Module – II

1. ENERGY STORAGE SYSTEMS

Energy storage (ES) has only recently been developed where it to a point can have a significant impact on modern technology. ln particular, ES is critically important to the success of any intermittent energy source in meeting demand. **Energy storage** is the capture of energy produced at one time for use at a later time to reduce imbalances between energy demand and energy production.

For example, the need for storage for solar energy applications is severe, especially when solar energy is least available, namely, in winter.

ES systems can contribute significantly to meeting society's needs for more efficient, environmentally energy use in building heating and cooling, aerospace power, and utility applications. The use of ES systems often results-in such significant benefits as

- reduced energy costs.
- reduced energy consumption.
- improved indoor air quality.
- increased flexibility of operation. and
- reduced initial and maintenance costs.

Advantages of ES:

- reduced equipment size;
- more efficient and effective utilization of equipment;
- conservation of fossil fuels (by facilitating more efficient energy use and/or fuelsubstitution);
- reduced pollutant emissions (e.g., CO_2, and chlorofluoro carbons (CFCs)).

1.1 Energy Demand

Energy demand in the commercial, industrial. public. residential, and utility sectors varies on a daily, weekly, and seasonal basis Ideally, these demands are matched by various energy- conversion systems that operate synergistically. Peak hours are the most difficult and expensive to supply. Peak electrical demands are generally met by conventional gas turbines or diesel generators, which are reliant on costly and relatively scarce oil or gas. ES provides an alternative method of supplying peak energy demands. Likewise, ES systems can improve the operation of cogeneration, solar, wind, and run-of river hydro facilities. Some details on these ES applicationsfollow:

Utility: Relatively inexpensive base-load electricity can be used to charge ES systems during evening or off-peak weekly or seasonal periods. The electricity is then used during peak periods. Reducing the reliance on conventional gas and oil peaking generators.

Industry: High-temperature waste heat from various industrial process can be stored for use in preheating and other heating operation.

Cogeneration: Since the closely coupled production of heat and electricity by a cogenerationsystem rarely matches demand exactly, excess electricity or heat can be stored for subsequent use.**wind and run-of-river hydro:** Conceivably, these systems can operate around the clock, chargingan electrical storage system during low-demand hours and later using that electricity for peaking purposes. ES increases the capacity factor for these devices, usually enhancing their economicvalue.

Solar energy systems: By storing excess solar energy received on sunny days for use on cloudydays or at night, ES systems can increase the capacity factor of solar energy systems.

2. Energy storage Systems

2.1 Mechanical and hydraulic Energy storage systems usually store energy by converting electricity into energy of compression, elevation, or rotation. Pumped storage is proven, but quite limited in its applicability by site considerations. Compressed-air ES has been tried successfully in Europe, although limited applications appear in the United States. This concept can be applied on a large scale using depleted natural gas fields for the storage reservoir. Alternatively, energy can be stored chemically as hydrogen in exhausted gas fields. Energy of rotation can be stored in flywheels, but advanced designs with high tensile materials appear to be needed to reduce the price and volume of storage. A substantial energy penalty of up to 50% is generally incurred by mechanical and hydraulic systems in a complete storage cycle because of inefficiencies.

2.2 Reversible chemical reactions can also be used to store energy. There is a growing interest in storing low-temperature heat in chemical form, but practical systems have not yet emerged. Another idea in the same category is the storage of hydrogen in metal hydrides (lanthanum, for instance). Tests of this idea are ongoing.

2.3 Electrochemical ES systems have better turnaround efficiencies but very high prices. lntensive research is now directed toward improving batteries, particularly by lowering their weight-to storage capacity ratios, as needed in many vehicle applications. As a successor to the lead-acid battery, sodium-sulfur and lithium sulfide alternatives, among others, are being tested. A differenttype of electrochemical system is the redox flow cell, so named because charging and dischargingis achieved through reduction and oxidation reactions occurring in fluids tored in two separate tanks. To make the leading candidate (an iron redox system) competitive with today's batteries, its price would have to be at least halved.

2.4 Thermal energy storage (TES) systems are varied and include designed containers, underground aquifers and soils and Lakes, bricks and ingots. Some systems using bricks are operating Europe. ln these systems, energy is stored as sensible heat. Alternatively, thermal energy can be stored inthe latent heat of melting in such materials as salts or paraffin. Latent storages can reduce the volume of the storage device by as much as 100 times, but after several

decades of research manyof their practical problems have still not been solved. Finally, electric energy can be stored in superconducting magnetic systems although the costs of such systems are high.

Some current research and development areas in the field of ES are follows: Advanced ES and conversion systems with phase transformation, chemical and electro chemicalreactions.

- fundamental phenomena inside a single cell as well as engineering integration of wholebattery packs into vehicles.
- high-dielectric-constant polymers.
- high K composites for capacitors.
- polymer electrode interfaces (low- and high-frequency effects):

- integrated Polymer capacitors.

3. Energy Storage Methods

For many energy technologies, storage is a crucial aspect. If we Consider the storage of fuels as the storage of the energy embedded in them, then oil is an excellent example. The massive amounts of petroleum stored worldwide are necessary for the reliable, economic availability of gasoline and petrochemicals.

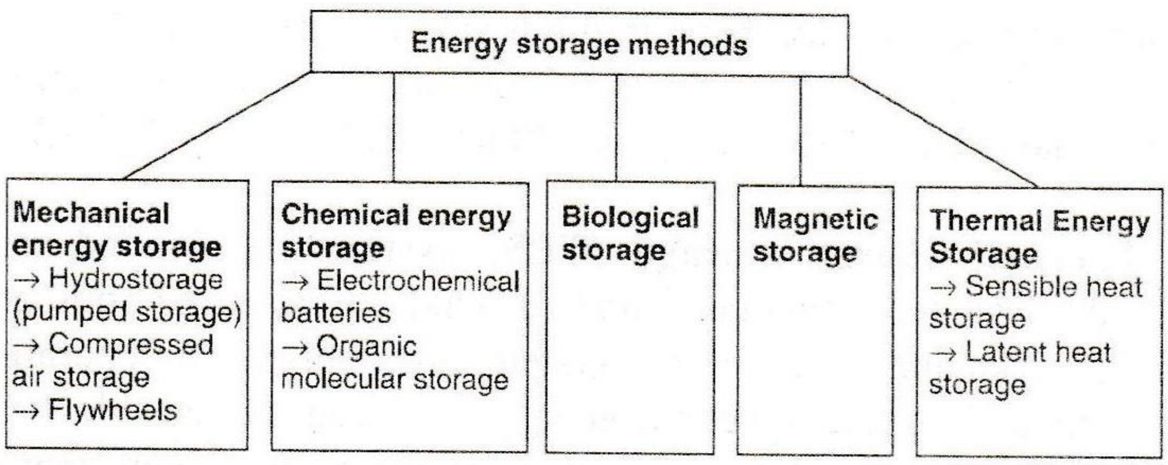


Fig: A classification of energy storage methods

3.1 MECHANICAL ENERGY STORAGE

Mechanical energy may be stored as the kinetic energy of linear or rotational motion as the potential energy in an elevated object, as the compression or strain energy of an elastic material, or as the compression energy in a gas. tt is difficult to store large quantities of energy in linear motion because one would have to chase after the storage medium continually. However, it is quite simple to store rotational kinetic energy. In fact, the potter's wheel, perhaps the first form of ES used by man, was developed several thousand years ago and is still being used there are three main mechanical storage types that have discuss in this section: hydro storage. compressed-air storage and flywheels.

