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ELECTRICAL ENERGY CONSERVATION AND AUDITING

MODULE 2: Energy Efficiency in Electrical Systems

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Electrical Energy Conservation and Auditing

Energy Efficiency in Electrical Systems

Comprehensive study of electricity billing, load management, power factor improvement, and energy efficient technologies

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Power System Overview

Generation to End User Distribution

System Components

Electric power supply systems comprise generating units that produce electricity, high voltage transmission lines for long-distance transport, distribution networks for consumer delivery, substations connecting system components, and energy control centers coordinating operations across the entire grid infrastructure.

Energy Losses

Standard technical losses average 17% in India with overall system efficiency of 83%. Industrial distribution networks achieve 95% efficiency, motors operate at 90% efficiency, while mechanical systems lose an additional 30%, resulting in overall plant efficiency of approximately 50% from generation to final output.

Electricity Billing Fundamentals

Understanding power consumption and tariff structures

Unit Definition

One unit equals 1 kWh representing 1000 watts consumed for one hour, equivalent to 3.6×10^6 joules of electrical energy.

Tariff Components

Electricity tariffs include maximum demand charges, energy charges based on consumption, power factor penalties or bonuses, fuel cost adjustments, electricity duty charges, and meter rentals. Time-of-day rates differentiate peak and non-peak hours, while penalties apply for exceeding contract demand. Analysis of utility bills helps identify cost reduction opportunities through available tariff provisions and energy budgeting strategies.

Maximum Demand Control Strategies

Load Management Approaches

1 **Load Curve Generation and Rescheduling**

Creating hourly and daily load curves enables identification of peak demand periods, allowing strategic rescheduling of large equipment operations across different shifts to minimize simultaneous maximum demand and improve load factor.

2 **Storage and Load Shedding Systems**

Building storage capacity for products, materials, and utilities enables off-peak operations. Automated demand monitoring systems shed non-essential loads when preset limits are approached, providing both manual and microprocessor-controlled options.

3 **Generation and Power Factor Compensation**

Strategic operation of captive generation during peak periods reduces grid demand charges. Reactive power compensation through capacitor banks with microprocessor control maintains optimal power factor and reduces maximum demand effectively.

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Power Factor Improvement Benefits

Active and reactive power management strategies

Power Fundamentals

Inductive loads require both active power (kW) for work and reactive power (kVAr) for electromagnetic fields.

Cost Benefits

Reduced kVA charges, lower distribution losses, and elimination of low power factor penalty charges.

Vector Relationships

Total apparent power (kVA) represents the vector sum of active and reactive power components.

Performance Gains

Better voltage at motor terminals improves equipment performance and extends operational life significantly.

Correction Methods

Capacitor banks act as reactive power generators, reducing total power demand from utilities effectively.

Infrastructure Savings

Reduced investment requirements for transformers, cables, and switchgear due to lower total power demand.

Transformer Efficiency Analysis

Performance comparison across different loading conditions

Transformer efficiency varies between 96-99% depending on design and operating load, with optimization achievable through proper loading and location strategies.

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Energy Efficient Motor Performance Data

Comparative analysis showing efficiency improvements and operational benefits of energy efficient motors versus standard motors across different load conditions and applications.

Motor Type	Efficiency (%)	Temperature (°C)	Life Expectancy	Maintenance Cost	Power Factor
Standard 5HP	85.2	75	15 years	High	0.82
EE 5HP	89.5	65	25 years	Low	0.86
Standard 25HP	90.1	78	18 years	High	0.84
EE 25HP	93.2	68	28 years	Low	0.88
Standard 100HP	93.5	80	20 years	Medium	0.86

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Variable Speed Drive Applications

