

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

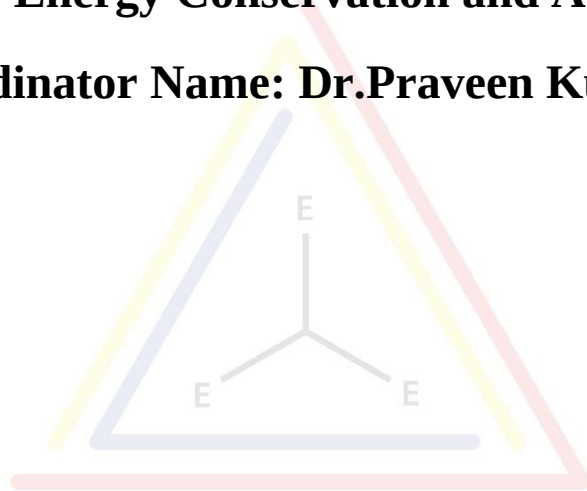
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Academic Year: 2026-27

Course Code : BEE755B

Course Title : Energy Conservation and Audit

Course Co-ordinator Name: Dr.Praveen Kumar M



Department of EEE
Emitting Elite Energy

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

Vision of the Institute Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources. Mission of the Institute • To keep pace with advancements in knowledge and make the students competitive and capable at the global level. • To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torch-bearers of tomorrow's society. • To strive to attain ever-higher benchmarks of educational excellence	Vision of the Department To create Electrical and Electronics Engineers who excel to be technically competent and fulfil the cultural and social aspirations of the society. Mission of the Department • To provide knowledge to students that builds a strong foundation in the basic principles of electrical engineering, problem solving abilities, analytical skills, soft skills and communication skills for their overall development. • To offer outcome based technical education. • To encourage faculty in training & development and to offer consultancy through research & industry interaction.
Program Educational Objectives (PEO's) • PEO1: To produce competent and ethical Electrical and Electronics Engineers who will exhibit the necessary technical and managerial skills to perform their duties in society. • PEO2: To make graduates continuously acquire and enhance their technical and socio-economic skills. • PEO3: To aspire graduates on R&D activities leading to offering solutions and excel in various career paths. • PEO4: To produce quality engineers who have the capability to work in teams and contribute to real time projects.	Program Specific Outcomes (PSO's) • PSO1: Apply the concepts of Electrical & Electronics Engineering to evaluate the performance of power systems and also to control industrial drives using power electronics. • PSO2: Demonstrate the concepts of process control for Industrial Automation, design models for environmental and social concerns and also exhibit continuous self- learning.

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

Program Outcomes (PO's)

PO1: Engineering Knowledge: Apply knowledge of mathematics, natural science, computing, engineering fundamentals and an engineering specialization as specified in WK1 to WK4 respectively to develop to the solution of complex engineering problems.

PO2: Problem Analysis: Identify, formulate, review research literature and analyze complex engineering problems reaching substantiated conclusions with consideration for sustainable development. (WK1 to WK4)

PO3: Design/Development of Solutions: Design creative solutions for complex engineering problems and design/develop systems/components/processes to meet identified needs with consideration for the public health and safety, whole-life cost, net zero carbon, culture, society and environment as required. (WK5)

PO4: Conduct Investigations of Complex Problems: Conduct investigations of complex engineering problems using research-based knowledge including design of experiments, modelling, analysis & interpretation of data to provide valid conclusions. (WK8).

PO5: Engineering Tool Usage: Create, select and apply appropriate techniques, resources and modern engineering & IT tools, including prediction and modelling recognizing their limitations to solve complex engineering problems. (WK2 and WK6)

PO6: The Engineer and The World: Analyze and evaluate societal and environmental aspects while solving complex engineering problems for its impact on sustainability with reference to economy, health, safety, legal framework, culture and environment. (WK1, WK5, and WK7).

PO7: Ethics: Apply ethical principles and commit to professional ethics, human values, diversity and inclusion; adhere to national & international laws. (WK9)

PO8: Individual and Collaborative Team work: Function effectively as an individual, and as a member or leader in diverse/multi-disciplinary teams.

PO9: Communication: Communicate effectively and inclusively within the engineering community and society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations considering cultural, language, and learning differences

PO10: Project Management and Finance: Apply knowledge and understanding of engineering management principles and economic decision-making and apply these to one's own work, as a member and leader in a team, and to manage projects and in multidisciplinary environments.

PO11: Life-Long Learning: Recognize the need for, and have the preparation and ability for i) independent and life-long learning ii) adaptability to new and emerging technologies and iii) critical thinking in the broadest context of technological change. (WK8)

MODULE 1

ENERGY SCENARIO

INTRODUCTION:

- Energy is one of the major inputs for the economic development of any country.
- In the case of the developing countries, the energy sector assumes a critical importance in view of the ever increasing energy needs requiring huge investments to meet them.
- Energy can be classified into several types based on the following criteria:
 - 1) Primary and Secondary energy
 - 2) Commercial and Non-commercial energy
 - 3) Renewable and Non-Renewable energy

PRIMARY AND SECONDARY ENERGY SOURCES:

a) PRIMARY ENERGY SOURCES:

- Primary energy sources are those that are either found or stored in nature.
- The Energy which is extracted from natural Sources.
- Primary energy can also be used directly
- Common primary energy sources are coal, oil, natural gas, and biomass (such as wood).
- Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to earth's gravity.

b) SECONDARY ENERGY SOURCES:

- Primary energy sources are mostly converted in industrial utilities into secondary energy sources.
- Transformed primary energy into more useful form.
- Example coal, oil or gas converted into steam and electricity.
- The major primary and secondary energy resources are:

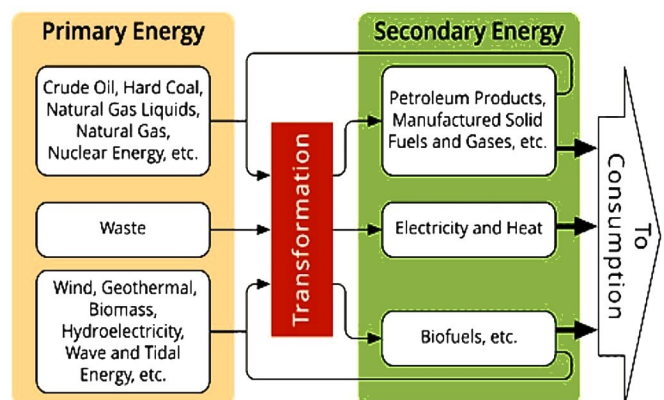
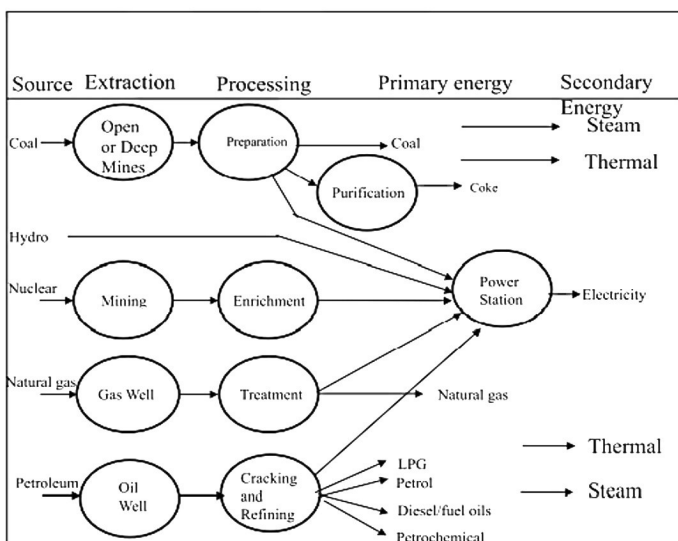


Figure: Major primary and secondary energy resources

COMMERCIAL AND NON-COMMERCIAL ENERGY SOURCES:

a) COMMERCIAL ENERGY SOURCES:

- The energy sources that are available in the market for a definite price are known as commercial energy
- The most important forms of commercial energy are electricity, coal and refined petroleum products.
- Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world.
- In the industrialized countries, commercialized fuels are predominant source not only for economic production, but also for many household tasks of general population.
- Examples: Electricity, lignite, coal, oil, natural gas etc.

b) NON-COMMERCIAL ENERGY SOURCES:

- The energy sources that are not available in the commercial market for a price are classified as non-commercial energy.
- Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural households.
- These are also called traditional fuels.
- Non-commercial energy is often ignored in energy accounting
- Example: Firewood, agro waste in rural areas; solar energy for water heating, electricity generation, for drying grain, fish and fruits; animal power for transport, threshing, lifting water for irrigation, crushing sugarcane; wind energy for lifting water and electricity generation.

RENEWABLE AND NON-RENEWABLE ENERGY SOURCES:

a) RENEWABLE ENERGY SOURCES:

- Renewable energy is energy obtained from sources that are essentially inexhaustible.
- The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants.
- Example: wind power, solar power, geothermal energy, tidal power and hydroelectric power.

b) NON-RENEWABLE ENERGY SOURCES:

- Non-renewable energy is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.
- The major Renewable and non-renewable energy sources are

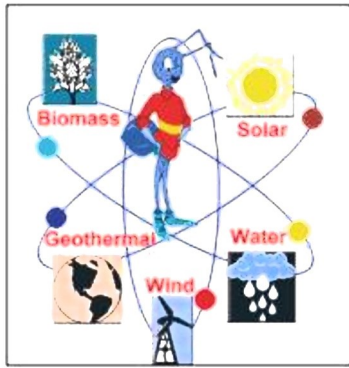


Figure: Renewable energy

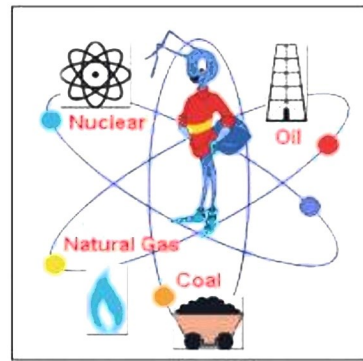


Figure: Non-Renewable energy

GLOBAL PRIMARY ENERGY RESERVES:

a) Coal:

- The proven global coal reserve was estimated to be 9,84,453 million tonnes by end of 2003.
- The USA had the largest share of the global reserve which is equal to 25.4%.
- The share of the global reserve of Russia is 15.9%.
- The share of the global reserve of China is 11.6%.
- India was 4th in the list with global reserve of 8.6%.

Country	Global Coal reserve in %
USA	25.4%
Russia	15.9%
China	11.6%
India	8.6%

b) Oil:

- The global proven oil reserve was estimated to be 1147 billion barrels by the end of 2003.
- One barrel of oil is approximately 160 litres.
- Around 50% of reserves are in middle east.
- Saudi Arabia had the largest share of the reserve with almost 23%.
- India has only 0.3% of total world reserves

Country	Global Oil reserve in %
Saudi Arabia	23%
Canada	10.3%
Iran	9.3%
Iraq	8.9%
India	0.3%

c) Natural Gas:

- The global proven gas reserve was estimated to be 176 trillion cubic metres by the end of 2003.
- The Russian Federation had the largest share of the reserve with almost 27%.
- India has only 0.7% of total world reserve.

Country	Global Natural reserve in %
Russia	27%
Iran	18.2%
USA	5%
India	0.7%

GLOBAL PRIMARY ENERGY CONSUMPTION:

- The global primary energy consumption at the end of 2003 was equivalent to 9741 million tonnes of oil equivalent (Mtoe).
- Major primary energy consuming resources are:

Resources	%
Oil	33%
Coal	30%
Natural Gas	24%

- India's absolute primary energy consumption is only
 - 1/29th of the world
 - 1/7th of USA
 - 1/16th of Japan
- India's absolute primary energy consumption is 1.1, 1.3, 1.5 times that of Canada, France and U.K.

➤ Energy Distribution Between Developed and Developing Countries.

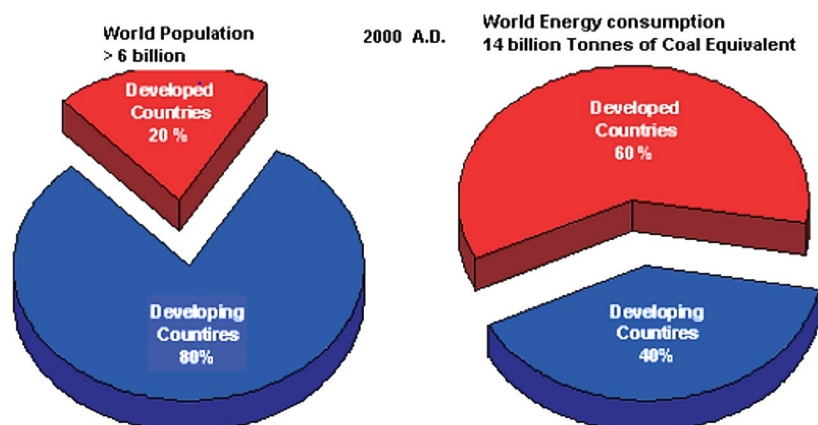


Figure: Energy Distribution between developed and developing countries.

- Although 80% of the world's population lies in the developing countries, their energy consumption amounts to only 40% of the world total energy consumption.
- The high standards of living in the developed countries are attributable to high energy consumption levels.
- Also, the rapid population growth in the developing countries has kept the per capita energy consumption low compared with that of highly industrialized developed countries.
- The world average energy consumption per person is equivalent to 2.2 tonnes of coal.
- In industrialized countries, people use four to five times more than the world average, and nine times more than the average for the developing countries.
- An American uses 32 times more commercial energy than an Indian

INDIAN ENERGY SCENARIO:

- Coal dominates the energy mix in India, contributing to 55% of the total primary energy production.
- Over the years, there has been a marked increase in the share of natural gas in primary energy production from 10% in 1994 to 13% in 1999.
- There has been a decline in the share of oil in primary energy production from 20% to 17% during the same period.