3.1.1 HYDROSTORAGE (PUMPED STORAGE)

Upper reservoir: like a conventional hydropower plant, a dam creates a reservoir. The water in this reservoir flows through the hydropower plant to create electricity. Using a reversible turbine, the plant can pump water back to the upper reservoir. This is done in off-peak hours. Essentially, the second reservoir refills the upper reservoir.

Lower reservoir: Water exiting the hydropower plant flows into a lower reservoir other than re-entering the river and flowing downstream.

Reversible turbine pump: water back to the upper reservoir, this is done in off-peak hours. By pumping water back to upper reservoir, plant has more water to generate electricity during periodsof peak consumption.

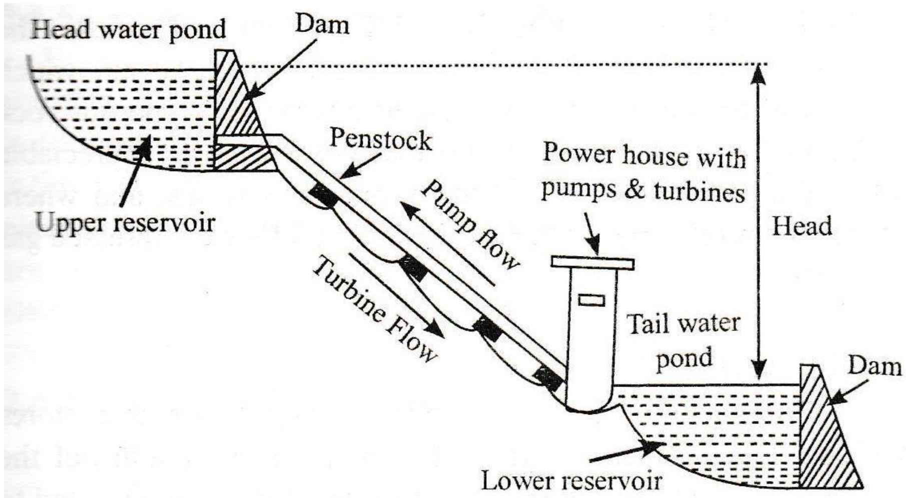


Fig: Pump Storage

3.1.2 COMPRESSED.AIR STORAGE

In a compressed-air ES system, air is compressed during off- peak hours and stored in large underground reservoirs, which may be naturally occurring caverns, salt domes. abandoned mine shafts, depleted gas and oil fields, or man-made caverns. During peak hours, the air is released to drive a gas turbine generator.

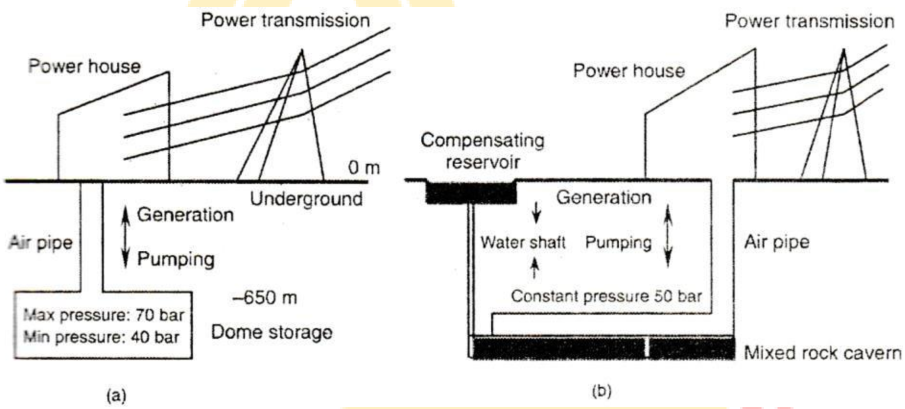


Fig: Compresses air ES systems (a) Sliding Pressure System (b) Compensated PressureSystem

The technique used by such a system to compress air to store energy is relatively straightforward. ln a conventional gas turbine, high-pressure hot gas is supplied. and about two-thirds of the gross power output is used to drive the compressor. A compressed-air ES system decouples the compressor and the turbine and operates the former during off-peak hours to produce compressed air, which is stored in natural cavefish. old oil or gas wells, or porous rock formations. Such ES storage is advantageous when an appreciable part of the power load is carried by nuclear stations. and where suitable spent salt caverns make it easy to build the compressed gas reservoirs.

3.1.3 FLYWHEELS

The flywheel, a wheel of relatively large mass that stores rotational kinetic energy. has long beenused to smooth out the shaft power output from one- or two cycle (stroke) engines and to adjust for uneven loads. New uses of this device, and of the other two mechanical storage techniques discussed in this section, take advantage of the ability of the electric motor/generator operation toreverse. Such a device can be designed to rvork both as a motor when driven by electric power andas a generator when driven by mechanical power.

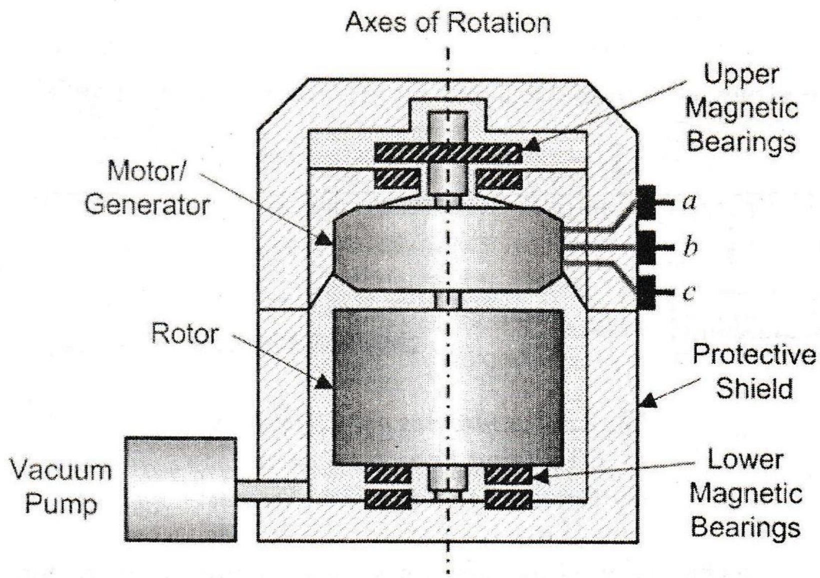


Fig: Flywheel Storage Energy

3.2 Chemical Energy Storage

Energy may be stored in systems composed of one or more chemical compounds that release or absorb energy when they react to form other compounds. The most familiar chemical energy storage device is the battery. Energy stored in batteries is frequently referred to as electrochemical energy because chemical reactions in the battery are caused by electrical energy and subsequently produce electrical energy. Power to gas and Power to liquid are two methods of chemical ES system.

Power to gas: Power to gas is a technology that uses electric power to produce a gaseous fuel such as hydrogen or methane. When using surplus power (Excess electricity is surplus electrical energy that must be dumped (or curtailed) because it cannot be used to serve a load or charge batteries) from wind generation, the concept is sometimes called wind gas. The three commercial methods use electricity to reduce water into hydrogen and oxygen by means of electrolysis.

In the first method, hydrogen is injected into the natural gas grid or is used for transportation. The second method is to combine the hydrogen with CO2 to produce methane using a methanation reaction such as the Sabatier reaction, or biological methanation, resulting in an extra energy conversion loss of 8%. The methane may then be fed into the natural gas grid. The third method uses the output gas of a wood gas generator or a biogas plant, after the biogas upgrader is mixed with the hydrogen from the electrolyzer, to upgrade the quality of the biogas.

