and reactive power is called **apparent power (S)**.

$$\text{Apparent Power (kVA)} = \sqrt{P^2 + Q^2}$$

- Horizontal side → Active Power (kW)
- Vertical side → Reactive Power (kVAR)
- Hypotenuse → Apparent Power (kVA)

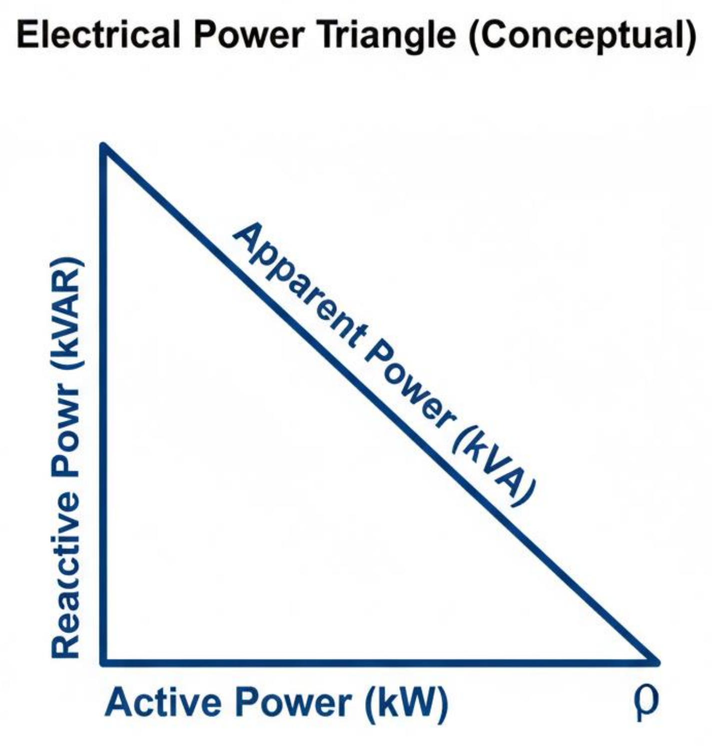

Fig. 3.1 Right-angled power triangle

2.4 What is Power Factor (PF)?

Power Factor is the ratio of active power to apparent power.

$$\boxed{\text{Power Factor} = \cos\phi = \frac{\text{kW}}{\text{kVA}}}$$

- PF varies between **0 and 1**
- Ideal PF = **1 (unity)**

📌 *Key Interpretation:*
Higher power factor means **less reactive power for the same useful work**.

2.5 Causes of Low Power Factor

- Inductive loads (motors, transformers)
- Lightly loaded motors
- Poor system design
- Long transmission lines
- Old or inefficient equipment

📌 *Fun Fact:*
A lightly loaded motor has **worse power factor** than a fully loaded motor.

2.6 Effects of Low Power Factor

Low power factor causes:

- Higher line current
- Increased copper losses (I^2R)
- Larger cable size required
- Reduced system capacity
- Penalty from electricity utility

📌 *Technical Insight:*
For the same kW load, **lower PF → higher current → higher losses**.

2.7 Leading and Lagging Power Factor

- **Lagging PF:**
  Caused by inductive loads (most common)

- **Leading PF:**
  Caused by capacitive loads

📌 *Engineering Practice:*
Capacitors are used to **compensate lagging reactive power**.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:**
  Install capacitor banks to improve power factor and avoid penalties.
- **Utilities:**
  Monitor PF to reduce transmission losses.
- **Energy Auditors:**
  Analyze reactive power to recommend compensation.
- **Design Engineers:**
  Size transformers, cables, and generators considering PF.

📌 *Practical Example:*
Improving PF from 0.7 to 0.95 can reduce current by **25–30%** for the same load.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Reactive power is essential for AC systems but does no useful work.
- Power factor indicates how effectively electrical power is utilized.
- Low power factor increases current, losses, and cost.
- Most industrial loads have lagging power factor.
- Improving power factor improves system efficiency.

Lecture 2 - Topic 3.2: Causes of Low Power Factor (with Examples) & Topic 3.3: Advantages of Reactive Power Compensation

(Unit–3: Reactive Power Compensation | 60-minute classroom session)

---

1. Hook / Introduction (≈ 5 minutes)

Imagine two factories producing the **same output**, but one receives a **penalty on the electricity bill** every month while the other does not.
What could be the reason?

The most common reason is **low power factor**. Industries do not pay penalties just for consuming more units—they pay because their equipment **draws excessive reactive power**.
In this lecture, we will understand **why power factor becomes low** and **how reactive power compensation solves this problem**, both technically and economically.

---

2. Core Concepts (≈ 40 minutes)

Topic 3.2: Causes of Low Power Factor

1. Inductive Loads (Major Cause)

Most electrical loads are **inductive**:

- Induction motors
- Transformers
- Fluorescent lamps
- Welding machines

These loads require **magnetizing current**, which draws reactive power and causes **lagging power factor**.

📌 *Example:*
A 10 HP induction motor typically operates at **0.7–0.8 PF** at partial load.

---

2. Lightly Loaded Motors

- Motors designed for higher capacity
- Operated at low load

- Magnetizing current remains nearly constant
- Active power reduces → PF decreases

📌 *Fun Fact:*
A motor at **30% load** has poorer PF than at full load.

---

3. Transformers at No Load or Light Load

- Core magnetizing current flows even without load
- Causes reactive power consumption
- Low PF during idle operation

📌 *Example:*
Distribution transformers at night operate at low load with poor PF.

---

4. Arc Furnaces and Welding Equipment

- Highly inductive and fluctuating loads
- Cause sudden PF variation
- Increase system losses

---

5. Long Transmission and Distribution Lines

- Line inductance draws reactive power
- More pronounced at high voltages and long distances

---

6. Low Supply Voltage

- Motors draw more current
- Reactive component increases
- PF reduces further

Topic 3.3: Advantages of Reactive Power Compensation

Reactive power compensation is mainly achieved using **capacitors**, which supply leading reactive power to cancel lagging reactive power.

---

1. Improvement in Power Factor

- Reduces reactive power demand
- Brings PF closer to unity
- Most important advantage

📌 *Example:*
Improving PF from **0.75 to 0.95** significantly reduces current.

---

2. Reduction in Line Current

For same kW load:

$$I \propto \frac{1}{\cos \phi}$$

Higher PF → Lower current

📌 *Result:*
Lower current reduces losses and heating.

---

3. Reduction in Copper Losses

$$\text{Copper Loss} = I^2 R$$

- Lower current → Lower losses
- Improves system efficiency

---

4. Improved Voltage Regulation

- Reduced voltage drop in cables and lines
- Better equipment performance

---

5. Increased System Capacity

- Same transformer and cables can supply **more active power**
- Avoids infrastructure upgrade

---

6. Reduction in Electricity Bill

- Avoids PF penalty
- Gains PF incentive from utility
- Reduces energy losses

📌 *Industry Practice:*
Utilities often require PF ≥ **0.9 or 0.95**.

---

7. Longer Equipment Life

- Reduced heating
- Less stress on insulation
- Improved reliability

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Install capacitor banks to maintain PF
- **Utilities:** Encourage PF correction to reduce losses
- **Energy Auditors:** Recommend optimal capacitor sizing
- **Design Engineers:** Optimize cable and transformer sizing

📌 *Practical Example:*
Installing capacitor banks in a textile mill can save **lakhs of rupees annually**.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Low PF is mainly due to inductive loads and light loading
- Low PF causes higher current and losses
- Reactive power compensation improves PF
- PF improvement reduces cost and increases efficiency
- Capacitors are the most common compensation devices

Lecture 3 - Topic 3.4: Methods of Reactive Power Compensation – Centralized, Group & Individual

(Unit–3: Reactive Power Compensation | 60-minute detailed classroom session)

---

1. Hook / Introduction (≈ 5 minutes)

Suppose an industry installs a large capacitor bank at one location and still faces **voltage drop near machines**.
Why does this happen?

The reason is **where and how** reactive power compensation is applied. Power factor correction is not only about **how much kVAR** we install, but also **at what location**. In this lecture, we will study the **three main methods of compensation—Centralized, Group, and Individual**, their working, advantages, limitations, and applications.

---

2. Core Concepts (≈ 40 minutes)

Reactive power compensation is achieved mainly using **capacitors**. Depending on installation location, compensation methods are classified as:

1. **Centralized Compensation**
2. **Group Compensation**
3. **Individual Compensation**

---

1. Centralized Compensation

Concept

In centralized compensation, a **common capacitor bank** is installed at:

- Main LT panel
- Substation
- Incoming feeder

All loads draw reactive power from this centralized capacitor bank.

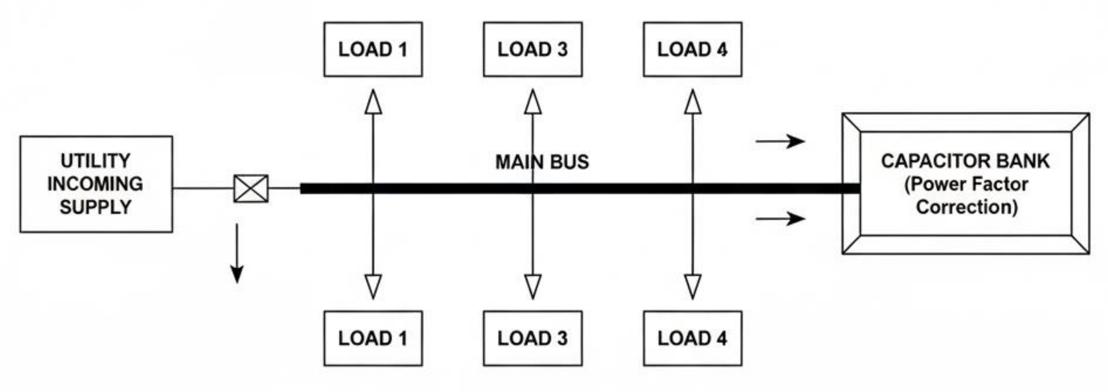

Fig. 3.2 Single-line diagram showing capacitor bank at main bus supplying multiple loads.

Advantages

- Easy installation and maintenance
- Lower initial cost
- Suitable for industries with **varying loads**

Disadvantages

- Reactive current still flows in feeders
- Limited voltage improvement at load end
- Less effective for long cable runs

Applications

- Small and medium industries
- Buildings with centralized distribution
- Loads that vary frequently

---

2. Group Compensation

Concept

In group compensation, capacitor banks are installed for a **group of similar loads**.

📌 *Example:*
One capacitor bank for all motors in a production section.

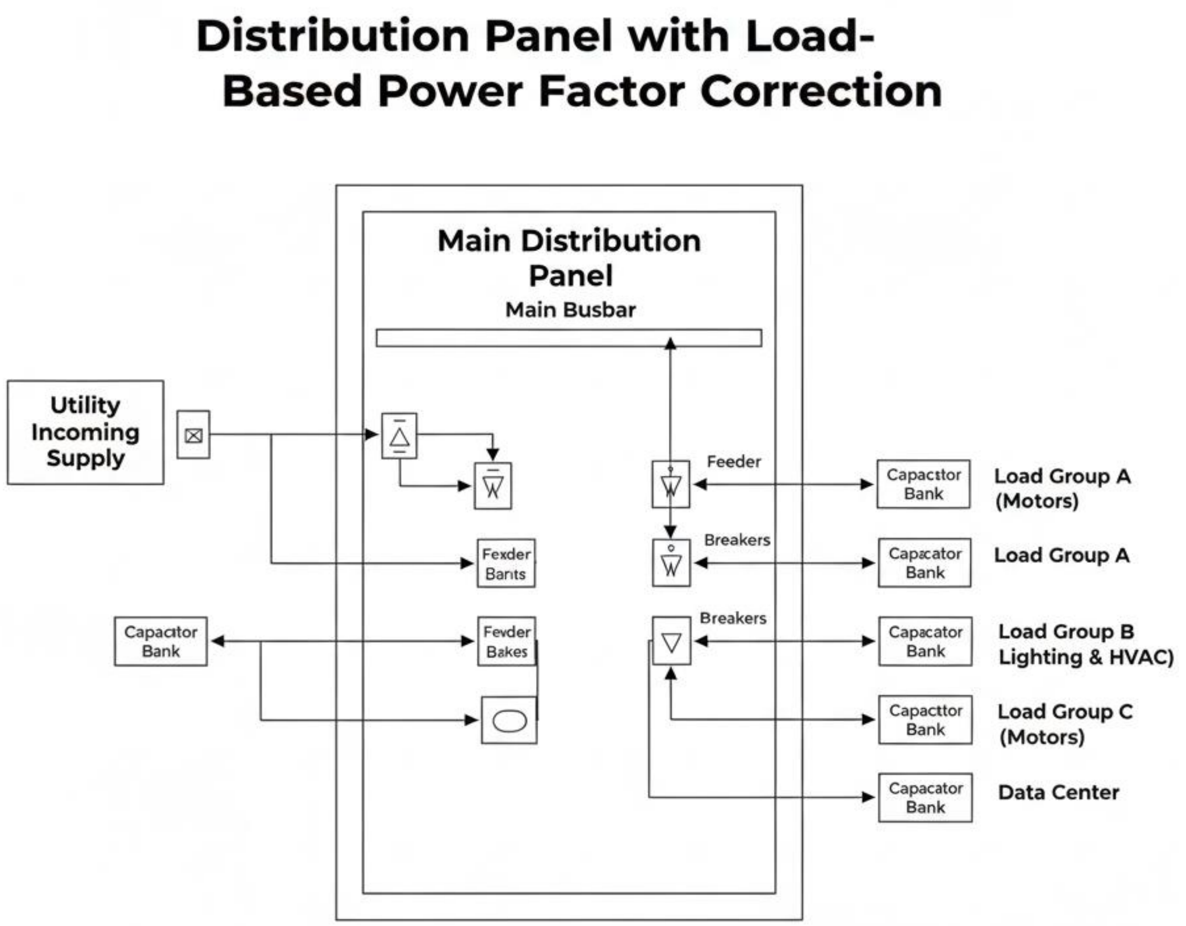

Fig. 3.3 Distribution panel with separate capacitor banks for load groups.

Advantages

- Better voltage improvement near load
- Reduced feeder current
- Balanced cost and performance

Disadvantages

- Higher cost than centralized
- Requires proper grouping and planning

Applications

- Industrial plants with sectional loads
- Workshop areas
- Process industries

3. Individual Compensation

Concept

In individual compensation, a **capacitor is connected directly across each inductive load**, such as a motor.

📌 *Example:*
Capacitor connected across motor terminals.

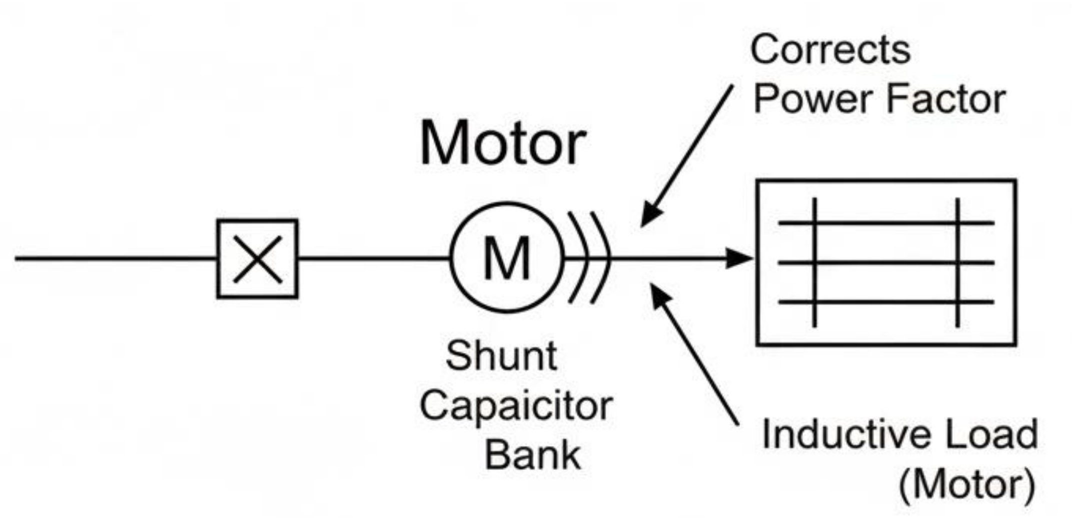

Fig. 3.4 Motor with shunt capacitor connected in parallel.

Advantages

- Maximum PF improvement
- Minimum reactive current in system
- Best voltage regulation
- Reduced losses in cables and transformers

Disadvantages

- Higher initial cost
- Requires switching control
- Risk of overcompensation if load changes

Applications

- Large motors
- Constant load equipment
- Pumps, compressors

Comparison of Compensation Methods

Parameter	Centralized	Group	Individual
Cost	Low	Medium	High
Effectiveness	Low	Medium	High
Voltage improvement	Poor	Better	Best
Maintenance	Easy	Moderate	Complex

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Combine group and individual compensation
- **Utilities:** Encourage centralized PF correction
- **Energy Auditors:** Recommend optimal compensation method
- **Design Engineers:** Decide location based on load pattern

📌 *Practical Example:*
Large motor gets individual capacitor, while small motors use group compensation.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Location of capacitor is as important as rating
- Centralized is economical but less effective
- Group offers balanced performance
- Individual gives best PF improvement
- Selection depends on load type and variation

Lecture 4 - Topic 3.5: Capacitor Rating for Power Factor Improvement

(Unit–3: Reactive Power Compensation | 60-minute detailed classroom session)

---

1. Hook / Introduction (≈ 5 minutes)

Imagine an industry that installs capacitors randomly without calculation and ends up with a **leading power factor**, causing equipment damage and penalties.
So the big question is: **How much capacitor kVAR is actually required?**

Power factor improvement is not guesswork—it is a **calculated engineering decision**. In this lecture, we will learn **how to calculate capacitor rating using formulas and standard tables**, which is one of the **most important numerical topics in Unit–3**.

---

2. Core Concepts (≈ 40 minutes)

2.1 Why Capacitor Rating Calculation is Required

- To improve PF to desired value (usually 0.95 or above)
- To avoid under-compensation or over-compensation
- To minimize losses and penalties
- To ensure safe and economical operation

📌 *Key Idea:*
Capacitor supplies **leading reactive power (kVAR)** to cancel lagging reactive power of inductive loads.

2.2 Power Triangle Concept (Revision)

From the power triangle:

- Active Power = **P (kW)**
- Reactive Power = **Q (kVAR)**
- Apparent Power = **S (kVA)**

$$Q = P \tan \phi$$

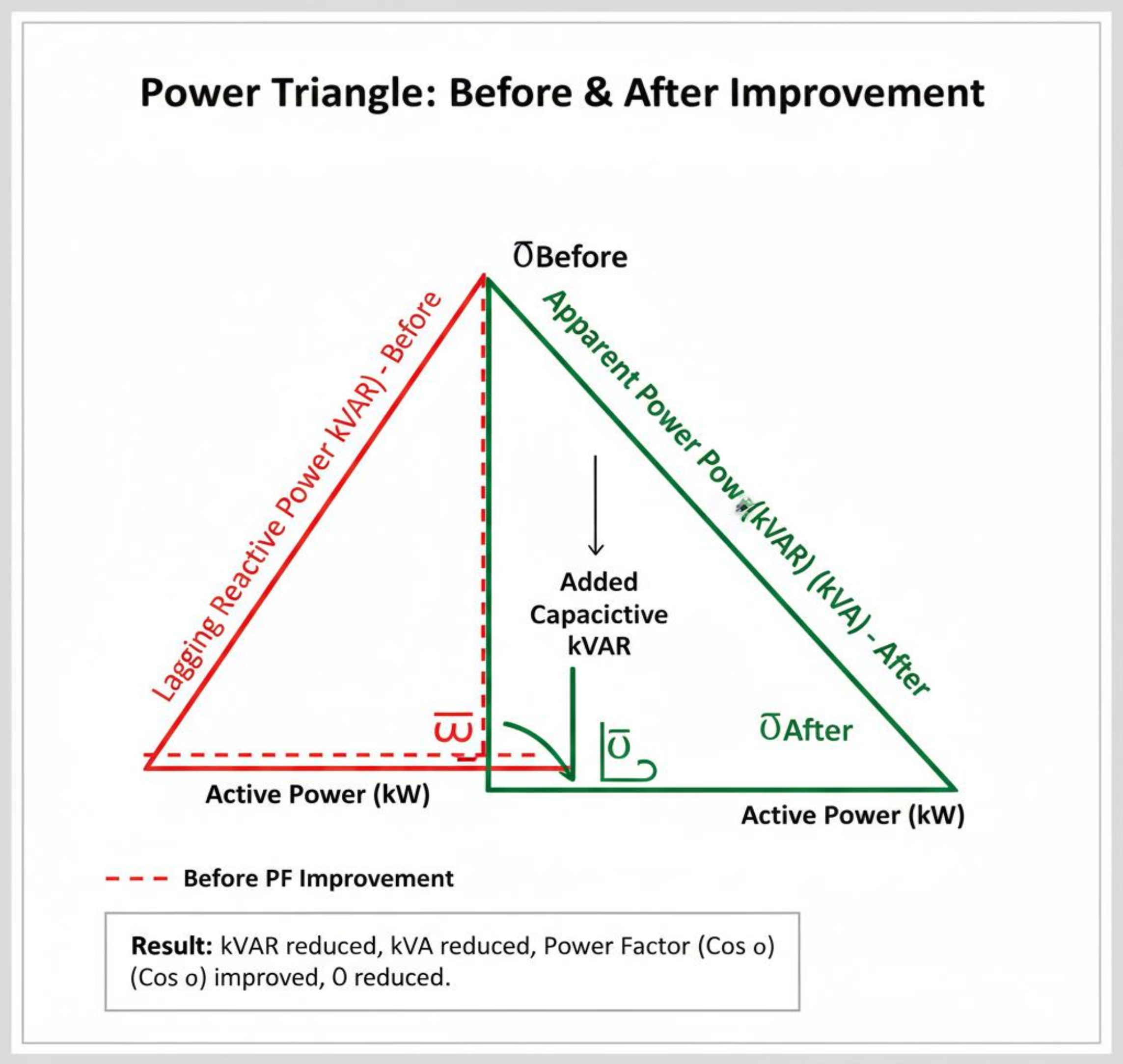

Fig. 3.5 Power triangle showing before and after PF improvement.

2.3 Capacitor Rating Using Formula Method

Given Parameters

- Load power = **P (kW)**
- Initial power factor = $\cos\varphi_1$
- Final (desired) power factor = $\cos\varphi_2$

Step-by-Step Formula

1. Calculate initial angle:
   $$\phi_1 = \cos^{-1}(\text{Initial PF})$$

2. Calculate final angle:
   $\phi_2 = \cos^{-1}(\text{Final PF})$
3. Calculate required capacitor kVAR:
   $\boxed{Q_c = P(\tan\phi_1 - \tan\phi_2)}$

Numerical Example – Formula Method

Given:

- Load = 100 kW
- Initial PF = 0.8
- Desired PF = 0.95

$$\phi_1 = \cos^{-1}(0.8) = 36.87^\circ$$

$$\phi_2 = \cos^{-1}(0.95) = 18.19^\circ$$

$$Q_c = 100(\tan 36.87^\circ - \tan 18.19^\circ)$$

$$Q_c = 100(0.75 - 0.328) = 42.2\ \text{kVAR}$$

📌 **Conclusion:**
A **42.2 kVAR capacitor bank** is required.

2.4 Capacitor Rating Using Standard Table Method

To simplify calculations, **standard PF correction tables** are used.

Steps

1. Find initial PF
2. Find desired PF
3. Refer PF correction factor from table
4. Multiply by load kW

Sample Standard PF Correction Table (Indicative)

Initial PF	PF = 0.95	PF = 0.90
0.7	0.62	0.42
0.75	0.55	0.35
0.8	0.42	0.26
0.85	0.28	0.15

📌 *Meaning:*
For PF improvement from **0.8 to 0.95**, capacitor kVAR = **0.42 × kW**.

Numerical Example – Table Method

Given:

- Load = 50 kW
- PF improved from 0.8 to 0.95

$$Q_c = 50 \times 0.42 = 21 \text{ kVAR}$$

📌 **Advantage:**
Quick calculation, less time in exams.

2.5 Selection of Standard Capacitor Sizes

Capacitors are available in standard ratings:

- 5 kVAR
- 10 kVAR
- 20 kVAR
- 25 kVAR
- 50 kVAR

📌 *Engineering Practice:*
Select **nearest higher rating** to ensure adequate compensation.

2.6 Precautions in Capacitor Selection

- Avoid overcompensation
- Consider load variation

- Use automatic PF correction panels
- Ensure proper protection (fuses, contactors)

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Design of capacitor banks
- **Utilities:** Enforce PF standards
- **Energy Auditors:** Calculate kVAR requirement
- **Maintenance Engineers:** Retrofit PF correction systems

📌 *Practical Example:*
Improving PF from 0.75 to 0.95 reduces transformer loading significantly.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Capacitor rating must be calculated accurately
- Formula method is exact and exam-oriented
- Table method is fast and practical
- Proper selection avoids penalties and losses
- PF correction improves efficiency and reduces cost

Lecture 5 - Topic 3.6 – Effect of Power Factor on Line Current (Case Study) & Topic 3.7 – Effect of Power Factor on Copper Losses (Case Study)

(Unit–3: Reactive Power Compensation / 60-minute detailed lecture session)

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1. Hook / Introduction (≈ 5 minutes)

Let us start with a practical observation.
Two factories consume the **same kW power**, yet one has **thicker cables, higher losses, and more heating** in conductors. Why?

The reason is **power factor (PF)**. Even if useful power (kW) is the same, a **low PF forces higher line current**, which directly increases **losses and cost**.
In today's lecture, we will clearly understand—**with numerical case studies**—how PF affects **line current** and **copper losses**, two of the **most scoring and practical topics** in Unit–3.

