ENERGY AUDIT AND EFFICIENCY
ENIE 435

Lecture : 3 **Year : IV**
Tutorial : 2 **Part : I**
Practical : 1

Course Objectives:
The objective of the course is to provide theoretical and practical foundation in energy auditing and management within industrial and commercial sectors. Students will systematically analyze energy flow, utilize diagnostic instrumentation and evaluate the performance of critical electrical and thermal utilities, including boilers, furnaces and HVAC systems.

1 Introduction to Energy Audit (5 hours)

1.1 Definition, objectives and scope of energy auditing
1.2 Energy index and Sankey diagrams: Visualizing energy flow and charts
1.3 Preliminary, detailed and post-audit activities
1.4 Energy audit instrumentation: Thermal, mechanical and electrical tools

2 Energy Efficiency and Management (5 hours)

2.1 Need for energy efficiency management and energy conservation
2.2 Principle of energy management, rules for efficient energy conservation
2.3 Technologies and strategies for energy conservation
2.4 Global and national standards for energy efficiency ratings

3 Electrical Utilities and Demand Management (6 hours)

3.1 Electrical energy demand analysis, power factor management
3.2 Supply side options, demand side options, maximum demand controller, transmission and distribution side option
3.3 Distribution loss in industrial system
3.4 Tariff analysis: Structure and optimization based on NEA categories
3.5 Energy efficient motors: Characteristics, selection and variable frequency drives
3.6 Energy efficient lighting system
3.7 Energy conservation opportunities in lighting system and motors

4 Mechanical Utility Appliances (6 hours)

4.1 Compressed air system: Capacity assessment, leakage and its test and system pressure optimization

4.2 Fans and blowers: Performance evaluation, efficient system operation, flow control strategies
4.3 Pumping systems: Best efficiency point (BEP), impeller trimming, variable frequency drive (VFD) applications
4.4 Cooling tower: Range and approach of thermal performance and water quality management

5 Boilers and Steam Distribution Systems (5 hours)

5.1 Fuel and combustion: Stoichiometric air and excess air requirements
5.2 Performance evaluation by direct and indirect (Heat Loss) methods
5.3 Boiler breakdown, blowdown management and feed water treatment
5.4 Steam distribution system and insulation/leakage audit analysis
5.5 Energy conservation (ENCON) opportunities in steam cycles and reporting of its energy audit

6 Industrial Furnaces (5 hours)

6.1 Classification and heat transfer mechanisms in furnaces
6.2 Performance evaluation of furnace: Wall losses, opening losses and storage heat analysis
6.3 Fuel economy measures in furnaces with draft control, ceramic coatings and proper heat distribution
6.4 Diagnostic tools: Fishbone diagrams for identifying furnace inefficiencies

7 Waste Heat Recovery System and Cogeneration (4 hours)

7.1 Grading of waste heat sources
7.2 Heat recovery technologies: Heat exchangers, recuperators, regenerators and economizers
7.3 Cogeneration, combined heat and power (CHP) principles and heat-to-power ratios
7.4 Performance parameters and relative merits of cogeneration system

8 Heating Ventilation and Air Conditioning and Refrigeration Systems (4 hours)

8.1 Types of refrigeration system and selection criteria
8.2 COP, energy efficiency ratio (EER) and Seasonal energy efficiency ratio (SEER) calculations
8.3 Measurement and field testing of chillers and heat pump
8.4 Refrigerant selection and its anthropogenic and natural impact

9 Financial Analysis for Energy Projects (5 hours)

9.1 Fixed and variable costs of energy saving measures

9.2 Simple payback period (SPP) and return on investment (ROI)
9.3 Net present value (NPV) and internal rate of return (IRR)
9.4 Risk assessment: Sensitivity analysis and factors affecting discounted cash flow

Tutorial **(30 hours)**

1. Analysis of industrial electricity bills to identify peak demand penalties and NEA tariff optimization opportunities
2. Calculation of the required capacitor bank rating for power factor improvement in a multi-load industrial feeder
3. Evaluation of the thermal efficiency of a fire-tube boiler using both direct and indirect (Heat loss) methods
4. Assessment of compressed air system leakages and calculation of the annual energy cost of air loss at various operating pressures
5. Determination of the return on investment (ROI) and net present value (NPV) for the installation of a waste heat recovery recuperator in an industrial furnace
6. Development of a comprehensive Sankey diagram for an industrial plant to visualize energy conversion stages and system losses
7. Drafting of an executive summary and technical recommendations for a detailed energy audit report targeting plant management