Hydrogen: The element hydrogen can be a form of stored energy. Hydrogen can produce electricity via a hydrogen fuel cell [A fuel cell is an electrochemical cell that converts the chemical energy of a fuel (often hydrogen) and an oxidizing agent (often oxygen) into electricity through a pair of redox reactions]. Underground hydrogen storage is the practice of hydrogen storage in caverns, salt domes and depleted oil and gas fields. Large quantities of gaseous hydrogen have been stored in caverns by Imperial Chemical Industries for many years without any difficulties.

Methane: Methane is the simplest hydrocarbon with the molecular formula CH4. Methane is more easily stored and transported than hydrogen. Storage and combustion infrastructure (pipelines, gasometers, power plants) are mature. Synthetic natural gas (syngas or SNG) can be created in a multi-step process, starting with hydrogen and oxygen. Hydrogen is then reacted with carbon dioxide in a Sabatier process, producing methane and water. Methane can be stored and later used to produce electricity. The resulting water is recycled, reducing the need for water. In the electrolysis stage, oxygen is stored for methane combustion in a pure oxygen environment at an adjacent power plant, eliminating nitrogen oxides. Methane combustion produces carbon dioxide (CO2) and water. The carbon dioxide can be recycled to boost the Sabatier process and water can be recycled for further electrolysis. Methane production, storage and combustion recycles the reaction products. The CO2 has economic value as a component of an energy storage vector, not a cost as in carbon capture and storage.

Power to liquid: Power to liquid is similar to power to gas except that the hydrogen is converted into liquids such as methanol or ammonia. These are easier to handle than gases, and requires fewer safety precautions than hydrogen. They can be used for transportation, including aircraft, but also for industrial purposes or in the power sector.

3.2.1 Electrochemical batteries

Batteries chemically store energy and release it as electric energy on demand. Batteries are a stable form of storage and can provide high energy, such as those needed for transportation. The lead-sulfuric acid battery has long been considered to be advantageous and has been widely applied. Recently. fuel cells have demonstrated the ability to act as large-scale chemical storages like batteries.

3.2.2 Organic molecular storage

The intermittent availability of solar radiation, its seasonal and geographical variations, and its relatively- low intensity. will limit the exploitation of that resource until it can be converted to forms of energy that can be efficiently stored and transported. However, most technologies that are presently available for the utilization of solar energy depend on the direct conversion of solar radiation to low-grade heat or electricity, both of which are difficult to store.

3.3 BIOLOGICAL STORAGE

Biological storage is the storage of energy in chemical form by means of biological processes and is considered an important method of storage for long periods of time.

3.4 MAGNETIC STORAGE

Energy can be stored in a magnetic field (e.g., in a large electromagnet). An advanced scheme that employs superconducting materials is under development. At temperatures near absolute zero. certain metals have almost no electrical resistance and thus large currents can circulate in them with almost no losses. Because this scheme stores DC electricity. some losses are incurred in converting standard AC power to and from DC, and some energy is used to drive the refrigerationdevice to maintain the requisite low temperatures. overall storage efficiencies of 80-90% are anticipated for these superconducting magnetic ES systems.

Magnetic storage is considered for two main purposes. First, large superconducting magnets capable of storing 1000-10,000 MWh of electricity could be attractive as load-leveling devices for central power stations, and may be cost-effective at such capacities. Second, smaller magnets withstorage capacities in the 10-kWh range may be cost-effective in smoothing out transmission line loads, to better match short-term customer demands and generating equipment characteristics. A small superconducting magnet that can help in meeting customer peak needs at the far end of a transmission line could increase the effective load that the line can serve by as much as 25%. producing cost savings that could offset in whole or part the additional costs of expanding the transmission line capability.

3.5 THERMAL ENERGY STORAGE (TES)WHY THERMAL STORAGE

- Primary energy source -Hydro, Gas, Coal and Nuclear fuels transformed directly intoelectricity as a power source for industrial and household appliances.
- In principle, electricity generation has to be balanced with the exact time of theconsumption to satisfy the fluctuating demand at the lowest possible cost.
- Fluctuating seasonal and specific time demands outside their control .
- Utility companies generate electricity using different types of primary energy sources tooffset peak.
- Almost every modern society has a mid-day or late evening peak electricity demand
- This essential demand force utility companies to build new additional peak demand powerstations -> considerable investment that operate only during peak demand periods and shutdown the rest of the time.
- They use expensive primary energy stores and are subject to the standard cost of maintenance, consequently production cost per kWh is 3-4 times higher than the standard base load electricity Production cost.

DEFINITION OF THERMAL STORAGE

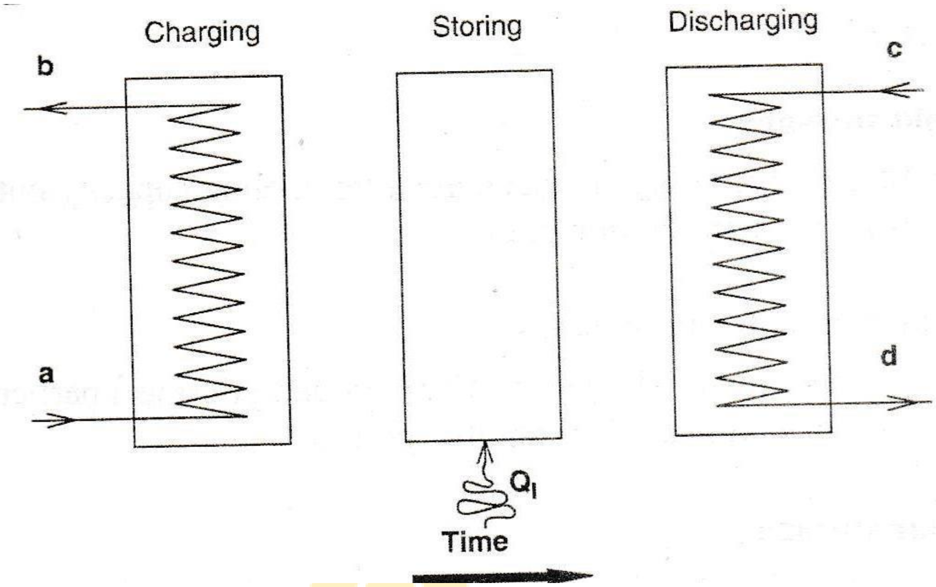


Fig: The Three processes in a general TES system

- Charging (left), storing (middle), and discharging (right). Here the heat Q_1 is infiltrating and ispositive in value for a cold thermal storage. If it is released, it will be toward the surroundings and Q_1 will be negative. The heat flow is illustrated for the storing process, but can occur in all three processes.
- Thermal storage for HVAC applications Storage at various temperatures associated with heating or cooling.
- The collection of heat from solar energy for later use ,hours, days or many months later . at individual building, multiuser building.
- Ex: energy demand can be balanced between day time and night time; summer heat from solar collectors can be stored inter seasonally for use in winter. And cold obtained from winter air can be provided for summer air conditioning.

TYPES OF THERMAL STORAGE SYSTEMS

1. Cold storage
2. Fabric and slab energy storage
3. Solar storage
4. Packed Rock Beds
5. Low temperature CO_2 Storage System
6. Thermo chemical Energy Storage
7. Sensible heat
8. Latent heat

1. **Cold storage:** Storage receiving and accumulating cooling capacity output from the refrigeration plant.
2. **Fabric & Slab energy storage:** Building materials absorbed heat/ cooling during a particular period and release it at anotherperiod.
3. **Solar storage:** Solar collector along with its associated pump to convert solar radiation into heat. The store which receives the heated water from the collector delivers heated water to thespace heating heat exchanger. It contributes to the building's hot water requirements of between 6% and 12%.