Energy savings potential in different motor control applications

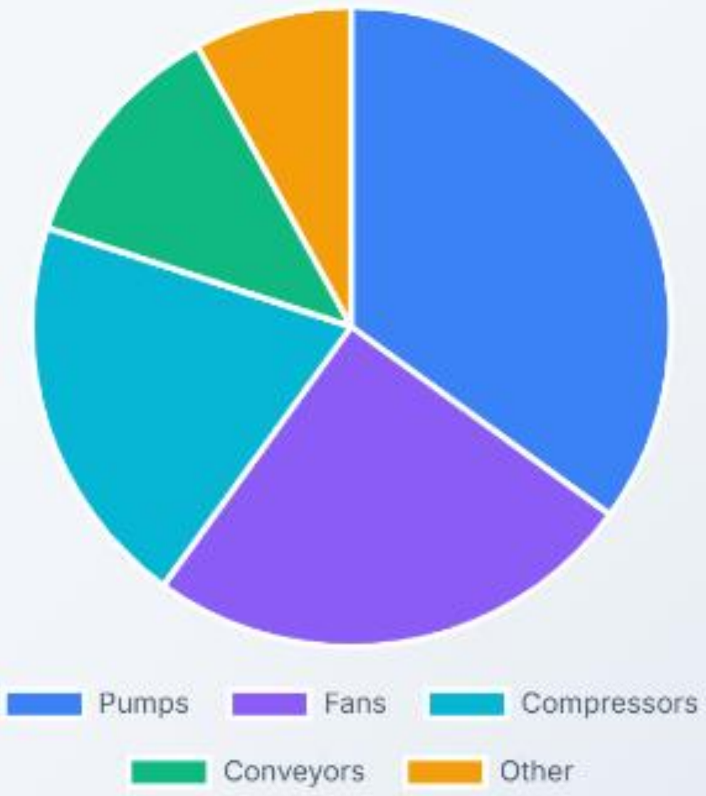
VFD Technology

Variable frequency drives control motor speed by varying supply frequency, providing precise control and significant energy savings. Modern VFDs use advanced microprocessor control with IGBT power devices, offering improved reliability, reduced size, and enhanced programmability for diverse industrial applications.

Energy Savings

Variable torque applications like centrifugal pumps and fans show greatest energy savings potential compared to constant torque applications.

Load Distribution



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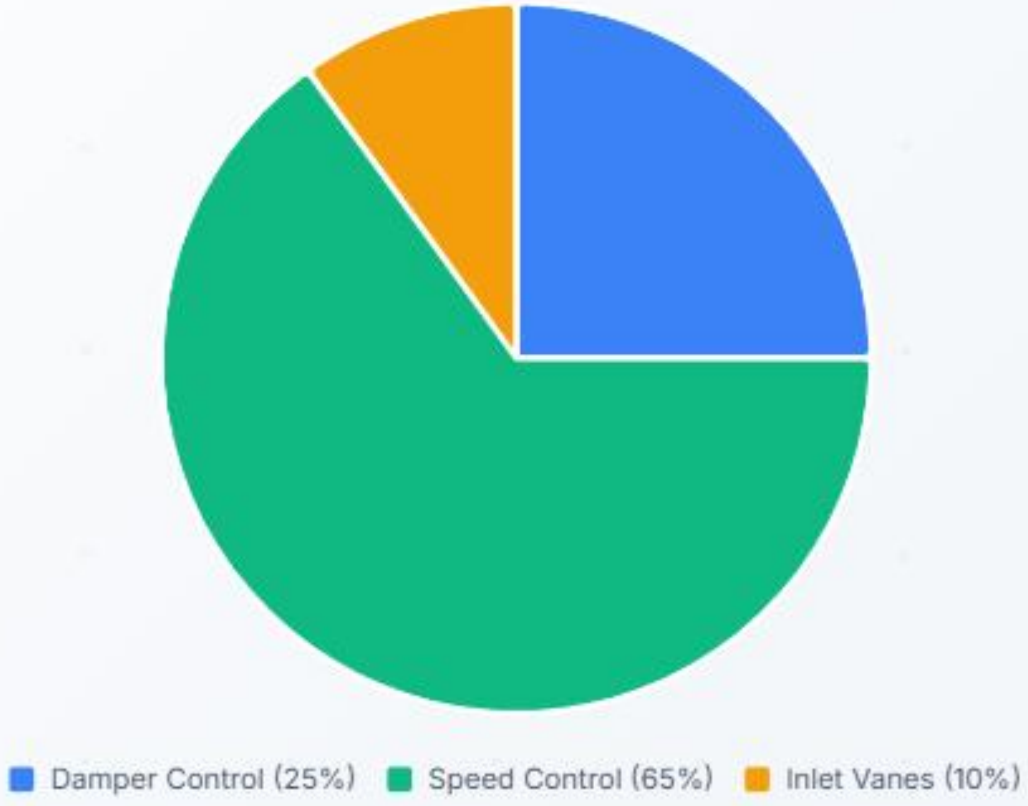
Fan Performance Optimization Methods