Primary Energy sources	% of consumption
Coal	55%
Oil	29.5%
Natural Gas	78%
Hydro power	5%
Renewable energy	2%
Nuclear Energy	1.3%

➤ **Energy Supply:**

a) Coal Supply:

- ❖ India has huge coal reserves, at least 84,396 million tonnes of proven recoverable reserves at the end of 2003.
- ❖ This amounts to almost 8.6% of the world reserves and it may last for about 230 years at the current Reserve to Production (R/P) ratio.
- ❖ In contrast, the world's proven coal reserves are expected to last only for 192 years at the current R/P ratio.
- ❖ **Reserves/Production (R/P) ratio:** If the reserves remaining at the end of the year are divided by the production in that year, the result is the length of time that the remaining reserves would last if production were to continue at that level.
- ❖ India is the fourth largest producer of coal and lignite in the world.

❖ Coal production is concentrated in these states

- ✓ Andhra Pradesh
- ✓ Uttar Pradesh
- ✓ Bihar
- ✓ Madhya Pradesh
- ✓ Maharashtra
- ✓ Orissa
- ✓ Jharkhand
- ✓ West Bengal

b) Oil Supply:

- ❖ Oil accounts for about 36 % of India's total energy consumption.
- ❖ India today is one of the top ten oil-guzzling nations in the world
- ❖ India will soon overtake Korea as the third largest consumer of oil in Asia after China and Japan.
- ❖ The country's annual crude oil production is peaked at about 32 million tonne.
- ❖ The current peak demand of about 110 million tonne.
- ❖ India will have to pay an oil bill of roughly \$50 billion, assuming a weighted average price of \$50 per barrel of crude.
- ❖ The majority of India's roughly 5.4 billion barrels in oil reserves are located in
 - ✓ Bombay High
 - ✓ Upper Assam
 - ✓ Cambay
 - ✓ Krishna-Godavari.
- ❖ In terms of sector wise petroleum product consumption, transport accounts for 42% followed by domestic and industry with 24% and 24% respectively.

Transport	42%
Domestic	24%
Industry	24%

- ❖ India spent more than Rs.1,10,000 crore on oil imports at the end of 2004.

c) Natural Gas supply:

- ❖ Natural gas accounts for about 8.9% of energy consumption in the country.
- ❖ The current demand for natural gas is about 96 million cubic metres per day (mcmd).
- ❖ The availability of natural gas is about 67 mcmd.
- ❖ By 2007, the demand is expected to be around 200 mcmd.
- ❖ Natural gas reserves are estimated at 660 billion cubic meters.

d) Electrical Energy Supply:

- ❖ The all India installed capacity of electric power generating stations under utilities was 1,12,581 MW as on 31st May 2004
- ❖ Consisting of 28,860 MW- hydro, 77,931 MW - thermal and 2,720 MW- nuclear and 1,869 MW- wind (Ministry of Power).

Hydro	28860 MW
Thermal	77931 MW
Nuclear	2720 MW
Wind	1869 MW

- ❖ The gross generation of power in the year 2002-2003 stood at 531 billion units (kWh).

e) Nuclear Power Supply:

- ❖ Nuclear Power contributes to about 2.4 % of electricity generated in India.
- ❖ India has ten nuclear power reactors at five nuclear power stations producing electricity.
- ❖ More nuclear reactors have also been approved for construction.

f) Hydro Power supply:

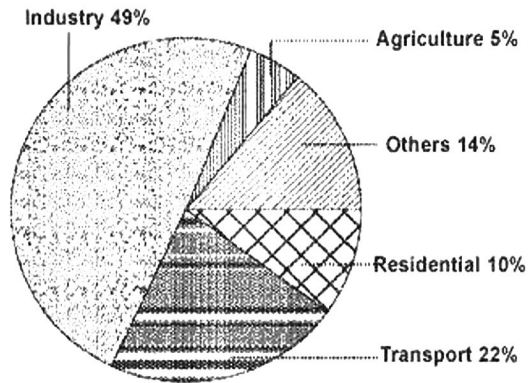
- ❖ India is endowed with a vast and viable hydro potential for power generation of which only 15% has been harnessed so far.
- ❖ The share of hydropower in the country's total generated units has steadily decreased and it presently stands at 25% as on 31st May 2004.
- ❖ It is assessed that exploitable potential at 60% load factor is 84,000 MW.

FINAL ENERGY CONSUMPTION

- Final energy consumption is the actual energy demand at the user end.
- This is the difference between primary energy consumption and the losses that takes place in transport, transmission & distribution and refinement.
- The actual final energy consumption is given in Table 1.2.

TABLE 1.2 DEMAND FOR COMMERCIAL ENERGY FOR FINAL CONSUMPTION (BAU SCENARIO)					
Source	Units	1994-95	2001-02	2006-07	2011-12
Electricity	Billion Units	289.36	480.08	712.67	1067.88
Coal	Million Tonnes	76.67	109.01	134.99	173.47
Lignite	Million Tonnes	4.85	11.69	16.02	19.70
Natural Gas	Million Cubic Meters	9880	15730	18291	20853
Oil Products	Million Tonnes	63.55	99.89	139.95	196.47
Source: Planning Commission <i>BAU: _Business As Usual</i>					

- Sector Wise Energy Consumption in India
- The major commercial energy consuming sectors in the country are classified as shown in the Figure.



- Industry remains the biggest consumer of commercial energy and its share in the overall consumption is 49%.

ENERGY NEEDS OF GROWING ECONOMY:

- Economic growth is desirable for developing countries, and energy is essential for economic growth.
- However, the relationship between economic growth and increased energy demand is not always a straightforward linear one.
- For example, under present conditions, 6% increase in India's Gross Domestic Product (GDP) would impose an increased demand of 9 % on its energy sector.
- The ratio of energy demand to GDP is a useful indicator.
- A high ratio reflects energy dependence and a strong influence of energy on GDP growth.
- The developed countries, by focusing on energy efficiency and lower energy-intensive routes, maintain their energy to GDP ratios at values of less than 1.
- The ratios for developing countries are much higher.

➤ India's Energy Needs:

- The plan outlay vis-à-vis share of energy is given in Figure.

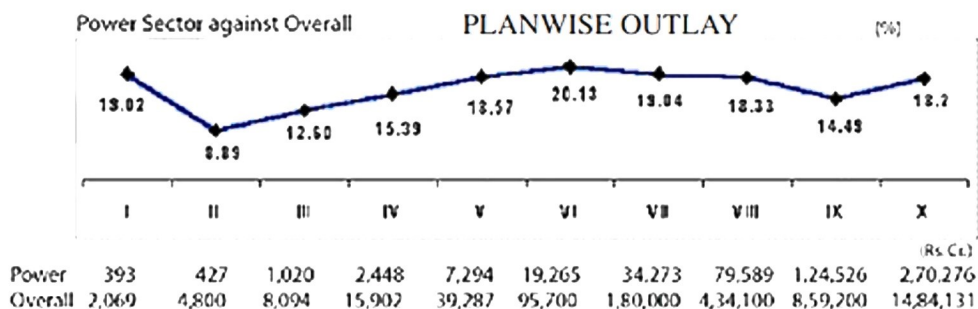


Figure : Expenditure Towards Energy Sector

- As seen from the Figure, 18.0% of the total five-year plan outlay is spent on the energy sector.

➤ Per Capita Energy Consumption:

- The per capita energy consumption is too low for India as compared to developed countries.
- It is just 4% of USA and 20% of the world average.

- The per capita consumption is likely to grow in India with growth in economy thus increasing the energy demand.

➤ **Energy Intensity:**

- Energy intensity is energy consumption per unit of GDP.
- Energy intensity indicates the development stage of the country.
- India's energy intensity is
 - ✓ 3.7 times of Japan,
 - ✓ 1.55 times of USA,
 - ✓ 1.47 times of Asia,
 - ✓ 1.5 times of World average.

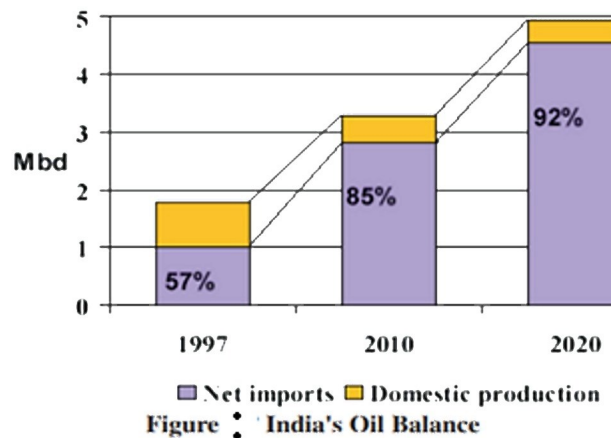
LONG TERM ENERGY SCENARIO FOR INDIA:

a) Coal:

- Coal is the predominant energy source for power production in India, generating approximately 70% of total domestic electricity.
- Energy demand in India is expected to increase over the next 10-15 years
- Although new oil and gas plants are planned, coal is expected to remain the dominant fuel for power generation.
- Despite significant increases in total installed capacity during the last decade, the gap between electricity supply and demand continues to increase.
- The resulting shortfall has had a negative impact on industrial output and economic growth.
- To meet expected future demand, indigenous coal production will have to be greatly expanded.
- Production currently stands at around 290 Million tonnes per year, but coal demand is expected to more than double by 2010.
- Indian coal is typically of poor quality and as such requires to be beneficiated to improve the quality.
- Coal imports will also need to increase dramatically to satisfy industrial and power generation requirements.

b) Oil:

- India's demand for petroleum products is likely to rise from 97.7 million tonnes in 2001-02 to around 139.95 million tonnes in 2006-07.
- Domestic crude oil production is likely to rise marginally from 32.03 million tonnes in 2001-02 to 33.97 million tonnes by the end of the 2006-07.
- India's self-sufficiency in oil has consistently declined from 60% in the 50s to 30% currently.
- Same is expected to go down to 8% by 2020.



- As shown in the Figure, around 92% of India's total oil demand by 2020 has to be met by imports.

c) Natural Gas:

- India's natural gas production is likely to rise from 86.56 million cmpd in 2002-03 to 103.08 million cmpd in 2006-07.
- It is mainly based on the strength of a more than doubling of production by private operators to 38.25 mm cmpd.

d) Electricity:

- India currently has a peak demand shortage of around 14% and an energy deficit of 8.4%.
- Keeping this in view and to maintain a GDP growth of 8% to 10%, the Government of India has very prudently set a target of 215,804 MW power generation capacity by March 2012 from the level of 100,010 MW as on March 2001,
- i.e. a capacity addition of 115,794 MW in the next 11 years.
- In the area of nuclear power, the objective is to achieve 20,000 MW of nuclear generation capacity by the year 2020.

ENERGY PRICING IN INDIA

- Price of energy does not reflect true cost to society.
- The basic assumption underlying efficiency of market place does not hold in our economy, since energy prices are undervalued and energy wastages are not taken seriously.
- Pricing practices in India like many other developing countries are influenced by political, social and economic compulsions at the state and central level.
- This has been the foundation for energy sector policies in India.
- The Indian energy sector offers many examples of cross subsidies e.g., diesel, LPG and kerosene being subsidised by petrol, petroleum products for industrial usage and industrial, and commercial consumers of electricity subsidising the agricultural and domestic consumers.

a) Coal:

- Grade wise basic price of coal at the pithead excluding statutory levies for run-of-mine (ROM) coal are fixed by Coal India Ltd from time to time.
- The pithead price of coal in India compares favourably with price of imported coal.
- In spite of this, industries still import coal due its higher calorific value and low ash content.

b) Oil:

- As part of the energy sector reforms, the government has attempted to bring prices for many of the petroleum products in line with international prices.
- The most important achievement has been the linking of diesel prices to international prices and a reduction in subsidy.
- However, LPG and kerosene, consumed mainly by domestic sectors, continue to be heavily subsidised.
- Subsidies and cross-subsidies have resulted in serious distortions in prices, as they do not reflect economic costs in many cases.

c) Natural Gas:

- The government has been the sole authority for fixing the price of natural gas in the country.
- It has also been taking decisions on the allocation of gas to various competing consumers.
- The gas prices vary from Rs 5 to Rs.15 per cubic metre.

d) Electricity:

- Electricity tariffs in India are structured in a relatively simple manner.
- High tension consumers are charged based on both demand (kVA) and energy (kWh),
- Low-tension (LT) consumer pays only for the energy consumed (kWh) as per tariff system in most of the electricity boards.
- The price per kWh varies significantly across States as well as customer segments within a State.
- Tariffs in India have been modified to consider the time of usage and voltage level of supply.
- In addition to the base tariffs, some State Electricity Boards have additional recovery from customers in form of fuel surcharges, electricity duties and taxes.

ENERGY SECTOR REFORMS:

- Since the initiation of economic reforms in India in 1991, there has been a growing acceptance of the need for deepening these reforms in several sectors of the economy, which were essentially in the hands of the government for several decades.
- It is now being realized that if substance has to be provided to macroeconomic policy reform, then it must be based on reforms that concern the functioning of several critical sectors of the economy, among which the infrastructure sectors in general and the energy sector in particular, are paramount.

a) Coal:

- The government has recognized the need for new coal policy initiatives and for rationalization of the legal and regulatory framework that would govern the future development of this industry.
- One of the key reforms is that the government has allowed importing of coal to meet our requirements.
- Private sector has been allowed to extract coal for captive use only.
- Further reforms are contemplated for which the Coal Mines Nationalization Act needs to be amended for which the Bill is awaiting approval of the Parliament.
- The ultimate objective is to see that a competitive environment is created for the functioning of various entities in this industry.
- This would not only bring about gains in efficiency but also effect cost reduction, which would consequently ensure supply of coal on a larger scale at lower prices.
- Competition would also have the desirable effect of bringing in new technology, for which there is an urgent and overdue need since the coal industry has suffered a prolonged period of stagnation in technological innovation.

b) Oil and Natural Gas:

- Since 1993, private investors have been allowed to import and market liquefied petroleum gas (LPG) and kerosene freely.
- Private investment is also been allowed in lubricants, which are not subject to price controls.
- Prices for naphtha and some other fuels have been liberalized.
- In 1997 the government introduced the New Exploration Licensing Policy (NELP) in an effort to promote investment in the exploration and production of domestic oil and gas.
- The refining sector has been opened to private and foreign investors in order to reduce imports of refined products and to encourage investment in downstream pipelines.
- Attractive terms are being offered to investors for the construction of liquefied natural gas (LNG) import facilities.

c) Electricity:

- The enactment of the Electricity Regulatory Commission Legislation, the Central Electricity Regulatory Commission (CERC) was set up, with the main objective of regulating the Central power generation utilities.
- State level regulatory bodies have also been set up to set tariffs and promote competition.
- Private investments in power generation were also allowed.
- The State SEBs were asked to switch over to separate Generation, Transmission and Distribution corporations.
- There are plans to link all SEB grids and form a unified national power grid.