Practical **(15 hours)**

1. Configuration of energy audit diagnostic instrumentation including thermal imagers, ultrasonic leak detectors and flue gas analyzers
2. Execution of compressor performance and leakage tests to quantify volumetric efficiency and unintended air discharge
3. Determination of motor and pump efficiency through field measurements of electrical input and hydraulic output parameters
4. Performance evaluation of fans and blowers by measuring air flow, static pressure and specific power consumption
5. Conducting an electrical power quality audit utilizing a three-phase power analyzer to identify harmonic distortion and phase imbalance
6. Assessment of lighting system efficacy and motor load factors to identify immediate energy conservation opportunities (ECOs)
7. Verification of HVAC system performance through the measurement of cooling/heating capacities and coefficient of performance (COP)
8. Measurement of Boiler and furnace efficiency using flue gas temperature and oxygen concentration data

Final Exam

The questions will cover all the chapters in the syllabus. The evaluation scheme will be as indicated in the table below:

Chapters	Hours	Mark distribution*
1, 2	10	12
3	6	8
4	6	8
5, 6	10	14
7	4	6
8	4	6
9	5	6
Total	**45**	**60**

* There may be minor deviation in marks distribution.

References

1. Abbi, Y. P., Jain, S. (2015). Handbook on energy audit and environment management. TERI Press.
2. Capehart, B. L., Turner, W. C., Kennedy, W. J. (2020). Guide to energy management. Fairmont Press.
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4. Grubb, M. (2023). Planetary economics: Energy, climate change and the three domains of sustainable development. Routledge.
5. Thumann, A., Niehus, T., Younger, W. J. (2022). Handbook of energy audits. Fairmont Press.
6. Trinks, W., Mawhinney, M. H., Shannon, R. A., Reed, R. J., Garvey, J. R. (2003). Industrial furnaces. Wiley.
7. Witte, L. C., Schmidt, P. S., Brown, D. R. (2018). Industrial energy management and utilization. CRC Press.

INDUSTRIAL SERVICES
ENIE 436

Lecture : 3 **Year : IV**
Tutorial : 2 **Part : I**
Practical : 1

Course Objectives:
The objective of this course is to provide knowledge about industry related services and make students able to select mechanical, electrical and plumbing (MEP) components and perform essential engineering calculations for piping, cabling and ducting. The course enables students to design integrated factory service layouts and develop accurate bill of quantities (BoQ) and cost estimates.

1 Introduction (5 hours)

1.1 Role of MEP and supporting services in industrial production
1.2 Mapping service requirements to production units and workflow
1.3 Reading and interpreting industrial utility diagrams (Piping and instrumentation diagram, single line diagrams, HVAC schematics)
1.4 Estimating approximate utility loads (Steam, electricity, water, compressed air) from sample factory layouts

2 Mechanical Utility Design and Selection (8 hours)

2.1 Steam systems
    2.1.1 Boiler types, mountings, accessories
    2.1.2 Steam load calculation for processes
    2.1.3 Pipe sizing and layout principles
    2.1.4 Condensate recovery design
    2.1.5 Equipment selection criteria
2.2 Compressed air systems
    2.2.1 Compressor types and capacities
    2.2.2 Air treatment with dryers and filters
    2.2.3 Receiver sizing, piping layout and leakage allowance
    2.2.4 Calculation of air demand for workshop tools
    2.2.5 Equipment selection criteria
2.3 HVAC and refrigeration
    2.3.1 Heat load estimation for rooms and workshops
    2.3.2 Duct sizing and layout planning
    2.3.3 AHU, chiller and cooling tower selection
    2.3.4 Preparation of schematic HVAC layout

3 Electrical Service Design (8 hours)

- 3.1 Industrial load estimation: Connected load, diversity factor and maximum demand calculations
- 3.2 Transformer, substation and generator selection based on calculated loads, preparation of single line diagram (SLD)
- 3.3 Industrial wiring design
  - 3.3.1 Power factor correction and cable sizing
  - 3.3.2 Bus-bar selection
  - 3.3.3 Breaker calculation
  - 3.3.4 Earthing and lightning protection
- 3.4 Lighting design
  - 3.4.1 Application of lumen method
  - 3.4.2 Fixture selection and layout for workshop and office spaces
  - 3.4.3 Cost estimation of lighting systems
- 3.5 Backup power planning for generator
- 3.6 UPS sizing with approximate cost calculation

4 Plumbing, Water and Fire Services (8 hours)

- 4.1 Industrial water supply systems
  - 4.1.1 Pumps, storage tanks, piping materials and fittings
  - 4.1.2 Calculation of water demand for process, domestic, cooling and firefighting
- 4.2 Pipe sizing using velocity or head-loss methods
- 4.3 Pump selection and power calculation
- 4.4 Preparation of piping layout for water and fire systems
- 4.5 Fire protection systems:
  - 4.5.1 Fire pump room, hydrant and sprinkler layout
  - 4.5.2 Procedure of hose reel placement
  - 4.5.3 Fire water tank sizing
- 4.6 Drainage and wastewater systems
  - 4.6.1 Floor drains, sewer layout and basic effluent treatment
  - 4.6.2 Pipe sizing and slope planning integrated with plant layout

