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NEW ENERGY RESOURCES

DRE 105

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DRE 105 NEW ENERGY RESOURCES 3

UNIT-1: BACKGROUND

UNIT STRUCYTURE

OBJECTIVE

This unit presents a brief overview of the needs for energy systems supplementing energy conservation efforts, addressing environmental concerns and suitability of Clean Development Mechanism (CDM).

INTRODUCTION

Energy is an indispensable component for the development of human society. History explains the trends of exploring various forms energy since the primitive age to the modern society. However, the continuous exploitation of certain energy sources has raised some alarming issues, namely fossil fuel depletion and environmental degradation. These issues are threatening the survival of man and animal as well as various other species on the earth. The exploration and exploitation of new energy resources can play a major role in alleviating the risk of such adverse effects.

1.1 NEED FOR ENERGY SYSTEMS AND MATERIALS

Energy is an essential requirement for survival of the human being. It is also one of the key factors which govern the economic development of a nation. These facts basically drive the human folk for consuming more and more energy as well as producing the same for fulfilling the requirement. The demand for energy has been continuously increasing day by day creating a gap between demands and supply.

The development of the modern society is primarily based on energy. In fact, there is a link between human civilization and energy consumption throughout the evolution of human societies. The progressive development of human civilization becomes possible due to continuous efforts to harness and consume more and more energy resources.

Over thousands of years people were primarily using their own physical energy (muscle power) for various activities. This physical energy is limited in nature, which depends on the body as well as the food. This in turn restricts the human being from performing certain activities. When people acquire the art of creating tools, they became gradually capable of harnessing other sources of energy and became capable of doing more works which were earlier not possible by their physical strength.

The primitive tools used for hunting animals, catching fishes etc can be referred to as a kind of energy tools. The skill of lighting a fire and the advent of wheel had changed the human civilization drastically. With the aid of various kinds of tools, gradually developed through time and experience, people were capable of doing more works with less effort as well as became able to perform tasks which seemed to be impossible earlier.

1.1.1 FORMS OF ENERGY

Energy is defined as the capacity or ability to do work. Also, energy can neither be created or nor can be destroyed. However, it is possible to transform energy from one form to another one.

The various forms of energy can be categorized as thermal energy, chemical energy, electrical energy, radiant energy, mechanical energy, nuclear energy or thermal energy. All these forms can be converted from one form to another. The process of conversion of energy from one form to another may not be simple in all cases. For example, one of the simple energy conversion processes is associated with the combustion of wood. The burning of wood converts its stored chemical energy into heat or thermal energy as well as light or radiant energy. On the other hand, a locomotive engine involves a somewhat complex conversion processes where the chemical energy of the fuel is first converted into thermal energy and finally into mechanical energy.

The various forms of energy can be classified into two basic types - potential energy or kinetic energy. The potential energy refers to the stored energy or energy at rest, whereas, the kinetic energy refers to the energy of motion. Energy possessed by a body by virtue of its position (for example stored water in a dam) or stored chemical energy within fuel is called potential energy. The moving objects, electricity, sound, radiation etc are forms of kinetic energy. It is possible to transform energy from potential to kinetic energy.

Energy is measured by several units. Calorie, kWh, Joule are commonly used units of energy. The SI unit of energy is Joule**.**

1.1.2 SOURCES OF ENERGY

In the context of energy studies, the term energy often refers to the energy sources. For example, solar energy refers to the energy coming from the Sun, wind energy refers to the energy exploited from the wind, geothermal energy refers to the thermal energy inside earth and so on. The most common sources of energy are the fossil fuels, namely, coal, oil and natural gas. All such energy sources are classified into different types based on several criteria. These classifications are discussed in brief as below.

1.1.2.1 PRIMARY AND SECONDARY ENERGY SOURCES

One type of classification is primary and secondary energy. The sources of energy which exist in nature or found in nature - are termed as primary energy sources. The secondary energy is the energy derived from the primary energy sources through some processes or transformations for the purpose of using it in a more flexible or convenient way. Coal, oil, natural, gas or biomass such as wood, etc are primary energy. Such type of energy sources can also be used directly for applications like heating. On the other hand steam, electricity etc can be termed as secondary energy sources as these sources are basically derived from primary energy sources like coal, oil or natural gas with the help of certain processes or technology.