Comparing flow control strategies for energy conservation

Control Methods



Key Insights

Damper Control

Restricting airflow through dampers creates higher system resistance, requiring greater pressure and consuming more energy while providing reduced flow rates through the system.

Speed Control

Reducing fan speed maintains full damper opening, achieving same flow reduction at lower pressure requirements, resulting in significantly improved energy efficiency and reduced power consumption.

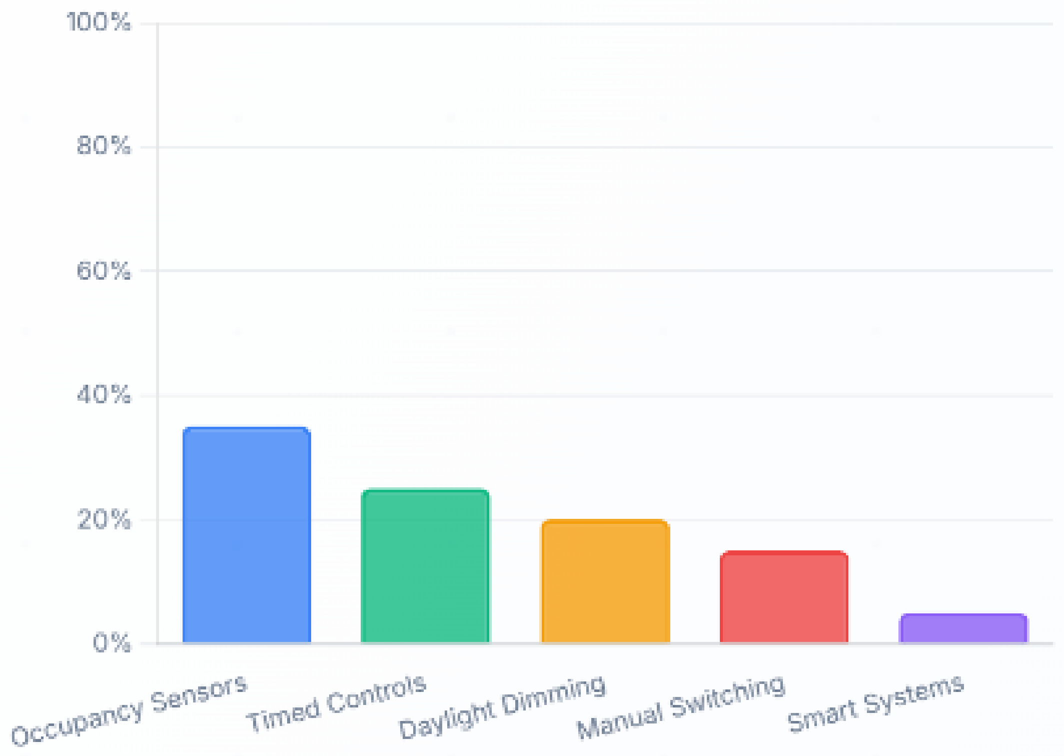
Performance Assessment

Field testing measures flow, static pressure, velocity pressure, and total pressure using pitot tubes and manometers to evaluate actual fan performance against design specifications.

Energy Efficient Lighting Control Systems

Automated lighting management for optimal efficiency

Control Types



Implementation Benefits

Occupancy sensors using infrared, acoustic, or ultrasonic detection automatically switch lighting based on room occupancy, preventing energy waste in unoccupied spaces. Timed-based controls offer cost-effective automation with spring-wound or electronic switches providing preset operation intervals. Daylight dimming systems adjust artificial lighting levels based on available natural light, maximizing energy savings while maintaining desired illumination levels. Localized switching enables zone-specific control in large spaces, allowing individual occupant control while facilitating targeted energy conservation measures.