Electricity Act, 2003:

- The government has enacted Electricity Act, 2003 which seeks to bring about a qualitative transformation of the electricity sector.
- The Act seeks to create liberal framework of development for the power sector by distancing Government from regulation.
- It replaces the three existing legislations, namely, Indian Electricity Act, 1910, the Electricity (Supply) Act, 1948 and the Electricity Regulatory Commissions Act, 1998.
- The objectives of the Act are "to consolidate the laws relating to generation, transmission, distribution, trading and use of electricity and generally for taking measures conducive to development of electricity industry, promoting competition therein, protecting interest of consumers and supply of electricity to all areas, rationalization of electricity tariff, ensuring transparent policies regarding subsidies, promotion of efficient and environmentally benign policies, constitution of Central Electricity Authority, Regulatory Commissions and establishment of Appellate Tribunal and for matters connected therewith or incidental thereto."

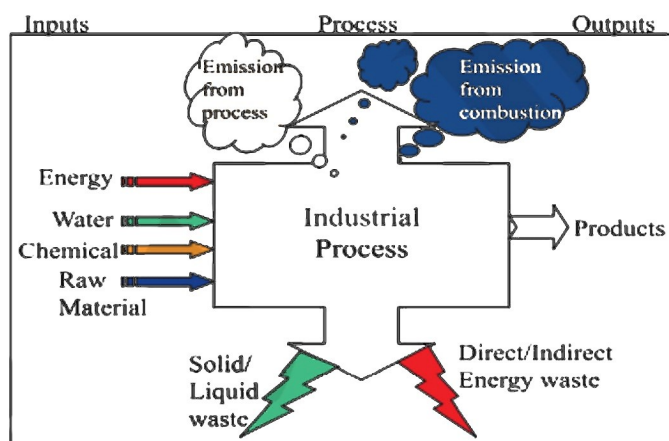
The salient features of the Electricity Act, 2003 are:

- The Central Government to prepare a National Electricity Policy in consultation with State Governments.
- Thrust to complete the rural electrification and provide for management of rural distribution by Panchayats, Cooperative Societies, non-Government organizations, franchisees etc.
- Provision for license free generation and distribution in the rural areas.
- Generation being delicensed and captive generation being freely permitted. Hydro projects would, however, need clearance from the Central Electricity Authority.
- Transmission Utility at the Central as well as State level, to be a Government company - with responsibility for planned and coordinated development of transmission network.
- Provision for private licensees in transmission and entry in distribution through an independent network.
- Open access in transmission from the outset.
- Open access in distribution to be introduced in phases with surcharge for current level of cross subsidy to be gradually phased out along with cross subsidies and obligation to supply. SERCs to frame regulations within one year regarding phasing of open access.
- Distribution licensees would be free to undertake generation and generating companies would be free to take up distribute
- The State Electricity Regulatory Commission is a mandatory requirement.
- Provision for payment of subsidy through budget.
- Trading, a distinct activity is being recognized with the safeguard of the Regulatory Commissions being authorized to fix ceilings on trading margins, if necessary.

- Provision for reorganization or continuance of SEBs.
- Metering of all electricity supplied made mandatory.
- An Appellate Tribunal to hear appeals against the decision of the CERC and SERCs.
- Provisions relating to theft of electricity made more stringent.
- Provisions safeguarding consumer interests.

ENERGY AND ENVIRONMENT:

- The usage of energy resources in industry leads to environmental damages by polluting the atmosphere.
- Few of examples of air pollution are:
 - ✓ sulphur dioxide (SO_2), nitrous oxide (NO_x) and carbon monoxide (CO) emissions from boilers and furnaces
 - ✓ Chloro-fluoro carbons (CFC) emissions from refrigerants use, etc.
 - ✓ In chemical and fertilizers industries, toxic gases are released.
 - ✓ Cement plants and power plants spew out particulate matter.
- Typical inputs, outputs, and emissions for a typical industrial process are shown in Figure



a) Air Pollution:

- A variety of air pollutants have known or suspected harmful effects on human health and the environment.
- These air pollutants are basically the products of combustion from fossil fuel use.
- Air pollutants from these sources may not only create problems near to these sources but also can cause problems far away.
- Air pollutants can travel long distances, chemically react in the atmosphere to produce secondary pollutants such as acid rain or ozone.
- In both developed and rapidly industrialising countries, the major historic air pollution problem has typically been high levels of smoke and SO_2 arising from the combustion of sulphur containing fossil fuels such as coal for domestic and industrial purposes.

- Smogs resulting from the combined effects of black smoke, sulphate / acid aerosol and fog have been seen in European cities until few decades ago and still occur in many cities in developing world.
- In developed countries, this problem has significantly reduced over recent decades as a result of changing fuel-use patterns. The increasing use of cleaner fuels such as natural gas, and the implementation of effective smoke and emission control policies.
- In both developed and developing countries, the major threat to clean air is now posed by traffic emissions.
- Petrol- and diesel-engined motor vehicles emit a wide variety of pollutants, principally carbon monoxide (CO), oxides of nitrogen (NO_x), volatile organic compounds (VOCs) and particulates, which have an increasing impact on urban air quality.
- Photochemical reactions resulting from the action of sunlight on NO₂ and VOCs from vehicles leads to the formation of ozone, a secondary long-range pollutant, which impacts in rural areas often far from the original emission site.
- Acid rain is another long-range pollutant influenced by vehicle NO_x emissions.
- Industrial and domestic pollutant sources, together with their impact on air quality, tend to be steady-state or improving over time.

➤ **Sulphur dioxide:**

- It is a corrosive acid gas, which combines with water vapour in the atmosphere to produce acid rain.
- SO₂ in ambient air is also associated with asthma and chronic bronchitis.
- The principal source of this gas is power stations and industries burning fossil fuels, which contain sulphur.

➤ **Nitrogen oxides:**

- Nitrogen oxides are formed during high temperature combustion processes from the oxidation of nitrogen in the air or fuel.
- The principal source of nitrogen oxides - nitric oxide (NO) and nitrogen dioxide (NO₂), collectively known as NO_x - is road traffic.
- Nitrogen dioxide has a variety of environmental and health impacts.
- It irritates the respiratory system and may worsen asthma and increase susceptibility to infections.
- In the presence of sunlight, it reacts with hydrocarbons to produce photochemical pollutants such as ozone.
- Nitrogen oxides combine with water vapour to form nitric acid.
- This nitric acid is in turn removed from the atmosphere by direct deposition to the ground, or transfer to aqueous droplets (e.g. cloud or rainwater), thereby contributing to acid deposition.

➤ **Carbon monoxide:**

- Carbon monoxide (CO) is a toxic gas, which is emitted into the atmosphere as a result of combustion processes, and from oxidation of hydrocarbons and other organic compounds.
- CO is produced almost entirely 90% from road traffic emissions.
- CO at levels found in ambient air may reduce the oxygen-carrying capacity of the blood.
- It survives in the atmosphere for a period of approximately 1 month and finally gets oxidised to carbon dioxide (CO₂).

➤ **Ground-level ozone:**

- Ground-level ozone (O₃) is a secondary pollutant produced by reaction between nitrogen dioxide (NO₂), hydrocarbons and sunlight.
- Ozone can irritate the eyes and air passages causing breathing difficulties and may increase susceptibility to infection.
- It is a highly reactive chemical, capable of attacking surfaces, fabrics and rubber materials.
- Ozone is also toxic to some crops, vegetation and trees.

➤ **Hydrocarbons:**

- There are two main groups of hydrocarbons of concern: volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs).
- VOCs are released in vehicle exhaust gases either as unburned fuels or as combustion products, and are also emitted by the evaporation of solvents and motor fuels.

➤ **TOMPs (Toxic Organic Micropollutants):**

- TOMPs are produced by the incomplete combustion of fuels.
- They comprise a complex range of chemicals some of which, although they are emitted in very small quantities, are highly toxic or and carcinogenic.
- Compounds in this category include:
 - ✓ PAHs (PolyAromatic Hydrocarbons)
 - ✓ PCBs (PolyChlorinated Biphenyls)
 - ✓ Dioxins
 - ✓ Furans

➤ **Heavy Metals and Lead:**

- Particulate metals in air result from activities such as fossil fuel combustion, metal processing industries and waste incineration
- Lead is a cumulative poison to the central nervous system, particularly detrimental to the mental development of children
- Lead is the most widely used non-ferrous metal and has a large number of industrial applications.
- It is also used in paints, glazes, alloys, radiation shielding, tank lining and piping.

b) Climatic Change:

- Human activities, particularly the combustion of fossil fuels, have made the blanket of greenhouse gases Such as water vapour, carbon dioxide, methane, ozone etc around the earth thicker.
- The resulting increase in global temperature is altering the complex web of systems that allow life to thrive on earth such as rainfall, wind patterns, ocean currents and distribution of plant and animal species.

➤ Greenhouse Effect and the Carbon Cycle:

- Life on earth is made possible by energy from the sun, which arrives mainly in the form of visible light.
- About 30 percent of the sunlight is scattered back into space by outer atmosphere and the balance 70 percent reaches the earth's surface, which reflects it in form of infrared radiation.
- The escape of slow moving infrared radiation is delayed by the greenhouse gases.
- A thicker blanket of greenhouse gases traps more infrared radiation and increase the earth's temperature.
- Human activities that are responsible for making the greenhouse layer thicker are emissions of carbon dioxide from the combustion of coal, oil and natural gas; by additional methane and nitrous oxide from farming activities.
- The increase in greenhouse gases is happening at an alarming rate.
- If greenhouse gases emissions continue to grow at current rates, it is almost certain that the atmospheric levels of carbon dioxide will increase twice or thrice from pre-industrial levels during the 21st century.
- Even a small increase in earth's temperature will be accompanied by changes in climate such as cloud cover, precipitation, wind patterns and duration of seasons.
- Carbon dioxide is responsible for 60 percent of the "enhanced greenhouse effect".
- Humans are burning coal, oil and natural gas at a rate that is much faster than the rate at which these fossil fuels were created.
- This is releasing the carbon stored in the fuels into the atmosphere and upsetting the carbon cycle.

➤ Current Evidence of Climatic Change:

- Cyclones, storm, hurricanes are occurring more frequently and floods and draughts are more intense than before.
- This trend toward more powerful storms and hotter, longer dry periods is predicted by computer models.
- Warmer temperatures mean greater evaporation, and a warmer atmosphere is able to hold more moisture and hence there is more water aloft that can fall as precipitation.

- Similarly, dry regions are prone to lose still more moisture if the weather is hotter and hence this leads to more severe droughts and desertification.

➤ **Future Effects:**

- The global temperature may climb from 1.4 to 5.8 degrees C.
- The sea level may rise from 9 to 88 cm.
- Thus, increases in sea level this century are expected to range from significant to catastrophic.
- This uncertainty reflects the complexity, interrelatedness, and sensitivity of the natural systems that make up the climate.

❖ **Severe Storms and Flooding:**

- The minimum warming forecast for the next 100 years is more than twice the 0.6-degree C increase.
- Extreme weather events, as predicted by computer models, are striking more often and can be expected to intensify and become still more frequent.
- A future of more severe storms and floods along the world's increasingly crowded coastlines is likely.

❖ **Food Shortages:**

- Although regional and local effects may differ widely, a general reduction is expected in potential crop yields in most tropical and sub-tropical regions.
- Mid-continental areas such as the United States' "grain belt" and vast areas of Asia are likely to become dry.
- Sub-Saharan Africa where dryland agriculture relies solely on rain, the yields would decrease dramatically even with minimum increase in temperature.
- Such changes could cause disruptions in food supply in a world is already afflicted with food shortages and famines.

❖ **Dwindling Freshwater supply:**

- Salt-water intrusion from rising sea levels will reduce the quality and quantity of freshwater supplies.
- This is a major concern, since billions of people on earth already lack access to freshwater.
- Higher ocean levels already are contaminating underground water sources in many parts of the world.

❖ **Loss of Biodiversity:**

- Loss of Biodiversity Most of the world's endangered species may become extinct over the next few decades as warmer conditions alter the forests, wetlands, and rangelands they depend on, and human development blocks them from migrating elsewhere.

❖ **Increased Diseases:**

- Higher temperatures are expected to expand the range of some dangerous "vector-borne" diseases, such as malaria, which already kills 1 million people annually, most of them children.