🔷 PART–A: Topic 3.6 – Effect of Power Factor on Line Current (≈ 30 minutes)

---

2. Core Concept

For a three-phase system:

$$\boxed{I = \frac{P}{\sqrt{3}V\ \cos\phi}}$$

Where:

- (I) = Line current (A)
- (P) = Active power (kW)
- (V) = Line voltage (kV)
- (\cos\phi) = Power factor

📌 **Key Insight:**
For the same **kW and voltage**, **lower PF → higher current**.

---

3. Case Study – Effect of PF on Line Current

Given Data

- Load power = **100 kW**
- Supply voltage = **415 V (0.415 kV)**
- Case-1 PF = **0.7**
- Case-2 PF = **0.95**

Case-1: Line Current at PF = 0.7

$$I_1 = \frac{100}{\sqrt{3} \times 0.415 \times 0.7}$$

$$I_1 = \frac{100}{0.503} \approx 199 \text{ A}$$

Case-2: Line Current at PF = 0.95

$$I_2 = \frac{100}{\sqrt{3} \times 0.415 \times 0.95}$$

$$I_2 = \frac{100}{0.683} \approx 146 \text{ A}$$

Comparison

Parameter	PF = 0.7	PF = 0.95
Line Current	199 A	146 A

📌 **Observation:**
Improving PF from **0.7 to 0.95 reduces line current by ~27%**.

Engineering Interpretation

- Lower current → Smaller cable size
- Reduced heating

- Improved voltage regulation
- Higher system capacity

🔷 PART–B: Topic 3.7 – Effect of Power Factor on Copper Losses (≈ 25 minutes)

---

4. Core Concept

Copper loss in conductors:

$$\boxed{\text{Copper Loss} = I^2 R}$$

Where:

- (I) = Line current
- (R) = Resistance of conductor

📌 **Important:**
Copper loss depends on **square of current**, so even a small current reduction gives **large loss reduction**.

---

5. Case Study – Effect of PF on Copper Losses

Assume:

- Conductor resistance (R = 0.05,\Omega) per phase
- Currents from previous case study

Case-1: Copper Loss at PF = 0.7

$$\text{Loss}_1 = I_1^2 R = (199)^2 \times 0.05$$

$$\text{Loss}_1 = 39601 \times 0.05 = 1980 \text{ W}$$

Case-2: Copper Loss at PF = 0.95

$$\text{Loss}_2 = (146)^2 \times 0.05$$

$$\text{Loss}_2 = 21316 \times 0.05 = 1066 \text{ W}$$

Loss Reduction

$$\text{Loss Saving} = 1980 - 1066 = 914 \text{ W}$$

📌 **Percentage Reduction:**

$$\frac{914}{1980} \times 100 \approx 46\%$$

---

6. Key Observations from Case Study

- PF improvement reduces current significantly
- Copper loss reduces **nearly by half**
- Less heating → Longer cable and equipment life
- Direct energy saving → Lower electricity bill

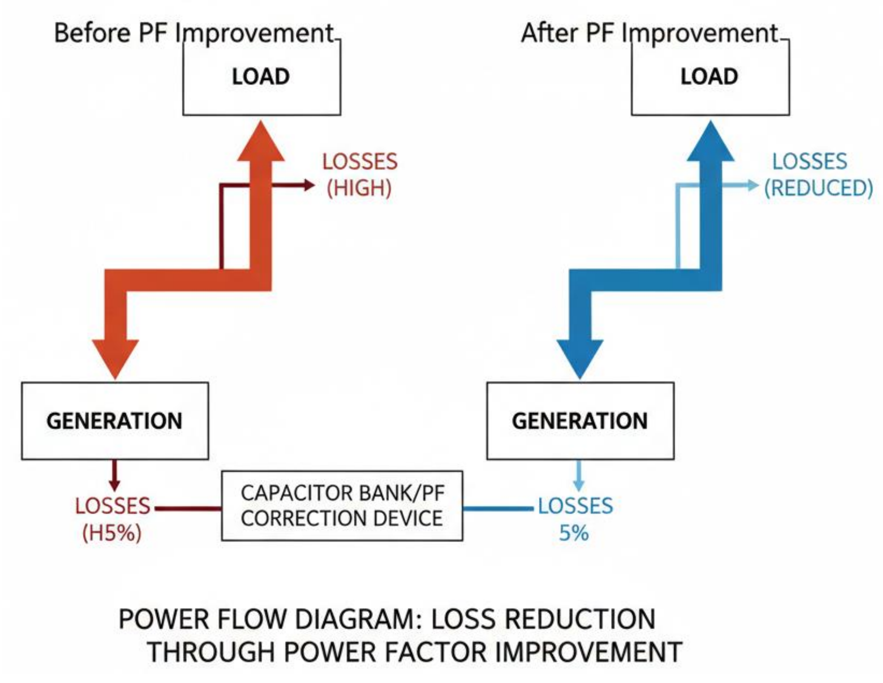

Fig. 3.6 Power flow diagram showing loss reduction after PF improvement.

---

7. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Reduce cable heating and transformer losses
- **Utilities:** Lower transmission and distribution losses
- **Energy Auditors:** Justify PF correction investment
- **Design Engineers:** Optimize cable and transformer sizing

📌 *Practical Example:*
PF improvement allows existing transformer to carry **more useful load without upgrade**.

---

8. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Line current is inversely proportional to power factor
- Low PF causes high current even for same kW
- Copper loss varies as square of current
- PF improvement gives large loss reduction
- Case studies prove PF correction is economically justified

Lecture 6 - Topic 3.8 – Capacitor Rating for Star & Delta Connection & Topic 3.9 – Effect of Power Factor on Cable Size & Energy Saving (Case Study)

(Unit–3: Reactive Power Compensation / 60-minute detailed lecture session)

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1. Hook / Introduction (≈ 5 minutes)

You have correctly calculated the required capacitor kVAR—but the capacitor bank still doesn't give the expected improvement. Why?
Because **connection matters**. A capacitor's **kVAR contribution depends on whether it is connected in Star or Delta**. Also, improving power factor does more than reduce losses—it can **reduce cable size and save capital cost**. Today's lecture ties these ideas together with **clear formulas and case studies**.

🔷 PART–A: Topic 3.8 – Capacitor Rating for Star & Delta Connection (≈ 30 minutes)

2. Core Concepts

Capacitors provide **leading reactive power**. The **same line voltage** produces **different kVAR** depending on the connection.

Voltage Across Capacitor

- Star (Y): $V_{ph} = \frac{V_L}{\sqrt{3}}$
- Delta (Δ): $V_{ph} = V_L$

Reactive Power of a Capacitor (per phase)

$$Q_{ph} = \frac{V_{ph}^2}{X_C}$$

Total kVAR depends on the connection.

---

3. Key Result (Exam Favorite)

For the **same capacitance** and **same line voltage**:

$$\boxed{Q_\Delta = 3\,Q_Y}$$

📌 **Interpretation:**
Delta connection supplies **three times** the kVAR of star connection.

---

4. Selection Logic (Practical)

- **Star connection:**
  - Lower kVAR per capacitor
  - Lower stress per phase
  - Often used at **higher voltages**
- **Delta connection:**
  - Higher kVAR output
  - Smaller capacitance needed
  - Common in **LT systems**

---

5. Numerical Example – Star vs Delta

Given: Required PF correction = **30 kVAR**, line voltage = **415 V**

If Delta Connected

- Total kVAR = **30 kVAR**
- Per phase = **10 kVAR**

If Star Connected

- Total kVAR must still be **30 kVAR**
- Since $Q_\Delta = 3Q_Y$, star requires **three times capacitance** to deliver the same kVAR at the line level.

---

6. Advantages & Precautions

Delta:

- ✓ Higher kVAR output
- ✓ Compact bank
- ⚠ Higher current per phase

Star:

- ✓ Lower phase voltage
- ✓ Safer insulation stress
- ⚠ Larger capacitance required

🔷 PART–B: Topic 3.9 – Effect of PF on Cable Size & Energy Saving (≈ 25 minutes)

7. Core Concept

For a three-phase system:

$$\boxed{I = \frac{P}{\sqrt{3}\,V\ \cos\phi}}$$

Lower PF → Higher current → **Larger cable size** and **higher losses**.

---

8. Case Study – Cable Size Reduction with PF Improvement

Given:

- Load = **100 kW**
- Voltage = **415 V**
- Initial PF = **0.7**
- Improved PF = **0.95**

Current Calculation

At PF = 0.7

$$I_1 = \frac{100}{\sqrt{3} \times 0.415 \times 0.7} \approx 199 \text{ A}$$

At PF = 0.95

$$I_2 = \frac{100}{\sqrt{3} \times 0.415 \times 0.95} \approx 146 \text{ A}$$

📌 **Current Reduction ≈ 27%**

---

9. Impact on Cable Size

Typical current ratings:

- 199 A → requires **~120 mm²** cable
- 146 A → **~70 mm²** cable sufficient

📌 **Result:**
PF improvement allows **smaller cable size**, saving copper/aluminium cost.

---

10. Energy Saving Due to Loss Reduction (Case Study)

Assume cable resistance (R = 0.05,\Omega) per phase.

Copper Loss

$$\text{Loss} = I^2 R$$

- At PF 0.7: ((199)^2 \times 0.05 \approx 1980 \text{ W})
- At PF 0.95: ((146)^2 \times 0.05 \approx 1066 \text{ W})

Loss Saving ≈ 914 W (~46%)

📌 Over long hours, this becomes **significant annual energy saving**.

---

11. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Reduce cable cost during expansion by improving PF
- **Utilities:** Lower T&D losses and improve voltage profile

- **Energy Audits:** Justify PF correction via capex + opex savings
- **Design Offices:** Optimize conductor sizing

---

12. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Delta connection provides **3× kVAR** of star for the same capacitor
- PF improvement reduces current substantially
- Lower current enables **smaller cable size**
- Copper losses drop sharply (I^2R effect)
- PF correction yields **both capital and energy savings**

● PHASE 3: STUDENT AI TOOLKIT (25 PROMPTS)

A. Low-Level Prompts (Remember & Understand) – 10 Prompts

1. *"Explain active power, reactive power, and apparent power in simple words with one daily-life example."*
2. *"Define power factor and explain why it is less than unity in most electrical systems."*
3. *"List common causes of low power factor in industries and commercial installations."*
4. *"Explain why inductive loads draw reactive power."*
5. *"What is reactive power compensation? Explain its need in simple terms."*
6. *"Explain the role of capacitors in power factor improvement."*
7. *"Differentiate between kW, kVA, and kVAR in simple exam-oriented points."*
8. *"Explain centralized, group, and individual power factor compensation in brief."*
9. *"What are copper losses? Why do they increase at low power factor?"*
10. *"Summarize Unit-3: Reactive Power Compensation in 8–10 easy revision points."*

B. Moderate-Level Prompts (Apply & Analyze) – 10 Prompts

11. *"Compare centralized, group, and individual compensation using a table with advantages and disadvantages."*
12. *"Explain the effect of low power factor on line current and kVA demand with a simple numerical example."*
13. *"Analyze how power factor improvement reduces copper losses and improves system efficiency."*
14. *"Calculate the required capacitor kVAR to improve power factor from 0.75 to 0.95 for a given load."*
15. *"Explain the effect of power factor on three-phase cable size with a practical example."*
16. *"Compare star-connected and delta-connected capacitor banks for power factor correction."*
17. *"Explain the impact of low power factor on electricity billing for LTMD or HTP consumers."*
18. *"Analyze a case study showing energy savings achieved after installing capacitor banks."*
19. *"Explain why over-compensation of power factor should be avoided."*
20. *"Prepare short exam-oriented notes on advantages of reactive power management."*

C. High-Level Prompts (Design & Create) – 5 Prompts

21. *“Design a power factor improvement scheme for a small industry indicating type of compensation, capacitor rating, and expected benefits.”*
22. *“Create a step-by-step method to calculate capacitor bank size for a three-phase induction motor.”*
23. *“Develop a case study comparing energy losses and electricity bill before and after power factor improvement.”*
24. *“Prepare a concept map connecting reactive power, power factor, losses, tariff penalties, and energy savings.”*
25. *“Design a simple maintenance and monitoring plan for capacitor banks used in industrial installations.”*

● PHASE 4: MASTERY CHECK

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1. Key Definitions / Glossary (Top 15 Terms)

1. **Reactive Power** – Power that oscillates between source and load and does not perform useful work, measured in kVAR.
2. **Active Power** – Power that performs actual work in an electrical system, measured in kW.
3. **Apparent Power** – Product of RMS voltage and current in an AC circuit, measured in kVA.
4. **Power Factor (PF)** – Ratio of active power (kW) to apparent power (kVA).
5. **Low Power Factor** – Condition where PF is significantly less than unity due to inductive loads.
6. **Power Factor Improvement** – Method of increasing PF by reducing reactive power demand.
7. **Capacitor Bank** – Group of capacitors connected to supply reactive power locally.
8. **Centralized Compensation** – PF correction using a single capacitor bank at the main bus.
9. **Group Compensation** – PF correction for a group of similar loads.
10. **Individual Compensation** – PF correction at individual equipment terminals.
11. **kVAR Rating** – Reactive power rating of a capacitor or capacitor bank.
12. **Star Connection** – Capacitor or load connection where one end of each phase is connected to a common point.
13. **Delta Connection** – Capacitor or load connection where phases are connected end-to-end.
14. **Copper Losses** – I^2R losses in conductors and windings due to current flow.
15. **Energy Saving** – Reduction in energy losses achieved by PF improvement and current reduction.

---

2. FAQ & Assessment Section

A. Multiple Choice Questions (MCQs)

Q1. Reactive power is measured in:
A) kW
B) kVA
C) kVAR
D) kWh

Q2. Power factor is given by:
A) kVAR/kVA
B) kVA/kW
C) kW/kVA
D) kW/kVAR

Q3. Low power factor is mainly caused by:
A) Resistive loads
B) Capacitive loads
C) Inductive loads
D) Lighting loads

Q4. Which device is commonly used for PF improvement?
A) Inductor
B) Capacitor
C) Transformer
D) Rectifier

Q5. Centralized compensation is usually provided at:
A) Motor terminals
B) Load end
C) Main distribution board
D) Transmission line

Q6. Individual compensation is most suitable for:
A) Lighting circuits
B) Constant load motors
C) Variable load systems
D) Domestic loads

Q7. Power factor improvement results in:
A) Increase in current
B) Increase in losses
C) Reduction in line current
D) Increase in kVA demand

Q8. Copper losses are proportional to:
A) Voltage
B) Current
C) Current squared
D) Frequency

Q9. For PF improvement, required capacitor kVAR depends on:
A) Voltage only
B) Current only
C) Load kW and PF change
D) Frequency only

Q10. Which connection gives higher kVAR rating for same capacitor?
A) Star
B) Delta
C) Series
D) Parallel

Q11. Low PF causes which of the following?
A) Reduced losses
B) Smaller cable size
C) Increased kVA demand
D) Improved efficiency

Q12. Group compensation is best suited for:
A) Single large motor
B) Individual equipment
C) Group of similar loads
D) Transmission line

Q13. Improvement of PF leads to reduction in:
A) Voltage
B) Line current
C) Frequency
D) Power

Q14. Effect of PF on copper losses is:
A) No effect
B) Losses decrease as PF improves
C) Losses increase as PF improves
D) Losses remain constant

Q15. Capacitor rating for PF improvement is expressed in:
A) kW
B) kWh
C) kVAR
D) kVA

Q16. In star connection, line current compared to delta is:
A) Higher
B) Same
C) Lower
D) Infinite

Q17. PF improvement helps in reducing:
A) Voltage regulation
B) Energy losses
C) Output power
D) Frequency

Q18. Maximum benefit of PF improvement is obtained when capacitors are installed:
A) At generating station
B) At transmission end
C) Near the load
D) At substation only

Q19. Low PF increases which charge in industrial tariff?
A) Energy charge
B) Demand charge
C) Fixed charge
D) Meter rent

Q20. Overcompensation of PF may lead to:
A) Lagging PF
B) Unity PF
C) Leading PF
D) Zero PF

Answer Key (MCQs)

1. C
2. C
3. C
4. B
5. C
6. B
7. C
8. C
9. C
10. B
11. C
12. C
13. B
14. B
15. C

16. C
17. B
18. C
19. B
20. C

B. Short Answer / Viva Questions (10 Questions)

1. Define reactive power and explain its effect on the power system.
2. What is power factor? Why is low power factor undesirable?
3. List any four causes of low power factor.
4. Explain advantages of power factor improvement.
5. Differentiate between centralized, group, and individual compensation.
6. Why capacitors are used for reactive power compensation?
7. Explain the effect of power factor on line current.
8. Explain how power factor affects copper losses.
9. Compare star and delta connected capacitors for PF improvement.
10. Explain how PF improvement results in energy saving.

● PHASE 5: DIGITAL RESOURCE LIBRARY

AI & Digital Tools

- OpenDSS – PF analysis
- RETScreen – Energy saving estimation
- Excel – Capacitor calculation
- AI chatbots – Numerical problem solving

Video Learning (Search Keywords)

Topic	Platform	Keywords
Power Factor Basics	NPTEL	"Power factor compensation diploma"
Capacitor Bank	Electrical4U	"Capacitor bank PF improvement"
PF Numericals	YouTube	"PF improvement numerical problems"

● PHASE 6: EXTERNAL EXPOSURE

- **Emerging Tech:** APFC panels, smart PF controllers
- **MOOCs:**
    - NPTEL – Electrical Energy Management
- **Industry Visits:**
    - Manufacturing plants
    - Substations
    - Capacitor bank installations
- **Events:** IEEE Power & Energy conferences

● PHASE 7: PREDICTED QUESTION BANK

Most Repeated Questions

- Explain reactive power and power factor.
- Causes and effects of low power factor.
- Explain PF improvement using capacitors.
- Types of capacitor compensation.
- Calculate capacitor rating.

Application Questions

1. Calculate kVAR required to improve PF.
2. Explain PF effect on line current.
3. Analyze PF effect on copper losses.
4. Compare star and delta capacitor connections.
5. Explain energy saving due to PF improvement.

◆ UNIT– 4: ENERGY EFFICIENCY IN ELECTRICAL & UTILITY SYSTEMS

Subject: Energy Efficiency & Audit
Branch: Diploma Electrical Engineering
Semester: 4 (GTU)

● PHASE 1: UNIT– 4: UNIT–WISE STUDY PLAN

Topic No.	Topic Name	Nature	Hours	Exam Importance	Practical Relevance
4.1	Major Energy-Consuming Loads – Motors, lighting, HVAC, transformers, compressors	Core	1	High	Very High
4.2	Distribution transformer: Energy efficient distribution transformer, Methods of reducing core loss and load loss	Core	1	Very High	Very High
4.3	Compare amorphous and CRGO core material, Choice of liquid and dry transformer considering efficiency	Core	1	High	High
4.4	Effect of loading on transformer rating, Reduction of load loss due to increase in power factor	Core	1	High	Medium
4.5	Star level of distribution transformer, Total cost of ownership of transformer and case study	Supporting	1	Medium	Medium
4.6	Energy efficient induction motor: Energy efficient motors, international efficiency classes IE4, IE3, IE2 and IE1, Effect of load and power factor on efficiency	Core	1	High	High
4.7	Methods to minimize losses in motor, Calculate three phase unbalance voltage, effect of voltage unbalance on temperature rise, calculation of loading of motor	Core	1	Very High	High
4.8	Performance of induction motor in Star and Delta connection during light load, Case study	Core	1	Very High	Very High

Topic No.	Topic Name	Nature	Hours	Exam Importance	Practical Relevance
	of payback period of energy efficient motor is replaced by three phase induction motor				
4.9	Selection of proper capacitor bank for power factor improvement, Methods of load survey methodology – sampling, measurement, and analysis	Core	1	High	High
4.10	Lighting system: Relation between watt and lumens, Terminology: luminous flux, Illuminance, inverse square law, luminous efficacy, colour rendering index	Application	1	Very High	Very High
4.11	Working of LED, energy flow diagram of LED, Advantages of electronic ballast over magnetic ballast	Supporting	1	Medium	High
4.12	Lighting design: Light reflectance value, room index, utilization factor, number of light fittings, distance between two fixtures, Case study	Core	1	Very High	Very High
4.13	Replacement of LED by Fluorescent tube light, energy saving and payback period, case study	Core	1	High	High
4.14	Distribution System : Methods to determine energy loss: Direct method and Indirect Method, Causes of technical losses	Core	1	Medium	High
4.15	Measures to reduce technical losses, Commercial losses, Calculation of AT & C losses, measures to reduces commercial losses	Core	1	High	High
4.16	Demand Side Management (DSM) : Meaning of DSM, DSM Methodology, meaning of load shape objective	Core	1	High	High

● PHASE 2: DETAILED LECTURE SERIES

Lecture 1 - Topic 4.1: Major Energy-Consuming Loads – Motors, Lighting, HVAC, Transformers, Compressors

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Look around any industry, college campus, hospital, or shopping mall. You'll see machines moving, lights glowing, rooms being cooled, and power flowing continuously. Now ask yourself: **Which of these consume the most electricity—and why?**
Understanding *where* energy is used the most is the first step toward **energy efficiency**. In this lecture, we will identify the **major energy-consuming electrical loads** and learn *how engineers target them for maximum energy savings*.

---

2. Core Concepts (≈ 40 minutes)

Energy consumption in electrical systems is dominated by a few load categories. Improving efficiency in these areas gives the **highest return on effort and investment**.

A. Electric Motors (Largest Consumer)

- Motors are used in **pumps, fans, compressors, conveyors, elevators**.
- In industries, motors typically consume **60–70% of total electricity**.
- Losses occur due to:
    - Copper (I^2R) losses
    - Core losses
    - Mechanical losses

Efficiency Levers:

- Energy-efficient motors (IE3/IE4)
- Proper sizing (avoid oversized motors)
- Power factor improvement
- Variable Frequency Drives (VFDs)

B. Lighting Systems

- Lighting is essential but often **over-designed or inefficient**.
- Traditional lamps (incandescent, old fluorescent) waste energy as heat.
- Key parameters:
    - Luminous efficacy (lumens/watt)
    - Illuminance (lux)
    - Operating hours

Efficiency Levers:

- LED lighting
- Electronic ballasts
- Proper lighting design (room index, utilization factor)
- Controls: occupancy sensors, daylight sensors

Fun Fact:
Replacing fluorescent lamps with LEDs can save **40–60% energy**.

C. HVAC Systems (Heating, Ventilation & Air Conditioning)

- HVAC loads dominate in **commercial buildings**.
- High consumption due to:
    - Long operating hours
    - Compressor power
    - Poor control strategies

Efficiency Levers:

- Inverter (VFD) compressors
- Higher ISEER-rated ACs
- Proper insulation
- Smart controls and scheduling

D. Transformers

- Operate **24×7**, even at low load.
- Energy losses:
    - Core (no-load) loss – constant
    - Copper (load) loss – varies with load

Efficiency Levers:

- Energy-efficient / star-rated transformers
- Amorphous core transformers

- Proper loading (avoid under/over loading)

Key Insight:
Small loss reduction × 8760 hours = **large annual energy saving**.

E. Compressors (Air & Refrigeration)

- Used for compressed air, refrigeration, and HVAC.
- Often inefficient due to:
  - Air leaks
  - Poor maintenance
  - Constant-speed operation

Efficiency Levers:

- Leak detection and repair
- VFD compressors
- Correct pressure setting
- Heat recovery

Analogy:
Air leaks in compressors are like **holes in a water tank**—pure waste.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Energy Audits:** Identify top-consuming loads to prioritize improvements.
- **Industries:** Focus on motors and compressors for maximum savings.
- **Commercial Buildings:** Optimize HVAC and lighting through controls.
- **Utilities:** Promote star-rated transformers and DSM programs.
- **Daily Life:** Choosing LED lights and inverter ACs reduces bills significantly.

Practical Example:
An industry replacing standard motors with IE3 motors and adding VFDs often achieves **10–20% energy savings** with quick payback.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Motors are the largest energy consumers.
- Lighting and HVAC dominate in buildings.
- Transformers consume energy continuously.
- Compressors are often hidden energy wasters.
- Energy efficiency focuses on **right equipment + right control + right operation**.

Lecture 2 - Topic 4.2: Distribution Transformer – Energy-Efficient Transformers & Methods of Reducing Core and Load Losses

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Let me begin with a simple but powerful thought: **a distribution transformer never sleeps**. Unlike motors or lights, it operates **24 hours a day, 365 days a year**. Even when there is no load, it continues to consume energy.

So imagine this: if we reduce just **100 watts of loss** in one transformer, how much energy will be saved in a year?

$$100 \times 8760 = 876 \text{ kWh/year}$$

This is why **distribution transformers are a prime target for energy efficiency improvement**. In this lecture, we will understand **energy-efficient distribution transformers** and the **methods used to reduce core loss and load loss**.

---

2. Core Concepts (≈ 40 minutes)

2.1 What is an Energy-Efficient Distribution Transformer?

An **energy-efficient distribution transformer** is designed to:

- Minimize **core (no-load) losses**
- Minimize **load (copper) losses**
- Deliver power with **higher overall efficiency** throughout its life

📌 *Key Idea:*
Energy efficiency in transformers is about **loss reduction**, not increasing output.

2.2 Losses in a Distribution Transformer

Transformer losses are mainly of two types:

A. Core Loss (No-Load Loss)

- Occurs in the **transformer core**
- Present **even when no load is connected**
- Caused by:
  - Hysteresis loss
  - Eddy current loss
- Depends on:
  - Core material
  - Flux density
  - Frequency

📌 *Analogy:*
Core loss is like a **vehicle idling at a traffic signal**—fuel is consumed even without movement.