1.1.2.2 COMMERCIAL AND NON COMMERCIAL ENERGY SOURCES

Another type of classification is the commercial and non-commercial energy. As the term implies, commercial energy sources, namely, coal, natural gas, petroleum products etc, are available in the market for a price. The energy sources which are not available on a commercial basis are termed as non-commercial energy sources. Typical examples of non-commercial energy are solar energy, wind energy etc. These sources are the gift of nature and they are freely available.

1.1.2.3 CONVENTIONAL AND NON-CONVENTIONAL ENERGY SOURCES

The conventional sources of energy refer to those sources which are being continuously exploited (traditionally used) for fulfilling the energy needs of human since their discovery. Coal, oil, gas, uranium and hydro can be grouped under this category. The non-conventional energy sources include solar energy, wind energy and other renewable energy which are not in use in traditional practices.

1.1.2.4 RENEWABLE AND NON-RENEWABLE ENERGY SOURCES

The most important classification in the context of energy studies is the renewable and non-renewable energy sources. Renewable energy sources are those energy sources which are available in nature and are continuously renewed or replenished through natural processes. These sources are apparently inexhaustible and have attracted major focus in the globe for energy exploitation. Solar energy, wind energy, energy form biomass, ocean energy etc are the examples of renewable energy sources. These are also often referred to as non-conventional energy sources. On the other hand, the non-renewable energy sources, namely fossil fuels, are not renewed or replenished by nature in short time span. They accumulate over millions of years and undergo several transformation stages before reaching the final usable forms. Once exhausted, they cannot be quickly regenerated again.

1.1.3 PRESENT ENERGY SCENARIO

Energy is needed almost in every activity in our day-today life. In ancient times, people used to do their works mostly with the power of their own muscles. Animals were used to carry goods as well as a mode of transport. After the discovery of fossil fuels and related technology for harnessing them, people gradually became dependent on these energy sources. This dependence led to the exploitation of these sources in an increasing rate. As a result, the modern society is facing the challenge of depleting the fossil fuel reserves.

1.1.3.1 GLOBAL ENERGY RESERVE

Although a number of energy sources have been explored, developed or discovered, yet most of our energy needs are being fulfilled from the fossil fuels till date. Coal, oil and natural gas are still the dominating sources of energy.

According to the reported study (BP Statistical Review of World Energy, June 2010), the proven reserves of oil, gas and coal across the globe at the end of 2009 are estimated as 1,331.1 thousand million barrels, 187.49 trillion cubic metres and 8,26,001 million tones, respectively. These estimates are based on the geological and engineering information with reasonable certainty. The proven reserves refer to the recoverable quantities from the known reservoirs under existing economic and operating conditions.

The United states have the highest share of coal reserves as 28.9%. Next to the United States is the Russian Federation sharing 19% of total reserves. China and Australia share the global reserves with as 13.9% and 9.2%, respectively. India's share is 7.1% of the global coal reserves and ranks 5th in the global proven coal reserves.

In case of natural gas reserves, the Russian federation has the largest reserves with 23.7% of the total whereas India's share is 0.6% of the total. Saudi Arabia has the largest oil reserves with 264.6 thousand million barrels and shares 19.8% of the total global reserves. India contributes with 0.4% sharing having 5.8 thousand million barrels of proven oil reserves.

1.1.3.2 GLOBAL PRIMARY ENERGY CONSUMPTION

It is also reported that at the end of 2009, the total primary energy consumption around the world is 11164.3 Million tones oil equivalent (Mtoe) (Please refer to the box for unit conversion). India consumes about 468.9 Million tones oil equivalent and shares 4.2% of the global primary energy consumption. The United States tops the list with 19.5% (2182 Million tones oil equivalent) share. China is also almost in the same level with the consumption of 2177 Million tones oil equivalent. Here the primary energy refers to the commercial fuels and excludes other fuels like wood, peat, animal waste, wind, geothermal and solar power generation. The region wise consumption pattern is represented in the Fig 1.