➤ **Acid Rain:**

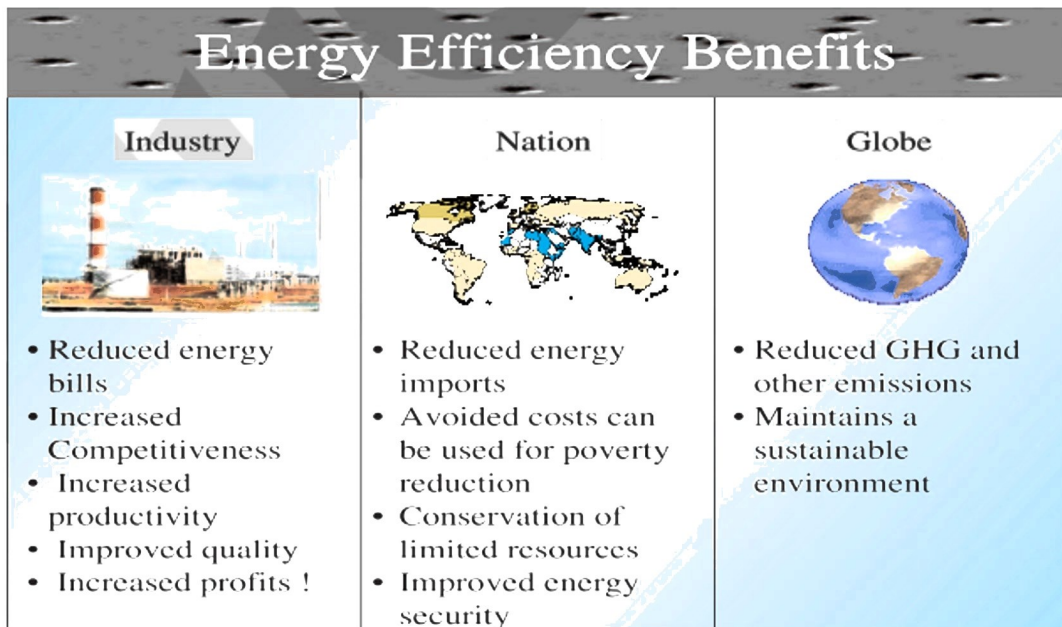
- Acid rain is caused by release of SOX and NOX from combustion of fossil fuels, which then mix with water vapour in atmosphere to form sulphuric and nitric acids respectively.
- The effects of acid rain are as follows:
 - ✓ Acidification of lakes, streams, and soils.
 - ✓ Direct and indirect effects (release of metals, for example: Aluminum which washes away plant nutrients)
 - ✓ Killing of wildlife such as trees, crops, aquatic plants, and animals.
 - ✓ Decay of building materials and paints, statues, and sculptures.
 - ✓ Health problems such as respiratory, burning- skin and eyes.

Energy Security:

- The basic aim of energy security for a nation is to reduce its dependency on the imported energy sources for its economic growth.
- India will continue to experience an energy supply shortfall throughout the forecast period.
- India has been unable to raise its oil production substantially in the 1990s.
- Rising oil demand of close to 10 percent per year has led to sizable oil import bills.
- Imports of oil and coal have been increasing at rates of 7% and 16% per annum respectively during the period 1991-99.
- The dependence on energy imports is projected to increase in the future.
- Estimates indicate that oil imports will meet 75% of total oil consumption requirements and coal imports will meet 22% of total coal consumption requirements.
- The imports of gas and LNG (liquefied natural gas) are likely to increase in the coming years.
- This energy import dependence implies vulnerability to external price shocks and supply fluctuations, which threaten the energy security of the country.
- Some of the strategies that can be used to meet future challenges to their energy security are:
 - ✓ Building stockpiles
 - ✓ Diversification of energy supply sources
 - ✓ Increased capacity of fuel switching
 - ✓ Demand restraint
 - ✓ Development of renewable energy sources
 - ✓ Energy efficiency
 - ✓ Sustainable development
- Although all these options are feasible, their implementation will take time.

Energy Conservation and its Importance:

- Energy conservation is achieved when growth of energy consumption is reduced, measured in physical terms.
- Energy Conservation can, therefore, be the result of several processes or developments, such as productivity increase or technological progress.
- Energy Conservation and Energy Efficiency are separate, but related concepts.
- Energy efficiency is achieved when energy intensity in a specific product, process or area of production or consumption is reduced without affecting output, consumption or comfort levels.
- Promotion of energy efficiency will contribute to energy conservation and is therefore an integral part of energy conservation promotional policies.
- Energy conservation is a part of the concept of Eco-sufficiency.
- Energy conservation measures (ECMs) in buildings reduce the need for energy services and can result in increased environmental quality, national security, personal financial security and higher savings.
- It is at the top of the sustainable energy hierarchy. It also lowers energy costs by preventing future resource depletion.
- Energy can be conserved by reducing wastage and losses, improving efficiency through technological upgrades, and improved operation and maintenance.
- On a global level, energy use can also be reduced by the stabilization of population growth.
- Promotion of energy efficiency will contribute to energy conservation and is therefore an integral part of energy conservation promotional policies.



Energy Strategy for the Future:

The energy strategy for the future could be classified into:

- a. Immediate-term strategy
- b. Medium-term strategy
- c. Long-term strategy.

a. Immediate-term strategy:

- Rationalizing the tariff structure of various energy products.
- Optimum utilization of existing assets.
- Efficiency in production systems and reduction in distribution losses, including those in traditional energy sources.
- Promoting R&D, transfer and use of technologies and practices for environmentally sound energy systems, including new and renewable energy sources.

b. Medium-term strategy:

- Demand management through greater conservation of energy, optimum fuel mix, structural changes in the economy, an appropriate modal mix in the transport sector, i.e. greater dependence on rail than on road for the movement of goods and passengers and a shift away from private modes to public modes for passenger transport; changes in design of different products to reduce the material intensity of those products, recycling, etc.
- There is need to shift to less energy-intensive modes of transport. This would include measures to improve the transport infrastructure viz. roads, better design of vehicles, use of compressed natural gas (CNG) and synthetic fuel, etc. Similarly, better urban planning would also reduce the demand for energy use in the transport sector.
- There is need to move away from non-renewable to renewable energy sources viz. solar, wind, biomass energy, etc.

c. Long-term strategy:

- Efficient generation of energy resources
 - Efficient production of coal, oil and natural gas
 - Reduction of natural gas flaring
- Improving energy infrastructure
 - Building new refineries
 - Creation of urban gas transmission and distribution network
 - Maximizing efficiency of rail transport of coal production.
 - Building new coal and gas fired power stations.
- Enhancing energy efficiency
 - Improving energy efficiency in accordance with national, socio-economic, and environmental priorities

- Promoting of energy efficiency and emission standards
- Labeling programmes for products and adoption of energy efficient technologies in large industries
- Deregulation and privatization of energy sector
 - Reducing cross subsidies on oil products and electricity tariffs
 - Decontrolling coal prices and making natural gas prices competitive
 - Privatization of oil, coal and power sectors for improved efficiency.
- Investment legislation to attract foreign investments.
 - Streamlining approval process for attracting private sector participation in power generation, transmission and distribution.

The Energy Conservation Act, 2001:

- With the background of high energy saving potential and its benefits, bridging the gap between demand and supply, reducing environmental emissions through energy saving, and to effectively overcome the barrier, the Government of India has enacted the Energy Conservation Act - 2001.
- Under the provisions of the Act, Bureau of Energy Efficiency has been established with effect from 1st March 2002.
- The Bureau would be responsible for implementation of policy programmes and coordination of implementation of energy conservation activities.

Features of the Energy Conservation Act:

- **Standards and Labeling:**
 - Standards and Labeling (S & L) has been identified as a key activity for energy efficiency improvement.
 - The S & L program, when in place would ensure that only energy efficient equipment and appliance would be made available to the consumers.
 - The main provision of EC act on Standards and Labeling are:
 - ✓ Evolve minimum energy consumption and performance standards for notified equipment and appliances.
 - ✓ Prohibit manufacture, sale and import of such equipment, which does not conform to the standards.
 - ✓ Introduce a mandatory labeling scheme for notified equipment appliances to enable consumers to make informed choices
 - ✓ Disseminate information on the benefits to consumers
- **Designated Consumers:**
 - The government would notify energy intensive industries and other establishments as designated consumers

- Schedule to the Act provides list of designated consumers which covered basically energy intensive industries, Railways, Port Trust, Transport Sector, Power Stations, Transmission & Distribution Companies and Commercial buildings or establishments;
- The designated consumer to get an energy audit conducted by an accredited energy auditor
- Energy managers with prescribed qualification are required to be appointed or designated by the designated consumers.
- Designated consumers would comply with norms and standards of energy consumption as prescribed by the central government

➤ **Certification of Energy Managers and Accreditation of Energy Auditing Firms:**

- A cadre of professionally qualified energy managers and auditors with expertise in policy analysis, project management, financing and implementation of energy efficiency projects would be developed through Certification and Accreditation programme.
- BEE to design training modules, and conduct a National level examination for certification of energy managers and energy auditors.

➤ **Energy Conservation Building Codes:**

- The BEE would prepare guidelines for Energy Conservation Building Codes (ECBC).
- These would be notified to suit local climate conditions or other compelling factors by the respective states for commercial buildings erected after the rules relating to energy conservation building codes have been notified. In addition, these buildings should have a connected load of 500 kW or contract demand of 600 kVA and above and are intended to be used for commercial purposes.
- Energy audit of specific designated commercial building consumers would also be prescribed.

➤ **Central Energy Conservation Fund:**

- The fund would be set up at the centre to develop the delivery mechanism for large-scale adoption of energy efficiency services such as performance contracting and promotion of energy service companies.
- The fund is expected to give a thrust to R & D and demonstration in order to boost market penetration of efficient equipment and appliances. It would support the creation of facilities for testing and development and to promote consumer awareness

➤ **Bureau of Energy Efficiency (BEE):**

- The mission of Bureau of Energy Efficiency is to institutionalize energy efficiency services, enable delivery mechanisms in the country and provide leadership to energy efficiency in all sectors of economy. The primary objective would be to reduce energy intensity in the Indian Economy.
- The general superintendence, directions and management of the affairs of the Bureau is vested in the Governing Council with 26 members. The Council is headed by Union Minister of Power and consists of members represented by Secretaries of various line Ministries, the

CEOs of technical agencies under the Ministries, members representing equipment and appliance manufacturers, industry, architects, consumers and five power regions representing the states. The Director General of the Bureau shall be the ex-officio member-secretary of the Council.

- The BEE will be initially supported by the Central Government by way of grants through budget, it will, however, in a period of 5-7 years become self-sufficient. It would be authorized to collect appropriate fee in discharge of its functions assigned to it.
- The BEE will also use the Central Energy Conservation Fund and other funds raised from various sources for innovative financing of energy efficiency projects in order to promote energy efficient investment

➤ **Role of Bureau of Energy Efficiency:**

- The role of BEE would be to prepare standards and labels of appliances and equipment, develop a list of designated consumers, specify certification and accreditation procedure, prepare building codes, maintain Central EC fund and undertake promotional activities in co-ordination with center and state level agencies.
- The role would include development of Energy service companies (ESCOs), transforming the market for energy efficiency and create awareness through measures including clearing house

➤ **Role of Central and State Governments:**

- **Central** - To notify rules and regulations under various provisions of the Act, provide initial financial assistance to BEE and EC fund, Coordinate with various State Governments for notification, enforcement, penalties and adjudication.
- **State** - To amend energy conservation building codes to suit the regional and local climatic condition, to designate state level agency to coordinate, regulate and enforce provisions of the Act and constitute a State Energy Conservation Fund for promotion of energy efficiency.

➤ **Enforcement through Self-Regulation:**

E.C. Act would require inspection of only two items. The following procedure of self-regulation is proposed to be adopted for verifying areas that require inspection of only two items that require inspection.

- The certification of energy consumption norms and standards of production process by the Accredited Energy Auditors is a way to enforce effective energy efficiency in Designated Consumers.
- For energy performance and standards, manufacturer's declared values would be checked in Accredited Laboratories by drawing sample from market. Any manufacturer or consumer or consumer association can challenge the values of the other manufacturer and bring to the notice of BEE. BEE can recognize for challenge testing in disputed cases as a measure for self-regulation.

➤ **Penalties and Adjudication:**

- Penalty for each offence under the Act would be in monetary terms i.e. Rs.10,000 for each offence and Rs.1,000 for each day for continued non Compliance.
- The initial phase of 5 years would be promotional and creating infrastructure for implementation of Act. No penalties would be effective during this phase.
- The power to adjudicate has been vested with state Electricity Regulatory Commission which shall appoint any one of its member to be an adjudicating officer for holding an enquiry in connection with the penalty imposed.

Objectives of energy conservation Act, 2001:

- To serve the efficient and effective use of energy and its conservation.
- Give an approach system and direction to national energy conservation activities.
- Organize policies and programmes on the effective utilization of energy with shareholders.
- Build up framework and strategies to verify measures and monitor energy efficiency improvements in the private and public sector at an individual and national level.
- Leverage the support of multilateral, bilateral and private sectors to make into effect the Energy Conservation Act.
- Show Energy efficiency delivery system through a public-private partnership.
- Advance energy efficiency in the nation.
- To plan, manage and actualize energy conservation programs as visualized in the Energy Conservation Act.

MODULE 2

ENERGY EFFICIENCY IN ELECTRICAL SYSTEMS

INTRODUCTION TO ELECTRIC POWER SUPPLY SYSTEMS

Electric power supply system in a country comprises of

- Generating units that produce electricity
- High voltage transmission lines that transport electricity over long distances
- Distribution lines that deliver the electricity to consumers
- Substations that connect the pieces to each other and
- Energy control centers to coordinate the operation of the components.

The Figure 1 shows a simple electric supply system with transmission and distribution network and linkages from electricity sources to end-user.