Power Generation Plants

Energy sources and conversion technologies in India

Energy Sources

Fossil fuels including coal, oil, natural gas, nuclear energy, and hydroelectric power are primary energy sources for electricity generation.

Indian Context

Approximately 70% of India's power generating capacity comes from coal-based thermal power plants. These facilities convert chemical energy stored in coal into electrical energy through thermodynamic cycles. Coal remains the dominant fuel source due to abundant domestic reserves, though renewable energy capacity is rapidly expanding to meet growing demand and environmental commitments.

Transmission and Distribution System

Voltage Levels and Infrastructure

1

Primary Transmission (400kV/220kV)

Power plants generate AC power at 50 Hz with voltages between 11kV-33kV, then stepped up to high voltage levels for long-distance transmission to minimize losses.

2

Secondary Transmission (132kV/110kV/66kV/33kV)

Power is stepped down at receiving stations to secondary transmission levels for regional distribution networks and bulk power transfer to major substations.

3

Primary Distribution (11kV/6.6kV/3.3kV)

Final voltage reduction occurs at substations for bulk consumers and local distribution networks, enabling efficient power delivery to industrial and commercial users.

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Industrial Energy Flow

From grid connection to mechanical output

Grid to Motor

Power reaches industrial premises through transformers, switchgear, cables, and distribution networks. Transformer efficiency is typically very high at 95%, while motor efficiency averages 90%. Distribution network components including transformers, lines, and protective equipment contribute to overall system losses.

Mechanical Systems

Mechanical systems including couplings, drive trains, pumps, and control valves account for 30% energy loss (70% efficiency). Overall system efficiency from generation to mechanical output becomes approximately 50% ($0.83 \times 0.95 \times 0.9 \times 0.70 = 0.50$), highlighting significant improvement opportunities.

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Energy Meter Reading and Calculation

Understanding consumption measurement and billing calculations

Meter Reading

Energy consumption measured through consecutive kWh readings over billing period.

Calculation Method

Total consumption equals final reading minus initial reading (y-x) kWh.

Unit Conversion

Since 1 Unit = 1 kWh, total units consumed = (y-x) Units.

Tariff Components

Maximum demand charges based on peak 30-minute power usage during billing cycle.

Additional Charges

Power factor penalties, fuel cost adjustments, and electricity duty charges.

Special Rates

Time-of-day rates, lighting loads, and contract demand penalty provisions.

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Trivector Meter Functions

Advanced Metering Infrastructure

1

Maximum Demand Measurement

Records peak power demand in preset intervals (typically 30 minutes), reset at end of each billing cycle. Measures time-integrated demand rather than instantaneous values.

2

Energy Measurements

Captures active energy (kWh), reactive energy (kVArh), and apparent energy (kVAh) during complete billing cycles for comprehensive power quality assessment.

3

Billing Applications

Electromagnetic or electronic trivector meters provide essential data for utility billing calculations, demand charge assessment, and power factor penalty determination.

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Need for Load Management

Addressing capacity constraints and demand optimization

Market Drivers

Growing electricity demand and diverse end-use segments create capacity shortfalls requiring immediate attention.

Management Strategy

Since capacity addition is costly and time-consuming, effective load management at user level minimizes peak demands on utility infrastructure while optimizing power plant capacity utilization. Utilities employ tariff structures including time-of-use rates, maximum demand penalties, and night tariff concessions to influence consumer behavior and promote efficient load management practices.

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Load Curve Analysis

Understanding demand patterns for optimization

Curve Types

Load curves present consumer demand against time periods. Hourly load curves show 24-hour patterns for single days, revealing peak and off-peak periods. Daily load curves plot daily demands over monthly periods, identifying weekly patterns and seasonal variations. These graphical representations enable identification of load management opportunities and demand optimization strategies for industrial facilities.

Industrial Applications

Engineering industries utilize load curve analysis to identify peak demand periods and optimize equipment scheduling. Typical industrial load curves show distinct patterns based on production schedules, shift operations, and equipment usage. Analysis enables strategic load rescheduling, storage system optimization, and demand response planning to minimize maximum demand charges and improve overall load factor performance.