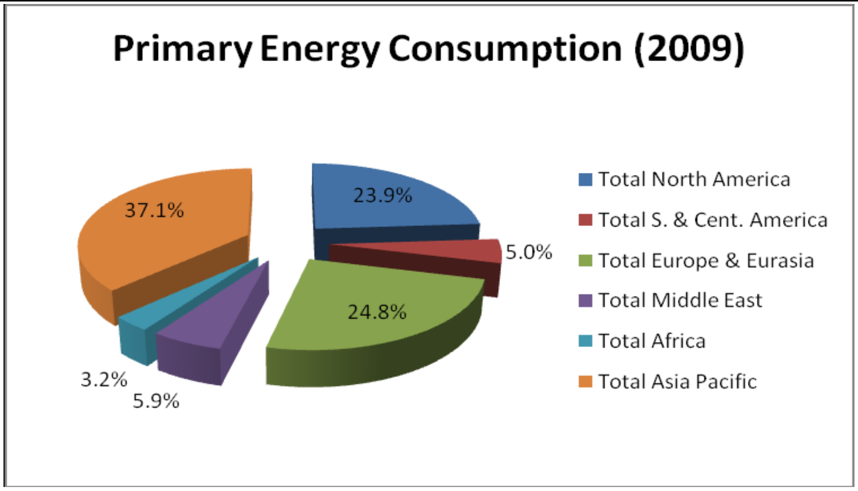


Fig. 1- Region wise percentage sharing of Global Primary energy consumption (11164.3 Mtoe) at the end of 2009.

Approximate conversion factors

Crude oil*

From	To: tonnes (metric)	kilolitres	barrels	US gallons	tonnes per year
	Multiply by				
Tonnes (metric)	1	1.165	7.33	307.86	–
Kilolitres	0.8581	1	6.2898	264.17	–
Barrels	0.1364	0.159	1	42	–
US gallons	0.00325	0.0038	0.0238	1	–
Barrels per day	–	–	–	–	49.8

*Based on worldwide average gravity.

Products

	To convert: barrels to tonnes	tonnes to barrels	kilolitres to tonnes	tonnes to kilolitres
	Multiply by			
Liquefied petroleum gas (LPG)	0.086	11.6	0.542	1.844
Gasoline	0.118	8.5	0.740	1.351
Kerosene	0.128	7.8	0.806	1.240
Gas oil/diesel	0.133	7.5	0.839	1.192
Fuel oil	0.149	6.7	0.939	1.065

Natural gas (NG) and liquefied natural gas (LNG)

From	To: billion cubic metres NG	billion cubic feet NG	million tonnes oil equivalent	million tonnes LNG	trillion British thermal units	million barrels oil equivalent
	Multiply by					
1 billion cubic metres NG	1	35.3	0.90	0.74	35.7	6.60
1 billion cubic feet NG	0.028	1	0.025	0.021	1.01	0.19
1 million tonnes oil equivalent	1.11	39.2	1	0.82	39.7	7.33
1 million tonnes LNG	1.36	48.0	1.22	1	48.6	8.97
1 trillion British thermal units	0.028	0.99	0.025	0.021	1	0.18
1 million barrels oil equivalent	0.15	5.35	0.14	0.11	5.41	1

Units

1 metric tonne = 2204.62lb
= 1.1023 short tons
1 kilolitre = 6.2898 barrels = 1 cubic metre
1 kilocalorie (kcal) = 4.187kJ = 3.968Btu
1 kilojoule (kJ) = 0.239kcal = 0.948Btu
1 British thermal unit (Btu) = 0.252kcal
= 1.055kJ
1 kilowatt-hour (kWh) = 860kcal
= 3600kJ = 3412Btu

Calorific equivalents

One tonne of oil equivalent equals approximately:

Heat units	10 million kilocalories 42 gigajoules 40 million British thermal units
Solid fuels	1.5 tonnes of hard coal 3 tonnes of lignite
Gaseous fuels	See Natural gas and liquefied natural gas table
Electricity	12 megawatt-hours

One million tonnes of oil or oil equivalent produces about 4400 gigawatt-hours (= 4.4 terawatt-hours) of electricity in a modern power station.

Source: BP Statistical Review of World Energy June 2010

The increasing demand for energy is creating a great concern worldwide due to the depletion of fossil fuel reserves. It is to be noted that only a part of the world known fossil fuel reserves, in particular the petroleum reserves, can be technically and economically explored. The current and the expected rate of energy consumption indicates that world oil reserves may last for about 45 years, gas reserves for 65 years, and the coal reserves may last for around 200 years. Therefore, it becomes urgent need for exploring the other sources of energy in order to meet our energy requirement. The situation also demands for employing effective practices in the energy consumption pattern which can save a lot of energy while without compromising the product output as well as without restricting our essential activities.