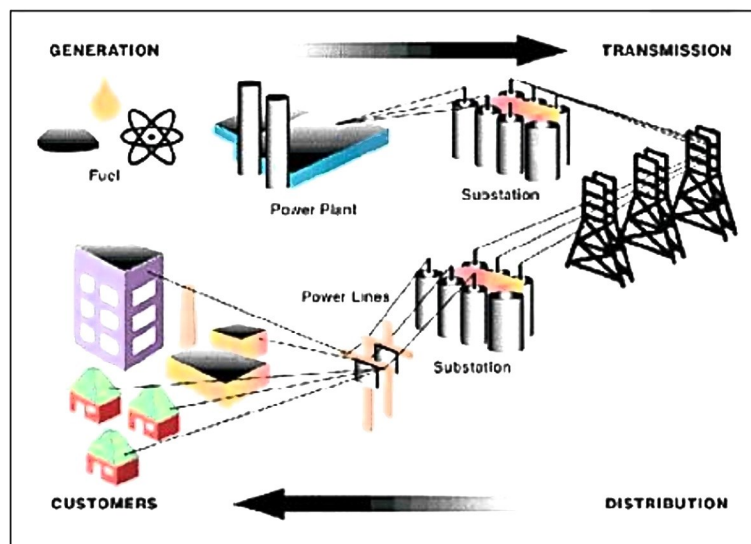


Figure 1: Typical Electric Power Supply Systems

POWER GENERATION PLANT:

- The fossil fuels such as coal, oil and natural gas, nuclear energy, and falling water (hydel) are commonly used energy sources in the power generating plant.
- A wide and growing variety of unconventional generation technologies and fuels have also been developed, including cogeneration, solar energy, wind generators, and waste materials.
- About 70 % of power generating capacity in India is from coal based thermal power plants.
- The principle of coal-fired power generation plant is shown in figure 2.
- Energy stored in the coal is converted in to electricity in thermal power plant.
- Coal is pulverized to the consistency of talcum powder.
- Then powdered coal is blown into the water wall boiler where it is burned at temperature higher than 1300°C.
- The heat in the combustion gas is transferred into steam.

- This high-pressure steam is used to run the steam turbine to spin.
- Finally, turbine rotates the generator to produce electricity.

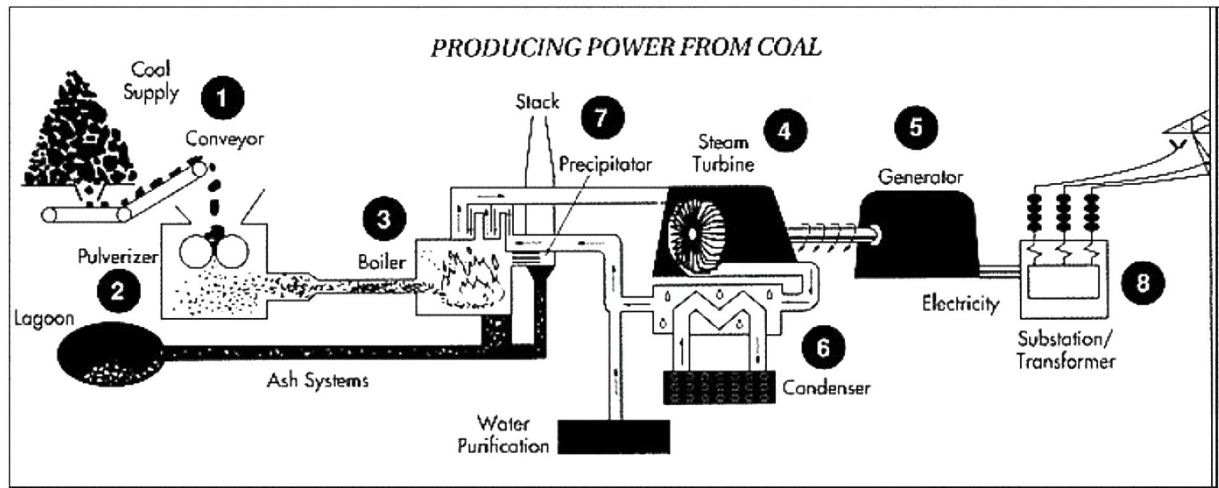


Figure 2: Principle of Thermal Power Generation

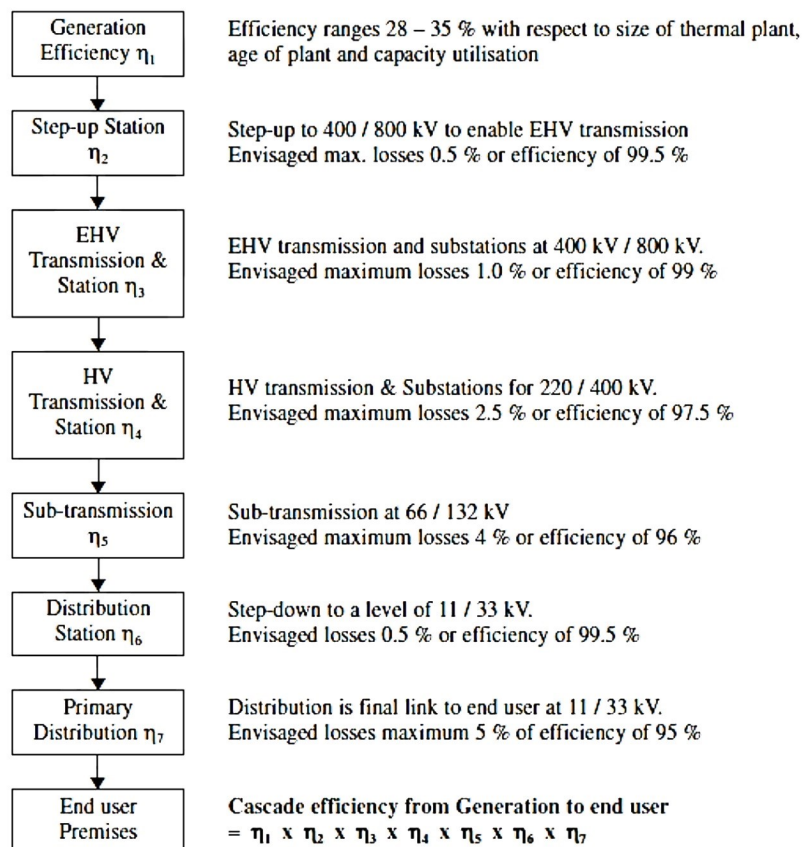
- In India, for the coal based power plants, the overall efficiency ranges from 28% to 35% depending upon the size, operational practices and capacity utilization.

TRANSMISSION AND DISTRIBUTION LINES:

- Power plants generate the AC power at 50 Hz frequency, with the voltages between 11kV and 33kV.
- The Power generated is stepped up to High voltage and Extra high voltage for transmission purpose over a long distance i.e 400 kV or 220 kV minimize the losses (Primary transmission).
- This is further step down 132 kV/110kV/66kV or 33 kV at receiving station (Secondary transmission).
- At substation this voltage is reduced to 11kV/6.6kV/3.3kV, these voltage is supplied for bulk consumers (Primary Distribution).
- Then distribution voltage is again stepped down to 440 and 230 volts.
- This power is then supplied for commercial and residential consumer through distribution lines. (Secondary Distribution).
- There is no difference between a transmission line and a distribution line except for the voltage level and power handling capability.
- Transmission lines are usually capable of transmitting large quantities of electric energy over great distances. They operate at high voltages. Distribution lines carry limited quantities of power over shorter distances.
- The power loss in line is proportional to resistance and square of current. (i.e. $P_{loss} = I^2 R$).
- Higher voltage transmission and distribution thus would help to minimize line voltage drop in the ratio of voltages, and the line power loss in the ratio of square of voltages.
- Lower voltage transmission and distribution also calls for bigger size conductor on account of current handling capacity needed.

CASCADE EFFICIENCY:

- The primary function of transmission and distribution equipment is to transfer power economically and reliably from one location to another.
- Conductors in the form of wires and cables strung on towers and poles carry the high-voltage, AC electric current.
- A large number of copper or aluminum conductors are used to form the transmission path. Energy loss in transmission lines is wasted in the form of I^2R losses.
- Capacitors are used to correct power factor by causing the current to lead the voltage. When the AC currents are kept in phase with the voltage, operating efficiency of the system is maintained at a high level.
- Circuit-interrupting devices are switches, relays, circuit breakers, and fuses. Each of these devices is designed to carry and interrupt certain levels of current. Making and breaking the current carrying conductors in the transmission path with a minimum of arcing is one of the most important characteristics of this device. Relays sense abnormal voltages, currents, and frequency and operate to protect the system.
- Transformers are placed at strategic locations throughout the system to minimize power losses in the T&D system. They are used to change the voltage level from low-to-high in step-up transformers and from high-to-low in step-down units.
- If we consider the electricity flow from generation to the user in terms of cascade energy efficiency, typical cascade efficiency profile from generation to 11 – 33 kV user will be as below:



- The cascade efficiency in the T&D system from output of the power plant to the end use is 87% (i.e. $0.995 \times 0.99 \times 0.975 \times 0.96 \times 0.995 \times 0.95 = 87\%$).

INDUSTRIAL END USER:

- At the industrial end user premises, again the plant network elements like transformers at receiving sub-station, switchgear, lines and cables, load-break switches, capacitors cause losses, which affect the input-received energy. However the losses in such systems are meager and unavoidable.
- ONE Unit saved = TWO Units Generated
- After power generation at the plant it is transmitted and distributed over a wide network.
- The standard technical losses are around 17 % in India (Efficiency = 83%). But the figures for many of the states show T & D losses ranging from 17 – 50 %.
- All these may not constitute technical losses, since un-metered and pilferage are also accounted in this loss.
- When the power reaches the industry, it meets the transformer. The energy efficiency of the transformer is generally very high.
- Next, it goes to the motor through internal plant distribution network. A typical distribution network efficiency including transformer is 95% and motor efficiency is about 90%.
- Another 30 % (Efficiency = 70%) is lost in the mechanical system which includes coupling/ drive train, a driven equipment such as pump and flow control valves/throttling etc.
- Thus the overall energy efficiency becomes 50%. ($0.83 \times 0.95 \times 0.9 \times 0.70 = 0.50$, i.e. 50% efficiency)
- Hence one unit saved in the end user is equivalent to two units generated in the power plant. (1Unit / 0.5Eff = 2 Units)

ELECTRICITY BILLING:

- The electricity billing by utilities for medium & large enterprises, in High Tension (HT) category, is often done on two-part tariff structure, i.e. one part for capacity or demand drawn and the second part for actual energy drawn during the billing cycle.
- Capacity or demand is in kVA (apparent power) or kW terms.
- The reactive energy (i.e.) kVA_{rh} drawn by the service is also recorded and billed for in some utilities, because this would affect the load on the utility.
- Accordingly, utility charges for maximum demand, active energy and reactive power drawn (as reflected by the power factor) in its billing structure. In addition, other fixed and variable expenses are also levied.
- **The tariff structure generally includes the following components:**
 - a) Maximum demand Charges: These charges relate to maximum demand registered during month/billing period and corresponding rate of utility.

- b) Energy Charges: These charges relate to energy (kilowatt hours) consumed during month / billing period and corresponding rates, often levied in slabs of use rates. Some utilities now charge on the basis of apparent energy (kVAh), which is a vector sum of kWh and kVArh.
- c) Power factor penalty or bonus rates, as levied by most utilities, are to contain reactive power drawn from grid.
- d) Fuel cost adjustment charges as levied by some utilities are to adjust the increasing fuel expenses over a base reference value.
- e) Electricity duty charges levied w.r.t units consumed.
- f) Meter rentals
- g) Lighting and fan power consumption is often at higher rates, levied sometimes on slab basis or on actual metering basis.
- h) Time of Day (TOD) rates like peak and non-peak hours are also prevalent in tariff structure provisions of some utilities.
- i) Penalty for exceeding contract demand.
- j) Surcharge if metering is at LT side in some of the utilities.
- Analysis of utility bill data and monitoring its trends helps energy manager to identify ways for electricity bill reduction through available provisions in tariff framework, apart from energy budgeting.
- The utility employs an electromagnetic or electronic trivector meter, for billing purposes.
- **The minimum outputs from the electromagnetic meters are:**
 - Maximum demand registered during the month, which is measured in preset time intervals (say of 30-minute duration) and this is reset at the end of every billing cycle.
 - Active energy in kWh during billing cycle
 - Reactive energy in kVArh during billing cycle and
 - Apparent energy in kVAh during billing cycle
- It is important to note that while maximum demand is recorded, it is not the instantaneous demand drawn, but the time integrated demand over the predefined recording cycle.

Example:

In an industry, if the drawl over a recording cycle of 30 minutes is:

2500 kVA for 4 minutes

3600 kVA for 12 minutes

4100 kVA for 6 minutes

3800 kVA for 8 minutes

Solution:

The MD recorder will be computing MD as

$$\frac{(2500 * 4) + (3600 * 12) + (4100 * 6) + (3800 * 8)}{30} = 3606.67\text{kVA}$$

- The month's maximum demand will be the highest among such demand values recorded over the month.
- The meter registers only if the value exceeds the previous maximum demand value and thus, even if, average maximum demand is low, the industry / facility has to pay for the maximum demand charges for the highest value registered during the month, even if it occurs for just one recording cycle duration i.e., 30 minutes during whole of the month.
- **Demand Curve:**

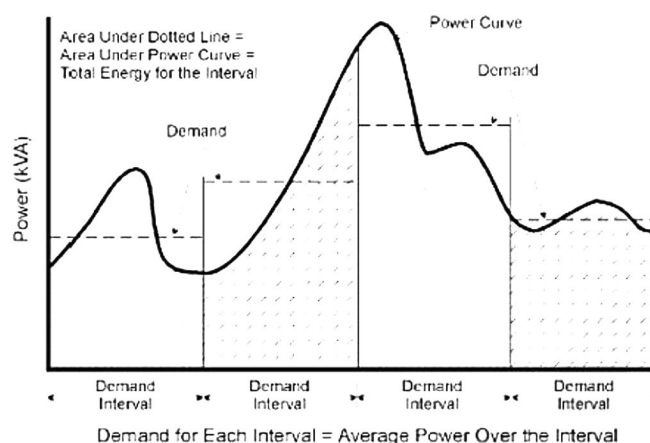


Figure: Demand Curve

- A typical demand curve is shown in Figure. It is observed that the demand varies from time to time. The demand is measured over predetermined time interval and averaged out for that interval as shown by the horizontal dotted line.
- Most electricity boards have changed over from conventional electromechanical trivector meters to electronic meters, which have some excellent provisions that can help the utility as well as the industry. These provisions include:
 - Substantial memory for logging and recording all relevant events
 - High accuracy up to 0.2 class
 - Amenability to time of day tariffs
 - Tamper detection /recording
 - Measurement of harmonics and Total Harmonic Distortion (THD)
 - Long service life due to absence of moving parts
 - Amenability for remote data access/downloads
- Trend analysis of purchased electricity and cost components can help the industry to identify key result areas for bill reduction within the utility tariff available framework along the following lines.