4. Packed Rock Beds

- A Packed rock bed utilizes the available thermal energy by means of circulating through a packed rock bed to add heat or remove heat from the system for charging and discharging respectively.
- The energy can be transferred from a fluid but the most common systems utilize air due to tire high heat transfer coefficient between air and rock.

Advantages of packed bed storage

1) Solid material like rocks and oxides can be more easily contained than water.
2) Easily used for thermal storage at temperature above 100^0C.
3) The heat transfer between air and solid is high and hence the efficiency of the unit is high.
4) The cost of storage material and unit is low
5) Conductivity of bed is low, hence heat losses are less.

5. Low Temperature CO_2 Storage System

- Carbon dioxide offers the most compact latent heat storage system due to the commerciallyobtainable triple point which allows the utilization of a single substance as static latent heatof fusion storage.
- Carbon dioxide can be stored at it's triple point of -57^0C And 518 kPa with solid fraction of 70-80% by mass and the system can provide 140 kJ/kg thermal storage capacity.

6. Thermochemical Energy Storage

- Recent research shows that various alcohols and ketones are potential thermochemical storage media but due to the relative cost and complexity, no commercially viable systemshave yet emerged.
- Typical examples are the mixture of Sulphuric Acid and water, and alliteratively Sodium Hydroxide and water.
- Systems in which the water is separated by the heat input to the mixture and as soon as the two substances are mixed the chemical reaction of the substances liberates heat.

7. Sensible heat storage:

A heat storage system that uses a heat storage medium, and where the additional or removal of heatresults in a change in temperature.

Solar pond Technology

- The vertical configuration of salt-gradient solar pond consists of following three zones: Adjacent the surface there is a homogeneous convective zone that serves as a buffer zone between environmental fluctuations at the surface and conductive heat transport from the layer below. This is the upper convective zone (UCZ).
- At the bottom of the pond there is another convective zone, the lower convective zone or LCZ. Tiris is the layer with the highest salt concentration and where the high temperature are built up.
- For given salinities and temperature in the upper and lower convective zones, there exists a stable intermediate gradient zone. This zone keeps the two convective zones apart and gives the solar pond its unique thermal performance. This intermediate zone provides excellent insulations for the storage layer. While simultaneously transmitting the solar radiation. To nraintain a solar pond in this non-equilibrium stationary state, it is necessary to replace the amount of salt that is transpofied by rnolecular diffusion from the LCZ to the UCZ. This means that salt must be added to the LCZ, and fresh waier to the UCZ whilst- brine is removed. The brine can be recycled, divided into water and salt (by solardistillation) and retumed to the pond.
- The major heat loss occurs from the surface of the small pond. This heat loss can be prevented by

spreading a plastic grid over the ponds surface to prevent disturbance by thewind. Disturbed water tends to lose heat transfer faster than when calm.

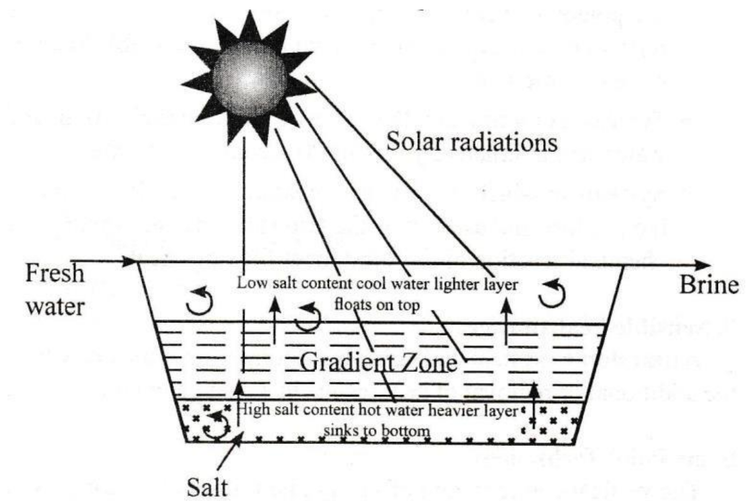


Fig: Principle of solar pond

8. Latent heat storage:

A heat storage system that uses the energy absorbed or released during a change in phase, withouta change in temperature(isothermal).

Phase Change Materials (PCMs)

When a material melts or vaporizes, it absorbs heat; when it changes to a solid (crystallizes) or to a Liquid (condenses), it releases this heat. This phase change is used for storing heat in PCMs typical PCMs are ice, salt hydrates, and certain polymers. The eutectic salt does not expandor contract when it freezes and Melts; so. there is no fatigue on the plastic container. The eutecticSalt -filled containers are placed in a tank, typically in a below-grade concrete structure.The containers occupy about two-thirds of the tank's volume. so that one-third of the tank is occupied by the water used as the heat-transfer medium. Since energy densities for latent TES exceed those for sensible TES, smaller and lighter storage devices and lower storage losses normally result.

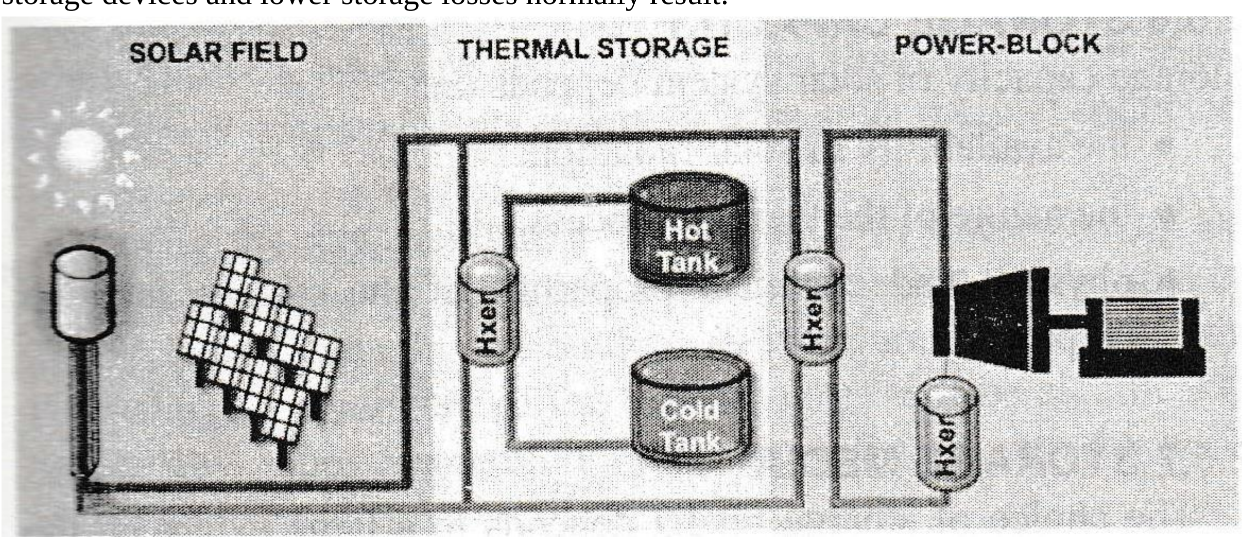


Fig: Principle of use of PCM

Other early applications of PCMs included "eutectic plates" used for cold storage in trucking andrailroad transportation applications. another important application of PCMs is association with space technology, with NASA sponsoring a project on PCM applications for thermal control of electronic packages.

Advantages of latent heat storage systems

1) More compact storage systems as compared to sensible heat storage systems.
2) Energy stored per unit volume is high.
3) Variety of materials are available to suit the applications.