B. Load Loss (Copper Loss)

- Occurs in **primary and secondary windings**
- Depends on load current
- Proportional to $\mathbf{I^2R}$
- Increases with load

📌 *Key Point:*
Load loss is zero at no load and maximum at full load.

2.3 Methods of Reducing Core Loss

1. Use of High-Quality Core Material

- Cold Rolled Grain Oriented (CRGO) steel
- Amorphous metal core

📌 *Benefit:*
Lower hysteresis and eddy current losses.

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2. Thin Laminations

- Reduces eddy current path
- Lower eddy current loss

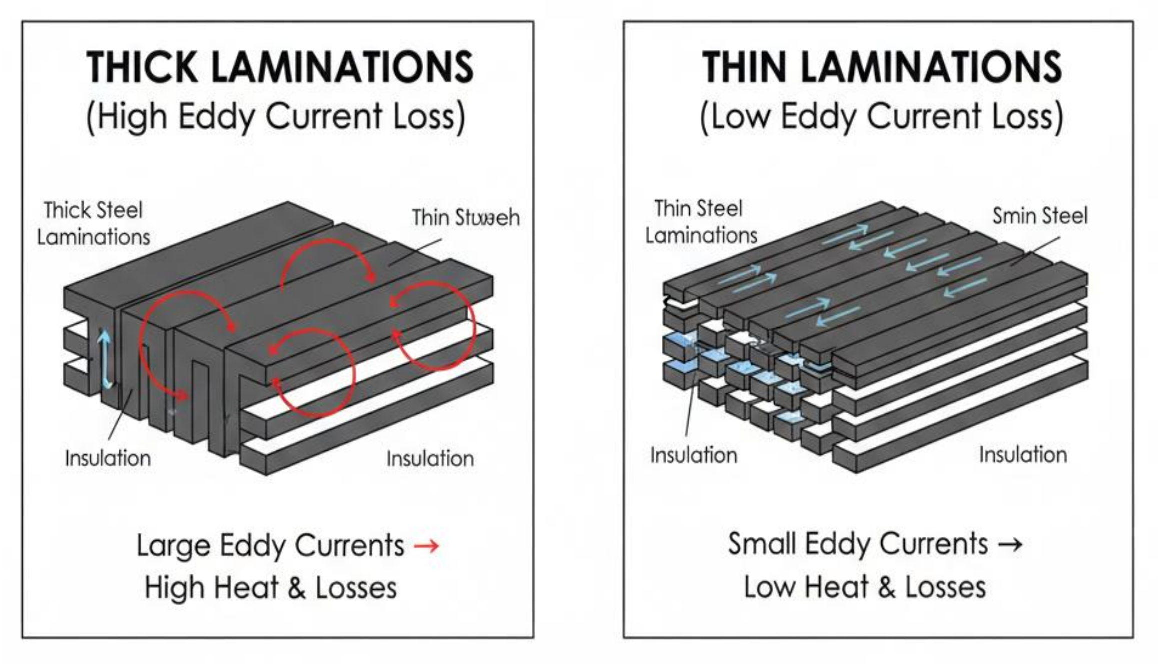

Fig. 4.1 Comparison of thick vs thin laminated cores.

---

3. Proper Core Design

- Optimized flux density
- Improved joint design (step-lap joints)

📌 *Fun Fact:*
Amorphous core transformers can reduce **core loss by 60–70%** compared to conventional cores.

2.4 Methods of Reducing Load Loss

1. Use of Larger Cross-Section Conductors

- Reduces resistance (R)
- Reduces I^2R losses

---

2. Use of Copper Instead of Aluminium

- Copper has lower resistivity
- Results in lower copper losses

---

3. Improved Winding Design

- Shorter length of conductor
- Better cooling
- Reduced hot spots

---

4. Power Factor Improvement

- Higher PF → Lower current
- Lower current → Lower I^2R loss

📌 *Link to Unit-3:*
Reactive power compensation indirectly improves transformer efficiency.

2.5 Energy-Efficient Transformer Features

- Low-loss core material
- Optimized conductor size
- Better cooling design
- High efficiency at normal operating load

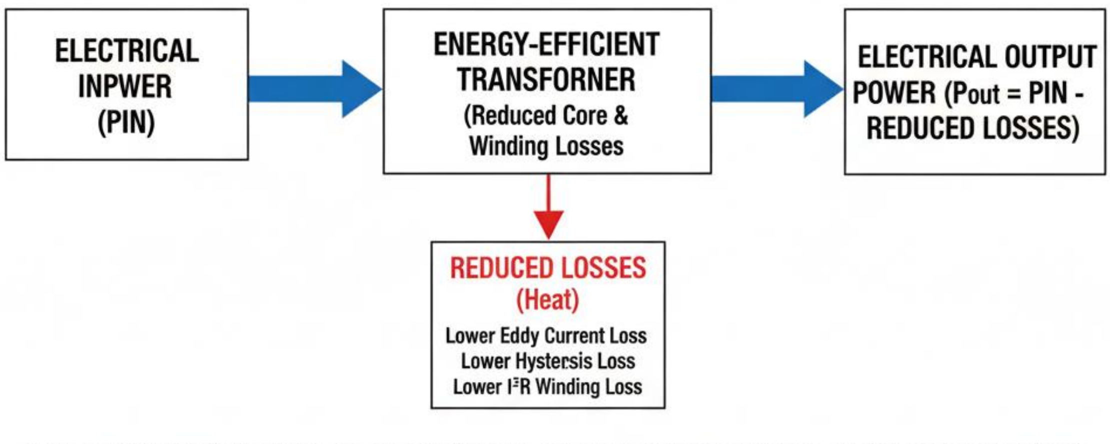

Fig. 4.2 Block diagram power flow with reduced losses.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Utilities:** Use star-rated and amorphous core transformers to reduce T&D losses.
- **Industries:** Install energy-efficient transformers to lower operating cost.
- **Rural Electrification:** Efficient transformers reduce losses and improve voltage.

- **Energy Audits:** Transformer loss analysis is a key audit activity.

📌 *Practical Example:*
Replacing a conventional transformer with an energy-efficient one can save **thousands of units over its life**.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Distribution transformers operate continuously.
- Core loss occurs even at no load.
- Load loss increases with current.
- Energy-efficient transformers reduce both losses.
- Small loss reduction gives large annual energy saving.

Lecture 3 - Topic 4.3: Comparison of Amorphous & CRGO Core Materials and Choice of Liquid & Dry-Type Transformers (Considering Efficiency)

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Imagine two distribution transformers of the same rating installed side by side. Both supply the same load, yet one **consumes noticeably less energy day and night**. What makes the difference?
The answer often lies in **core material** and **cooling/insulation type**. In this lecture, we will compare **amorphous core** and **CRGO core** materials and then learn how to **choose between liquid-filled and dry-type transformers** from an energy-efficiency point of view—knowledge that directly impacts **loss reduction and life-cycle cost**.

---

2. Core Concepts (≈ 40 minutes)

2.1 Transformer Core Materials: Why They Matter

The transformer core carries alternating magnetic flux. The **magnetic properties** of the core material determine **core (no-load) losses**, which exist **24×7**, irrespective of load. Hence, choosing the right core material is critical for energy efficiency.

2.2 CRGO (Cold Rolled Grain Oriented) Steel Core

Characteristics

- Silicon steel with grains oriented in rolling direction
- Widely used in conventional transformers
- Moderate core losses

Advantages

- Good magnetic permeability
- Proven and robust technology
- Lower initial cost
- Easy availability

Limitations

- Higher hysteresis loss compared to amorphous
- Core loss higher at no-load

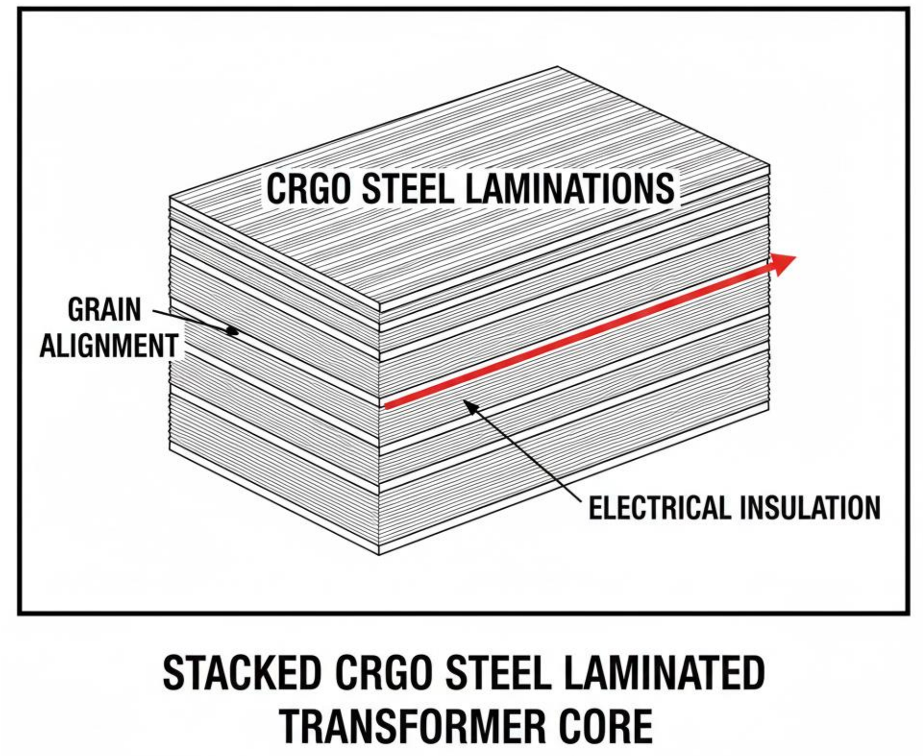

Fig. 4.3 Stacked laminated core with grains aligned in one direction.

2.3 Amorphous Metal Core

Characteristics

- Non-crystalline (random atomic structure)
- Very thin ribbons
- Extremely low hysteresis loss

Advantages

- **60–70% lower core loss** than CRGO
- Excellent for transformers that operate continuously
- Significant annual energy savings

Limitations

- Higher initial cost
- Slightly larger size
- Handling and manufacturing complexity

Fun Fact:
Amorphous core transformers are sometimes called **"low-loss transformers"** due to their outstanding no-load loss performance.

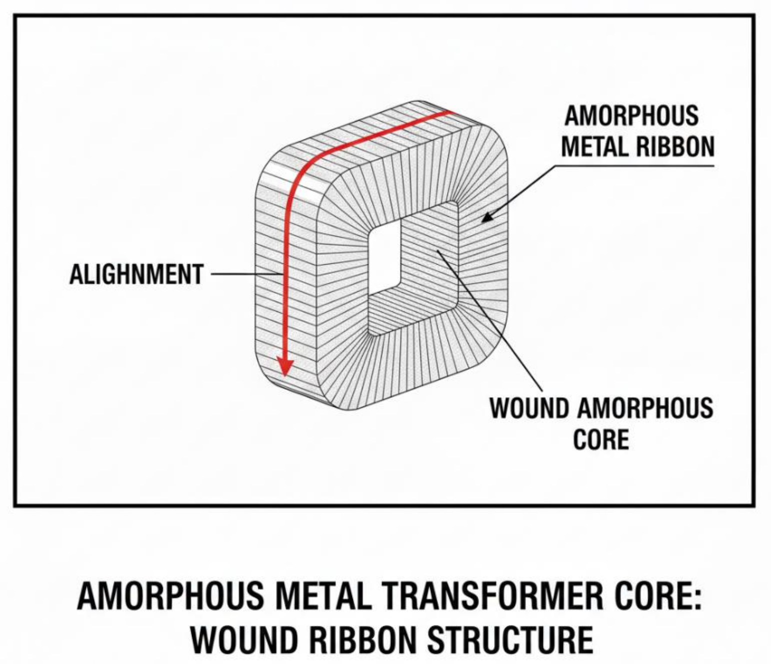

Fig. 4.4 Ribbon-like amorphous strips wound into a core

2.4 Comparison: Amorphous vs CRGO Core

Parameter	CRGO Core	Amorphous Core
Core loss	Higher	Very low
No-load efficiency	Moderate	Excellent
Initial cost	Lower	Higher
Operating cost	Higher	Lower
Best application	Moderate-load	24×7 operation

2.5 Transformer Insulation & Cooling Types

Transformers are also classified by **insulation and cooling medium**, which affects efficiency, losses, and application suitability.

A. Liquid-Filled (Oil-Immersed) Transformers

Features

- Uses mineral oil or ester oil for insulation and cooling
- Better heat dissipation

Efficiency Perspective

- Lower winding temperature
- Lower copper losses due to effective cooling
- Generally **higher efficiency** for medium to high ratings

Applications

- Outdoor substations
- Distribution networks
- Industrial plants

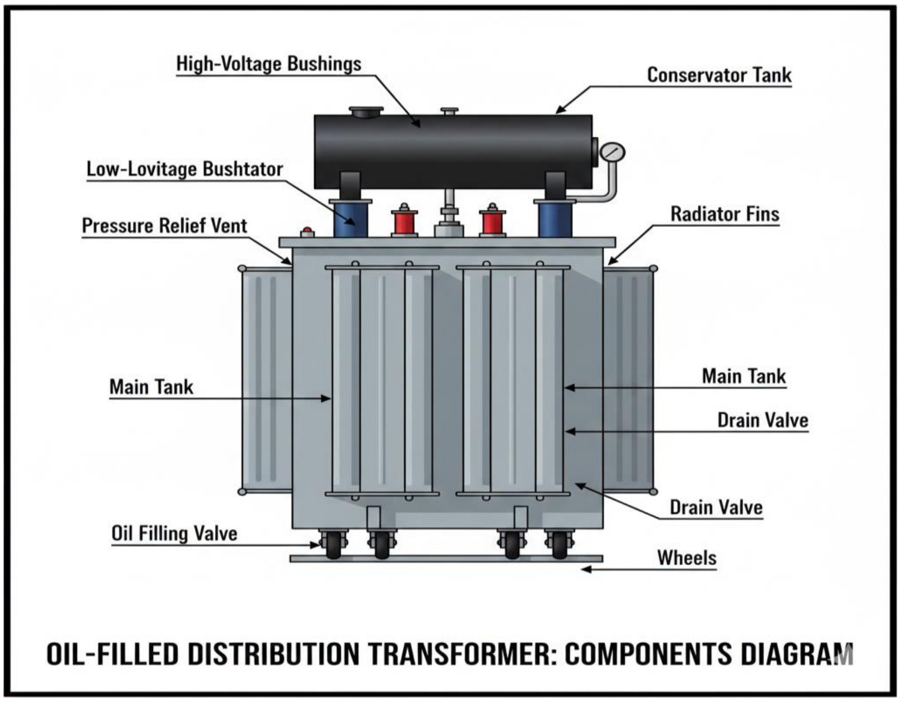

Fig. 4.5 Oil-filled transformer with radiator fins and conservator tank

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B. Dry-Type Transformers

Features

- Uses air or resin for insulation
- No oil—safer for indoor use

Efficiency Perspective

- Slightly higher losses than oil-filled
- Limited cooling capability
- Efficiency acceptable for small to medium ratings

Applications

- Buildings, hospitals, malls
- Fire-sensitive areas

2.6 Choosing Between Liquid & Dry Transformers (Efficiency-Based)

Criteria	Liquid-Filled	Dry-Type
Cooling	Excellent	Moderate
Losses	Lower	Slightly higher
Efficiency	Higher	Moderate
Safety	Requires oil care	Fire-safe
Best use	Outdoor, utilities	Indoor, commercial

Key Insight:
For **maximum energy efficiency**, liquid-filled transformers are preferred; for **safety and indoor use**, dry-type transformers are chosen.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Utilities:** Prefer **amorphous core, oil-filled** transformers to minimize T&D losses.
- **Industries:** Use oil-filled transformers for higher efficiency and continuous loads.
- **Commercial Buildings:** Choose dry-type transformers for safety with acceptable efficiency.
- **Energy Audits:** Recommend amorphous core upgrades where transformers run lightly loaded but continuously.

Practical Example:
Replacing a CRGO transformer with an amorphous core unit can save **thousands of kWh annually**, especially in rural feeders with low average load.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Core material strongly affects no-load losses.
- Amorphous cores offer very low core loss and high efficiency.
- CRGO cores are economical with moderate efficiency.
- Oil-filled transformers are more efficient than dry-type.
- Selection should be based on **efficiency, safety, application, and life-cycle cost**.

Lecture 4 - Topic 4.4: Effect of Loading on Transformer Rating & Reduction of Load Loss due to Increase in Power Factor

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Have you ever noticed that a transformer of **high kVA rating** is installed, but the connected load is much smaller most of the time?
Or why utilities insist on maintaining a **high power factor**, even though transformers are rated in kVA?

The reason lies in **transformer loading** and **power factor**. These two directly decide **current, losses, efficiency, and life of a transformer**. In this lecture, we will understand **how transformer loading affects its rating and efficiency**, and **how improving power factor reduces load losses**, making transformers more energy efficient.

---

2. Core Concepts (≈ 40 minutes)

2.1 Transformer Rating and Loading

Transformer Rating

- Transformers are rated in **kVA**, not kW
- kVA depends on **voltage and current**
- Heating of transformer depends on **current**

📌 *Key Insight:*
Transformer does not "know" power factor; it only responds to **current**.

Effect of Loading on Transformer

Transformer loading can be:

- **Under-loaded**
- **Optimally loaded**
- **Over-loaded**

A. Under-Loading of Transformer

- Load much less than rated kVA
- Core loss remains constant
- Load loss is small

📌 *Result:*
Overall efficiency becomes **low** because fixed core losses dominate.

📌 *Analogy:*
Like running a large engine at idle speed—fuel is wasted.

B. Optimal Loading of Transformer

- Occurs when:

  Core loss = Load loss

- At this load, transformer efficiency is **maximum**

📌 **Visual to draw (Exam-Oriented):**
Efficiency vs load curve showing **maximum efficiency point**.

C. Over-Loading of Transformer

- Current exceeds rated value
- Load loss (I^2R) increases sharply
- Excessive heating

📌 *Result:*

- Reduced insulation life
- Higher failure risk
- Lower efficiency

2.2 Relationship Between Power Factor, Current & Transformer Loading

For a three-phase system:

$$I = \frac{P}{\sqrt{3}\,V\ \cos\phi}$$

- For same kW and voltage:
  - Lower PF → Higher current
  - Higher PF → Lower current

📌 *Important:*
Higher current means **higher kVA loading** on transformer.

2.3 Reduction of Load Loss Due to Increase in Power Factor

Load Loss (Copper Loss)

$$\text{Load loss} = I^2 R$$

- Directly proportional to square of current
- Even small current reduction gives large loss reduction

Conceptual Case Study (Simple)

Assume:

- Same load power (kW)
- Same transformer
- Two PF conditions: 0.7 and 0.95

📌 At PF = 0.7

- Current is high
- Load loss is high

📌 At PF = 0.95

- Current reduces significantly
- Load loss reduces sharply

📌 *Conclusion:*
Improving PF reduces transformer copper loss and heating.

Impact on Transformer Rating

- At low PF, transformer reaches rated kVA earlier
- At high PF, same transformer can carry **more kW load safely**

📌 *Engineering Benefit:*
PF improvement **releases transformer capacity** without upgrading.

2.4 Combined Effect on Efficiency

- Proper loading + high PF =
    - Lower current
    - Lower losses
    - Higher efficiency
    - Longer transformer life

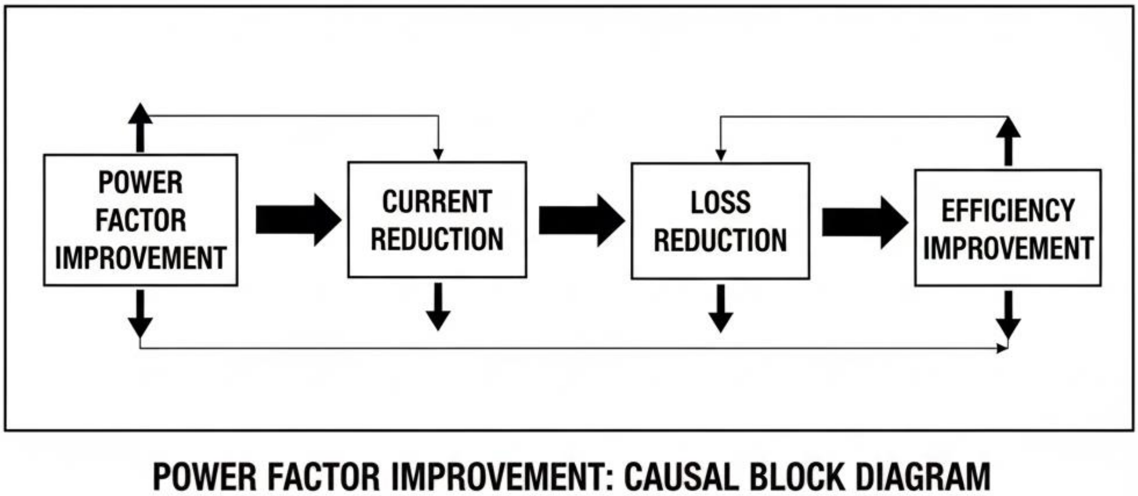

Fig. 4.6 Block diagram showing PF improvement

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3. Real-World / Industry Applications (≈ 10 minutes)

- **Utilities:** Improve PF to reduce transformer overloading and losses
- **Industries:** Use capacitor banks to free transformer capacity
- **Energy Auditors:** Recommend PF correction to improve transformer efficiency
- **Design Engineers:** Select optimal transformer rating based on actual load and PF

📌 *Practical Example:*
An industry improved PF from 0.75 to 0.95 and avoided purchasing an additional transformer.

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Transformer rating depends on current (kVA), not kW
- Under-loading and over-loading both reduce efficiency
- Maximum efficiency occurs at optimal loading
- Low PF increases current and load loss
- Improving PF reduces losses and releases transformer capacity

Lecture 5 - Topic 4.5: Star Level of Distribution Transformer & Total Cost of Ownership (TCO) – with Case Study

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Suppose a utility purchases a **cheaper transformer** today—but over the next 25 years it pays **much more in electricity losses** than the initial saving. Was it really economical?
This is why modern engineering decisions are not based only on **purchase price**, but on **Star Level (efficiency class)** and **Total Cost of Ownership (TCO)**. In this lecture, we'll learn how **BEE star levels for distribution transformers** guide efficiency selection and how **TCO analysis** proves the true economical choice—supported by a simple case study.

---

2. Core Concepts (≈ 40 minutes)

2.1 Star Level of Distribution Transformers (BEE)

The **Bureau of Energy Efficiency (BEE)** assigns **star ratings (1–5 stars)** to distribution transformers based on **loss levels**:

- **No-load (core) loss**
- **Load (copper) loss**

📌 *Key Principle:*
Higher star level = **lower losses** = **higher efficiency**.

Why star rating matters for transformers:

- Transformers operate **24×7**
- Even small loss reduction saves large annual energy
- Star rating ensures **standardized efficiency comparison**

2.2 What Improves Star Level?

- Use of **amorphous or high-grade CRGO cores** (reduces core loss)
- Optimized conductor size and winding design (reduces load loss)
- Better cooling and construction

📌 *Fun Fact:*
A **5-Star transformer** can save **thousands of kWh per year** compared to a 1-Star unit of the same rating.

2.3 Understanding Total Cost of Ownership (TCO)

TCO is the **total cost incurred over the transformer's life**, not just purchase price.

$$\boxed{\text{TCO} = \text{Initial Cost} + \text{Cost of Losses over Life} + \text{Maintenance Cost}}$$

Components explained:

1. **Initial Cost:** Purchase + installation
2. **Cost of Losses:**
   - Core loss cost (24×7, all year)
   - Load loss cost (depends on loading)
3. **Maintenance Cost:** Oil testing, inspections, repairs

📌 *Analogy:*
Buying a transformer is like buying a car—**fuel cost over life** matters more than showroom price.

2.4 Why TCO is Crucial in Transformer Selection

- Losses are paid for **every year**
- Electricity cost increases over time
- Efficient transformers have **lower operating cost**
- TCO reveals the **true economical option**

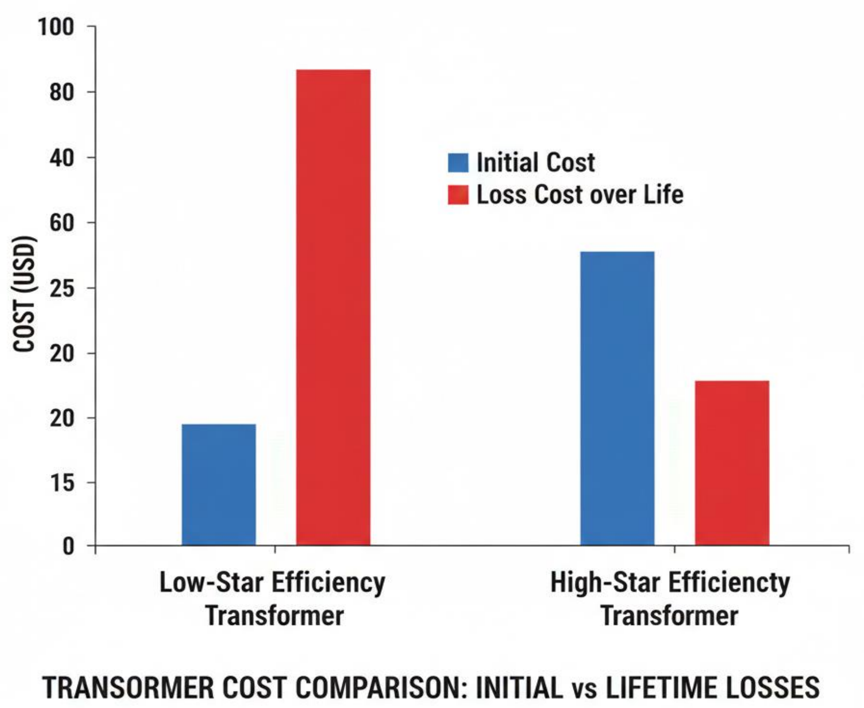

Fig. 4.7 comparing Initial Cost vs Loss Cost over Life for low-star and high-star transformers.