ELECTRICAL LOAD MANAGEMENT AND MAXIMUM DEMAND CONTROL

Need for Electrical Load Manage:

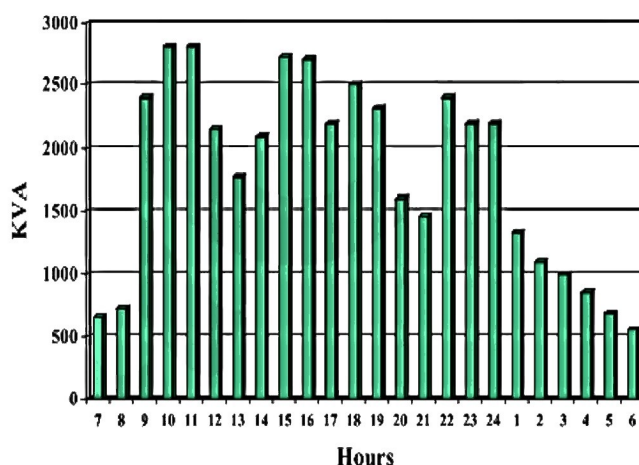
- The growth in the electricity use and diversity of end use segments in time of use has led to shortfalls in capacity to meet demand.

- As capacity addition is costly and only a long time prospect, better load management at user end helps to minimize peak demands on the utility infrastructure as well as better utilization of power plant capacities.
- The utilities (State Electricity Boards) use power tariff structure to influence end user in better load management through measures like time of use tariffs, penalties on exceeding allowed maximum demand, night tariff concessions etc.
- The growth in the electricity use and diversity of end use segments in time of use has led to shortfalls in capacity to meet demand.
- Load management is a powerful means of efficiency improvement both for end user as well as utility.
- As the demand charges constitute a considerable portion of the electricity bill, from user angle too there is a need for integrated load management to effectively control the maximum demand.

Step by Step Approach for Maximum Demand Control

1. Load Curve Generation:

- Presenting the load demand of a consumer against time of the day is known as a Load curve.
- If it is plotted for the 24 hours of a single day, it is known as an Hourly Load curve.
- If daily demands plotted over a month, it is called Daily Load curves.
- A typical hourly load curve for an engineering industry is shown in Figure.



2. Rescheduling of Loads:

- Rescheduling of large electric loads and equipment operations, in different shifts can be planned and implemented to minimize the simultaneous maximum demand.
- For this purpose, it is advisable to prepare an operation flow chart and a process chart.
- Analyzing these charts and with an integrated approach, it would be possible to reschedule the operations and running equipment in such a way as to improve the load factor which in turn reduces the maximum demand.

3. Storage of Products/in process material/process utilities like refrigeration:

- It is possible to reduce the maximum demand by building up storage capacity of products/materials, water, chilled water / hot water, using electricity during off peak periods.

- Off peak hour operations also help to save energy due to favorable conditions such as lower ambient temperature etc.
- Example: Ice bank system is used in milk & dairy industry. Ice is made in lean period and used in peak load period and thus maximum demand is reduced.

4. Shedding of Non-Essential Loads:

- When the maximum demand tends to reach preset limit, shedding some of non-essential loads temporarily can help to reduce it.
- It is possible to install direct demand monitoring systems, which will switch off non-essential loads when a preset demand is reached.
- Simple systems give an alarm, and the loads are shed manually.
- Sophisticated microprocessor controlled systems are also available, which provide a wide variety of control options like:
 - ✓ Accurate prediction of demand
 - ✓ Graphical display of present load, available load, demand limit
 - ✓ Visual and audible alarm
 - ✓ Automatic load shedding in a predetermined sequence
 - ✓ Automatic restoration of load
 - ✓ Recording and metering

5. Operation of Captive Generation and Diesel Generation Sets:

- When diesel generation sets are used to supplement the power supplied by the electric utilities, it is advisable to connect the D.G. sets for durations when demand reaches the peak value.
- This would reduce the load demand to a considerable extent and minimize the demand charges.

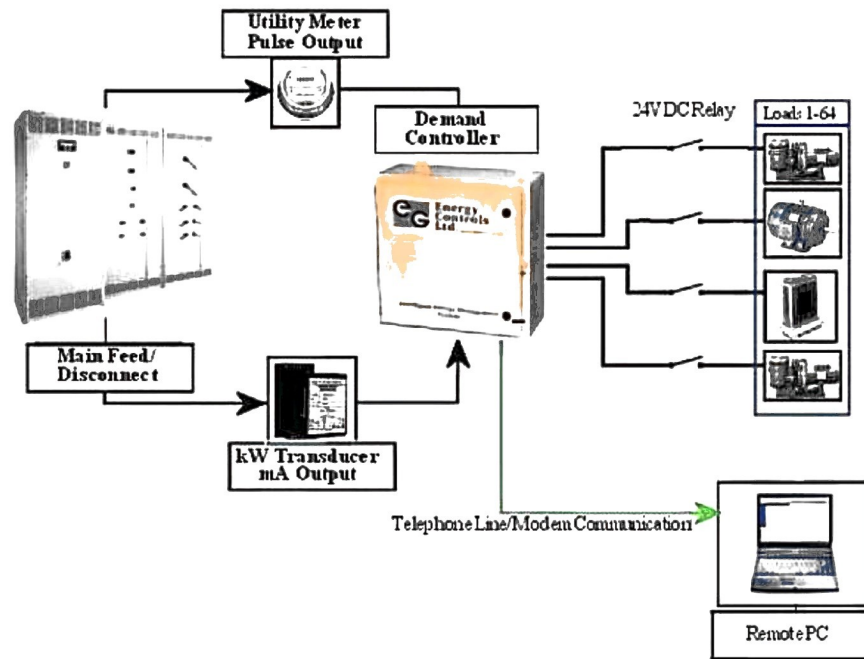
6. Reactive Power Compensation

- The maximum demand can also be reduced at the plant level by using capacitor banks and maintaining the optimum power factor.
- Capacitor banks are available with microprocessor based control systems.
- These systems switch on and off the capacitor banks to maintain the desired Power factor of system and optimize maximum demand thereby

MAXIMUM DEMAND CONTROLLERS:

- High-tension (HT) consumers have to pay a maximum demand charge in addition to the usual charge for the number of units consumed.
- This charge is usually based on the highest amount of power used during some period (say 30 minutes) during the metering month.
- The maximum demand charge often represents a large proportion of the total bill and may be based on only one isolated 30-minute episode of high power use.

- Considerable savings can be realised by monitoring power use and turning off or reducing non-essential loads during such periods of high power use.



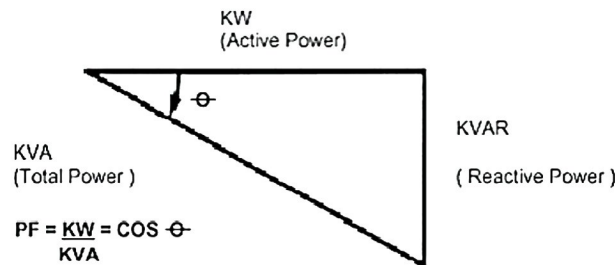
- Maximum Demand Controller is a device designed to meet the need of industries conscious of the value of load management as shown in figure.
- Alarm is sounded when demand approaches a preset value.
- If corrective action is not taken, the controller switches off non-essential loads in a logical sequence.
- This sequence is predetermined by the user and is programmed jointly by the user and the supplier of the device.
- The plant equipments selected for the load management are stopped and restarted as per the desired load profile.
- Demand control scheme is implemented by using suitable control contactors.
- Audio and visual annunciations could also be used.

POWER FACTOR IMPROVEMENT AND BENEFITS:

Power Factor Basics

- In all industrial electrical distribution systems, the major loads are resistive and inductive.
- Resistive loads are incandescent lighting.
- In case of pure resistive loads, the voltage (V), current (I), resistance (R) relations are linearly related, i.e $V = I \times R$ and $P = V \times I$
- Typical inductive loads are A.C. Motors, induction furnaces, transformers and ballast-type lighting.
- Inductive loads require two kinds of power:
 - a. Active (or working) power to perform the work
 - b. Reactive power to create and maintain electro-magnetic fields

- Active power is measured in kW (Kilo Watts) and Reactive power is measured in kVAr (Kilo Volt-Amperes Reactive).



- The vector sum of the active power and reactive power make up the total (or apparent) power used.
- This is the power generated by the SEBs for the user to perform a given amount of work. Total Power is measured in kVA (Kilo Volts-Amperes).
- The vector sum of the two is called the apparent power or kVA, as illustrated above and the kVA reflects the actual electrical load on distribution system.
- The ratio of kW to kVA is called the power factor, which is always less than or equal to unity.

$$\text{Power factor } \cos \phi = \frac{\text{Active Power}}{\text{Apprrent power}} = \frac{Kw}{KVA}$$

- when electric utilities supply power, if all loads have unity power factor, maximum power can be transferred for the same distribution system capacity.
- As the loads are inductive in nature, with the power factor ranging from 0.2 to 0.9, the electrical distribution network is stressed for capacity at low power factors.

Improving Power Factor:

- The solution to improve the power factor is to add power factor correction capacitors to the plant power distribution system.
- They act as reactive power generators, and provide the needed reactive power to accomplish kW of work.
- This reduces the amount of reactive power, and thus total power, generated by the utilities.

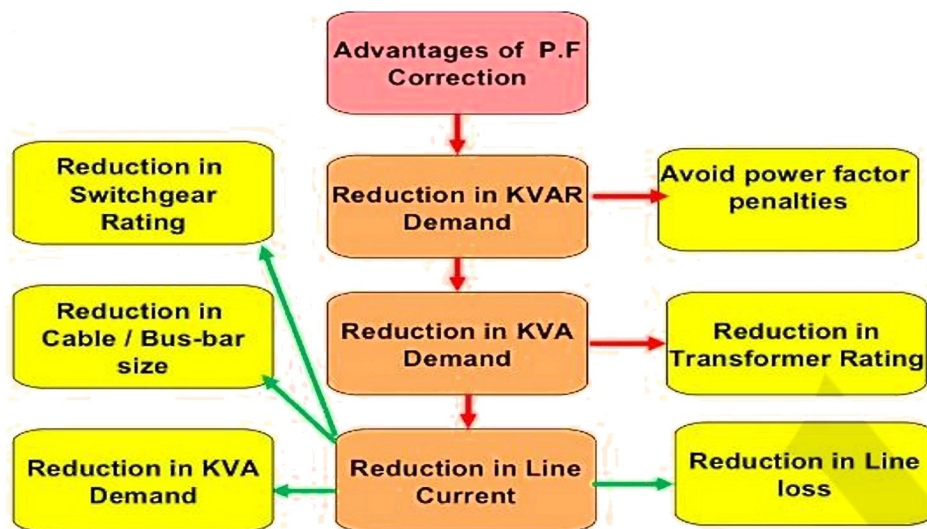
The advantages of PF improvement by capacitor addition:

- Reactive component of the network is reduced and so also the total current in the system from the source end.
- I^2R power losses are reduced in the system because of reduction in current.
- Voltage level at the load end is increased.
- kVA loading on the source generators as also on the transformers and lines upto the capacitors reduces giving capacity relief. A high power factor can help in utilising the full capacity of your electrical system.

Cost benefits of PF improvement

- Reduced kVA (Maximum demand) charges in utility bill.
- Reduced distribution losses (KWH) within the plant network.
- Better voltage at motor terminals and improved performance of motors.

- d) A high power factor eliminates penalty charges imposed when operating with a low power factor
- e) Investment on system facilities such as transformers, cables, switchgears etc for delivering load is reduced.



AUTOMATIC POWER FACTOR CONTROLLERS:

- Various types of automatic power factor controls are available with relay / microprocessor logic.
- Two of the most common controls are:
 1. Voltage Control and
 2. KILOVAR (kVAr) Control

1. Voltage Control:

- Voltage alone can be used as a source of intelligence when the switched capacitors are applied at point where the circuit voltage decreases as circuit load increases.
- Generally, where they are applied the voltage should decrease as circuit load increases and the drop in voltage should be around 4 – 5 % with increasing load.
- Voltage is the most common type of intelligence used in substation applications, when maintaining a particular voltage is of prime importance.
- This type of control is independent of load cycle.
- During light load time and low source voltage, this may give leading PF at the substation, which is to be taken note of.

2. KILOVAR (kVAr) Control:

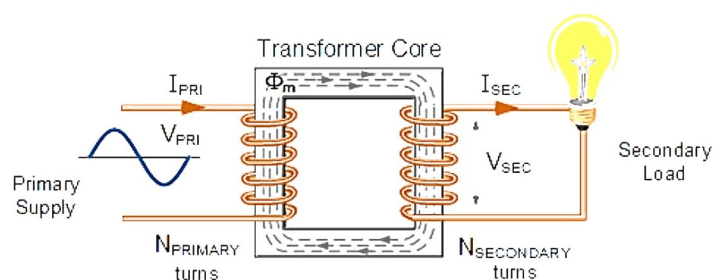
- KiloVAR sensitive controls are used at locations where the voltage level is closely regulated and not available as a control variable.
- The capacitors can be switched to respond to a decreasing power factor as a result of change in system loading.
- This type of control can also be used to avoid penalty on low power factor by adding capacitors in steps as the system power factor begins to lag behind the desired value.