SITUATIONS FAVOR THE USE OF THERMAL STORAGE SYSTEMS

The storage systems are most likely to be cost-effective in situations when :-

- A facility's maximum cooling load is much greater than the average load.
- Limited electric power is available at the site;
- Backup cooling capacity is desirable;
- Loads are of short duration, infrequently, cyclical in nature
- Loads are not well matched to the availability of the energy source

WHY STORE SOLAR ENERGY

- solar energy is a time-dependent energy resource
- load does not match available energy
- cost consideration (avoid peak use)
- short term or long-term storage

STORAGE CAPACITY

Storage capacity of solar system depends on:

- The availability of solar radiation.
- The nature of the thermal process.
- physical and chemical properties of the storage medium employed.

STORAGE MEDIA

The choice of storage media depends to a large extent on the nature of the solar thermal process.

- water storage.
- air based thermal storage (e.g., packed-bed storage).
- storage walls and floors. buried earth thermal storage.

WATER STORAGE

Water is the ideal material in which to store useable heat because it is low in cost and has a high specific heat. The use of water is particularly convenient when water is used also as the mass and heat transfer medium in the solar collector and load heat exchanger.

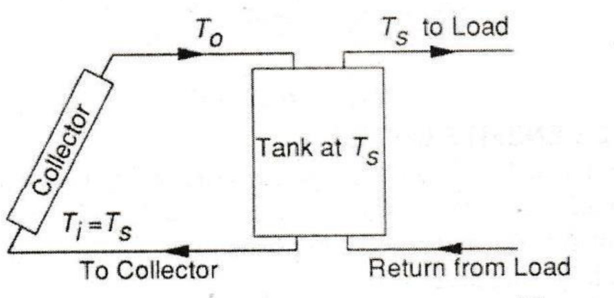


Fig : Water storage System

A typical system using water tank storage, with water circulation through collector to add energy and through the load to remove energy.

3.5.1 Benefits of Thermal Energy Storage

Although TES is used in a wide variety of applications, all are designed to operate on a cyclical basis (usually daily, occasionally, seasonally). The systems achieve benefits by fulfilling one or more of the following purposes:

Increase generation capacity. Demand for heating, cooling, or power is seldom constant over time and the excess generation available during low-demand periods can be used to charge a TES in order to increase the effective generation capacity during high-demand periods. This process allows a smaller production unit to be installed (or to add capacity without purchasing additional units), and results in a higher load factor for the units.

Enable better operation of cogeneration plants. Combined heat and power, or cogeneration, plants are generally operated to meet the demands of the connected thermal load, which often results in excess electrical generation during periods of low electricity use. By incorporating TES the plant need not be operated to follow a load. Rather it can be dispatched in more advantageous ways (within some constraints).

Shift energy purchases to low-cost periods. This measure constitutes the demand-side application of the first purpose listed, and allows energy consumers subject to time-of-day pricing to shift energy purchases from high- to low-cost periods.

Increase system reliability. Any form of energy storage. from the uninterruptable power supply of a small personal computer to a large pumped storage project, normally increases system reliability.

Integration with other functions. In applications where on-site water storage is needed for fire protection, it may be feasible to incorporate thermal storage into a common storage tank. Likewise, equipment designed to solve prover-quality problems may be adaptable to energy storage purposes.

4. ENERGY SAVINGS

Thermal energy storage (TES) is a key component of many successful thermal systems. TES should allow for the minimum reasonable thermal energy losses and the corresponding energy savings, while permitting the highest appropriate extraction efficiency of the stored thermal energy.

TES systems are an important element of many energy-saving programs in a variety of sectors, residential, commercial, industrial, and utility, as well as in the transportation sector.

TES can be employed to reduce energy consumption or to transfer an energy load from one period to another. The consumption reduction can be achieved by storing excess thermal energy that would normally be released as waste, such as heat produced by equipment and appliances, bylighting, and even by occupants. Energy-load transfer can be achieved by storing energy at a given time for later use, and can be applied to TES for either heating or cooling capacity.

4.1 STORAGE WALL

A storage wall (Storage Walls e.g. Trombe wall) is a sun-facing wall built from material that acts as a thermal mass (such as stone, concrete, adobe or water tanks) combined with an air space, insulated glazing and vents to form a large solar thermal collector.

During the day, sunlight would shine through the glazing and warm the surface of the thermal mass. At night, if the glazing insulates well enough, and outdoor temperatures are not too low the average temperature of the thermal mass will be significantly higher than room temperature, and heat will flow into the house interior.

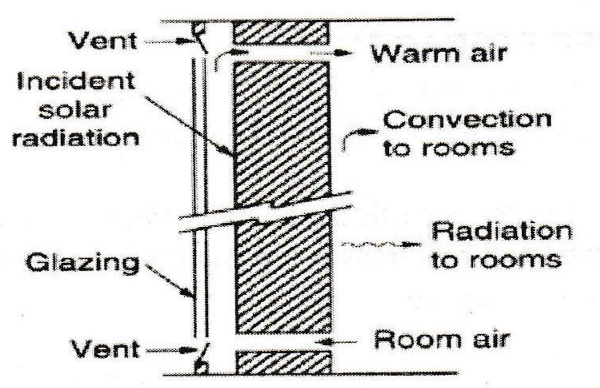


Fig: Storage Wall

- **5. Energy management**

Business, industry and government organizations have all been under tremendous economic and environmental pressures in the last few years. Being economically competitive in the global marketplace and meeting increasing environmental standards to reduce air and water pollution have been the major driving factors in most of the recent operational cost and capital cost investment decisions for all organizations.

Energy management has been an important tool to help organizations meet these critical objectives for their short-term survival and long-term success. The fundamental goal of energy management is to produce goods and provide services with the least cost and least environmental effect.

One definition of energy management is: “The strategy of adjusting and optimizing energy, using systems and procedures so as to reduce energy requirements per unit of output while holding constant or reducing total costs of producing the output from these systems”.

The objective of Energy Management is to achieve and maintain optimum energy procurement and utilization throughout the organization and a) To minimize energy costs/waste without affecting production & quality. B) To minimize environmental effects

5.1 WHAT IS ENERGY MANAGEMENT

- Utilization of minimum quantity of energy for a task at an appropriate quality neither better nor worse than needed. "Task in energy use"
- To minimize the energy cost without effecting production & quality.
- Energy forms of high-quality grade shouldn't use for low grade applications.
- The fundamental goal of energy management is to produce goods and provide services with the least

cost and least environmental effect.

5.2 PRINCIPLES OF ENERGY MANAGEMENT

- Historical Energy Use
- Energy Audits
- Housekeeping & maintenance
- Analysis of Energy use
- More efficient equipment’s
- more efficient process
- Energy containment -confine energy, reduce losses & recover heat
- Substitute materials
- Aggregation of Energy sources
- Alternative Energy Sources
- Construction of new facilities.
- Manage the energy at the highest energy efficiency.
- Reuse and recycle energy by cascading.
- Use most appropriate technology.
- Reduce the available losses.
- Economic Evaluation

5.3 Energy demand estimation

Energy Demand estimation (EDE) means managing of the demand for power by utilities distribution companies, among some or all its customers to meet current or future needs. EDE programs result in energy and / or demand reduction. For example. under this process, the demand can be shifted from peak to off peak hours thereby reducing the need for buying expensive imported power during peak hours. EDE also enables end users to better manage their load curve and thus improves the profitability" potential energy saving through EDE is treated same as new additions on the supply side in MWs. EDE can reduce the capital needs for power capacity expansion.