2.5 Case Study: TCO Comparison

Given (Typical):

- Rating: **100 kVA**
- Life: **25 years**
- Electricity cost: **₹6 per kWh**

Option A: 2-Star Transformer

- Initial cost: ₹3,00,000
- Total annual losses: 4,000 kWh
- Annual loss cost: ₹24,000

Option B: 5-Star Transformer

- Initial cost: ₹3,80,000
- Total annual losses: 2,000 kWh
- Annual loss cost: ₹12,000

Loss Cost over 25 Years:

- Option A: ₹6,00,000
- Option B: ₹3,00,000

TCO:

- Option A: ₹3,00,000 + ₹6,00,000 = **₹9,00,000**
- Option B: ₹3,80,000 + ₹3,00,000 = **₹6,80,000**

📌 **Conclusion:**
Despite higher initial cost, the **5-Star transformer is cheaper by ₹2,20,000** over its life.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Utilities:** Mandate 4-Star/5-Star transformers to cut T&D losses
- **Industries:** Use TCO to justify efficient transformer procurement
- **Energy Auditors:** Recommend upgrades based on TCO savings
- **Policy Makers:** Promote star-rated transformers for national energy savings

📌 *Practical Insight:*
Large-scale replacement with high-star transformers saves **MWs of power nationally**.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- BEE star level indicates transformer efficiency
- Higher star = lower losses
- TCO includes purchase + loss + maintenance costs
- Efficient transformers have **lower life-cycle cost**
- TCO-based decisions are technically and economically sound

Lecture 6 - Topic 4.6: Energy-Efficient Induction Motors – IE Classes, Effect of Load & Power Factor on Efficiency

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Let me ask you a simple question: **If a motor costs more to buy but saves electricity every hour it runs, is it really expensive?**
In industries, motors run day and night—sometimes for **thousands of hours every year**. Even a small improvement in motor efficiency can lead to **huge energy and cost savings** over time. That is why modern industries are shifting from conventional motors to **energy-efficient induction motors** with international **IE efficiency classes**. In this lecture, we will understand these motors, their efficiency classes, and how **load and power factor** affect motor efficiency.

---

2. Core Concepts (≈ 40 minutes)

2.1 What is an Energy-Efficient Induction Motor?

An **energy-efficient induction motor** is designed to:

- Reduce electrical and mechanical losses
- Deliver the same output with **less input power**
- Operate with **higher efficiency and better power factor**

Loss reduction is achieved by:

- Better core material
- Larger copper cross-section in windings
- Improved cooling and air-gap design

📌 *Key Idea:*
Efficiency improvement is about **loss minimization**, not increasing motor power.

2.2 International Efficiency (IE) Classes

To standardize motor efficiency globally, motors are classified as:

IE Class	Description	Efficiency Level
IE1	Standard Efficiency	Lowest

IE Class	Description	Efficiency Level
IE2	High Efficiency	Better
IE3	Premium Efficiency	High
IE4	Super-Premium Efficiency	Very High

📌 *Important:*
Higher IE class → **Lower losses** → **Higher efficiency**

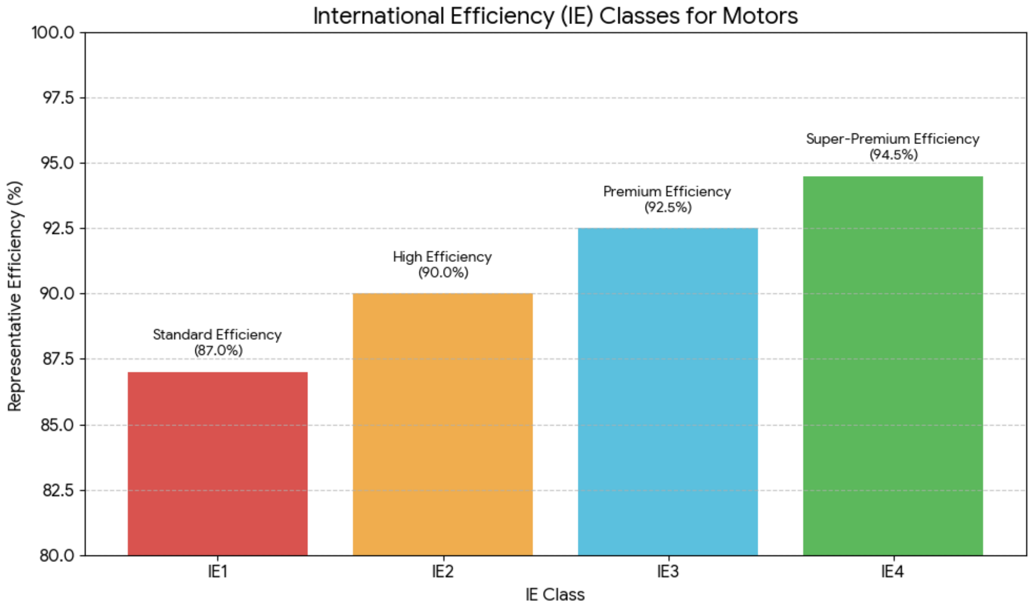

Fig. 4.8 Bar graph showing efficiency increasing from IE1 → IE4.

2.3 Why Higher IE Motors are More Efficient

- Lower stator copper losses (thicker conductors)
- Lower rotor losses
- Reduced core losses
- Improved ventilation

📌 *Fun Fact:*
An **IE3 motor** may consume **3–5% less energy** than an IE1 motor for the same output.

2.4 Effect of Load on Motor Efficiency

Motor efficiency is **not constant**; it varies with load.

- **At no load:**
  Efficiency is low (losses dominate)

- **At 75–100% load:**
  Efficiency is maximum
- **At overload:**
  Efficiency reduces and heating increases

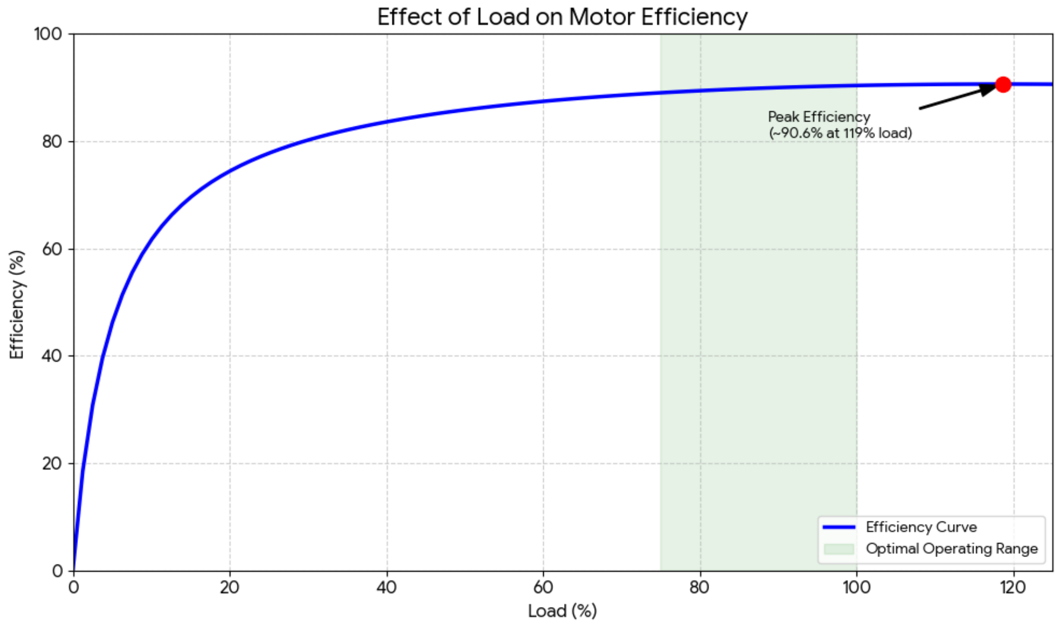

Fig. 4.9 Efficiency vs Load (%) curve showing peak efficiency near rated load.

📌 *Engineering Practice:*
Motors should be selected to operate near **75–90% of rated load**.

2.5 Effect of Power Factor on Motor Efficiency

- Induction motors draw **lagging reactive power**
- Low power factor means:
  - Higher current
  - Higher copper losses
- Higher power factor reduces current and losses

📌 *Key Insight:*
Improving power factor **indirectly improves motor efficiency** by reducing I^2R losses.

2.6 Combined Effect: Load & Power Factor

- Proper loading + good power factor =
  - Lower current
  - Lower losses
  - Higher efficiency

- Longer motor life

📌 *Link to Unit-3:*
Capacitor banks are often used to improve motor PF.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Replace IE1 motors with IE3/IE4 motors for pumps, fans, compressors
- **Energy Audits:** Motor efficiency analysis is a key audit activity
- **Utilities:** Promote high-efficiency motors to reduce demand
- **Maintenance:** Correct motor sizing improves efficiency and reliability

📌 *Practical Example:*
Replacing an old IE1 motor with an IE3 motor in a pump running 6000 hours/year gives **quick payback** due to energy savings.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Energy-efficient motors reduce electrical losses
- IE classes standardize motor efficiency
- Higher IE class = higher efficiency
- Motor efficiency is highest near rated load
- Power factor improvement reduces losses and improves efficiency

Lecture 7 - Topic 4.7: Methods to Minimize Losses in Induction Motors, Three-Phase Voltage Unbalance & Motor Loading Calculation

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Have you ever seen a motor that **runs hot even though it is lightly loaded**?
Or a motor that fails repeatedly although its rating seems correct?

In most such cases, the real reasons are **losses, voltage unbalance, and improper loading**—not poor motor quality. Today's lecture focuses on **how motor losses can be minimized**, how to **calculate three-phase voltage unbalance**, its **effect on temperature rise**, and how to **calculate proper motor loading**. These concepts are extremely important for **energy efficiency, reliability, and exam numericals**.

---

2. Core Concepts (≈ 40 minutes)

2.1 Methods to Minimize Losses in Induction Motors

Motor losses are mainly:

- Stator copper loss
- Rotor copper loss
- Core loss
- Mechanical losses

A. Electrical Loss Reduction

- Use **energy-efficient (IE3/IE4) motors**
- Maintain **proper power factor**
- Avoid over-voltage and under-voltage
- Ensure balanced three-phase supply

B. Mechanical Loss Reduction

- Proper lubrication of bearings
- Correct alignment of shaft
- Avoid excessive belt tension

C. Operational Practices

- Operate motor near **75–90% rated load**
- Avoid frequent starting and stopping
- Use **VFDs** for variable-load applications

📌 *Analogy:*
Loss reduction is like **tuning a vehicle engine**—small adjustments give better mileage.

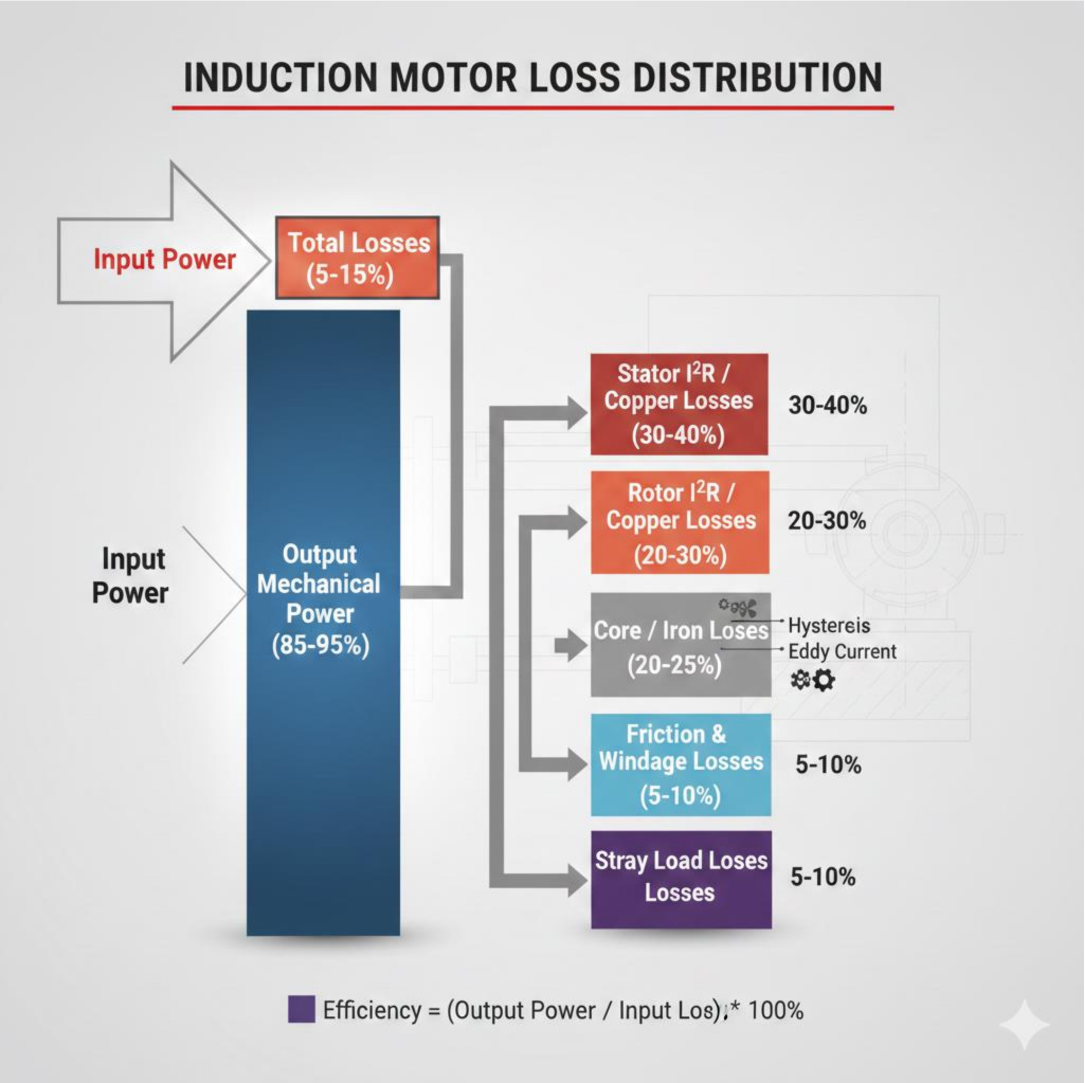

Fig. 4.10 Loss distribution diagram of an induction motor.

2.2 Three-Phase Voltage Unbalance

What is Voltage Unbalance?

Voltage unbalance occurs when the three-phase voltages are **unequal in magnitude**.

Formula for Percentage Voltage Unbalance

$$\%\text{Voltage Unbalance} = \frac{\text{Maximum deviation from average voltage}}{\text{Average voltage}} \times 100$$

Numerical Example

Given:

- (V_R = 410V)
- (V_Y = 400V)
- (V_B = 390V)

Average voltage:

$$V_{avg} = \frac{410 + 400 + 390}{3} = 400\,V$$

Maximum deviation:

|410 - 400| = 10V

$$\%\text{Unbalance} = \frac{10}{400} \times 100 = 2.5\%$$

2.3 Effect of Voltage Unbalance on Motor Temperature

- Causes **unbalanced currents**
- Increases negative sequence currents
- Results in **excessive heating**

📌 *Important Rule:*
1% voltage unbalance can cause 6–10% increase in temperature rise.

📌 *Fun Fact:*
A motor may need to be **derated** if voltage unbalance exceeds permissible limits.

2.4 Calculation of Motor Loading

Motor Loading Formula

$$\%\text{Loading} = \frac{\text{Actual kW}}{\text{Rated kW}} \times 100$$

Example

Given:

- Rated motor = **15 kW**
- Measured load = **10.5 kW**

$$\%\text{Loading} = \frac{10.5}{15} \times 100 = 70\%$$

📌 *Interpretation:*
Motor is operating near **optimal efficiency zone**.

2.5 Combined Effect on Efficiency

- Balanced voltage + proper loading + good PF =
  - Lower losses
  - Lower temperature
  - Longer motor life
  - Higher efficiency

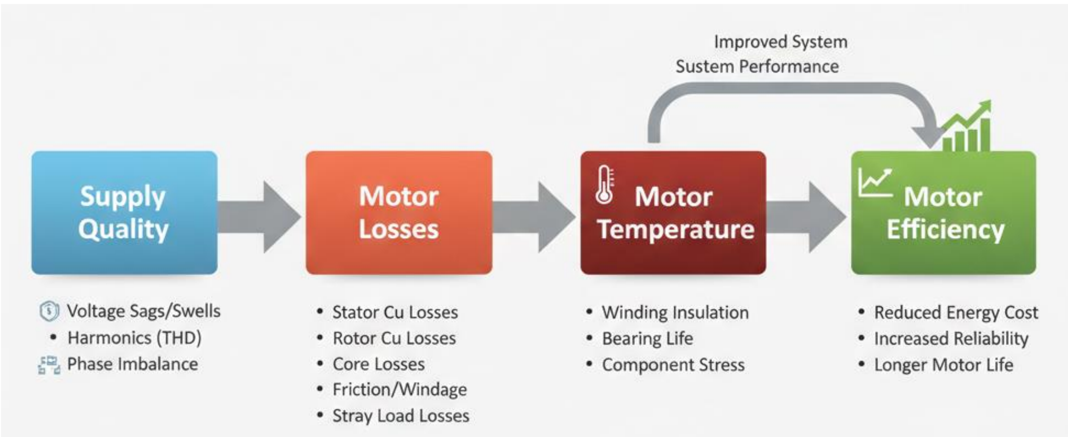

Fig. 4.11 Flowchart showing combined effect on efficiency.

3. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Monitor voltage balance to prevent motor failure
- **Energy Audits:** Identify losses due to unbalance and improper loading
- **Maintenance:** Correct phase imbalance and resizing of motors
- **Utilities:** Improve feeder balance to enhance motor performance

📌 *Practical Example:*
Correcting voltage unbalance in a plant reduced motor temperature and avoided frequent rewinding.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Motor losses can be minimized by proper design, operation, and maintenance
- Voltage unbalance causes excessive heating
- Even small unbalance greatly affects temperature
- Motor loading calculation ensures efficient operation
- Balanced supply and correct loading extend motor life

Lecture 8 - Topic 4.8: Performance of Induction Motor in Star & Delta Connection During Light Load & Case Study on Payback Period of Energy-Efficient Motor Replacement

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Have you ever noticed that a motor connected in **star** draws less current and runs cooler at light load compared to **delta** connection?
And why do industries sometimes replace a working motor with a new **energy-efficient motor**, even though the old one is still operational?

The answer lies in **connection strategy**, **operating load**, and **life-cycle energy cost**. In this lecture, we will understand **how star and delta connections affect motor performance at light load** and then study a **simple payback period case study** to justify replacing a conventional motor with an energy-efficient one.

---

2. Core Concepts (≈ 40 minutes)

2.1 Star and Delta Connection – Quick Revision

- **Star (Y) Connection**
  - Phase voltage = Line voltage / √3
  - Lower current
  - Lower torque
- **Delta (Δ) Connection**
  - Phase voltage = Line voltage
  - Higher current
  - Higher torque

2.2 Motor Performance During Light Load

Motor Behavior at Light Load

- Active power drawn is low
- Magnetizing current remains nearly constant
- Efficiency and PF reduce

Star Connection During Light Load

Advantages

- Lower phase voltage
- Reduced magnetizing current
- Lower copper losses
- Lower temperature rise

Limitations

- Reduced torque
- Not suitable for heavy load

📌 *Engineering Insight:*
Star connection is **energy-efficient for light-load operation**.

Delta Connection During Light Load

Characteristics

- Full line voltage across windings
- Higher current
- Higher copper losses
- More heating

📌 *Conclusion:*
Delta connection at light load causes **unnecessary losses**.

Comparison Table

Parameter	**Star**	**Delta**
Phase Voltage	Low	High
Current	Low	High
Losses	Low	High
Efficiency at light load	Better	Poor
Torque	Low	High

📌 *Key Point:*
For lightly loaded motors, **star connection is preferable**.

2.3 Case Study: Payback Period of Energy-Efficient Motor Replacement

Given Data

- Old motor efficiency = **88%**
- Energy-efficient motor efficiency = **93%**
- Motor rating = **15 kW**
- Operating hours = **6000 h/year**
- Electricity cost = **₹7/unit**
- Additional cost of efficient motor = **₹30,000**

Step 1: Input Power Calculation

Old Motor

$$P_{in1} = \frac{15}{0.88} = 17.05 \text{ kW}$$

Efficient Motor

$$P_{in2} = \frac{15}{0.93} = 16.13 \text{ kW}$$

Step 2: Energy Saving

$$\Delta P = 17.05 - 16.13 = 0.92 \text{ kW}$$

Annual energy saving:

$$0.92 \times 6000 = 5520 \text{ kWh}$$

Step 3: Annual Cost Saving

$$5520 \times 7 = ₹38,640$$

Step 4: Simple Payback Period

$$\boxed{\text{Payback Period} = \frac{30000}{38640} \approx 0.78 \text{ years}}$$

📌 *Result:*
Payback period is **less than 1 year**.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Operate lightly loaded motors in star mode
- **Energy Audits:** Recommend motor replacement based on payback
- **Maintenance:** Reduce overheating and insulation failure
- **Utilities:** Promote energy-efficient motors for DSM

📌 *Practical Example:*
Using star connection during low-load periods reduces energy losses and extends motor life.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Star connection is beneficial for light-load operation
- Delta connection is suitable for rated load
- Light-load delta operation causes higher losses
- Energy-efficient motors reduce energy consumption
- Payback period justifies motor replacement

Lecture 9 - Topic 4.9: Selection of Proper Capacitor Bank for Power Factor Improvement & Load Survey Methodology – Sampling, Measurement and Analysis

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Imagine an industry that installs a **large capacitor bank**, yet still faces **power factor penalties**. Why does this happen?
Because **selecting the correct capacitor bank** is not only about kVAR—it also depends on **load pattern, variation, and actual measurements**. That is why **load survey methodology** becomes essential before deciding any energy efficiency measure. In this lecture, we will learn **how to select a proper capacitor bank** and **how load surveys (sampling, measurement, and analysis)** support accurate engineering decisions.

---

2. Core Concepts (≈ 40 minutes)

2.1 Selection of Proper Capacitor Bank for PF Improvement

Step 1: Determine Existing Power Factor

- Measure kW, kVA, and PF using energy meter or power analyzer
- Identify average and minimum PF

📌 *Important:*
PF during peak load hours is most critical.

Step 2: Decide Target Power Factor

- Utilities typically require PF ≥ **0.95**
- Avoid over-compensation (leading PF)

Step 3: Calculate Required Capacitor kVAR

$$Q_c = P(\tan\phi_1 - \tan\phi_2)$$

Where:

- (P) = Load (kW)
- $(\phi 1)$ = Initial PF angle
- $(\phi 2)$ = Target PF angle

Step 4: Decide Type of Capacitor Bank

- **Fixed capacitor bank**
  - For constant loads
- **Automatic PF correction (APFC) panel**
  - For varying loads
  - Uses steps (5, 10, 20 kVAR)

📌 *Fun Fact:*
Most industries use **APFC panels** to avoid overcompensation.

Step 5: Select Connection & Location

- Star or Delta connection
- Centralized, group, or individual compensation
- Near inductive loads for best results

📌 *Engineering Tip:*
Capacitors should be installed **as close as possible to the load**.

2.2 Load Survey Methodology

A **load survey** is a systematic study of how electrical load behaves over time.

A. Sampling

- Select representative loads
- Choose appropriate time interval (15 min, 30 min)
- Cover normal and peak operating conditions

📌 *Example:*
Sampling motor loads during production hours.

B. Measurement

Use instruments such as:

- Energy meters
- Power analyzers
- Clamp meters

Parameters measured:

- Voltage
- Current
- kW, kVA, kVAR
- Power factor
- Demand profile

C. Analysis

- Identify peak demand
- Observe PF variation
- Determine load diversity
- Detect inefficient or oversized equipment

📌 *Outcome:*
Accurate data for selecting capacitor banks and energy-saving measures.

2.3 Importance of Load Survey

- Prevents over- or under-sizing of capacitor bank
- Helps design APFC panel steps
- Improves system reliability
- Provides baseline for energy audit

📌 *Analogy:*
Load survey is like **medical diagnosis before treatment**.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Select proper capacitor banks based on real load data
- **Energy Auditors:** Use load surveys to recommend PF correction
- **Utilities:** Encourage load studies for demand-side management
- **Maintenance Engineers:** Identify load imbalance and inefficiencies

📌 *Practical Example:*
Load survey revealed PF dropping during partial load; APFC panel solved penalty issues.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Capacitor bank selection requires accurate load data
- PF improvement should be targeted and controlled
- APFC panels suit variable loads
- Load survey involves sampling, measurement, and analysis
- Proper load survey ensures reliable and economical PF correction

Lecture 10 - Topic 4.10: Lighting Systems – Watt–Lumen Relation & Essential Lighting Terminology

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Have you noticed that a **9-watt LED** can produce the same brightness as a **60-watt incandescent lamp**?
If both give similar light, why does one consume so much less power?

The answer lies in understanding **lumens, not watts**. In lighting engineering, **brightness and energy consumption are different concepts**. Today's lecture will help you clearly understand the **relation between watt and lumens** and the **key lighting terminologies** used in energy-efficient lighting design—concepts that are essential for **energy audits, lighting design, and exam numericals**.

---

2. Core Concepts (≈ 40 minutes)

2.1 Relation Between Watt and Lumens

- **Watt (W):** Electrical power consumed
- **Lumen (lm):** Total visible light output

📌 *Key Insight:*
Watt tells how much power is used; lumen tells how much light is produced.