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Load Rescheduling Implementation Strategy

Optimizing equipment operations across shifts

1

Process Analysis

Prepare detailed operation flow charts and process charts for comprehensive analysis.

2

Equipment Mapping

Identify large electric loads and their operational requirements and constraints.

3

Shift Planning

Reschedule operations across different shifts to minimize simultaneous demand.

4

Load Factor

Improve load factor through integrated approach reducing maximum demand effectively.

Storage and Off-Peak Operations

Maximizing efficiency through strategic energy use

Storage Systems

Building storage capacity for products, materials, water, chilled water, and hot water enables electricity usage during off-peak periods. This strategy shifts energy consumption to times when utility rates are lower and grid demand is reduced, resulting in significant cost savings and improved system efficiency.

Operational Benefits

Off-peak operations provide favorable conditions including lower ambient temperatures, reduced utility rates, and improved equipment performance. Strategic storage system implementation enables maximum demand reduction while maintaining production requirements and operational flexibility for industrial processes.

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Load Shedding System Framework

Automated demand management for peak control

Manual Systems

Simple demand monitoring systems provide alarms when preset demand levels are approached. Operators manually shed non-essential loads based on predetermined priority lists. These cost-effective systems require trained personnel for effective operation and quick response to demand alerts during peak usage periods.

Automated Systems

Sophisticated microprocessor-controlled systems offer advanced features including accurate demand prediction, graphical displays of current load status, and automatic load shedding in predetermined sequences. These systems provide visual and audible alarms with automatic load restoration capabilities.

Control Features

Advanced systems display present load, available capacity, and demand limits in real-time. They provide comprehensive recording and metering functions for analysis and optimization. Integration with plant control systems enables seamless load management without operational disruption.

Implementation Benefits

Automated load shedding systems prevent maximum demand exceedance, reduce utility charges, and maintain operational continuity. They enable precise control over non-essential loads while protecting critical processes from interruption during peak demand periods.

Captive Generation Integration

Strategic use of backup power systems

Diesel Generation

Diesel generation sets supplement utility power supply during peak demand periods. Strategic connection of DG sets when demand reaches peak values significantly reduces grid load demand and minimizes demand charges. Proper scheduling ensures optimal utilization while maintaining cost-effectiveness through fuel consumption management and operational efficiency optimization.

Operational Strategy

Integration timing is crucial for maximum benefit realization. DG sets should operate during utility peak hours to achieve maximum demand reduction. Coordination with load management systems ensures seamless transition between grid and captive power. Regular maintenance and fuel quality management maintain reliability and efficiency of captive generation systems.

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Maximum Demand Controller Operation

Intelligent load management for cost optimization

Alarm System

Audio and visual alerts when demand approaches critical thresholds for immediate action.

Logical Sequence

Predetermined load shedding order based on operational priorities and user requirements.

Control Integration

Suitable control contactors implement demand control schemes for seamless equipment management.

MDC Functions

Automated device for industries implementing strategic load management through intelligent monitoring and control.

Controller sounds alarms when demand approaches preset values. Without corrective action, automatically switches off non-essential loads in logical, predetermined sequences programmed jointly by user and supplier.

Equipment Selection

Plant equipment chosen for load management based on operational criticality and flexibility.

Profile Control

Equipment stopped and restarted according to desired load profile and demand requirements.

Cost Savings

Significant utility bill reductions through strategic maximum demand charge management and optimization.

Transformer Types and Classifications

Power and distribution transformer applications

Power Transformers

Used in transmission networks for high voltage applications including 400kV, 200kV, 110kV, 66kV, and 33kV systems.

Step-up Applications

Increase voltage levels for efficient long-distance power transmission with reduced losses.

Network Integration

Connect generation facilities to high voltage transmission grid infrastructure systems.

Distribution Transformers

Serve lower voltage distribution networks providing end-user connectivity and local power supply.

Voltage Levels

Handle 11kV, 6.6kV, 3.3kV, 440V, and 230V for residential, commercial, and industrial applications.

User Connectivity

Final voltage conversion stage delivering appropriate power levels to end consumers.