6 ENERGY PRICING

Understanding energy cost is vital factor for awareness creation and saving calculation. In many industries sufficient meters may not be available to measure all the energy used. In such cases, invoices for fuels and electricity will be useful. The annual company balance sheet is the other sources where fuel cost and power are given with production related information. Energy invoices can be used for the following purposes:

- They provide a record of energy purchased in a given year, which gives a base-line for futurereference
- Energy invoices may indicate the potential for savings when related to productionrequirements or to air conditioning requirements/space heating etc.
- When electricity is purchased on the basis of maximum demand tariff
- They can suggest where savings are most likely to be made.
- ln later years invoices can be used to quantify the energy and cost savings made throughenergy conservation measures.

6.1 POWER COSTS

Electricity price in India not only varies from State to State, but also city to city and consumer to consumer though it does the same work everywhere. Many factors are involved in deciding final cost of purchased electricity such as:

- Energy Charges, kWh (i.e., How much electricity is consumed?)
- TOD Charges, Peak/Non-Peak Period(i.e. When electricity is utilized?)
- Power factor Charge, P.F (i.e., Real power use versus Apparent power use factor)
- Other incentives and penalties applied from time to time
- High tension tariff and low-tension tariff rate changes
- Slab rate cost and its variation
- Type of tariff clause and rate for various categories such as commercial, residential,industrial, Government, agricultural, etc.
- Tariff rate for developed and underdeveloped area/States
- Tax holiday for new Projects

7 Energy audit

Energy Audit is defined as "the verification, monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption".

7.1 Need for energy audit

In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials. If one were to relate to the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker.

Energy Audit will help to understand more about the ways energy and fuel are used in any industry, and help in identifying the areas where waste can occur and where scope for improvement exists. The primary objective of Energy Audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. Energy Audit provides a "bench-mark"(Reference point) for managing energy in the organization and also provides the basis for planning a more effective use of energy throughout the organization.

The type of Energy Audit to be performed depends on

- Function and type of industry
- Depth to which final audit is needed, and
- Potential and magnitude of cost reduction desired.

Thus, Energy Audit can be classified into the following two types.

i) **Preliminary Audit**
ii) **Detailed Audit**

Preliminary Energy Audit Methodology

- Preliminary energy audit is a relatively quick exercise to:
- Establish energy consumption in the organization
- Estimate the scope for saving
- Identify the most likely (and the easiest areas for attention
- Identify immediate (especially no-/low-cost) improvements/ savings

- Set a 'reference point'
- Identify areas for more detailed study/measurement
- Preliminary energy audit uses existing, or easily obtained data

Detailed Energy Audit Methodology

A comprehensive audit provides a detailed energy project implementation plan for a facility, since it evaluates all major energy using systems. This type of audit offers the most accurate estimate of energy savings and cost. It considers the interactive effects of all projects, accounts for the energy use of all major equipment, and includes detailed energy cost saving calculations and project cost. In a comprehensive audit, one of the key elements is the energy balance. This is based on an inventory of energy using systems, assumptions of current operating conditions and calculations of energy use is estimated then compared to utility bill charges.

The detailed energy auditing is carried out in three phases:

- Phase I – Pre-Audit Phase
- Phase II - Audit Phase
- Phase III - Post Audit Phase

Phase I -Pre Audit Phase Activities

A structured methodology to carry out an energy audit is necessary for efficient working. An initial study of the site should always be carried out, as the planning of the procedures necessary for an audit is most important.

Initial Site Visit and Preparation Required for Detailed Auditing

An initial site visit may take one day and gives the Energy Auditor/Engineer an opportunity to meet the personnel concerned, to familiarize him with the site and to assess the procedures necessary to carry out the energy audit. During the initial site visit the Energy Auditor/Engineer should carry out the following actions: -

- Discuss with the site's senior management the aims of the energy audit.
- Discuss economic guidelines associated with the recommendations of the audit.
- Analyze the major energy consumption data with the relevant personnel.
- Obtain site drawings where available - building layout, steam distribution, compressed air distribution, electricity distribution etc.
- Tour the site accompanied by engineering/production

The main aims of this visit are: -

- To finalize Energy Audit team
- To identify the main energy consuming areas/plant items to be surveyed during the audit.
- To identify any existing instrumentation/ additional metering required.
    - To decide whether any meters will have to be installed prior to the audit eg. kWh, steam, oil or gas meters.
- To identify the instrumentation required for carrying out the audit.
- To plan with time frame
- To collect macro data on plant energy resources, major energy consuming centers

- To create awareness through meetings/programme

Phase II- Detailed Energy Audit Activities

- Depending on the nature and complexity of the site, a comprehensive audit can take from several weeks to several months to complete. Detailed studies to establish, and investigate, energy and material balances for specific plant departments or items of process equipmentare carried out.
- Whenever possible, checks of plant operations are carried out over extended periods of time, at nights and at weekends as well as during normal daytime working hours, to ensure that nothing is overlooked.
- The audit report will include a description of energy inputs and product outputs by major department or by major processing function, and will evaluate the efficiency of each step of the manufacturing process.
- Means of improving these efficiencies will be listed, and at least a preliminary assessmentof the cost of the improvements will be made to indicate the expected payback on any capital investment needed.
- The audit report should conclude with specific recommendations for detailed engineeringstudies and feasibility analyses, which must then be performed to justify the implementation of those conservation measures that require investments.

Phase –III- Post Audit Phase

On completion of energy audit, energy action plan should be prepared. The energy action plan list the ENCONs which should be implemented first, and suggest an overall implementation schedule. Energy audit is incomplete without monitoring and its associated feedback. Monitoring consists of collecting and interpreting data. The data to be collected depends upon goals chosen in the energy action plan. Electrical power consumption and fuel consumption must be evaluated and monitored.

The monitoring data should provide direct feedback to those most able to implement the changes. often additional instruments should be installed in various department in addition to main metering.

7.2 Energy Audit Reporting Format

After successfully carried out energy audit energy manager/energy auditor should report to the top management for effective communication and implementation in a typical energy audit report format. This format may vary with the type of the company also format can be suitably modified for specific requirement applicable for a particular type of industry.

7.3 Organizing Energy management in Industries

Following are the guidelines for carrying out energy management in industries

- Developing ideas and plans for enlisting employee support and participation
- Planning and participation in energy audits
- Surveying and literature on the ways to conserve energy and communicating these ideas and suggestions.
- Establishing realistic and achievable energy conservation goals.
- Developing uniform record keeping, reporting and energy auditing.
- Planning and conducting continuing program of activities to stimulate interest in energy conservation efforts.

7.4 Duties and responsibilities of energy manager

- Creation of a data base related to inputs and outputs of the manufacturing process. For this purpose, extensive metering instrumentation at various points of energy and material flows through the plant might be required.
- To carry out energy audits from the data base on a regular basis and to reconcile energy audits with financial audits.
- To analyze energy consumption centers such as boilers, furnaces, electric motor driven instruments like compressors, pumps etc and to identify the energy conservation opportunities.
- To report plant's energy conservation progress to the top management.
- To advise the top-level management as the ways of long-term energy conservation opportunities.
- To coordinate energy consumption between energy consuming centers.
- To build thorough inventory of all machines, equipment and facilities which consume energy – their capacity, time worked since installation, parts and components repaired or replaced and other working specifications.
- To survey and review the literature on energy development and to properly disseminate this information.
- To develop and communicate energy saving technique and ideas to divisional heads.

Step No	**PLAN OF ACTION**	**PURPOSE/RESULTS**
Step 1	<u>Phase I- Pre Audit Phase</u> Plan and organize Walk through Audit Informal Interview with Energy Manager,Production/Plant Manager	• Resource planning, Establish/organize a Energy audit team • Organize Instruments& time frame. • Macro Data collection (suitable to type of industry.) • Familiarization of process/plantactivities. • First hand observation &Assessment of current level operation and practices.