Different lamps give different lumens for the same watt:

- Incandescent: ~10–15 lm/W
- CFL: ~50–70 lm/W
- LED: ~90–150 lm/W

📌 **Visual to draw:**
Bar chart showing **lumens per watt** for incandescent, CFL, and LED lamps.

2.2 Luminous Flux

- Definition: Total amount of visible light emitted by a source per second

- Unit: **Lumen (lm)**

📌 *Example:*
A 10 W LED producing 1000 lumens has higher luminous flux than a 10 W incandescent.

2.3 Illuminance

- Definition: Amount of light falling on a surface
- Unit: **Lux (lx)**

$$\text{Illuminance (lux)} = \frac{\text{Luminous flux (lumens)}}{\text{Area (m}^2\text{)}}$$

📌 *Example:*
A classroom requires about **300–500 lux** for comfortable reading.

📌 **Visual to draw:**
Light source illuminating a surface, labeling area and lux.

2.4 Inverse Square Law

This law states:

$$\boxed{E \propto \frac{1}{d^2}}$$

Where:

- (E) = Illuminance
- (d) = Distance from light source

📌 *Meaning:*
If distance doubles, illuminance becomes **one-fourth**.

📌 *Fun Fact:*
Poor fixture placement can waste light without increasing brightness.

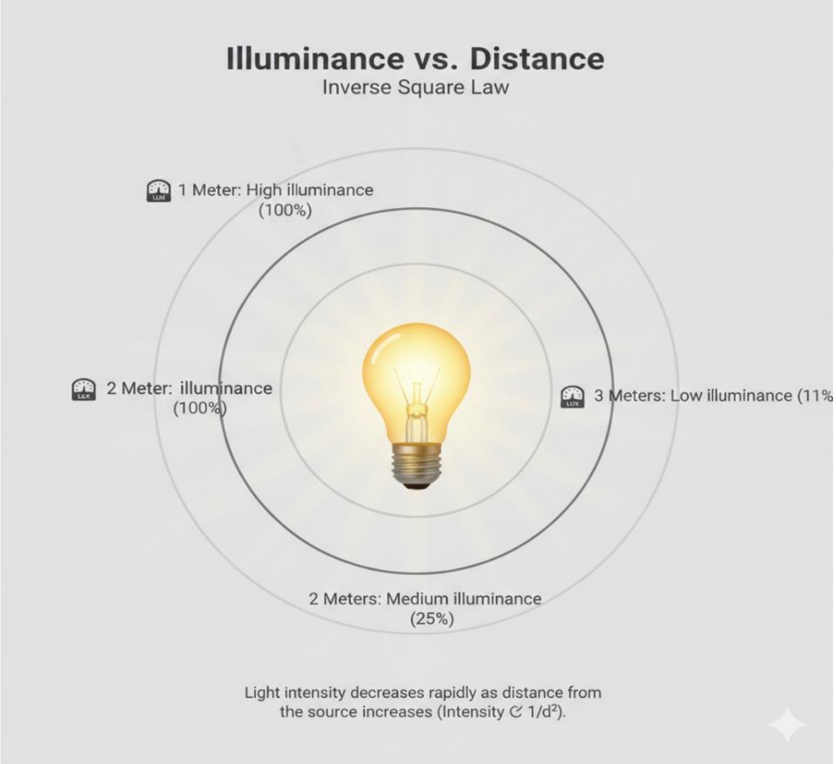

Fig. 4.12 Lamp at center with circles showing illuminance reducing as distance increases

---

2.5 Luminous Efficacy

- Definition: Ratio of light output to power input

$$\text{Luminous efficacy} = \frac{\text{Lumens}}{\text{Watt}}$$

- Unit: **lm/W**

📌 *Key Point:*
Higher luminous efficacy = **better energy efficiency**.

📌 *Example:*
LED lamps have the highest luminous efficacy.

2.6 Colour Rendering Index (CRI)

- Definition: Ability of a light source to show colors accurately compared to natural light
- Scale: **0 to 100**

📌 *Interpretation:*

- CRI ≥ 80 → Good color quality
- CRI ≥ 90 → Excellent (used in hospitals, showrooms)

📌 *Analogy:*
CRI is like **camera color accuracy**—higher CRI shows true colors.

2.7 Why These Terms Matter in Energy Efficiency

- Choosing lamps by **lumens and efficacy**, not watt
- Proper illuminance ensures comfort and productivity
- Correct fixture placement avoids energy waste
- High CRI improves visual quality without extra power

📌 **Visual to draw:**
Flowchart showing **lamp selection → lumens → illuminance → energy efficiency**.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Energy Audits:** Replace low-efficacy lamps with LEDs
- **Building Design:** Achieve required lux with minimum wattage
- **Industries:** Improve productivity with proper lighting
- **Homes:** Reduce bills by choosing high-lumen, low-watt lamps

📌 *Practical Example:*
Replacing 40 W fluorescent tubes with 18 W LEDs saves energy while maintaining lux levels.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Watt measures power; lumen measures brightness
- Luminous flux indicates total light output
- Illuminance tells how well an area is lit
- Inverse square law affects light distribution
- Luminous efficacy and CRI guide efficient lamp selection

Lecture 11 - Topic 4.11: Working of LED, Energy Flow Diagram of LED & Advantages of Electronic Ballast over Magnetic Ballast

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Have you ever wondered why **LED lamps switch ON instantly**, do not flicker, and consume far less power than old fluorescent lamps?
Earlier, lighting systems wasted a lot of energy as **heat and losses in ballasts**. Today's lighting technology focuses on **direct energy conversion into light with minimum loss**. In this lecture, we will understand **how an LED works**, study the **energy flow in an LED system**, and compare **electronic ballasts with magnetic ballasts** to clearly see why modern lighting systems are far more energy efficient.

---

2. Core Concepts (≈ 40 minutes)

2.1 Working Principle of LED (Light Emitting Diode)

An **LED** is a **semiconductor device** that emits light when electric current passes through it.

Basic Principle

- LED is made of **p-type and n-type semiconductor layers**
- When forward biased:
  - Electrons and holes recombine
  - Energy is released in the form of **photons (light)**

📌 *Key Point:*
LED produces light through **electroluminescence**, not heating.

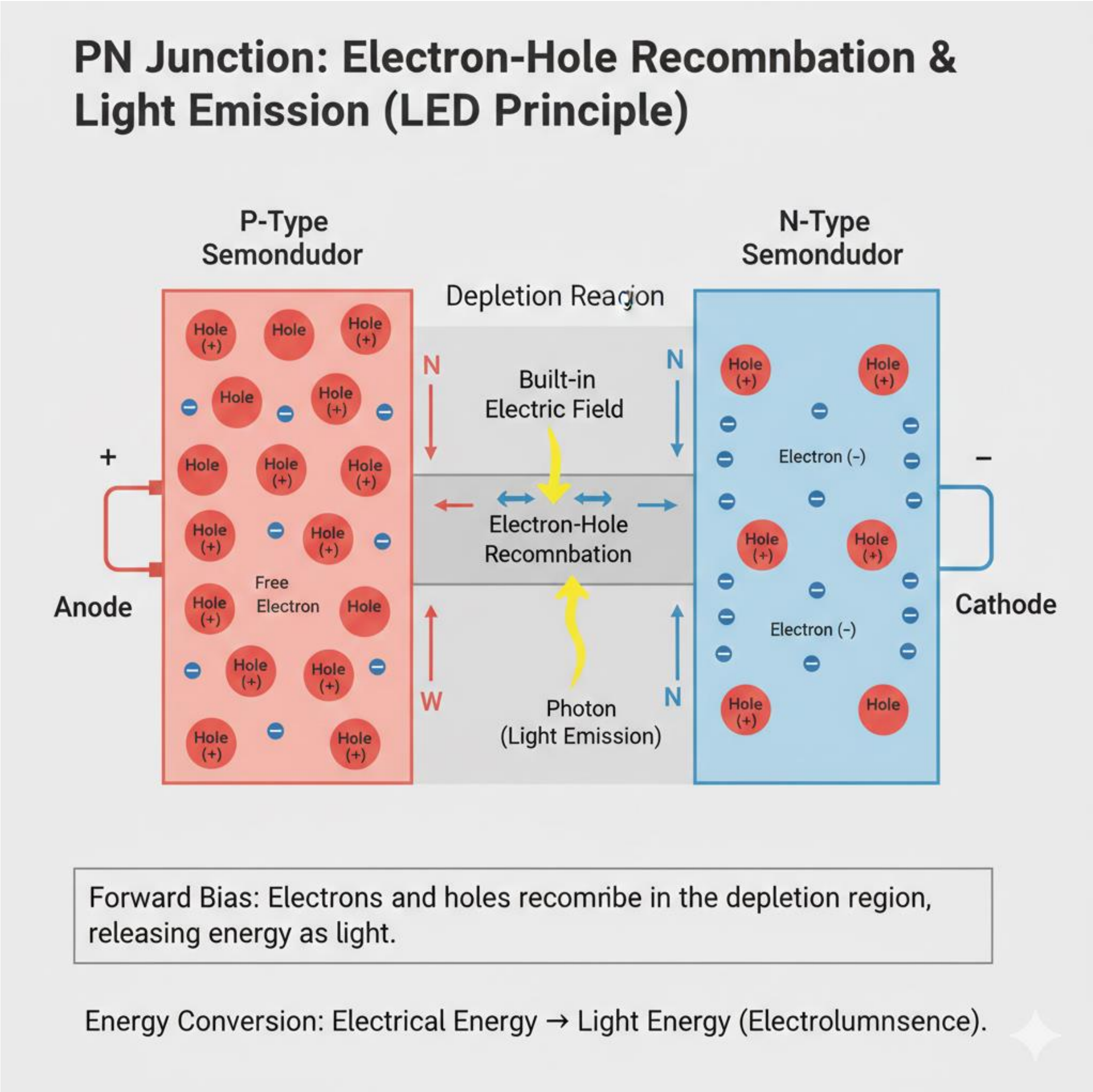

Fig. 4.13 PN junction diagram showing electron-hole recombination and light emission

---

2.2 Energy Flow in an LED System

An LED lamp does not directly operate on AC supply. It uses a **driver circuit**.

Energy Flow Steps

1. **AC Supply** → Rectifier
2. Rectifier → DC conversion
3. DC → Driver circuit (current control)
4. Driver → LED chip
5. LED chip → Light output

📌 *Energy Flow Diagram (Very Important):*
Draw a block diagram:
AC Supply → Rectifier → Driver Circuit → LED → Light + small heat loss

📌 *Fun Fact:*
LED converts **more electrical energy into light** and less into heat compared to traditional lamps.

2.3 Advantages of LED Lighting (Energy Perspective)

- High luminous efficacy (lm/W)
- Low power consumption
- Long life (50,000+ hours)
- Instant ON/OFF
- No mercury content
- Low maintenance cost

📌 *Analogy:*
LED is like a **fuel-efficient engine**—more output, less fuel.

2.4 Magnetic Ballast – Overview

Magnetic ballast is used with **fluorescent lamps** to:

- Limit current
- Provide starting voltage

Characteristics

- Heavy and bulky (iron core)
- Operates at supply frequency (50 Hz)
- Produces humming noise
- Higher losses
- Causes flicker

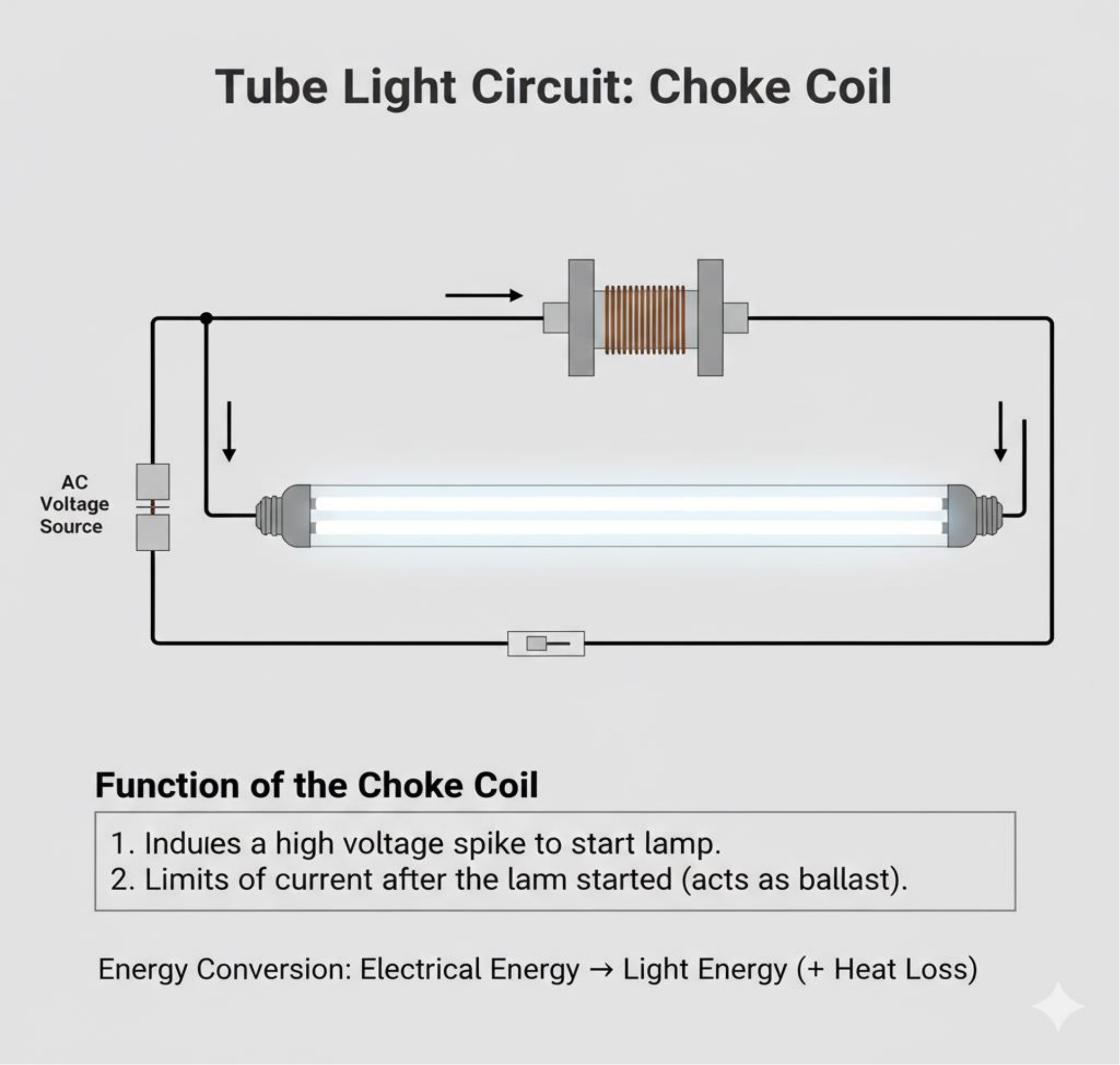

Fig. 4.14 Choke coil connected in series with tube light.

2.5 Electronic Ballast – Overview

Electronic ballast is a **solid-state device** that:

- Converts AC to high-frequency AC
- Controls lamp current electronically

Key Features

- Operates at high frequency (20–50 kHz)
- Lightweight and compact
- No flicker
- Silent operation
- Lower losses

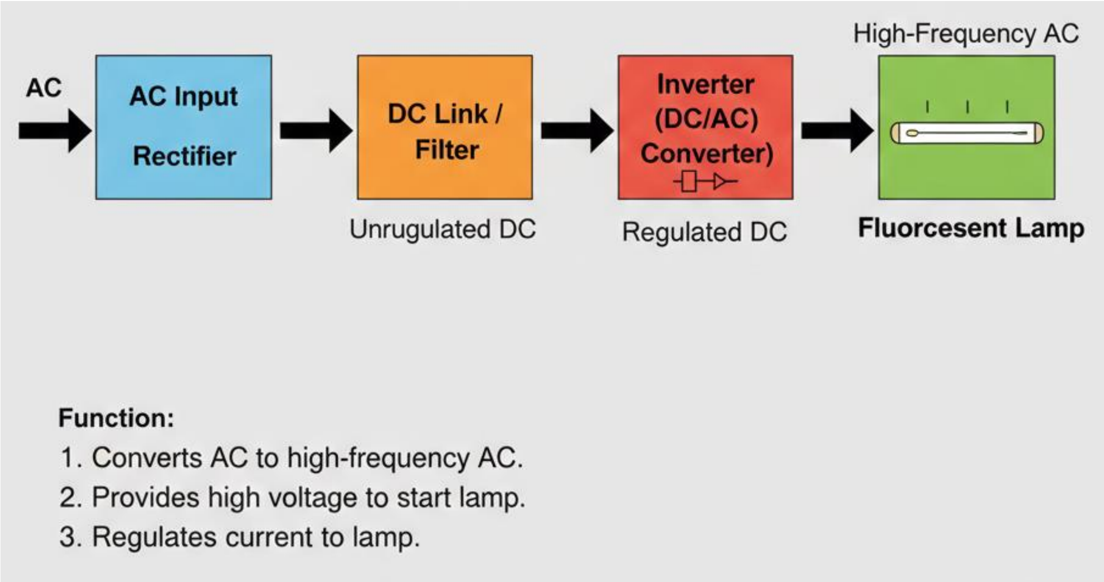

Fig. 4.15 Block diagram of Electronic ballast

2.6 Advantages of Electronic Ballast over Magnetic Ballast

Parameter	Magnetic Ballast	Electronic Ballast
Power loss	High	Low
Size & weight	Large & heavy	Small & light
Flicker	Yes	No
Noise	Audible hum	Silent
Efficiency	Lower	Higher

📌 *Key Result:*
Electronic ballast saves **15–25% energy** compared to magnetic ballast.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Replace magnetic ballasts with electronic ballasts
- **Commercial buildings:** Use LED lighting for energy saving
- **Energy audits:** Recommend LED retrofits
- **Street lighting:** LEDs reduce maintenance and energy costs

📌 *Practical Example:*
Replacing fluorescent lamps with LED panels in offices reduces electricity bills significantly.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- LED works on electroluminescence
- LED system uses a driver for current control
- Energy flow in LED is efficient
- Electronic ballast is superior to magnetic ballast
- Modern lighting systems focus on high efficiency and low loss

Lecture 12 - Topic 4.12: Lighting Design – Reflectance, Room Index, Utilization Factor, Number of Light Fittings, Spacing & Case Study

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Have you ever entered a classroom that feels **dim even with many lights ON**, or another that feels bright with fewer lamps?
The difference is not the number of lamps—it is **lighting design**. Proper lighting design ensures **required brightness with minimum energy**, while poor design wastes power and causes discomfort. In this lecture, we will learn the **basic principles of lighting design** using simple engineering terms and a **numerical case study**, exactly as expected at Diploma level.

---

2. Core Concepts (≈ 40 minutes)

2.1 Light Reflectance Value (LRV)

- Reflectance is the **percentage of light reflected** by a surface.
- Light-colored surfaces reflect more light.

Typical reflectance values:

- Ceiling: **70–80%**
- Walls: **50–70%**
- Floor: **20–40%**

📌 *Key Insight:*
Higher reflectance → Less lighting power required.

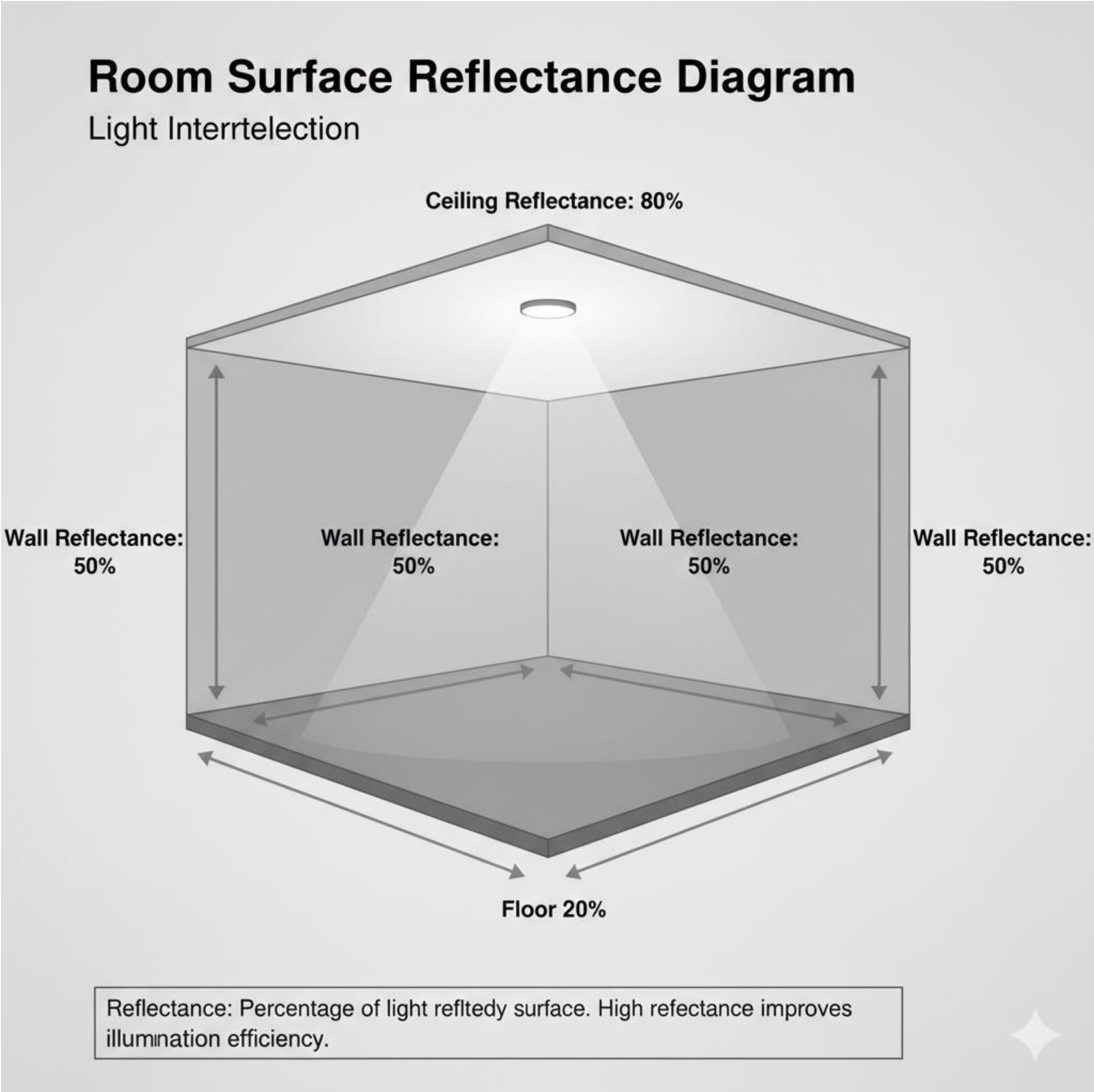

Fig. 4.16 Room showing ceiling, walls, and floor with reflectance percentages

---

2.2 Room Index (RI)

Room Index represents the **proportion of room dimensions**.

$$\text{Room Index (RI)} = \frac{L \times W}{H_m(L + W)}$$

Where:

- (L) = Length of room
- (W) = Width of room
- (H_m) = Mounting height above working plane

📌 *Importance:*
RI helps select **utilization factor** from standard tables.

2.3 Utilization Factor (UF)

- UF is the **fraction of lamp lumens reaching the working plane**.
- Depends on:
    - Room index
    - Reflectance values
    - Type of luminaire

📌 *Typical UF:* 0.4 to 0.7

2.4 Number of Light Fittings

The lumen method is used for lighting design.

$$\boxed{N = \frac{E \times A}{F \times UF \times MF}}$$

Where:

- (N) = Number of fittings
- (E) = Required illuminance (lux)
- (A) = Area (m^2)
- (F) = Luminous flux per lamp (lumens)
- (UF) = Utilization factor
- (MF) = Maintenance factor (≈ 0.8)

2.5 Distance Between Two Fixtures (Spacing)

- Spacing depends on **mounting height** and luminaire type.
- Rule of thumb:

$$\text{Spacing} \leq 1.5 \times H_m$$

📌 *Purpose:*
Uniform illumination without dark spots.

2.6 Case Study: Classroom Lighting Design

Given:

- Classroom size = **10 m × 6 m**
- Area = **60 m²**
- Required illuminance = **300 lux**
- Lamp output = **3000 lumens**
- UF = **0.6**
- MF = **0.8**

$$N = \frac{300 \times 60}{3000 \times 0.6 \times 0.8}$$

$$N = \frac{18000}{1440} = 12.5$$

📌 **Result:**
Use **13 LED fittings**.

📌 *Engineering Judgment:*
Round up for uniform lighting.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Educational buildings:** Design comfortable classrooms
- **Industries:** Ensure safe illumination in work areas
- **Commercial spaces:** Reduce lighting energy cost
- **Energy audits:** Optimize number and placement of lamps

📌 *Practical Example:*
Proper lighting design can reduce lighting energy consumption by **20–30%**.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Reflectance affects lighting efficiency
- Room index helps determine utilization factor
- UF shows how much light reaches working plane
- Correct number and spacing of fixtures ensure uniform lighting
- Lighting design saves energy and improves comfort

Lecture 13 - Topic 4.13: Replacement of Fluorescent Tube Light by LED – Energy Saving & Payback Period (Case Study)

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Look at any classroom, office, or corridor—lighting is ON for **many hours every day**. Now imagine replacing one old fluorescent tube with an LED. The saving may look small. But what if you replace **100 or 1000 lamps**? This is why **LED replacement is one of the fastest and easiest energy-saving measures**. In this lecture, we will understand **how replacing fluorescent tube lights with LEDs saves energy**, and we will calculate the **payback period using a simple case study**.