1.2 APPLICATION TO SUPPLEMENT AND EXPEDITE ENERGY CONSERVATION EFFORTS

The demand for more and more energy is continuously increasing mainly due to industrialization and urbanization. Two major factors fueling the increasing energy need are the population growth and improved lifestyle. Energy requirement changes with the advancement of human civilization. However, the conventional resources are apparently limited or exhaustible and the energy available or supplied is not able to match the current energy requirement in most of the cases. The crisis demands to harness more and more energy sources, preferably renewable sources wherever feasible, for the obvious reason. One more approach to tackle energy crisis is to adopt energy conservation practices.

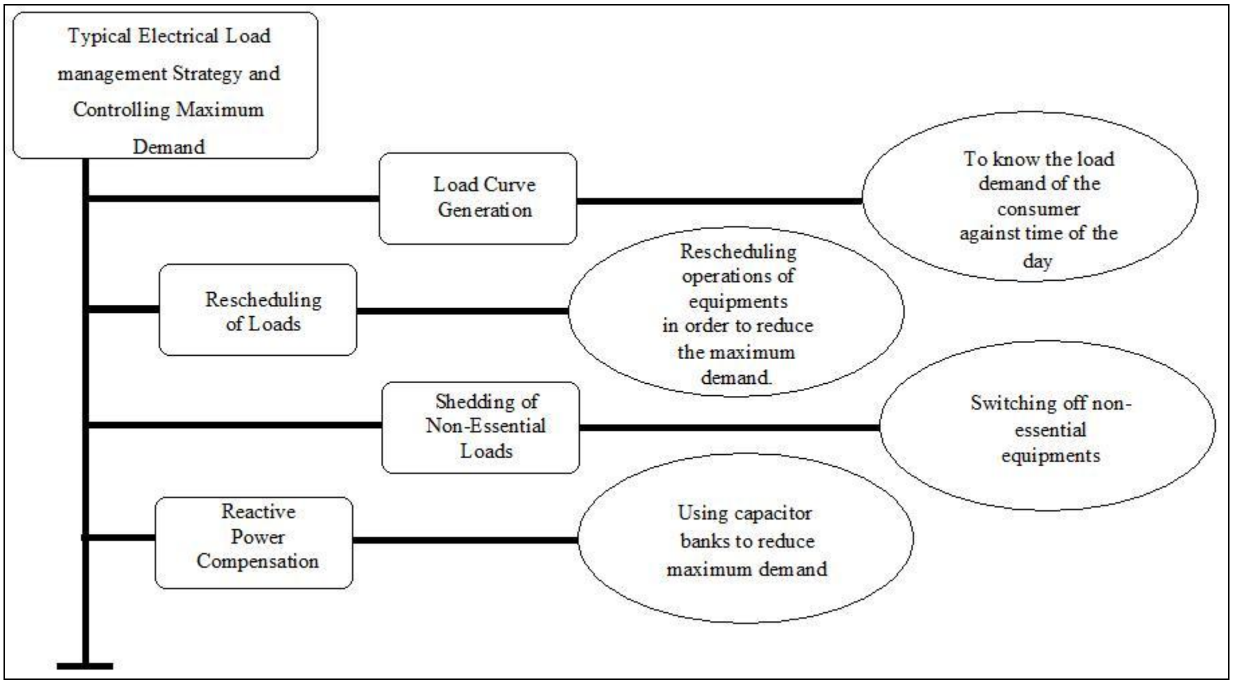
1.2.1 ENERGY CONSERVATION

We consume energy in various forms in our day to day life for performing different tasks. The industries or organizations are continuously expending energy for performing a process or running a system. In most of these cases, the required energy is usually coming from the fossil fuel sources. In order to defend the challenge posed by the present energy crisis or fossil fuel depletion, energy conservation is one of the best procedures.