- KiloVAR control requires two inputs - current and voltage from the incoming feeder, which are fed to the PF correction mechanism, either the microprocessor or the relay.

Automatic Power Factor Control Relay

- It controls the power factor of the installation by giving signals to switch on or off power factor correction capacitors.
- Relay is the brain of control circuit and needs contactors of appropriate rating for switching on/off the capacitors.
- There is a built-in power factor transducer, which measures the power factor of the installation and converts it to a DC voltage of appropriate polarity.
- This is compared with a reference voltage, which can be set by means of a knob calibrated in terms of power factor.
- When the power factor falls below setting, the capacitors are switched on in sequence.
- The relays are provided with First in First out (FIFO) and First in Last Out (FILO) sequence.
- The capacitors controlled by the relay must be of the same rating and they are switched on/off in linear sequence.
- To prevent over correction hunting, a dead band is provided.
- This setting determines the range of phase angle over which the relay does not respond; only when the PF goes beyond this range, the relay acts.
- When the load is low, the effect of the capacitors is more pronounced and may lead to hunting.
- Under current blocking (low current cut out) shuts off the relay, switching off all capacitors one by one in sequence, when load current is below setting.
- Special timing sequences ensure that capacitors are fully discharged before they are switched in. This avoids dangerous over voltage transient.
- The solid state indicating lamps (LEDs) display various functions that the operator should know and also indicate each capacitor switching stage.

TRANSFORMER:



- A transformer can accept energy at one voltage and deliver it at another voltage.
- This permits electrical energy to be generated at relatively low voltages and transmitted at high voltages and low currents, thus reducing line losses and voltage drop.
- Transformers consist of two or more coils that are electrically insulated, but magnetically linked.
- The primary coil is connected to the power source and the secondary coil connects to the load.

- The turn's ratio is the ratio between the number of turns on the secondary to the turns on the primary.
- The secondary voltage is equal to the primary voltage times the turn's ratio.
- Ampere-turns are calculated by multiplying the current in the coil times the number of turns.
- Primary ampere-turns are equal to secondary ampere-turns.
- Voltage regulation of a transformer is the percent increase in voltage from full load to no load.

Types of Transformers:

Transformers are classified as two categories:

1. Power transformers
2. Distribution transformers.

1. Power Transformer:

Power transformers are used in transmission network of higher voltages, deployed for step-up and step down transformer application (400 kV, 200 kV, 110 kV, 66 kV, 33kV).

2. Distribution Transformer:

Distribution transformers are used for lower voltage distribution networks as a means to end user connectivity. (11kV, 6.6 kV, 3.3 kV, 440V, 230V).

Rating of Transformer:

- Rating of the transformer is calculated based on the connected load and applying the diversity factor on the connected load, applicable to the particular industry and arrive at the kVA rating of the Transformer.
- Diversity factor is defined as the ratio of overall maximum demand of the plant to the sum of individual maximum demand of various equipment.
- Diversity factor varies from industry to industry and depends on various factors such as individual loads, load factor and future expansion needs of the plant.
- Diversity factor will always be less than one.

Location of Transformer:

- Location of the transformer is very important as far as distribution loss is concerned.
- Transformer receives HT voltage from the grid and steps it down to the required voltage.
- Transformers should be placed close to the load centre, considering other features like optimization needs for centralized control, operational flexibility etc.
- This will bring down the distribution loss in cables.

Transformer Losses and Efficiency:

- The efficiency varies anywhere between 96 to 99 percent.
- The efficiency of the transformers not only depends on the design, but also, on the effective operating load.
- Transformer losses consist of two parts:

1. No-load Loss

2. Load Loss

1. No-load Loss:

- No-load loss also called core loss is the power consumed to sustain the magnetic field in the transformer's steel core.
- Core loss occurs whenever the transformer is energized.
- Core loss does not vary with load.
- Core losses are caused by two factors: hysteresis and eddy current losses.
- Hysteresis loss is that energy lost by reversing the magnetic field in the core as the magnetizing AC rises and falls and reverses direction.
- Eddy current loss is a result of induced currents circulating in the core.

2. Load Loss:

- Load loss also called copper loss is associated with full-load current flow in the transformer windings.
- Copper loss is power lost in the primary and secondary windings of a transformer due to the ohmic resistance of the windings.
- Copper loss varies with the square of the load current. $P = I^2 R$
- Therefore, total losses of the transformer is given by
- Total losses = No load losses + n^2 Full load losses

where 'n' is the load factor.

$$n = \left(\frac{\text{Load KVA}}{\text{Rated KVA}} \right)^2 \times \text{Full losses}$$

System Distribution Losses:

- In an electrical system often the constant no load losses and the variable load losses are to be assessed alongside, over long reference duration, towards energy loss estimation.
- Identifying and calculating the sum of the individual contributing loss components is a challenging one, requiring extensive experience and knowledge of all the factors impacting the operating efficiencies of each of these components.

In system distribution loss optimization, the various options available include:

- Relocating transformers and sub-stations near to load centers
- Re-routing and re-conductoring such feeders and lines where the losses / voltage drops are higher.
- Power factor improvement by incorporating capacitors at load end.
- Optimum loading of transformers in the system.
- Opting for lower resistance All Aluminum Alloy Conductors (AAAC) in place of conventional Aluminum Cored Steel Reinforced (ACSR) lines
- Minimizing losses due to weak links in distribution network such as jumpers, loose contacts, old brittle conductors.

Energy Efficient Transformers:

- Most energy loss in dry-type transformers occurs through heat or vibration from the core.
- The new high-efficiency transformers minimise these losses.
- The conventional transformer is made up of a silicon alloyed iron core.
- The iron loss of any transformer depends on the type of core used in the transformer.
- However, the latest technology is to use amorphous material - a metallic glass alloy for the core.
- The expected reduction in energy loss over conventional transformers is roughly around 70%, which is quite significant.
- By using an amorphous core with unique physical and magnetic properties, these new type of transformers have increased efficiencies even at low loads – 98.5% efficiency at 35% load.
- Electrical distribution transformers made with amorphous metal cores provide excellent opportunity to conserve energy right from the installation.
- Though these transformers are a little costlier than conventional iron core transformers, the overall benefit towards energy savings will compensate for the higher initial investment. At present amorphous metal core transformers are available up to 1600 kVA.

ENERGY EFFICIENT MOTORS:

Minimizing Watts Loss in Motors:

- Improvements in motor efficiency can be achieved without compromising motor performance - at higher cost - within the limits of existing design and manufacturing technology.
- The improvement in motor efficiency must result from reducing the Watts losses.
- In terms of the existing state of electric motor technology, a reduction in watts losses can be achieved in various ways.
- All of these changes to reduce motor losses are possible with existing motor design and manufacturing technology.
- They would, however, require additional materials and/or the use of higher quality materials and improved manufacturing processes resulting in increased motor cost.

Reduced Losses = Improved Efficiency

Watts Loss Area	Efficiency Improvement
1. Iron	Use of thinner gauge, lower loss core steel reduces eddy current losses. Longer core adds more steel to the design, which reduces losses due to lower operating flux densities.
2. Stator $I^2 R$	Use of more copper and larger conductors increases cross sectional area of stator windings. This lowers resistance (R) of the windings and reduces losses due to current flow (I).
3. Rotor $I^2 R$	Use of larger rotor conductor bars increases size of cross section, lowering conductor resistance (R) and losses due to current flow (I).
4. Friction & Windage	Use of low loss fan design reduces losses due to air movement.
5. Stray Load Loss	Use of optimised design and strict quality control procedures minimizes stray load losses.

- Thus energy-efficient electric motors reduce energy losses through improved design, better materials, and improved manufacturing techniques.
- Replacing a motor may be justifiable solely on the electricity cost savings derived from an energy-efficient replacement.
- This is true if the motor runs continuously, power rates are high, the motor is oversized for the application, or its nominal efficiency has been reduced by damage or previous rewinds.

Technical aspects of Energy Efficient Motors:

- Energy-efficient motors last longer, and may require less maintenance. At lower temperatures, bearing grease lasts longer; required time between re-greasing increases. Lower temperatures translate to long lasting insulation. Generally, motor life doubles for each 10°C reduction in operating temperature.
- Select energy-efficient motors with a 1.15 service factor, and design for operation at 85% of the rated motor load.
- Electrical power problems, especially poor incoming power quality can affect the operation of energy-efficient motors.
- Speed control is crucial in some applications. In polyphase induction motors, slip is a measure of motor winding losses. The lower the slip, the higher the efficiency. Less slippage in energy efficient motors results in speeds about 1% faster than in standard counterparts.
- Starting torque for efficient motors may be lower than for standard motors. Facility managers should be careful when applying efficient motors to high torque applications.

SOFT STARTER:

- When starting, AC Induction motor develops more torque than is required at full speed.
- This stress is transferred to the mechanical transmission system resulting in excessive wear and premature failure of chains, belts, gears, mechanical seals, etc.
- Additionally, rapid acceleration also has a massive impact on electricity supply charges with high inrush currents drawing +600% of the normal run current.
- The use of Star Delta only provides a partial solution to the problem. Should the motor slow down during the transition period, the high peaks can be repeated and can even exceed direct on line current.
- Soft starter provides a reliable and economical solution to these problems by delivering a controlled release of power to the motor, thereby providing smooth, step less acceleration and deceleration.
- Motor life will be extended as damage to windings and bearings is reduced.
- Soft Start & Soft Stop is built into 3 phase units, providing controlled starting and stopping with a selection of ramp times and current limit settings to suit all applications

Advantages of Soft Start

- Less mechanical stress

- Improved power factor
- Lower maximum demand
- Less mechanical maintenance

VARIABLE SPEED DRIVES:

Speed Control of Induction Motors

- Induction motor is the workhorse of the industry.
- It is cheap rugged and provides high power to weight ratio.
- On account of high cost-implications and limitations of D.C. System, induction motors are preferred for variable speed application, the speed of which can be varied by changing the supply frequency.
- The speed can also be varied by varying the input voltage, varying the resistance of the rotor circuit, using multi speed windings, using Scherbius or Kramer drives, using mechanical means such as gears and pulleys and eddy-current or fluid coupling, or by using rotary or static voltage and frequency converters.

Variable Frequency Drive

- The VFD operates on a simple principle. The rotational speed of an AC induction motor depends on the number of poles in that stator and the frequency of the applied AC power.
- Although the number of poles in an induction motor cannot be altered easily, variable speed can be achieved through a variation in frequency.
- The VFD rectifies standard 50 cycle AC line power to DC, then synthesizes the DC to a variable frequency AC output.
- Motors connected to VFD provide variable speed mechanical output with high efficiency.
- These devices are capable of up to a 9:1 speed reduction ratio (11 percent of full speed), and a 3:1 speed increase (300 percent of full speed).
- The technology of AC variable frequency drives (VFD) has evolved into highly sophisticated digital microprocessor control, along with high switching frequency IGBTs (Insulated Gate Bi Polar Transistors) power devices.
- This has led to significantly advanced capabilities from the ease of programmability to expanded diagnostics.
- The two most significant benefits from the evolution in technology have been that of cost and reliability, in addition to the significant reduction in physical size.

Variable Torque Vs. Constant Torque

- Variable speed drives, and the loads that are applied to, can generally be divided into two groups:
 1. Constant torque
 2. Variable torque.

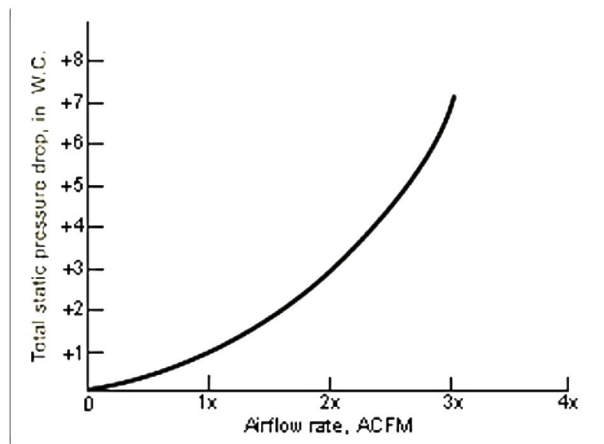
- The energy savings potential of variable torque applications is much greater than that of constant torque applications.
- Constant torque loads include vibrating conveyors, punch presses, rock crushers, machine tools, and other applications where the drive follows a constant V/Hz ratio.
- Variable torque loads include centrifugal pumps and fans, which make up the majority of HVAC applications.

PERFORMANCE EVALUATION OF FANS:

- Fans and blowers provide air for ventilation and industrial process requirements.
- Fans generate a pressure to move air (or gases) against a resistance caused by ducts, dampers, or other components in a fan system.
- The fan rotor receives energy from a rotating shaft and transmits it to the air.