---

2. Core Concepts (≈ 40 minutes)

2.1 Conventional Fluorescent Tube Light System

A typical fluorescent lighting system includes:

- Tube lamp (36–40 W)
- Magnetic or electronic ballast
- Starter (in magnetic type)

📌 *Actual Power Consumption:*

- Tube light = **40 W**
- Magnetic ballast loss = **8–12 W**
- **Total ≈ 48–52 W**

2.2 LED Tube Light System

- LED tube light typically consumes **18–20 W**
- No external ballast or starter
- Uses an **internal driver circuit**

📌 *Key Advantage:*
Same or better brightness with **less than half the power**.

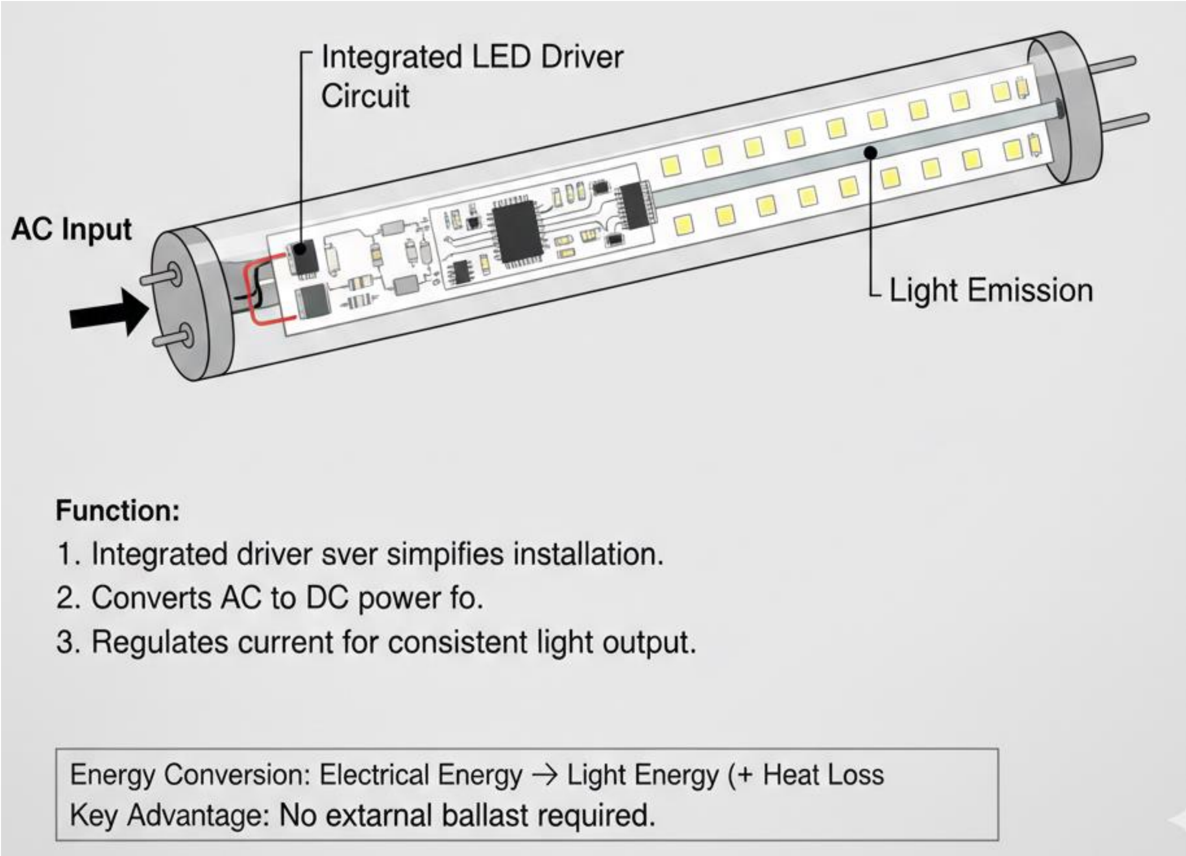

Fig. 4.17 LED tube with internal driver block.

2.3 Energy Saving Mechanism

Energy saving occurs due to:

- Higher luminous efficacy
- No ballast losses
- Directional lighting
- Lower heat loss

📌 *Fun Fact:*
LEDs convert most energy into light, not heat.

2.4 Case Study: Energy Saving & Payback Period

Given Data

- Number of lamps = **100**
- Fluorescent lamp power = **50 W (including ballast)**
- LED lamp power = **20 W**

- Operating hours = **10 hours/day**
- Working days = **300 days/year**
- Electricity cost = **₹7 per unit**
- Cost of one LED tube = **₹600**

Step 1: Annual Energy Consumption

Fluorescent System

$$100 \times 50 \times 10 \times 300 = 15,00,000 \text{ Wh} = 15,000 \text{ kWh}$$

LED System

$$100 \times 20 \times 10 \times 300 = 6,00,000 \text{ Wh} = 6,000 \text{ kWh}$$

Step 2: Annual Energy Saving

$$15,000 - 6,000 = 9,000 \text{ kWh}$$

Step 3: Annual Cost Saving

$$9,000 \times 7 = ₹63,000$$

Step 4: Investment Cost

$$100 \times 600 = ₹60,000$$

Step 5: Payback Period

$$\boxed{\text{Payback Period} = \frac{60,000}{63,000} \approx 0.95 \text{ years}}$$

📌 **Result:**
Investment recovered in **less than 1 year**.

2.5 Additional Benefits of LED Replacement

- Longer life (50,000 hours)
- Lower maintenance cost
- Better illumination
- No flicker or humming
- Environment-friendly

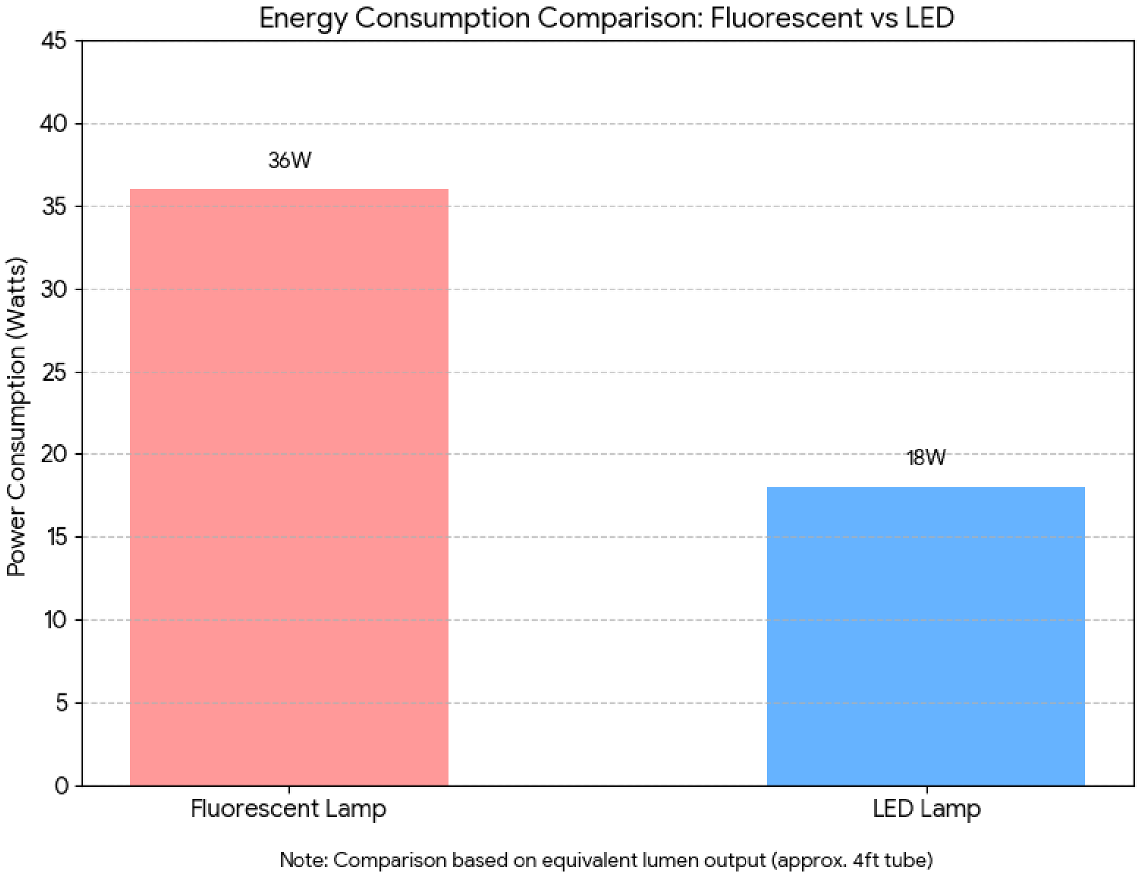

Fig. 4.18 Bar chart showing energy consumption: Fluorescent vs LED.

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3. Real-World / Industry Applications (≈ 10 minutes)

- **Educational institutes:** Reduce electricity bills
- **Industries:** Improve lighting quality and safety
- **Commercial buildings:** Quick ROI projects
- **Energy audits:** LED retrofit as a priority measure

📌 *Practical Insight:*
LED replacement is often the **first recommendation** in energy audits.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Fluorescent lamps consume more power due to ballast losses
- LEDs provide same brightness at much lower wattage
- Energy savings are significant when many lamps are replaced
- Payback period is usually less than 1 year
- LED replacement improves efficiency and comfort

Lecture 14 - Topic 4.14: Distribution System – Methods to Determine Energy Loss: Direct & Indirect Methods and Causes of Technical Losses

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Have you ever wondered why the energy generated at a power plant is **always more** than the energy billed to consumers? Where does the missing energy go?
The answer lies in **distribution system losses**. For utilities and industries, identifying **how much energy is lost and where** is the first step toward loss reduction. In today's lecture, we'll learn **two practical methods to determine energy losses—Direct and Indirect**—and understand the **technical causes** behind these losses, using clear concepts and field-oriented examples.

---

2. Core Concepts (≈ 40 minutes)

2.1 Energy Losses in Distribution Systems

Energy losses occur between:

- **Sending end (substation)** and
- **Receiving end (consumer meters)**

Losses are broadly classified into:

- **Technical losses** (due to physical/electrical reasons)
- **Commercial losses** (metering, billing, theft—covered later)

Today's focus: **Determining losses** and **technical loss causes**.

2.2 Methods to Determine Energy Loss

A. Direct Method (Input–Output Method)

Concept:
Energy loss is calculated by measuring **energy input** into a system and **energy output** delivered to consumers.

$$\boxed{\text{Energy Loss} = \text{Energy Input} - \text{Energy Billed}}$$

Steps:

1. Measure energy at substation (kWh input)
2. Sum of all consumer meter readings (kWh billed)
3. Difference gives total loss

Advantages:

- Simple and quick
- Requires minimal data
- Suitable for feeders and substations

Limitations:

- Does not locate **where** losses occur
- Cannot separate technical and commercial losses

B. Indirect Method (Component-wise Method)

Concept:
Losses are calculated **individually for each component** and then added.

Components considered:

- Transformer losses (core + copper)
- Line losses (I^2R)
- Service line losses

$$\text{Total Loss} = \sum(\text{Transformer Loss} + \text{Line Loss} + \text{Other Technical Losses})$$

Steps:

1. Calculate transformer no-load and load losses
2. Calculate feeder and distributor I^2R losses
3. Add all component losses

Advantages:

- Identifies loss location
- Helps in planning loss reduction measures
- Separates technical losses clearly

Limitations:

- Requires detailed data

- Time-consuming

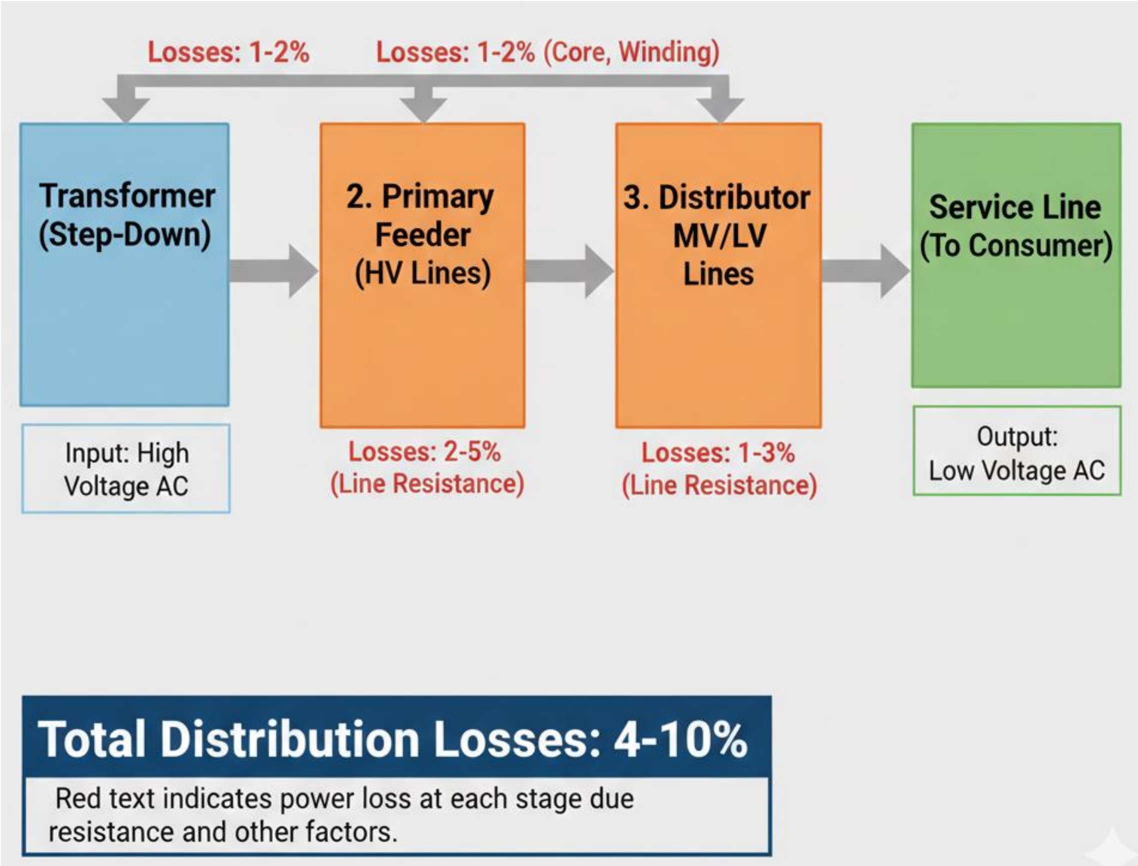

Fig. 4.19 Electricity Distribution System: Stages & Losses.

2.3 Comparison: Direct vs Indirect Method

Parameter	Direct Method	Indirect Method
Accuracy	Moderate	High
Data requirement	Low	High
Loss location	Not identified	Identified
Use	Quick assessment	Detailed analysis

2.4 Causes of Technical Losses

Technical losses occur due to **electrical characteristics and equipment**.

1. Line Losses (I^2R Losses)

- Due to resistance of conductors

- Increase with current
- High at low power factor

📌 *Example:* Long LT lines in rural areas.

---

2. Transformer Losses

- **Core loss:** Present 24×7
- **Copper loss:** Increases with load

---

3. Poor Power Factor

- Low PF → High current → High losses
- Major contributor in industrial feeders

---

4. Overloading of Lines and Transformers

- Increases current
- Causes overheating and higher losses

---

5. Unbalanced Loads

- Causes neutral current
- Increases losses in phases and neutral

---

6. Long Distribution Lines

- Especially in LT networks
- Higher resistance → higher losses

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Utilities:** Use direct method for feeder loss monitoring; indirect for planning upgrades
- **Energy Auditors:** Identify high-loss components
- **Distribution Engineers:** Reduce losses via PF correction, reconductoring
- **Policy Makers:** Target loss reduction programs

📌 *Practical Example:*
Reducing technical losses by improving PF and upgrading conductors can save **large MWs** at state level.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Energy losses are inevitable but reducible
- Direct method is simple but less detailed
- Indirect method is detailed and diagnostic
- Technical losses arise from I^2R losses, transformers, low PF, and overloading
- Loss identification is the first step to efficiency improvement

Lecture 15 - Topic 4.15: Measures to Reduce Technical Losses, Commercial Losses, AT&C Loss Calculation & Loss Reduction Measures

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Imagine a water tank with two problems—**leakage in pipes** and **water theft**. Even if the pump works perfectly, the consumer never receives full water.
The electrical distribution system faces a similar challenge in the form of **technical losses** and **commercial losses**. Together, these are measured as **AT&C losses**, a key performance indicator for utilities. In this lecture, we will learn **how to reduce technical losses**, understand **commercial losses**, calculate **AT&C losses**, and study practical measures to reduce them.

---

2. Core Concepts (≈ 40 minutes)

2.1 Measures to Reduce Technical Losses

Technical losses are caused by physical and electrical factors. Key reduction measures include:

1. Power Factor Improvement

- Install capacitor banks
- Reduces line current
- Reduces I^2R losses

📌 *Link to Unit–3:*
PF correction directly reduces technical losses.

---

2. Use of Energy-Efficient Transformers

- Low-loss (star-rated) transformers
- Amorphous core transformers
- Proper transformer sizing

---

3. Reconductoring & Network Strengthening

- Replace undersized conductors
- Use higher cross-sectional area
- Reduces line resistance

---

4. Load Balancing

- Balance loads across phases
- Reduces neutral current and losses

---

5. Voltage Optimization

- Maintain rated voltage
- Avoid under-voltage and over-voltage

2.2 Commercial Losses

Commercial losses occur due to **non-technical reasons** such as:

- Energy theft (illegal connections)
- Faulty or tampered meters
- Unmetered supply
- Billing errors
- Collection inefficiencies

📌 *Key Point:*
Commercial losses do not waste energy—but they **waste revenue**.

2.3 Measures to Reduce Commercial Losses

1. Metering Improvements

- Accurate, tamper-proof meters
- Smart meters
- Regular meter testing

---

2. Billing & Collection Efficiency

- Timely and accurate billing
- Digital payment systems
- Strict collection policies

---

3. Theft Control

- Aerial bunched cables (ABC)
- Vigilance and inspection drives
- Legal enforcement

---

4. Consumer Awareness

- Educating consumers on legal and safety issues
- Incentives for regular payment

2.4 AT & C Losses (Aggregate Technical & Commercial Losses)

AT&C losses represent the **overall efficiency of the distribution system**.

Formula

$$\text{AT\&C Loss (\%)} = \left[1 - \left(\frac{\text{Energy Billed}}{\text{Energy Input}} \times \frac{\text{Revenue Collected}}{\text{Revenue Billed}}\right)\right] \times 100$$

Simple Numerical Example

Given:

- Energy input = 100 units
- Energy billed = 80 units
- Revenue billed = ₹800
- Revenue collected = ₹720

$$\text{AT\&C} = [1 - (0.8 \times 0.9)] \times 100$$

$$= (1 - 0.72) \times 100 = 28\%$$

📌 *Interpretation:*
28% of energy and revenue are lost due to technical and commercial losses combined.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Utilities:** Monitor AT&C losses feeder-wise
- **Distribution Engineers:** Plan network strengthening
- **Energy Auditors:** Identify loss reduction opportunities
- **Policy Makers:** Implement loss reduction schemes

📌 *Practical Insight:*
Reducing AT&C losses by even **5%** saves **huge revenue** at state level.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Technical losses arise from electrical characteristics
- Commercial losses arise from metering and billing issues
- AT&C losses combine both types
- Loss reduction requires technical + administrative measures
- Lower AT&C losses improve system reliability and finances

Lecture 16 - Topic 4.16: Demand Side Management (DSM) – Meaning, Methodology & Load Shape Objectives

(Unit–4: Energy Efficiency in Electrical & Utility Systems | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Why do power cuts usually occur during **evening peak hours**, even when power plants exist? Because the problem is not always **generation**, but **how and when consumers use electricity**. Instead of only increasing generation, modern power systems focus on **managing demand intelligently**—this approach is called **Demand Side Management (DSM)**. In today's lecture, we will clearly understand the **meaning of DSM**, its **methodology**, and the **concept of load shape objectives**, which are very important for exams, utilities, and future smart grids.

---

2. Core Concepts (≈ 40 minutes)

2.1 Meaning of Demand Side Management (DSM)

Demand Side Management refers to **planned actions taken at the consumer end** to:

- Reduce electricity consumption
- Shift load from peak to off-peak hours
- Improve overall energy efficiency

📌 *Simple Definition:*
DSM is about **using electricity wisely**, not wasting it.

📌 *Key Idea:*
DSM focuses on **demand control**, not supply expansion.

2.2 Objectives of DSM

- Reduce peak demand
- Improve load factor
- Defer investment in new power plants
- Reduce energy costs for consumers
- Improve system reliability

📌 *Fun Fact:*
Reducing peak demand by **1 MW** can save crores in generation and infrastructure costs.

2.3 DSM Methodology

DSM implementation follows a systematic approach:

Step 1: Load Study

- Analyze daily and seasonal load curves
- Identify peak hours and base load

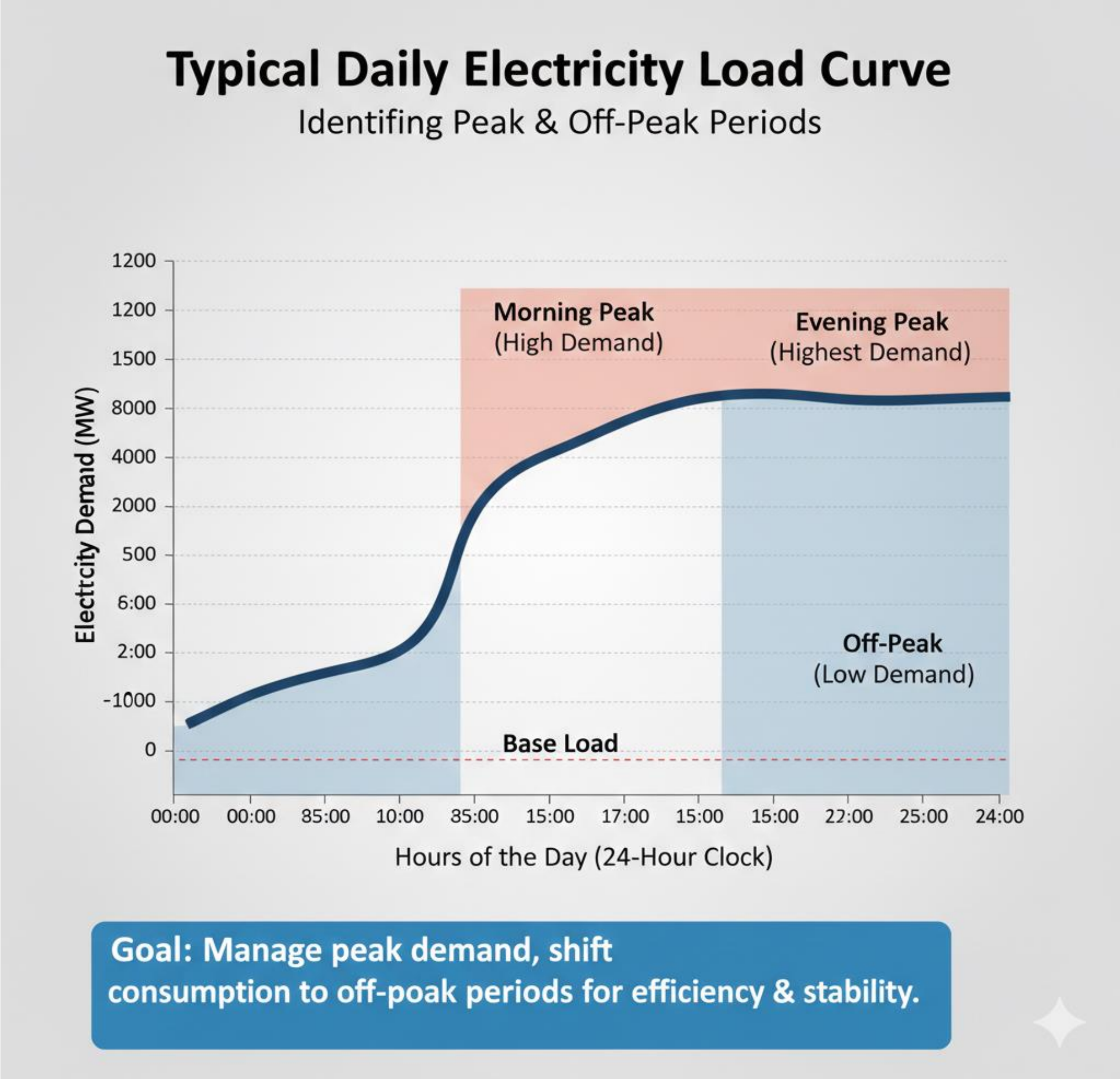

Fig. 4.20 Daily load curve showing peak and off-peak periods.

Step 2: Identify DSM Opportunities

- Energy-efficient appliances
- Load shifting possibilities
- Demand reduction measures

Step 3: Select DSM Measures

Common DSM measures include:

- Time-of-Use (TOU) tariffs
- Efficient motors and lighting
- Power factor improvement
- Load scheduling

Step 4: Implementation

- Consumer awareness programs
- Incentives and rebates
- Tariff modifications

Step 5: Monitoring & Evaluation

- Measure demand reduction
- Verify energy savings
- Continuous improvement

2.4 Load Shape Objectives

Load shape objectives describe **how the load curve is modified**.