Step 2	Conduct of brief meeting/awareness programme with all divisional heads and persons concerned (2-3 Hrs.)	Building up cooperation Issue questionnaire for each department Orientation, awareness creation.
Step 3	**<u>Phase II- Audit Phase</u>** Primary data gathering, Process Flow Diagram, & Energy Utility Diagram	Historic data analysis, baseline data collection Prepare process flow chart All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air & steam distribution. Design, operating data and schedule of operation Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview).
Step 4	Conduct survey and monitoring	Measurements: Motor survey, Insulation, and Lighting survey with portable instruments for collection of more and accurate data. Confirm and compare operating data with design data.
Step 5	Conduct of detailed trials/ experiments forselected energy guzzlers	Trials/ Experiments: 24 hours power monitoring (MD,PF, kWh etc.) Load variations trends in pumps,fan compressors etc. Boiler/Efficiency trails for (4-8hours) Furnace efficiency trials. Equipment/performance experiments etc.
Step 6	Analysis of energy use	Energy and material balance &energy loss/waste analysis

Step 7	Identification and development of energy conservation (ENCON) opportunities	Identification & consolidation ENCON measures Conceive, develop and refine ideas Review the previous ideas suggested by energy audit if any Use brainstorming and value analysis techniques Conduct vendors for new/efficient technology
Step 8	Cost benefit analysis	Assess technical feasibility, economic viability andprioritization of ENCON options for implementation Select the most promising projects Prioritise by low, medium, long term measures
Step 9	Reporting and presentation to the top management	Documentation, Report presentation to the top management.
Step10	**<u>Phase III- Post Audit Phase</u>** Implementation and follow up	Assist and Implement ENCON recommendation measures and Monitor the performance Action plan, Schedule for implementation Follow-up and periodic review

8. Economic Analysis

Among the most important indicators of the success of an engineering enterprise are the profit achieved and the return on investment. Therefore, economic considerations play a very important role in the decision-making processes that govern the design of a system. It is generally not enoughto make a system technically feasible and to obtain the desired quality of the product. The costs incurred must be taken into account to make the effort economically viable. It is necessary to finda balance between the product quality and the cost.

Because of the crucial importance of economic considerations in most engineering decisions, it is necessary to understand the basic principles of economics and to apply these to the evaluation of investments, in terms of costs, returns, and profits.

- **Simple interest**

If the interest is calculated only on the principal over a given duration, without considering the change in investment due to accumulation of interest with time and without including the interest with the principal for subsequent calculations, the resulting interest is known as *simple interest*. Then, the simple interest on the principal sum P invested over n years is simply Pni, and the final amount F consisting of the principal and interest after n years is given by $F = P(1 + ni)$.

- **Compound interest**

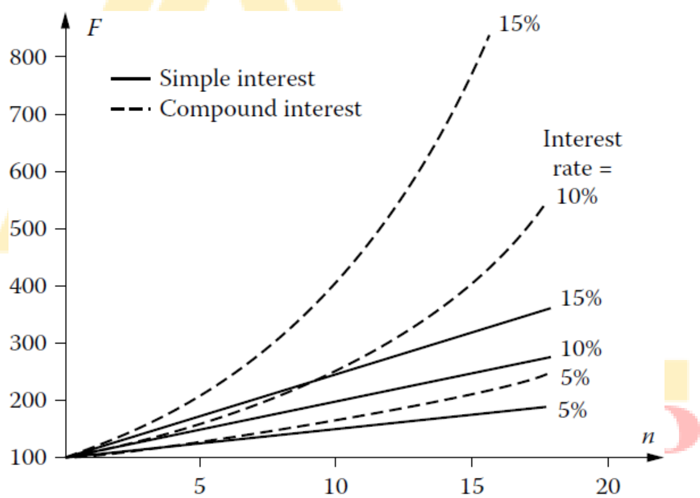
The interest may be calculated several times a year and then added to the amount on which interest is computed in order to determine the interest over the next time period. This procedure is known as compounding and interest is called as compound interest.

If the interest is compounded m times a year, the interest on a unit amount in the time between two compounding is i/m. Then the final sum F, which includes the principal and interest, is obtained after n years as

$$F = P\left(\frac{1}{m} + i\right)^{mn}$$

For monthly compounding m =12, daily compounding m =365 etc.

Variation of sum F consisting of the principal, and accumulated interest as a function of number of years for simple and compounding at different rates of interests are shown in the graph.



Two approaches that are commonly used for bringing all financial transactions to a common time frame are the present and future worth of an investment, expenditure, or payment.

- **Present worth**

Present worth (PW) of a lumped amount given at a particular time in the future is its value today. Thus, it is the amount that, if invested at the prevailing interest rate, would yield the given sum at the future date. If we consider the resulting sum F after n years at a nominal interest rate i, Then P is the present worth of sum F for the given duration and interest rate. Therefore, the present worth of a given sum F may be written, for yearly compounding,

$$\mathbf{PW = P = F(1+i)^{-n} = (F)\ (P/F,\ i,\ n)}$$

Where P/F is known as present worth factor and is given by

$$\boldsymbol{P/F = (1 + i)^{-n}}$$

The **future worth** of a lumped amount *P*, given at the present time, may similarly be determined after a specified period of time. Therefore, the future worth (FW) of *P* after *n* years with an interest rate of *i*, compounded yearly or *m* times yearly, are given, respectively, by the following equations:

$$\mathbf{FW= F= P(1+i)^{n} = (P)\ (F/P,\ I,\ n)}$$

$$\mathbf{FW= F= P\left(1+\frac{i}{m}\right)^{mn} = (P)\ \left(F/P, \frac{i}{m}, mn\right)}$$

Where *F/P* is known as the *future factor worth* or *compound amount factor*

- **SERIES OF PAYMENTS**

A common circumstance encountered in engineering enterprises is that of a series of payments. Frequently, a loan is taken out to acquire a given facility and then this loan is paid off in fixed payments over the duration of the loan. Recurring expenses for maintenance and labor may be treated similarly as a series of payments over the life of the project. Both fixed and varying amountsof payments are important, the latter frequently being the result of inflation, which gives rise to increasing costs. The series of payments is also brought to a given point in time for consideration with other financial aspects. As before, the time chosen may be the present or a time in the future.

- **FUTURE WORTH OF UNIFORM SERIES OF AMOUNTS**

Let us consider a series of payments, each of amount *S*, paid at the end of each year starting with the end of the first year. The future worth of this series at the end of *n* years is to be determined. This can be done easily by summing up the future worths of all these individual payments. The first payment accumulates interest for *n* – 1 years, the second for *n* – 2 years, and so on, with the second-to-last payment accumulating interest for 1 year and the last payment accumulating no interest. Therefore, if *i* is the nominal interest rate and yearly compounding is used, the future worth *F* of the series of payments is given by the expression

$$F = S\left(\frac{(1+i)^{n-1}}{(1+i)-1}\right) = S\left(\frac{(1+i)^{n-1}}{i}\right) = S\left(\frac{F}{S}, i, n\right)$$

Where F/S is often known as the series future worth factor or the series compound amount factor. It yields the future worth of a series of payments of equal amount *S* when *S* is multiplied by this factor. The amount *S* of a series of payments to pay off an amount *F*.

- **Taxes**

Government depends heavily on taxes to finance its operations and to provide services. It is necessary to include taxes in the evaluation of the overall return on the investment in anengineering enterprise and also for comparing different financial alternatives for a venture. Thereare two main forms of taxation that are of concern to an engineering company: income tax and realestate, or property, tax.