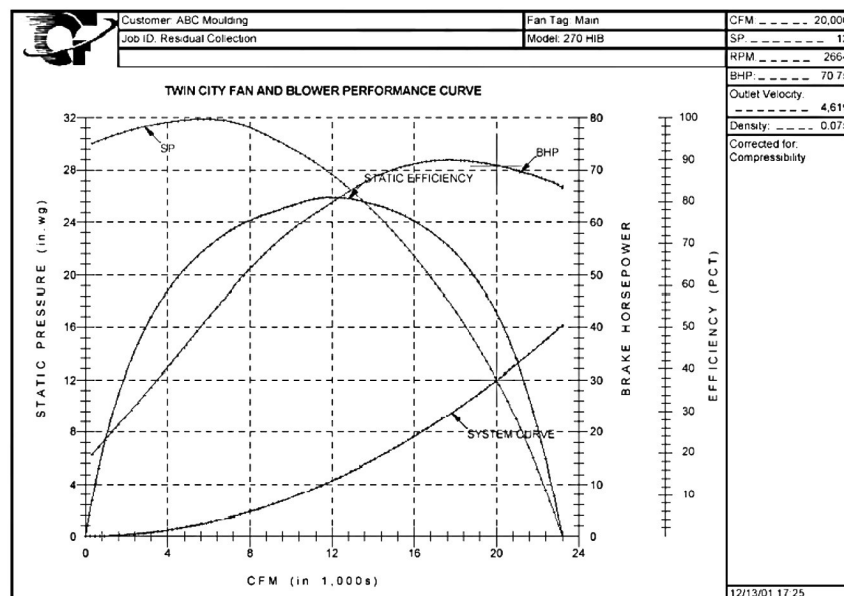
System Characteristics:

- The term "system resistance" is used when referring to the static pressure.
- The system resistance is the sum of static pressure losses in the system.
- The system resistance is a function of the configuration of ducts, pickups, elbows and the pressure drops across equipment for example backfilter or cyclone.
- The system resistance varies with the square of the volume of air flowing through the system.
- For a given volume of air, the fan in a system with narrow ducts and multiple short radius elbows is going to have to work harder to overcome a greater system resistance than it would in a system with larger ducts and a minimum number of long radius turns.
- Long narrow ducts with many bends and twists will require more energy to pull the air through them.
- For a given fan speed, the fan will be able to pull less air through this system than through a short system with no elbows.
- Thus, the system resistance increases substantially as the volume of air flowing through the system increases; square of air flow.
- Conversely, resistance decreases as flow decreases. To determine what volume the fan will produce, it is therefore necessary to know the system resistance characteristics.
- Typically a system resistance curve is generated with for various flow rates on the x-axis and the associated resistance on the y-axis.



Fan Characteristics:

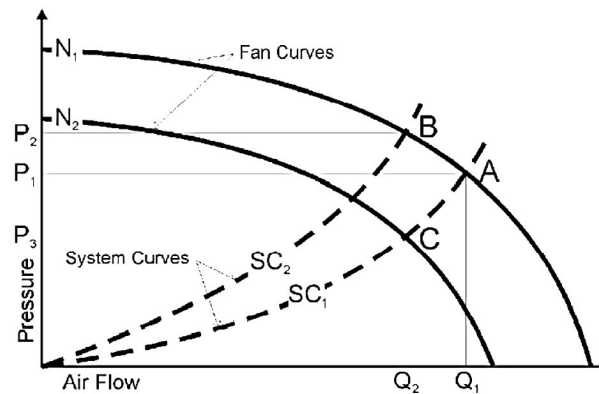
- Fan characteristics can be represented in form of fan curve(s).
- The fan curve is a performance curve for the particular fan under a specific set of conditions.
- The fan curve is a graphical representation of a number of inter-related parameters.
- Typically, a curve will be developed for a given set of conditions usually including: fan volume, system static pressure, fan speed, and brake horsepower required to drive the fan under the stated conditions.



- Some fan curves will also include an efficiency curve so that a system designer will know where on that curve the fan will be operating under the chosen conditions.
- The curve static pressure (SP) vs. flow is especially important.
- The intersection of the system curve and the static pressure curve defines the operating point.
- When the system resistance changes, the operating point also changes.
- Once the operating point is fixed, the power required could be found by following a vertical line that passes through the operating point to an intersection with the power (BHP) curve.
- A horizontal line drawn through the intersection with the power curve will lead to the required power on the right vertical axis.
- In the depicted curves, the fan efficiency curve is also presented.

System Characteristics and Fan Curves:

- In any fan system, the resistance to air flow (pressure) increases when the flow of air is increased.
- It varies as the square of the flow.
- The pressure required by a system over a range of flows can be determined and a "system performance curve" can be developed.



- This system curve can then be plotted on the fan curve to show the fan's actual operating point at "A" where the two curves (N1 and SC1) intersect.
- This operating point is at air flow Q1 delivered against pressure P1.
- A fan operates along a performance given by the manufacturer for a particular fan speed.
- At fan speed N1, the fan will operate along the N1 performance curve as shown in Figure.
- The fan's actual operating point on this curve will depend on the system resistance; fan's operating point at "A" is flow (Q1) against pressure (P1).
- Two methods can be used to reduce air flow from Q1 to Q2:

First method:

- First Method is to restrict the air flow by partially closing a damper in the system.
- This action causes a new system performance curve (SC2) where the required pressure is greater for any given air flow.
- The fan will now operate at "B" to provide the reduced air flow Q2 against higher pressure P2.

Second method:

- Second method to reduce air flow is by reducing the speed from N1 to N2, keeping the damper fully open.
- The fan would operate at "C" to provide the same Q2 air flow, but at a lower pressure P3.
- Thus, reducing the fan speed is a much more efficient method to decrease airflow since less power is required and less energy is consumed.

Fan Performance Assessment:

The fans are tested for field performance by measurement of flow, head, temperature on the fan side and electrical motor kW input on the motor side.

➤ Air flow measurement

- **Static pressure:**

Static pressure is the potential energy put into the system by the fan. It is given up to friction in the ducts and at the duct inlet as it is converted to velocity pressure. At the inlet to the duct, the static pressure produces an area of low pressure

- **Velocity pressure:**

Velocity pressure is the pressure along the line of the flow that results from the air flowing through the duct. The velocity pressure is used to calculate air velocity.

- **Total pressure:**

Total pressure is the sum of the static and velocity pressure. Velocity pressure and static pressure can change as the air flows through different size ducts, accelerating and decelerating the velocity. The total pressure stays constant, changing only with friction losses.

- **Measurement by Pitot tube:**

Total pressure is measured using the inner tube of pitot tube and static pressure is measured using the outer tube of pitot tube. When the inner and outer tube ends are connected to a manometer, we get the velocity pressure. For measuring low velocities, it is preferable to use an inclined tube manometer instead of U tube manometer.

FLOW CONTROL STRATEGIES:

- Once a fan system is designed and installed, the fan operates at a constant speed.
- There may be occasions when a speed change is desirable, i.e., when adding a new run of duct that requires an increase in air flow (volume) through the fan. There are also instances when the fan is oversized and flow reductions are required.
- Various ways to achieve change in flow are: pulley change, damper control, inlet guide vane control, variable speed drive and series and parallel operation of fans.

Pulley Change

- When a fan volume change is required on a permanent basis, and the existing fan can handle the change in capacity, the volume change can be achieved with a speed change.
- The simplest way to change the speed is with a pulley change.
- For this, the fan must be driven by a motor through a v-belt system.
- The fan speed can be increased or decreased with a change in the drive pulley or the driven pulley or in some cases, both pulleys.

Damper Controls

- Some fans are designed with damper controls. Dampers can be located at inlet or outlet.
- Dampers provide a means of changing air volume by adding or removing system resistance.
- This resistance forces the fan to move up or down along its characteristic curve, generating more or less air without changing fan speed.
- However, dampers provide a limited amount of adjustment, and they are not particularly energy efficient.

Inlet Guide Vanes

- Inlet guide vanes are another mechanism that can be used to meet variable air demand.
- Guide vanes are curved sections that lay against the inlet of the fan when they are open.
- When they are closed, they extend out into the air stream.
- As they are closed, guide vanes pre-swirl the air entering the fan housing.
- This changes the angle at which the air is presented to the fan blades, which, in turn, changes the characteristics of the fan curve.
- Guide vanes are energy efficient for modest flow reductions – from 100 percent flow to about 80 percent. Below 80 percent flow, energy efficiency drops sharply.
- Axial-flow fans can be equipped with variable pitch blades, which can be hydraulically or pneumatically controlled to change blade pitch, while the fan is at stationary.
- Variable-pitch blades modify the fan characteristics substantially and thereby provide dramatically higher energy efficiency than the other options discussed thus far.

Variable Speed Drives

- Variable speed drives are expensive, they provide almost infinite variability in speed control.
- Variable speed operation involves reducing the speed of the fan to meet reduced flow requirements.
- Fan performance can be predicted at different speeds using the fan laws. Since power input to the fan changes as the cube of the flow, this will usually be the most efficient form of capacity control.
- However, variable speed control may not be economical for systems, which have infrequent flow variations.

Series and Parallel Operation

- Parallel operation of fans is another useful form of capacity control.
- Fans in parallel can be additionally equipped with dampers, variable inlet vanes, variable-pitch blades, or speed controls to provide a high degree of flexibility and reliability.
- Combining fans in series or parallel can achieve the desired airflow without greatly increasing the system package size or fan diameter.
- Parallel operation is defined as having two or more fans blowing together side by side. The performance of two fans in parallel will result in doubling the volume flow, but only at free delivery.
- Series operation can be defined as using multiple fans in a push-pull arrangement. By staging two fans in series, the static pressure capability at a given airflow can be increased.
- In both series and parallel operation, particularly with multiple fans certain areas of the combined performance curve will be unstable and should be avoided.

ENERGY SAVING/ CONSERVATION OPPORTUNITIES IN FAN

1. Minimising excess air level in combustion systems to reduce FD fan and ID fan load.
2. Minimising air in-leaks in hot flue gas path to reduce ID fan load, especially in case of kilns, boiler plants, furnaces, etc. Cold air in-leaks increase ID fan load tremendously, due to density increase of flue gases and in-fact choke up the capacity of fan, resulting as a bottleneck for boiler / furnace itself.
3. In-leaks / out-leaks in air conditioning systems also have a major impact on energy efficiency and fan power consumption and need to be minimized.
4. The findings of performance assessment trials will automatically indicate potential areas for improvement, which could be one or a more of the following:
 - Change of impeller by a high efficiency impeller along with cone.
 - Change of fan assembly as a whole, by a higher efficiency fan
 - Impeller de-rating (by a smaller dia impeller)
 - Change of metallic / Glass reinforced Plastic (GRP) impeller by the more energy efficient hollow FRP impeller with aerofoil design, in case of axial flow fans, where significant savings have been reported.
 - Fan speed reduction by pulley dia modifications for derating.
 - Option of two speed motors or variable speed drives for variable duty conditions.
 - Option of energy efficient flat belts, or, cogged raw edged V belts, in place of conventional V belt systems, for reducing transmission losses.
 - Adopting inlet guide vanes in place of discharge damper control.
 - Minimizing system resistance and pressure drops by improvements in duct system.

ELECTRONIC BALLAST:

Role of Ballast

- In an electric circuit the ballast acts as a stabilizer.
- Fluorescent lamp is an electric discharge lamp.
- The two electrodes are separated inside a tube with no apparent connection between them.
- When sufficient voltage is impressed on these electrodes, electrons are driven from one electrode and attracted to the other.
- The current flow takes place through an atmosphere of low pressure mercury vapour.
- Since the fluorescent lamps cannot produce light by direct connection to the power source, they need an ancillary circuit and device to get started and remain illuminated.
- The auxillary circuit housed in a casing is known as ballast

Conventional Vs Electronic Ballasts

- The conventional ballasts make use of the kick caused by sudden physical disruption of current in an inductive circuit to produce the high voltage required for starting the lamp and then rely on reactive voltage drop in the ballast to reduce the voltage applied across the lamp.

- On account of the mechanical switch (starter) and low resistance of filament when cold the uncontrolled filament current, generally tend to go beyond the limits specified by Indian standard specifications.
- With high values of current and flux densities the operational losses and temperature rise are on the higher side in conventional choke.

The basic functions of electronic ballast are:

- To ignite the lamp
- To stabilize the gas discharge
- To supply the power to the lamp

ENERGY EFFICIENT LIGHTING CONTROLS:

Occupancy Sensors

- Occupancy-linked control can be achieved using infra-red, acoustic, ultrasonic or microwave sensors, which detect either movement or noise in room spaces.
- These sensors switch lighting on when occupancy is detected, and off again after a set time period, when no occupancy movement detected.
- They are designed to override manual switches and to prevent a situation where lighting is left on in unoccupied spaces.

Timed Based Control

- Timed-turnoff switches are the least expensive type of automatic lighting control.
- In some cases, their low cost and ease of installation makes it desirable to use them where more efficient controls would be too expensive.

Types and Features:

- The oldest and most common type of timed-turnoff switch is the "dial timer," a spring-wound mechanical timer that is set by twisting the knob to the desired time.
- Typical units of this type are vulnerable to damage because the shaft is weak and the knob is not securely attached to the shaft.
- Some spring-wound units make an annoying ticking sound as they operate.
- Newer types of timed-turnoff switches are completely electronic and silent.
- Electronic switches can be made much more rugged than the spring-wound dial timer.
- These units typically have a spring-loaded toggle switch that turns on the circuit for a preset time interval.
- Some electronic models provide a choice of time intervals, which you select by adjusting a knob located behind the faceplate

- Most models allow occupants to turn off the lights manually. Some models allow occupants to keep the lights on, overriding the timer
- Timed-turnoff switches are available with a wide range of time spans.
- The choice of time span is a compromise. Shorter time spans waste less energy but increase the probability that the lights will turn off while someone is in the space.
- Dial timers allow the occupant to set the time span, but this is not likely to be done with a view toward optimizing efficiency.
- For most applications, the best choice is an electronic unit that allows the engineering staff to set a fixed time interval behind the cover plate.

Daylight Linked Control:

- Photoelectric cells can be used either simply to switch lighting on and off, or for dimming.
- They may be mounted either externally or internally.
- It is however important to incorporate time delays into the control system to avoid repeated rapid switching caused, for example, by fast moving clouds.
- By using an internally mounted photoelectric dimming control system, it is possible to ensure that the sum of daylight & electric lighting always reaches the design level by sensing the total light in the controlled area and adjusting the output of the electric lighting accordingly.
- If daylight alone is able to meet the design requirements, then the electric lighting can be turned off.
- The energy saving potential of dimming control is greater than a simple photoelectric switching system.
- Dimming control is also more likely to be acceptable to room occupants.

Localized Switching

- Localized switching should be used in applications which contain large spaces.
- Local switches give individual occupants control over their visual environment and also facilitate energy savings.
- By using localized switching it is possible to turn off artificial lighting in specific areas, while still operating it in other areas where it is required, a situation which is impossible if the lighting for an entire space is controlled from a single switch.