1. Peak Clipping

- Reducing peak demand
- Example: Limiting AC use during peak hours

---

2. Valley Filling

- Increasing load during off-peak hours
- Example: Charging EVs at night

---

3. Load Shifting

- Moving load from peak to off-peak
- Example: Industrial process rescheduling

---

4. Strategic Conservation

- Reducing overall energy consumption
- Example: LED lighting

---

5. Strategic Load Growth

- Promoting beneficial electric loads
- Example: Electric cooking, EVs

2.5 Benefits of DSM

- Lower electricity bills
- Reduced power cuts
- Better utilization of existing infrastructure
- Environmental benefits (lower emissions)

📌 *Analogy:*
DSM is like **traffic management**—better flow, fewer jams.

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Utilities:** Implement TOU tariffs and peak load control
- **Industries:** Schedule heavy loads during off-peak hours
- **Residential consumers:** Use energy-efficient appliances
- **Smart Grids:** Use DSM with smart meters and automation

📌 *Practical Example:*
Night-time agricultural pumping reduces evening peak load.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- DSM manages electricity demand at consumer end
- It reduces peak load and improves system efficiency
- DSM methodology follows a systematic approach
- Load shape objectives modify demand pattern
- DSM supports reliable and sustainable power systems

● PHASE 3: STUDENT AI TOOLKIT (25 PROMPTS)

A. Low-Level Prompts (Remember & Understand) – 10 Prompts

1. *“Explain energy efficiency in simple words with one electrical example.”*
2. *“List major energy-consuming loads in an industry and explain their importance.”*
3. *“What is an energy-efficient distribution transformer? Explain its benefits.”*
4. *“Differentiate between core loss and copper loss in a transformer.”*
5. *“Explain the difference between amorphous core and CRGO core transformers.”*
6. *“Define IE1, IE2, IE3, and IE4 motor efficiency classes.”*
7. *“Explain luminous flux, illuminance, and luminous efficacy in simple terms.”*
8. *“What is voltage unbalance? Explain its effect on induction motor.”*
9. *“Define technical losses and commercial losses in a power system.”*
10. *“Summarize Unit–4: Energy Efficiency in Electrical & Utility Systems in 10 easy revision points.”*

B. Moderate-Level Prompts (Apply & Analyze) – 10 Prompts

11. *“Compare amorphous core and CRGO core transformers in terms of losses, efficiency, and cost.”*
12. *“Analyze the effect of load and power factor on efficiency of an induction motor.”*
13. *“Calculate percentage voltage unbalance for a three-phase motor and explain its impact.”*
14. *“Explain why star connection is preferred for induction motor during light load.”*
15. *“Compare energy consumption and payback period of standard motor vs energy-efficient motor using assumed data.”*
16. *“Explain the advantages of LED lighting over fluorescent and incandescent lamps.”*
17. *“Analyze the role of electronic ballast in reducing lighting energy consumption.”*
18. *“Explain direct and indirect methods of energy loss calculation in distribution systems.”*
19. *“Calculate AT & C losses using given data and interpret the result.”*
20. *“Explain Demand Side Management (DSM) methods with examples from electrical utilities.”*

C. High-Level Prompts (Design & Create) – 5 Prompts

21. *“Design an energy efficiency improvement plan for an industrial facility covering motors, transformers, and lighting systems.”*
22. *“Create a step-by-step lighting design method for a classroom using lumen method.”*

23. *“Develop a case study to evaluate energy savings and payback period by replacing old lighting with LED systems.”*
24. *“Prepare a system-level diagram showing technical and commercial losses in a distribution network and methods to reduce them.”*
25. *“Create a concept map linking energy efficiency, DSM, loss reduction, star labeling, and sustainability goals.”*

● PHASE 4: MASTERY CHECK

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1. Key Definitions / Glossary (Top 15 Terms)

1. **Energy Efficiency** – Using less energy to perform the same task or produce the same output.
2. **Energy Efficient Equipment** – Electrical equipment designed to consume less energy with minimum losses.
3. **Technical Losses** – Energy losses occurring due to resistance, leakage, and inefficiencies in electrical equipment and networks.
4. **Commercial Losses** – Energy losses due to theft, faulty metering, billing errors, and non-collection of revenue.
5. **AT & C Losses** – Aggregate Technical and Commercial losses representing overall distribution system efficiency.
6. **Energy Efficient Transformer** – Transformer designed with reduced core and copper losses.
7. **Amorphous Core Transformer** – Transformer using amorphous metal core with very low core losses.
8. **CRGO Core** – Cold Rolled Grain Oriented steel used in conventional transformer cores.
9. **IE Efficiency Class** – International classification (IE1 to IE4) of induction motors based on efficiency.
10. **Voltage Unbalance** – Condition where three-phase voltages are unequal in magnitude.
11. **Luminous Flux** – Total visible light output from a source, measured in lumens.
12. **Illuminance** – Amount of light falling on a surface, measured in lux.
13. **Luminous Efficacy** – Ratio of light output (lumens) to power input (watts).
14. **Load Survey** – Systematic study of electrical load pattern over a period of time.
15. **Demand Side Management (DSM)** – Techniques used to influence consumer electricity usage patterns to improve system efficiency.

---

2. FAQ & Assessment Section

A. Multiple Choice Questions (MCQs)

Q1. Energy efficiency means:
A) Increasing power generation
B) Reducing energy wastage
C) Increasing connected load
D) Increasing tariff

Q2. Which load consumes maximum energy in industries?
A) Lighting
B) Motors
C) Computers
D) Fans

Q3. Core losses in transformer occur due to:
A) Copper resistance
B) Eddy current and hysteresis
C) Load variation
D) Poor power factor

Q4. Amorphous core transformer is preferred because of:
A) High copper loss
B) High cost only
C) Very low core loss
D) Higher voltage rating

Q5. Which efficiency class represents the highest motor efficiency?
A) IE1
B) IE2
C) IE3
D) IE4

Q6. Voltage unbalance in a motor causes:
A) Reduced losses
B) Increase in temperature
C) Improved efficiency
D) Reduced current

Q7. One percent voltage unbalance can cause approximately how much increase in temperature?
A) 1%
B) 2%
C) 6–10%
D) 20%

Q8. Which connection is preferred for induction motor at light load?
A) Delta
B) Star
C) Zig-zag
D) Open delta

Q9. Luminous efficacy is measured in:
A) Lux
B) Lumen
C) Lumen/Watt
D) Watt

Q10. Which lighting source has highest luminous efficacy?
A) Incandescent lamp
B) CFL
C) Fluorescent lamp
D) LED

Q11. Direct method of loss calculation is based on:
A) Component losses
B) Input–output energy
C) Resistance measurement
D) Load survey

Q12. Indirect method of loss calculation is also called:
A) Energy method
B) Input method
C) Component-wise method
D) Billing method

Q13. Commercial losses are mainly due to:
A) Transformer losses
B) Line resistance
C) Energy theft and billing issues
D) Poor power factor

Q14. AT & C losses include:
A) Only technical losses
B) Only commercial losses
C) Technical + commercial losses
D) Transformer losses only

Q15. Load survey is useful for:
A) Increasing tariff
B) Selecting capacitor size
C) Reducing generation
D) Increasing losses

Q16. DSM mainly focuses on:
A) Generation side
B) Transmission side
C) Distribution side
D) Consumer side

Q17. Peak clipping in DSM means:
A) Increasing peak load
B) Reducing peak load
C) Shifting peak load
D) Filling valley

Q18. Which loss can be reduced by power factor improvement?
A) Commercial loss
B) Core loss
C) Copper loss
D) Theft loss

Q19. Electronic ballast is preferred over magnetic ballast because it:
A) Has higher losses
B) Operates at low frequency
C) Improves efficiency
D) Is heavier

Q20. Lighting design aims to achieve:
A) Maximum wattage
B) Required lux with minimum power
C) Maximum number of lamps
D) Higher voltage

Answer Key (MCQs)

1. B
2. B
3. B
4. C
5. D
6. B
7. C
8. B
9. C
10. D
11. B
12. C
13. C
14. C
15. B

16. D
17. B
18. C
19. C
20. B

B. Short Answer / Viva Questions (10 Questions)

1. Define energy efficiency and explain its importance.
2. List major energy-consuming loads in an industry.
3. Compare amorphous core and CRGO core transformers.
4. Explain IE efficiency classes of induction motors.
5. What is voltage unbalance and its effect on motor performance?
6. Why star connection is preferred at light load operation of motor?
7. Explain luminous flux and illuminance.
8. Differentiate between technical and commercial losses.
9. Explain AT & C losses with formula.
10. What is Demand Side Management (DSM) and state its objectives?

● PHASE 5: DIGITAL RESOURCE LIBRARY

Tools: RETScreen, OpenDSS, Lux meter apps, Excel
Videos:

- "Energy efficient motors NPTEL"
- "Lighting design diploma"
- "Distribution losses AT&C"

● PHASE 6: EXTERNAL EXPOSURE

- Transformer manufacturing units
- Motor testing labs
- DISCOM substations
- IEEE PES conferences

● PHASE 7: PREDICTED QUESTION BANK

Most Repeated

- Energy efficient transformer
- IE motor classes
- Lighting design
- AT&C losses
- DSM

Application

- Calculate motor payback
- Compare LED vs tube
- Analyze transformer losses
- DSM case study
- Lighting energy saving

◆ UNIT–5: TARIFF

Subject: Energy Efficiency & Audit
Branch: Diploma Electrical Engineering
Semester: 4 (GTU)

● PHASE 1: UNIT–5: UNIT–WISE STUDY PLAN

Topic No.	Topic Name	Nature	Hours	Exam Importance	Practical Relevance
5.1	Category of consumers: RGP, RGP (rural), GLP, Non- RGP, LTMD, LTP, AG, HTP-I to IV, LT & HV Electric Vehicle	Core	1	Very High	High
5.2	Terminology: Demand charge, contact demand, seasonal consumers, energy charge etc., Energy bill components for tariff of RGP and RGP (rural), GLP, NON – RGP	Core	1	Very High	Very High
5.3	Tariff for LTMD: Demand charge, energy charges, time of use charges, reactive energy charges, billing demand, minimum bill, seasonal consumer	Core	1	Very High	Very High
5.4	Tariff for LTP – Lift irrigation: Fixed charges and energy charge, Tariff for AG: HP based tariff, metered tariff	Core	1	Very High	Very High
5.5	Tariff for HTP-I & HTP-II: Demand charges, energy charges, time of use charges, billing demand, minimum bill, power factor adjusting charges, rebate	Supporting	1	Medium	High
5.6	Tariff for LT & HT Electric vehicle charging stations: Fixed charge & energy charge, Case study of electricity bill calculation for RGP, LTMD and HTP-1 considering all government charges	Application	1	Very High	Very High

---

● PHASE 2: DETAILED LECTURE SERIES

Lecture 1 - Topic 5.1: Categories of Electricity Consumers (Tariff Classification)

(Unit–5: Tariff | 60-minute classroom session)

---

1. Hook / Introduction (≈ 5 minutes)

Have you noticed that **your home electricity bill** looks very different from a **factory's bill** or a **shopping mall's bill**, even though electricity is the same?
This is because electricity tariffs are designed based on **how, where, and why electricity is used**. Utilities classify consumers into different **categories** to ensure **fair pricing, grid stability, and energy efficiency**. In today's lecture, we will clearly understand the **major consumer categories used in Indian electricity tariffs**, which is extremely important for **exam preparation, bill calculation, and practical engineering knowledge**.

---

2. Core Concepts (≈ 40 minutes)

2.1 Why Consumer Categorization is Necessary

Consumer categorization helps to:

- Charge electricity fairly
- Encourage efficient energy use
- Manage demand on the power system
- Provide subsidies where needed

📌 *Analogy:*
Electricity tariff is like a **transport ticket**—fare depends on distance and purpose.

2.2 Residential Consumers

A. RGP – Residential General Purpose

- Domestic households in urban areas
- Used for lighting, fans, TVs, refrigerators, ACs
- Low load and predictable usage

📌 *Typical voltage:* LT (230 V / 415 V)

B. RGP (Rural)

- Rural domestic consumers
- Often subsidized
- Lower consumption pattern

📌 *Objective:*
Promote rural electrification.

2.3 Commercial & General Consumers

C. GLP – General Lighting & Power

- Small shops, offices, schools, clinics
- Lighting + small motors allowed

📌 *Key Point:*
Higher tariff than residential due to commercial use.

D. Non-RGP

- Commercial consumers not covered under RGP
- Includes restaurants, hotels, showrooms

2.4 Low Tension Demand-Based Consumers

E. LTMD – Low Tension Maximum Demand

- Small and medium industries
- Demand measured in kVA
- Separate demand and energy charges

📌 *Important:*
Power factor and maximum demand matter.

F. LTP – Low Tension Power (Lift Irrigation)

- Used for irrigation pumps
- Seasonal load
- Often subsidized

G. AG – Agricultural Consumers

- Irrigation pump sets
- Tariff based on:
  - HP rating or
  - Metered energy

📌 *Fun Fact:*
AG tariff is one of the most subsidized categories.

2.5 High Tension Consumers

H. HTP-I to HTP-IV

- Large industrial and commercial users
- Supply at high voltage (11 kV, 33 kV, 66 kV)
- Categories include:
  - HTP-I: Industrial
  - HTP-II: Commercial
  - HTP-III: Railway traction
  - HTP-IV: Temporary supply / special purpose

📌 *Advantage:*
Lower technical losses due to high voltage supply.

2.6 Electric Vehicle (EV) Charging Consumers

I. LT & HV Electric Vehicle Charging Stations

- Dedicated tariff for EV charging
- Encourages electric mobility
- Time-of-use incentives available

📌 *Future Focus:*
EV tariffs support **DSM and clean energy goals**.

2.7 Summary Table

Category	Consumer Type	Supply Level
RGP	Domestic (Urban)	LT
RGP Rural	Domestic (Rural)	LT
GLP	Shops, offices	LT
LTMD	Small industries	LT
AG	Agriculture	LT
HTP I–IV	Large industries	HT
EV	Charging stations	LT / HT

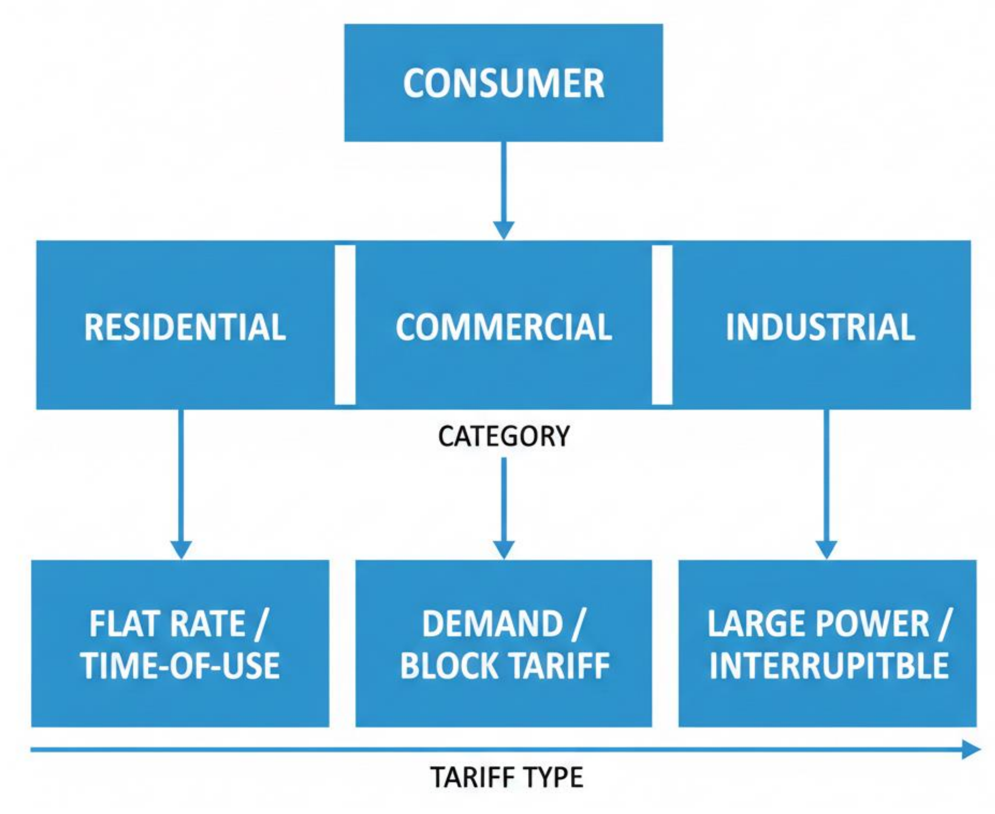

Fig. 5. 1 Flowchart showing consumer → category → tariff type.

3. Real-World / Industry Applications (≈ 10 minutes)

- **Utilities:** Apply correct tariff to consumers
- **Industries:** Plan energy cost based on category
- **Energy Auditors:** Verify correct billing
- **EV Infrastructure:** Design charging stations under suitable tariff

📌 *Practical Example:*
Incorrect consumer categorization can lead to **billing disputes and penalties**.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Tariff categories are based on usage type and voltage level
- Residential, commercial, agricultural, and industrial consumers differ
- LTMD and HTP tariffs include demand charges
- EV tariffs are future-oriented
- Correct categorization ensures fair billing

Lecture 2 - Topic 5.2: Electricity Tariff Terminology & Energy Bill Components (RGP, RGP–Rural, GLP & Non-RGP)

(Unit–5: Tariff | 60-minute classroom session)

---

1. Hook / Introduction (≈ 5 minutes)

When you look at an electricity bill, you may notice many terms like **energy charge, fixed charge, demand charge, contract demand**, and **government duty**.
Have you ever asked: *Why do two houses with similar consumption pay different amounts?*
The answer lies in **tariff terminology and bill structure**. In today's lecture, we will clearly understand the **important tariff terms** and the **energy bill components** used for **RGP, RGP (rural), GLP, and Non-RGP consumers**—a topic frequently asked in exams and very useful in practical life.

---

2. Core Concepts (≈ 40 minutes)

2.1 Important Tariff Terminology

1. Demand Charge

- Charge based on **maximum demand** recorded during billing period
- Applicable mainly to **LTMD and HT consumers**
- Unit: ₹/kVA or ₹/kW

📌 *Simple meaning:*
Payment for **capacity kept ready** by the utility.

---

2. Contract Demand

- Maximum demand agreed between consumer and utility
- Consumer is penalized if actual demand exceeds contract demand

📌 *Analogy:*
Like booking a hotel room capacity in advance.

---

3. Energy Charge

- Charge based on **actual energy consumed**
- Unit: ₹/kWh (unit)

$$\text{Energy Charge} = \text{Units consumed} \times \text{Rate}$$

---

4. Fixed Charge

- Monthly charge irrespective of energy consumption
- Based on connected load or sanctioned load

📌 *Purpose:*
Covers maintenance and infrastructure cost.

---

5. Seasonal Consumer

- Consumers who use electricity only during specific months
- Example: Agricultural pump users

---

6. Minimum Bill

- Minimum amount payable even if no energy is consumed
- Ensures revenue for utility

---

7. Government Charges

- Electricity duty
- Taxes and surcharges

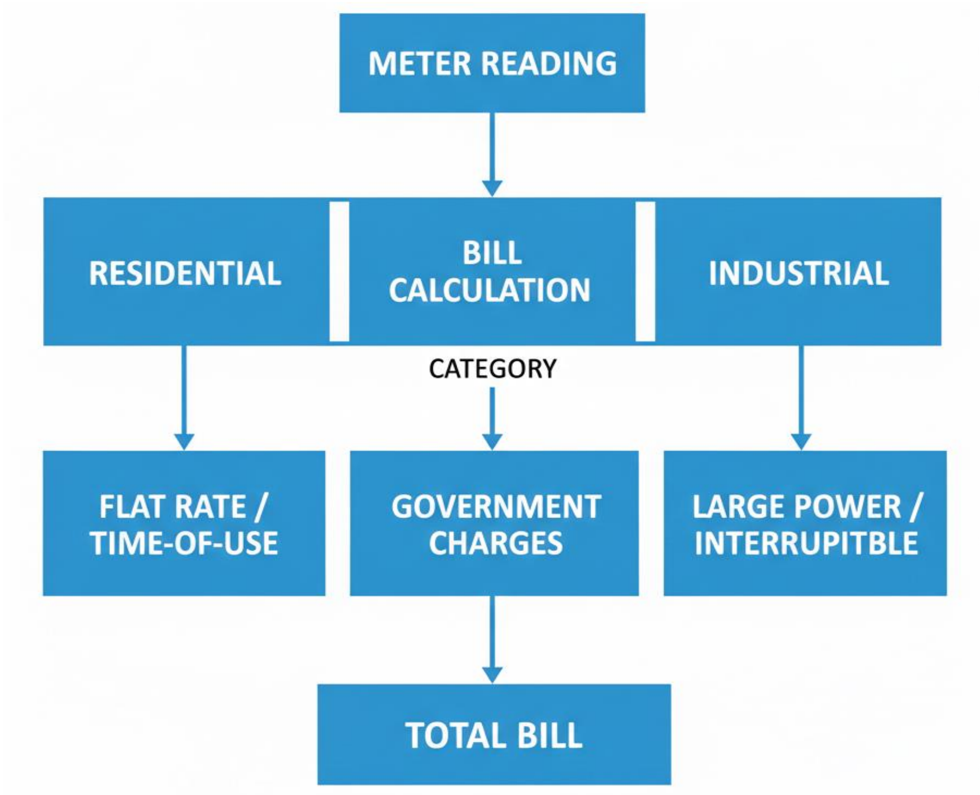

Fig. 5.2 Flowchart: Meter reading → Bill calculation → Government charges → Total bill

---

2.2 Energy Bill Components – RGP & RGP (Rural)

A. RGP (Residential General Purpose)

Bill components:

1. Fixed charge (₹/kW or ₹/connection)
2. Energy charge (slab-wise)
3. Electricity duty
4. Other government charges

📌 *Key Feature:*
Slab-based tariff encourages **energy conservation**.

B. RGP (Rural)

- Similar to RGP
- Lower tariff rates
- Higher subsidy component

📌 *Objective:*
Promote rural electrification and affordability.

2.3 Energy Bill Components – GLP (General Lighting & Power)

GLP consumers include shops, offices, and small commercial establishments.

Bill components:

1. Fixed charge (higher than RGP)
2. Energy charge (flat or slab rate)
3. Electricity duty
4. Fuel surcharge (if applicable)

📌 *Key Point:*
Commercial usage → higher tariff than residential.

2.4 Energy Bill Components – Non-RGP

Non-RGP consumers include hotels, restaurants, showrooms, and large commercial loads.

Bill components:

1. Fixed charge
2. Energy charge
3. Demand charge (in some cases)
4. Electricity duty
5. Other surcharges

📌 *Important:*
Non-RGP tariffs are designed to reflect **higher system load impact**.

2.5 Comparison Table (Exam-Oriented)

Consumer Category	Fixed Charge	Energy Charge	Demand Charge
RGP	Yes	Slab-wise	No
RGP (Rural)	Yes	Lower slabs	No

Consumer Category	Fixed Charge	Energy Charge	Demand Charge
GLP	Yes	Flat / slab	No
Non-RGP	Yes	Higher rate	Sometimes

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Consumers:** Understand and verify electricity bills
- **Energy Auditors:** Identify high-cost components
- **Utilities:** Design fair and efficient tariffs
- **Engineers:** Advise clients on tariff optimization

📌 *Practical Example:*
Shifting from Non-RGP to correct category avoids unnecessary charges.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- Tariff terminology explains how electricity cost is calculated
- Energy charge depends on consumption
- Fixed and demand charges recover infrastructure costs
- Different consumer categories have different bill structures
- Understanding bill components helps control electricity cost

Lecture 3 - Topic 5.3: Tariff for LTMD Consumers – Demand Charge, Energy Charge, TOU, Reactive Energy & Billing Provisions

(Unit–5: Tariff | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Why does a small factory sometimes pay **more electricity charges than expected**, even when energy consumption is controlled?
The reason is **Maximum Demand**. For LTMD consumers, the electricity bill depends not only on **units consumed**, but also on **how fast and when electricity is used**. In this lecture, we will clearly understand **LTMD tariff structure**, including **demand charge, energy charge, time-of-use (TOU) charges, reactive energy charges, billing demand, minimum bill, and seasonal consumer concept**—all crucial for exams and industrial practice.

---

2. Core Concepts (≈ 40 minutes)

2.1 LTMD – Low Tension Maximum Demand Consumers

- Applicable to **small and medium industries**
- Supply at LT (415 V)
- Maximum demand measured in **kVA**
- Separate meters for energy and demand

📌 *Key Difference:*
LTMD bills depend on **kVA demand**, not just kWh.

2.2 Demand Charge

- Based on **billing demand** in kVA
- Charged in ₹/kVA/month

$$\text{Demand Charge} = \text{Billing Demand (kVA)} \times \text{Rate}$$

📌 *Purpose:*
Recover cost of capacity kept ready by utility.

2.3 Billing Demand

Billing demand is the **higher** of:

- Recorded maximum demand, or
- Specified percentage (e.g., 85%) of contract demand

📌 *Example:*
If contract demand = 100 kVA
Minimum billing demand = 85 kVA

2.4 Energy Charges

- Charged on total energy consumed (kWh)
- Rate generally **lower than commercial tariff**
- Encourages industrial activity

$$\text{Energy Charge} = \text{Units consumed} \times \text{Energy rate}$$

2.5 Time of Use (TOU) Charges

- Different rates for:
    - Peak hours
    - Normal hours
    - Off-peak hours

📌 *Objective:*
Encourage load shifting to off-peak hours.