The overall profit made by a given company is the income that is taxed by the federal, state, and local governments. Though the federal taxation rate remains unchanged with location, the state and local taxes are strongly dependent on the location, varying from close to zero to as high as 20% across the country. However, the federal tax may vary with the size of the company and the nature of the industry. Since the amount paid in taxes is lost by the company, diligent efforts are made to reduce this payment by employing different legal means. Certainly, locating and registering the company at aplace where the local taxes are low is a common approach. Similarly, providing bonuses and additional benefits to the employees, expanding and upgrading facilities, and acquisition of new facilities or enterprises increase the expenses incurred and reduce the taxes owed by the company.

- **Real estate and local taxes**

Taxes are also levied on the property owned by the company. These may simply be real estate taxes on the value of the buildings and land occupied by the company or may include charges by the local authorities to provide services, such as access roads, security, and solid waste removal. All these are generally included as expenses in the operation of the company. Different alternativesinvolve different types of expenses and, therefore, the design of the system may be affected by these taxes. For instance, a system that involves a smaller floor area and, therefore, a smaller building and lower real estate taxes is more desirable than one that requires a large floor area. Similarly, the raw materials needed and the resulting waste are important in determining expenses for transportation and disposal, possibly making one system more cost effective than another.

- **Depreciation**

The decrease in the value of the power plant equipment and building due to constant use is known as depreciation. An important concept with respect to the calculation of taxes is that of depreciation. Since a given facility has a finite useful life, after which it must be replaced, it is assumed to depreciate in value as time elapses until it is sold or discarded at its salvage value. In essence, an amount is allowed to be put aside each year for its replacement at the end of its useful life. This amount is the depreciation and is taken as an expense each year, thus reducing the taxes to be paid by the company. There are several approaches to calculating depreciation, as allowed by the federal government

The book value of the item is the initial cost minus the total depreciation charged up to a given point in time. Therefore, the book value *B* at the end of the *j* th year is given by

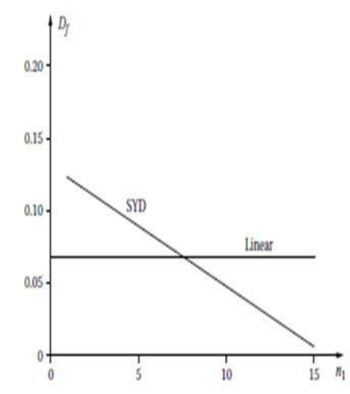
$$B = P - \frac{J}{n}(P - Q)$$

In actual practice, most facilities depreciate faster in the initial years than in later years, as anyone who has ever bought a new car knows very well. This is largely because of the lower desirability and unknown maintenance of the used item. As time elapses and the wear and tear are well established, the depreciation usually becomes quite small. Different distributions are used to represent this trend of greater depreciation rate in the early years. These include sum of-years digits (SYD), the declining balance, Modified accelerated cost recovery methods.

- **SYD method (Sum of the Years digits)**

$$\mathbf{D = \left[\frac{n - n1 + 1}{n(n+1)/2}\right](P\text{-}Q)}$$

Where the denominator is the sum n(n+1)/2 of the digits representing the years, 1,2,3….n. the numerator is the digit corresponding to the given year when the digits are arranged in reverse order, as n,n-1,n-2. And so on. By using this calculation procedure, the depreciation is larger than that obtained by the linear method in the early years and smaller in the later years.



Variation of the fractional depreciation D_j with the number of years under consideration n_1 for the linear and SYD depreciation calculation methods.

- **GENERAL CHARACTERISTICS OF CAPITAL INVESTMENTS**

When companies spend money, the outlay of cash can be broadly categorized into one of two classifications; expenses or capital investments. Expenses are generally those cash expenditures those are routine, on-going, and necessary for the ordinary operation of the business.

Capital investments, on the other hand, are generally more strategic and have long term effects. Decisions made regarding capital investments are usually made at higher levels within the organizational hierarchy and carry with them additional tax consequences as compared to expenses. Three characteristics of capital investments are of concern when performing life cycle cost analysis. First, capital investments usually require a relatively large initial cost. "Relatively large" may mean several hundred dollars to a small company or many millions of dollars to a large company. The initial cost may occur as a single expenditure such as purchasing a new heating system or occur over a period of several years such as designing and constructing a new building. It is not uncommon that the funds available for capital investments projects are limited. In other words, the sum of the initial costs of all the viable and attractive projects exceeds the total available funds. This creates a situation known as capital rationing which imposes special requirements on the investment analysis.

The second important characteristic of a capital investment is that the benefits (revenues or savings) resulting from the initial cost occur in the future, normally over a period of years. The period between the initial cost and the last future cash flow is the life cycle or life of the investment. It is the facts that cash flows occur over the investment's life that requires the introduction of time value of money concepts to properly evaluate investments. If multiple investments are being evaluated and if the lives of the investments are not equal, special consideration must be given tothe issue of selecting an appropriate planning horizon for the analysis.

The last important characteristic of capital investments is that they are relatively irreversible. Frequently, after the initial investment has been made, terminating or significantly altering the nature of a capital investment has substantial (usually negative) cost consequences.
This is one of the reasons that capital investment decisions are usually evaluated at higher levels of the organizational hierarchy than operating expense decisions.

Capital Investment Cost Categories

In almost every case, the costs which occur over the life of a capital investment can be classified into one of the following categories:

- Initial Cost,
- Annual Expenses and Revenues,
- Periodic Replacement and Maintenance, or
- Salvage Value.

As a simplifying assumption, the cash flows which occur during a year are generally summed and regarded as a single end-of-year cash flow. While this approach does introduce some inaccuracy in the evaluation, it is generally not regarded as significant relative to the level of estimation associated with projecting future cash flows. Initial costs include all costs associated with preparing the investment for service. This includes purchase cost as well as installation and preparation costs. Initial costs are usually nonrecurring during the life of an investment. Annual expenses and revenues are the recurring costs and benefits generated throughout the life of the investment. Periodic replacement and maintenance costs are similar to annual expenses and revenues except that they do not (or are not expected to) occur annually. The salvage (or residual) value of an investment is the revenue (or expense) attributed to disposing of the investment at the end of its useful life.

Cash Flow Diagrams

A convenient way to display the revenues (savings) and costs associated with an investment is a cashflow diagram. By using a cash flow diagram, the timing of the cash flows are more apparent and the chances of properly applying time value of money concepts are increased. With practice, different cash flow patterns can be recognized and they, in turn, may suggest the most direct approach for analysis.

It is usually advantageous to determine the time frame over which the cash flows occur first. This establishes the horizontal scale of the cash flow diagram. This scale is divided into time periods which are frequently, but not always, years. Receipts and disbursements are then located on the time scale in accordance with the problem specifications. Individual outlays or receipts are indicated by drawing vertical lines appropriately placed along the time scale. The relativemagnitudes can be suggested by the heights, but exact scaling generally does not enhance the meaningfulness of the diagram. Upward directed lines indicate cash inflow (revenues or savings) while downward directed lines indicate cash outflow (costs).

Theory questions:

1. List the difference types of thermal energy storage systems. Explain any two of them.

2. Elaborate the different phases involved in detailed energy audit methodology

3. What are the general characteristics of capital investment?

4. Explain in detail various phases of energy audit methodology

5. List the various thermal energy storage methods. Explain sensible heat and latentheat storage methods.

6. Define energy audit. Explain the need for energy audit.

7. Write a short note on energy demand estimation

8. Elaborate the benefits of thermal energy storage.