5 Supporting Services and Sustainability (6 hours)

- 5.1 Sanitary services
  - 5.1.1 Toilet, ventilation and worker comfort layout planning
  - 5.1.2 Sizing of piping and airflow
- 5.2 Noise, air and waste management services
  - 5.2.1 Identifying control measures
  - 5.2.2 Cost- effective implementation of waste management system
- 5.3 Green industrial practices
  - 5.3.1 Rainwater harvesting system design and sizing
  - 5.3.2 Solar water heating systems

5.3.3 Energy-efficient lighting calculation and integration into factory services

6 Integrated Factory Design and Costing (10 hours)

6.1 Utility load calculation

6.1.1 Combined calculation of electrical, steam, HVAC, compressed air and water demand for the factory

6.1.2 Preparation of a consolidated load report

6.2 Equipment selection and specification

6.2.1 Selection of boilers, pumps, compressors, chillers, fans, transformers, generators and UPS

6.2.2 Specification sheets with approximate cost

6.3 Service layout and routing

6.3.1 Integrated layout of steam, water, compressed air, HVAC ducts, electrical cables and fire piping

6.3.2 Factors to consider for accessibility, maintenance paths and service corridors

6.4 Bill of quantities (BoQ) and cost estimation

6.4.1 Quantification of materials (Pipes, valves, fittings, cables, ducts, lighting fixtures, pumps, fire equipment)

6.4.2 Estimation of installation and operational costs

6.5 Project implementation

6.5.1 Sequencing of service installation

6.5.2 Testing procedures, commissioning, safety measures and preparation of a simple project timeline

Tutorial (30 hours)

1. Estimation of connected load, calculate demand and suggest transformer/generator size
2. Calculation of illumination levels using the Lumen method for complex workshop floor plans and office spaces
3. Sizing of industrial water supply piping using the head-loss and velocity-limited methods
4. Design of a steam distribution loop including pipe sizing, expansion loops and steam trap selection for a process plant
5. Quantification of fire-water demand and sizing of hydrants, sprinklers and fire storage tanks per safety codes
6. Development of a comprehensive single line diagram (SLD) including breaker ratings and bus-bar sizing for a workshop
7. Preparation of a consolidated bill of quantities (BoQ) and technical specifications for a utility service package

Practical (15 hours)

1. Verification of lighting design through lux-meter measurements in varied industrial environments and comparison with design values

2. Execution of a pipe sizing and pump selection exercise for a simulated industrial water supply station
3. Drafting of integrated MEP service layouts using AutoCAD, focusing on the coordination between water, air and fire piping
4. Configuration of a professional-grade single line diagram (SLD) using electrical design software or CAD
5. Site Inspection of a boiler or compressor plant to identify mounting configurations, safety accessories and piping routes
6. Development of a project timeline (Gantt Chart) for the installation and commissioning phases of a selected industrial service

Final Exam

The questions will cover all the chapters in the syllabus. The evaluation scheme will be as indicated in the table below:

Chapter	Hours	Mark distribution*
1	5	6
2	8	10
3	8	12
4	8	10
5	6	8
6	10	14
Total	**45**	**60**

* There may be minor deviation in marks distribution.

References

1. Arora, C. P. (2017). Refrigeration and air conditioning. McGraw Hill.
2. American Society of Heating, Refrigerating and Air-Conditioning Engineers. (2021). ASHRAE handbook: Fundamentals. ASHRAE.
3. Chadderton, D. V. (2012). Building services engineering. Routledge.
4. Grondzik, W. T., Allison, K. W. (2019). Mechanical and electrical equipment for buildings. Wiley.
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6. Nayyar, M. L. (2019). Piping handbook. McGraw Hill.
7. Vedavarz, A., Kumar, S., Hussain, M. I. (2007). HVAC: The handbook of heating, ventilation and air conditioning for design and implementation. Industrial Press.

INDUSTRIAL AUTOMATION AND MECHATRONICS
ENIE 437

Lecture : 3 **Year : IV**
Tutorial : 2 **Part : I**
Practical : 1

Course Objectives:
The objective of this course is to provide students with a comprehensive understanding of industrial automation and mechatronics systems, focusing on the integration of mechanical, electronic and computer-based control components. The course also introduces computer numerical control (CNC) machine programming and specialized control structures like cascade and predictive control.