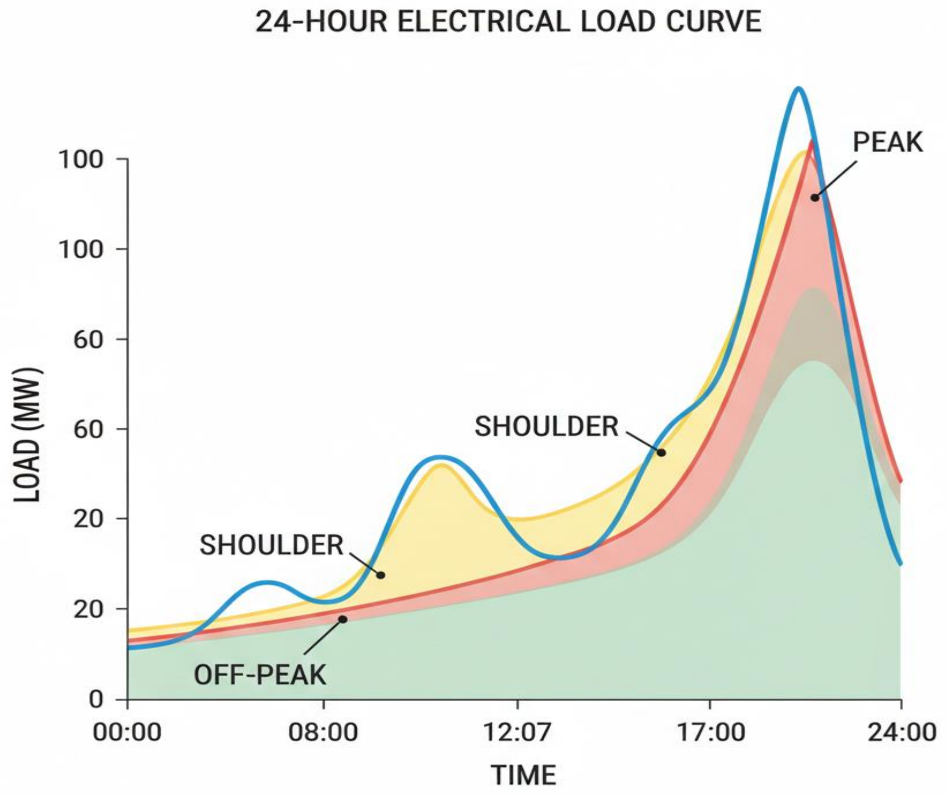

Fig. 5.3 24-hour load curve with peak, shoulder, and off-peak periods marked.

2.6 Reactive Energy Charges

- Applicable if power factor is below prescribed limit (e.g., 0.95)
- Charged for excess kVARh consumption

📌 *Key Point:*
Low PF increases current and system losses.

📌 *Solution:*
Install capacitor banks.

2.7 Minimum Bill

- Minimum amount payable every month
- Usually linked to **minimum billing demand**
- Applicable even if consumption is zero

📌 *Purpose:*
Ensure fixed revenue for utility.

2.8 Seasonal Consumer (LTMD)

- Industries operating only during certain months
- Pay charges only during operational season
- Special tariff provisions apply

📌 *Example:*
Sugar mills, cotton ginning factories.

2.9 Summary Table

Component	Basis
Demand Charge	Billing demand (kVA)
Energy Charge	Units consumed (kWh)
TOU Charge	Time of consumption
Reactive Charge	kVARh
Minimum Bill	Contract demand
Seasonal Consumer	Limited operating months

---

3. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Control demand to reduce charges
- **Energy Managers:** Optimize TOU usage
- **Utilities:** Encourage off-peak consumption
- **Engineers:** Design PF correction systems

📌 *Practical Example:*
Shifting heavy machinery operation to off-peak hours reduces TOU charges.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- LTMD tariff is demand-based
- Demand charge depends on billing demand
- TOU charges influence operating schedule
- Reactive energy charges penalize low PF
- Seasonal consumers get flexible billing

Lecture 4 - Topic 5.4: Tariff for LTP (Lift Irrigation) & Agricultural (AG) Consumers

(Unit–5: Tariff | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Why does a farmer with a **10 HP pump** often pay a **fixed seasonal charge**, while a factory pays based on demand and energy?
Electricity tariffs are not only technical—they are also **social and economic tools**.
Agricultural and lift irrigation tariffs are designed to **support food production and rural development**. In today's lecture, we will understand the **tariff structure for LTP (Lift Irrigation)** and **AG (Agricultural) consumers**, including **fixed charges, energy charges, HP-based tariffs, and metered tariffs**.

---

2. Core Concepts (≈ 40 minutes)

2.1 LTP – Lift Irrigation Tariff

What is Lift Irrigation?

Lift irrigation uses **electric pumps** to lift water from rivers, canals, or wells to higher levels for irrigation.

- Supply level: Low Tension (LT)
- Load: Pump sets and motors
- Operation: Seasonal

📌 *Key Feature:*
LTP tariff supports **group irrigation schemes**.

Components of LTP Tariff

A. Fixed Charges

- Based on:
    - Connected load (HP/kW)
    - Number of pumps
- Charged monthly or seasonally

📌 *Purpose:*
Covers infrastructure and maintenance cost.

B. Energy Charges

- Based on actual energy consumption (kWh)
- Rate is **lower than industrial tariff**

$$\text{Energy Charge} = \text{Units consumed} \times \text{Rate}$$

📌 *Note:*
Some states provide partial or full subsidy.

Special Provisions

- Seasonal billing
- Lower tariff during irrigation season
- Relaxed PF requirements

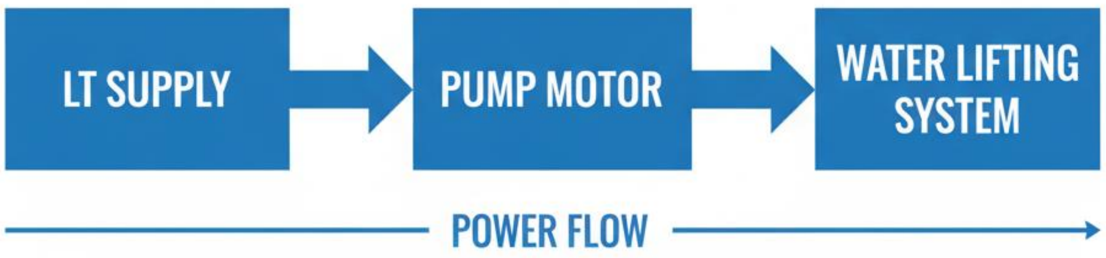

Fig. 5.4 Block diagram showing LT supply → Pump motor → Water lifting system.

2.2 AG – Agricultural Tariff

AG tariff applies to **individual farmers** using electricity for irrigation pump sets.

A. HP-Based Tariff

- Bill calculated based on **horsepower (HP) rating**
- No energy meter required
- Fixed charge per HP per month

📌 *Advantages:*

- Simple billing
- Low cost

📌 *Disadvantages:*

- No incentive to save energy
- Overuse of electricity possible

B. Metered Tariff

- Energy meter installed
- Charges based on **actual kWh consumed**
- Encourages energy-efficient practices

📌 *Government Preference:*
Shift from HP-based to **metered tariff** for better energy management.

Comparison: HP-Based vs Metered Tariff

Parameter	HP-Based	Metered
Meter	Not required	Required
Billing	Fixed per HP	Based on kWh
Energy saving	Not encouraged	Encouraged
Accuracy	Low	High

2.3 Subsidy in AG Tariff

- Government provides subsidies to farmers
- Promotes agricultural growth
- Utility compensated by government

📌 *Fun Fact:*
AG consumers often pay only a **small fraction** of actual electricity cost.

3. Real-World / Industry Applications (≈ 10 minutes)

- **Rural electrification:** Affordable irrigation power
- **Energy planners:** Promote efficient pump sets
- **Utilities:** Balance subsidy and revenue
- **Engineers:** Design efficient pumping systems

📌 *Practical Example:*
Replacing inefficient pumps under metered tariff reduces power consumption and improves groundwater sustainability.

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- LTP tariff supports lift irrigation schemes
- LTP includes fixed and energy charges
- AG tariff can be HP-based or metered
- Metered tariff promotes energy efficiency
- Subsidies play a major role in AG tariffs

Lecture 5 - Topic 5.5: Tariff for HTP-I & HTP-II Consumers – Demand, Energy, TOU, PF Adjustment & Rebates

(Unit–5: Tariff | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Why do **large industries** take supply at **11 kV or 33 kV** instead of 415 V?
Because **high voltage supply reduces losses and lowers cost**—but it also comes with a **detailed and strict tariff structure**. For **HTP-I and HTP-II consumers**, electricity billing depends not only on energy used, but also on **maximum demand, power factor, and time of use**. In this lecture, we will clearly understand the **HTP-I and HTP-II tariff components**, which are frequently asked in exams and essential for industrial power management.

---

2. Core Concepts (≈ 40 minutes)

2.1 HTP-I & HTP-II Consumers – Overview

- **HTP-I:** Large industrial consumers
- **HTP-II:** Large commercial consumers (malls, hotels, hospitals, IT parks)
- Supply voltage: **11 kV / 33 kV / 66 kV**
- Metering: **kWh, kVAh, kVARh**

📌 *Key Difference from LT:*
Billing is based on **kVA demand**, not just energy.

2.2 Demand Charges

- Based on **billing demand (kVA)**
- Charged in ₹/kVA/month

$$\text{Demand Charge} = \text{Billing Demand} \times \text{Demand Rate}$$

📌 *Purpose:*
Recover cost of infrastructure and capacity reserved.

2.3 Billing Demand

Billing demand is the **highest of**:

- Recorded maximum demand during billing period
- Specified percentage (e.g., 85–90%) of contract demand

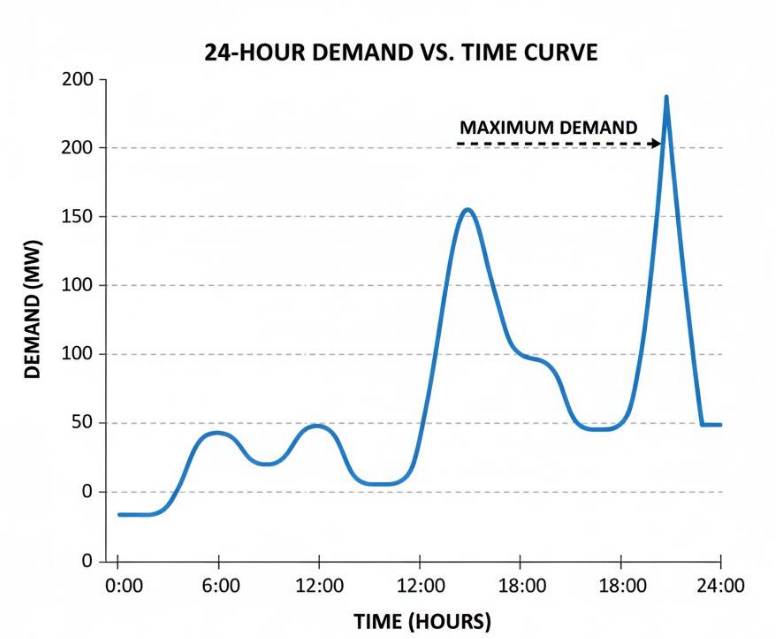

Fig. 5.5 Graph showing demand vs time with maximum demand marked

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2.4 Energy Charges

- Based on total energy consumption
- Charged per **kWh or kVAh**
- Lower per-unit rate compared to LT consumers

📌 *Engineering Insight:*
HT supply reduces current and I^2R losses.

2.5 Time of Use (TOU) Charges

- Different tariffs for:
  - Peak hours (higher rate)
  - Normal hours
  - Off-peak hours (lower rate)

📌 *Objective:*
Encourage industries to shift loads to off-peak hours.

2.6 Power Factor Adjusting Charges

- **Penalty** for low PF (below specified limit, e.g., 0.95)
- **Rebate** for high PF

📌 *Why PF matters:*
Low PF increases current, losses, and system stress.

📌 *Solution:*
Install capacitor banks or APFC panels.

2.7 Minimum Bill

- Minimum monthly charge payable
- Usually linked to:
  - Minimum billing demand, or
  - Percentage of contract demand

📌 *Purpose:*
Ensure minimum revenue for utility.

2.8 Rebates & Incentives

Utilities may provide rebates for:

- High power factor
- Off-peak usage
- Energy-efficient practices

📌 *Fun Fact:*
Some industries save lakhs per year by improving PF and TOU management.

2.9 Summary Table

Component	Basis
Demand Charge	Billing demand (kVA)
Energy Charge	kWh / kVAh
TOU Charge	Time of consumption
PF Adjustment	PF level
Minimum Bill	Contract demand
Rebate	High PF / Off-peak use

3. Real-World / Industry Applications (≈ 10 minutes)

- **Industries:** Optimize demand and PF to reduce bills
- **Energy Managers:** Plan TOU-based load shifting
- **Utilities:** Control peak load
- **Engineers:** Design HT substations and PF correction systems

📌 *Practical Example:*
Operating heavy machinery at night reduces TOU charges and improves load factor.

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- HTP tariffs are demand-oriented
- Demand and energy charges form major bill components
- TOU charges influence operating schedule
- PF adjustment charges reward efficient consumers
- Proper tariff management reduces industrial energy cost

Lecture 6 - Topic 5.6: Tariff for LT & HT Electric Vehicle (EV) Charging Stations & Case Study of Electricity Bill Calculation (RGP, LTMD, HTP-I)

(Unit–5: Tariff | 60-minute classroom session)

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1. Hook / Introduction (≈ 5 minutes)

Electric vehicles are increasing rapidly on Indian roads. But have you ever wondered—**how is electricity charged at an EV charging station?**
Is it the same as a home tariff, or like an industry?
To promote clean mobility, utilities have introduced **special EV tariffs** at both **LT and HT levels**. In today's lecture, we will first understand the **tariff structure for EV charging stations**, and then apply tariff concepts through **three practical case studies** of electricity bill calculation for **RGP, LTMD, and HTP-I consumers**, including **government charges**—a very high-scoring and practical topic.

---

2. Core Concepts (≈ 40 minutes)

2.1 Tariff for Electric Vehicle (EV) Charging Stations

EV charging stations are treated as a **separate consumer category** to encourage electric mobility.

A. LT EV Charging Stations

- Supply at **230 V / 415 V**
- Suitable for:
  - Residential societies
  - Public slow chargers
- Connected load is moderate

Bill Components:

1. **Fixed Charge** – based on connected load (kW)
2. **Energy Charge** – based on kWh consumed
3. Government charges (duty, tax)

📌 *Key Feature:*
Lower energy tariff compared to commercial category.

B. HT EV Charging Stations

- Supply at **11 kV / 33 kV**
- Used for:
  - Fast chargers
  - Highway charging stations
- High power demand

Bill Components:

1. **Demand Charge** – based on billing demand (kVA)
2. **Energy Charge** – kWh / kVAh
3. TOU charges (if applicable)
4. Government charges

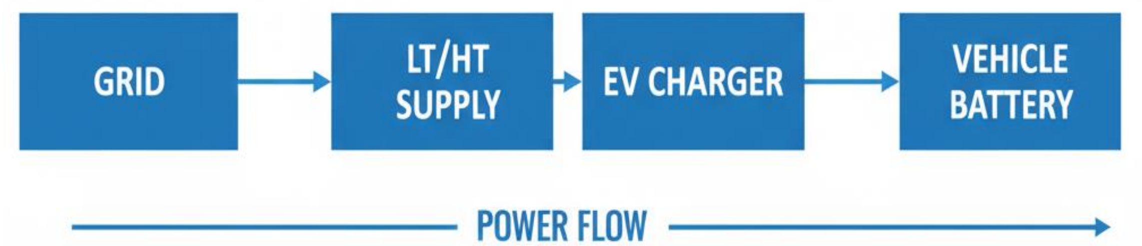

Fig. 5.6 Block diagram: Grid → LT/HT supply → EV charger → Vehicle battery

2.2 Case Study-1: Electricity Bill Calculation for RGP (Residential)

Given:

- Monthly energy consumption = **200 units**
- Energy rate = **₹5/unit**
- Fixed charge = **₹100**
- Electricity duty = **10% of energy charge**

Calculation:

- Energy charge = 200 × 5 = ₹1000
- Duty = 10% of 1000 = ₹100

Total Bill = 1000 + 100 + 100 = ₹1200

2.3 Case Study-2: Electricity Bill Calculation for LTMD Consumer

Given:

- Billing demand = **50 kVA**
- Demand charge = **₹200/kVA**
- Energy consumption = **10,000 units**
- Energy rate = **₹4/unit**
- Electricity duty = **10% of (demand + energy charges)**

Calculation:

- Demand charge = 50 × 200 = ₹10,000
- Energy charge = 10,000 × 4 = ₹40,000
- Sub-total = ₹50,000
- Duty = 10% = ₹5,000

Total Bill = ₹55,000

2.4 Case Study-3: Electricity Bill Calculation for HTP-I Consumer

Given:

- Billing demand = **200 kVA**
- Demand charge = **₹300/kVA**
- Energy consumption = **50,000 units**
- Energy rate = **₹3.5/unit**
- PF rebate = **₹5,000**
- Electricity duty = **10%**

Calculation:

- Demand charge = 200 × 300 = ₹60,000
- Energy charge = 50,000 × 3.5 = ₹1,75,000
- Sub-total = ₹2,35,000
- PF rebate = −₹5,000 → ₹2,30,000
- Duty (10%) = ₹23,000

Total Bill = ₹2,53,000

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3. Real-World / Industry Applications (≈ 10 minutes)

- **EV infrastructure developers:** Select LT or HT tariff wisely
- **Utilities:** Promote EV adoption through special tariffs
- **Energy auditors:** Verify correct billing category
- **Industries:** Optimize PF and demand to reduce cost

📌 *Practical Insight:*
EV tariffs combined with **off-peak charging** support DSM and grid stability.

---

4. Summary & Q&A (≈ 5 minutes)

Key Takeaways

- EV charging stations have special LT and HT tariffs
- LT EV tariff uses fixed + energy charges
- HT EV tariff includes demand charges
- RGP, LTMD, and HTP-I bills differ in structure
- Government charges significantly affect final bill

● PHASE 3: STUDENT AI TOOLKIT (25 PROMPTS)

A. Low-Level Prompts (Remember & Understand) – 10 Prompts

1. *"Explain the meaning of electricity tariff in simple words suitable for diploma students."*
2. *"List and explain different categories of electricity consumers such as RGP, LTMD, HTP, AG, and LTP."*
3. *"Define demand charge, energy charge, and billing demand with simple examples."*
4. *"What is Time of Use (TOU) tariff? Explain its purpose in brief."*
5. *"Explain power factor adjusting charges and why they are applied."*
6. *"What is a minimum bill? Why is it necessary for electricity utilities?"*
7. *"Explain seasonal consumer and give examples."*
8. *"What is electricity duty and who collects it?"*
9. *"Explain EV charging station tariff in simple language."*
10. *"Summarize Unit–5: Tariff in 10 easy revision points for exams."*

B. Moderate-Level Prompts (Apply & Analyze) – 10 Prompts

11. *"Differentiate between RGP and LTMD tariff with suitable examples."*
12. *"Explain the tariff structure of LTMD consumers including demand charge and energy charge."*
13. *"Analyze the tariff structure of HTP-I and HTP-II consumers with components."*
14. *"Explain how Time of Use (TOU) tariff helps in Demand Side Management."*
15. *"Compare HP-based tariff and metered tariff for agricultural consumers."*
16. *"Calculate a sample electricity bill for an RGP consumer using assumed data."*
17. *"Analyze the effect of power factor penalty on electricity bill of an industrial consumer."*
18. *"Explain the tariff structure for lift irrigation (LTP) consumers."*
19. *"Compare LT and HT EV charging station tariffs."*
20. *"Prepare short exam-oriented notes on the importance of tariff in energy management."*

C. High-Level Prompts (Design & Create) – 5 Prompts

21. *"Design a complete electricity bill calculation for an LTMD consumer including demand charge, energy charge, PF adjustment, and electricity duty."*
22. *"Create a case study comparing electricity bills of an industry before and after power factor improvement."*

23. *“Develop a decision-making guide to select the most economical tariff category for a new industrial consumer.”*
24. *“Prepare a flowchart showing step-by-step electricity bill calculation for RGP, LTMD, and HTP consumers.”*
25. *“Create a concept map connecting tariff, demand charge, TOU, PF adjustment, DSM, and energy efficiency.”*

● PHASE 4: MASTERY CHECK

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1. Key Definitions / Glossary (Top 15 Terms)

1. **Tariff** – Schedule of rates at which electrical energy is supplied to different categories of consumers.
2. **Consumer Category** – Classification of electricity consumers based on type of usage and load.
3. **RGP (Residential General Purpose)** – Tariff category for domestic electricity consumers.
4. **LTMD (Low Tension Maximum Demand)** – Tariff category for LT consumers billed based on maximum demand.
5. **HTP (High Tension Power)** – Tariff category for consumers taking supply at high voltage.
6. **Demand Charge** – Charge based on the maximum demand (kVA) recorded during billing period.
7. **Energy Charge** – Charge based on electrical energy consumed (kWh).
8. **Billing Demand** – Demand on which demand charges are calculated, usually the higher of recorded or contracted demand.
9. **Contract Demand** – Maximum demand agreed between consumer and utility.
10. **Time of Use (TOU) Tariff** – Tariff with different rates for peak and off-peak hours.
11. **Power Factor Adjusting Charge** – Penalty or rebate applied based on consumer’s power factor.
12. **Minimum Bill** – Minimum amount payable irrespective of energy consumption.
13. **Seasonal Consumer** – Consumer who operates only during a specific season.
14. **Electric Vehicle (EV) Tariff** – Special tariff category for EV charging stations.
15. **Electricity Duty** – Government tax levied on consumption of electrical energy.

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2. FAQ & Assessment Section

A. Multiple Choice Questions (MCQs)

Q1. Electricity tariff mainly depends on:
A) Colour of meter
B) Type of consumer
C) Frequency
D) Insulation level

Q2. RGP tariff is applicable to:
A) Industries
B) Commercial complexes
C) Domestic consumers
D) Agricultural pumps

Q3. LTMD consumers are billed based on:
A) kWh only
B) kW only
C) kVA demand and kWh
D) Voltage level

Q4. HTP consumers take supply at:
A) 230 V
B) 415 V
C) 11 kV and above
D) 110 V

Q5. Demand charge is calculated on the basis of:
A) Connected load
B) Energy consumed
C) Maximum demand
D) Power factor

Q6. Time of Use tariff aims to:
A) Increase peak load
B) Reduce tariff
C) Shift load from peak to off-peak
D) Increase consumption

Q7. Power factor penalty is applied when PF is:
A) High
B) Unity
C) Below specified limit
D) Leading

Q8. Which consumer generally pays the lowest tariff?
A) HTP industrial
B) Commercial
C) Agricultural
D) LTMD

Q9. Minimum bill is charged to:
A) Penalize consumers
B) Recover fixed cost of utility
C) Increase profit
D) Reduce losses

Q10. EV charging station tariff is introduced mainly to:
A) Increase revenue
B) Promote electric vehicles
C) Increase peak load
D) Reduce DSM

Q11. Energy charge is calculated using:
A) kVA
B) kVAR
C) kWh
D) HP

Q12. Billing demand is generally:
A) Lower than recorded demand
B) Higher of recorded or percentage of contract demand
C) Always equal to contract demand
D) Same for all consumers

Q13. Seasonal consumer is applicable to:
A) Residential users
B) Commercial shops
C) Industries operating seasonally
D) IT companies

Q14. PF rebate encourages consumers to:
A) Increase demand
B) Improve power factor
C) Increase losses
D) Reduce voltage

Q15. LTP tariff is applicable to:
A) Domestic lighting
B) Lift irrigation schemes
C) Commercial malls
D) EV charging

Q16. HP-based tariff is generally used for:
A) Industries
B) LTMD consumers
C) Agricultural consumers
D) Commercial consumers

Q17. Metered tariff is better than HP-based tariff because it:
A) Is costlier
B) Measures actual energy consumption
C) Encourages overuse
D) Removes meters

Q18. Electricity duty is levied by:
A) Utility company
B) Central government
C) State government
D) Consumer

Q19. TOU tariff is most beneficial for consumers who:
A) Operate during peak hours
B) Operate during off-peak hours
C) Have low PF
D) Have seasonal load

Q20. HTP consumers are encouraged to maintain high PF because:
A) It increases kVA demand
B) It reduces demand and penalty
C) It increases tariff
D) It reduces voltage

Answer Key (MCQs)

1. B
2. C
3. C
4. C
5. C
6. C
7. C
8. C
9. B
10. B
11. C
12. B
13. C
14. B
15. B

16. C
17. B
18. C
19. B
20. B

B. Short Answer / Viva Questions (10 Questions)

1. Define electricity tariff and explain its objectives.
2. Differentiate between RGP and LTMD tariff.
3. Explain demand charge and energy charge.
4. What is billing demand? Why is it important?
5. Explain Time of Use (TOU) tariff with example.
6. Why power factor adjustment charges are applied?
7. What is minimum bill and why is it necessary?
8. Explain AG tariff and LTP tariff.
9. What is EV charging station tariff and its significance?
10. Explain the role of tariff in Demand Side Management (DSM).

● PHASE 5: DIGITAL RESOURCE LIBRARY

AI & Tools

- Electricity bill calculators (DISCOM portals)
- Excel – bill calculation
- AI chatbots – numerical explanation

Video Resources (Search Keywords)

- "Electricity tariff calculation diploma"
- "LTMD tariff explained"
- "HT consumer electricity bill calculation"

● PHASE 6: EXTERNAL EXPOSURE

- DISCOM billing office visit
- Smart meter demonstration
- EV charging stations
- Regulatory workshops (GERC/CEA)

● PHASE 7: PREDICTED QUESTION BANK

Most Repeated Questions

- Explain consumer categories.
- Explain LTMD tariff.
- Explain HTP-I tariff.
- Define tariff terminology.
- Explain TOU charges.

Application Questions

1. Calculate electricity bill for RGP consumer.
2. Calculate LTMD bill considering TOU charges.
3. Analyze PF impact on tariff.
4. Explain EV charging tariff benefits.
5. Compare AG and LTP tariff.