1 Automation, Sensors and Actuators (6 hours)

1.1 Classification of industrial automation system
1.2 Factory and manufacturing environment for automation
1.3 Working principles and signal conditioning for proximity, position, light, flow, pressure, temperature, velocity, acceleration, force, signal interfacing, signal conditioning and data acquisition
1.4 Working of pneumatic/hydraulic cylinders and motors; AC/DC, servo and stepper motors
1.5 Fieldbus technology and network integration of sensors and actuators

2 Control System Theory (12 hours)

2.1 Open/closed-loop systems, transfer functions, modeling of mechanical systems/couplings, Laplace transforms
2.2 Unit step, ramp and sinusoidal responses
2.3 Elements and classification of two-position controller, P, I, PI, PD and PID control; Adaptive control and PID tuning methods
2.4 Concept of stability, Routh-Hurwitz criteria, root locus analysis and determination of Gain (K)

3 Implementation of Control Systems (6 hours)

3.1 Electrical and electronic controls: Relay and contactor logic; Transistor, Op-Amp and Logic gate based control; Micro-controller and IoT integration
3.2 Pneumatic and hydraulic logic; Flow, pressure and direction control valves; Limit switches, timers and counters
3.3 Introduction to Fuzzy logic, machine learning and AI-based controllers in automation

4 Programmable and Supervisory Control Systems (12 hours)

4.1 Programmable logic controllers (PLC): Architecture, I/O processing, ladder logic (LD), instruction list (IL), latching, timers, counters, shift registers and master control relays

4.2 SCADA and DCS: Architecture, communication protocols, LCU architecture, real-time data analysis and industrial case studies

4.3 Human Machine Interface (HMI): Design principles, I/O hardware, software lifecycle, evaluation techniques and graphical user interfaces

4.4 Safety standards in PLC/DCS automation; Levels of process safety; Application of standards in process safety control

5 Computer Numerical Control (CNC) (4 hours)

5.1 CNC fundamentals: Classification, machine components, controller panel, axis designation (X, Y, Z, A, B, C), coordinate systems

5.2 CNC programming: G-codes (Preparatory) and M-codes (Miscellaneous), job zero setting, tool offsets, canned cycles and subroutines

5.3 Error code reading, troubleshooting and preventive maintenance of CNC systems

6 Special Control Structures (5 hours)

6.1 Feed-forward, ratio control, cascade control, predictive control

6.2 Overriding, selective, split-range control and systems with Inverse response

6.3 Latest control software (MATLAB/Simulink, LabVIEW/ other) and industrial trends

Tutorial (30 hours)

1. Determination of sensor characteristics, static and dynamic response parameters, and sensitivity.
2. Design and analysis of signal conditioning circuits and data acquisition (DAQ) interfaces.
3. Calculation and selection of appropriate actuator sizing, pneumatic/hydraulic cylinders, and motor capacities.
4. Mathematical modeling and derivation of transfer functions for mechanical and coupled physical systems.
5. Simplification and reduction of control system structures using block diagram algebra and signal flow graphs.
6. Time-domain performance analysis of transient responses for step, ramp, and sinusoidal input signals.
7. Evaluation of steady-state errors and error constants for various control system types.
8. Determination of control system stability using the Routh-Hurwitz criterion.
9. Construction and interpretation of root locus plots for variable loop gain systems.

10. Tuning and optimization of PID controller parameters using classical tuning methods.
11. Development and verification of PLC ladder logic programs, including timers, counters, and registers.
12. Formulation of CNC part programs using G-codes and M-codes for 2D profile machining operations.

Practical **(15 hours)**

1. Simulation of control responses: Use MATLAB/Simulink to analyze step and impulse responses for 1st and 2nd order systems.
2. Mechanical system modeling: MATLAB simulation of mass-spring-damper systems
3. Basic PLC programming: Implementation of latch, timer and counter logic
4. Industrial PLC applications: Logic for object sorting and liquid filling (Soft-drink) machines
5. Motor Control Logic: Implementation of star-delta starter control for 3-phase motors
6. HMI Integration: Programming an HMI panel to interface with a PLC for machine switching
7. CNC Programming and Operation: Simple drilling/milling operations based on industrial drawings

Final Exam

The questions will cover all the chapters in the syllabus. The evaluation scheme will be as indicated in the table below:

Chapter	Hours	Mark distribution*
1	6	8
2	12	16
3	6	8
4	12	16
5	4	6
6	5	6
Total	**45**	**60**

* There may be minor deviation in marks distribution.

References

1. Saeed, S. H. (2002). Automatic control systems. S. K. Kataria & Sons.
2. Akande, O. (2023). Industrial automation from scratch. Packt Publishing.
3. Lamb, F. (2013). Industrial automation. McGraw Hill Education.
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7. HMT Limited. (2001). Mechatronics. Tata McGraw Hill.
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