The term conservation means the reduction of consumption of something so as to save it for future use. Energy conservation basically means to reduce the energy consumption. However, energy conservation does not prohibit from consuming energy since unless energy is consumed no activity would be done. In fact, energy conservation refers to the approach of utilizing energy in an economic way, or in an efficient manner, so as to eliminate its wastage, be it a process or a system or any other activity. This can alleviate to some extent the threat stemming from the fossil fuel crisis in future. Some common examples of energy conservation measures are the use of compact fluorescent lamp (CFL) in place of incandescent lamp, electronic choke in place of copper ballast in Fluorescent Lamps (FL) and use of improved cook stove for fire wood in place of traditional open air cook stove.

1.2.2 ENERGY MANAGEMENT

The energy conservation measures may include an installation for reducing energy consumption in an industry or in an existing facility. The installations may be a kind of energy efficient devices or in the form of using alternative energy sources. A modification of an existing installation for the purpose is also included in these measures. Also by managing the existing load appropriately, consumption of energy can significantly be reduced in an industry. Energy management has the primary objective of incurring least cost or environmental effect while producing goods or providing any service. By judicious use and application of energy efficient methodologies like incorporating measures to prevent or minimize any kind of waste, saving power consumption by replacing old and inefficient equipments or installation etc the profits can be maximized. (Please refer to Units 2, 6 & 7 of the course REEM 006 Energy Management & Auditing for details).

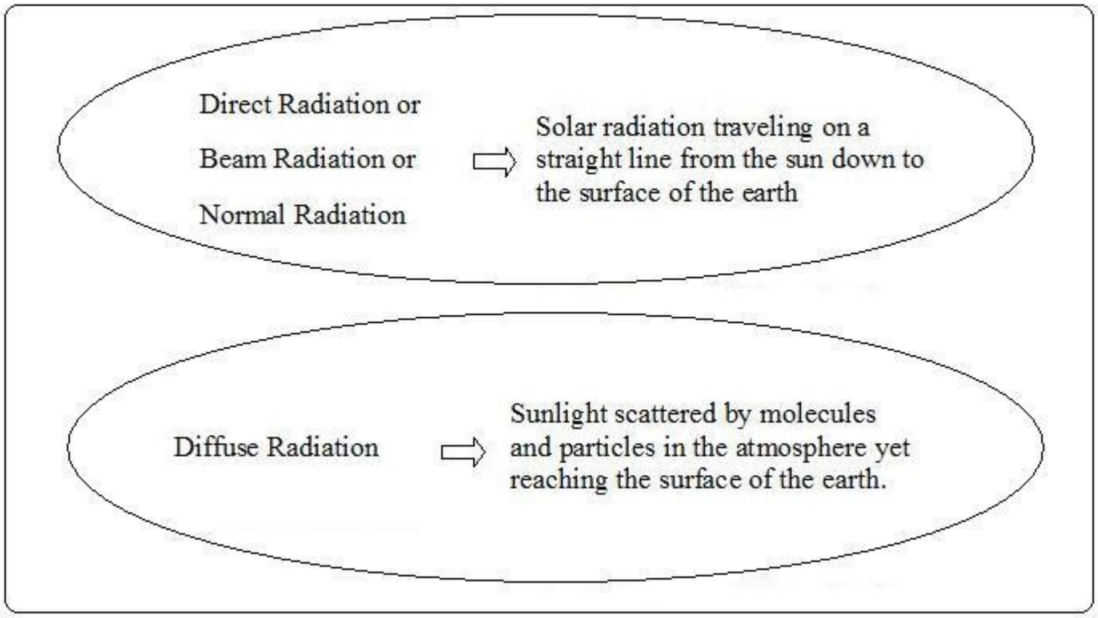


1.2.3 USE OF RENEWABLE ENERGY SOURCES

The use of renewable energy for fulfilling or supplementing the energy requirement involves the harnessing of renewable energy resources. These sources may be solar, wind, biomass, ocean, geothermal resources. One major benefit of using the renewable energy resources is that they produce significantly less pollution to the environment as compared to fossil fuel combustion apart from fossil fuel conservation. The application of new and renewable energy sources are briefly mentioned as below.

Solar energy

Solar energy, the most important one among all the renewable energy sources, can be suitably applied for both thermal as well as electrical applications. However, the availability of solar radiation varies from location to location and also on the varying weather conditions. Therefore, the systems based on the solar energy should be suitably designed to meet the energy requirement under these varying conditions. Typically, the upper atmosphere of the earth receives about 1,366 watts per square meter (W/m^2) out of which about 6% is reflected while about 16% is absorbed in the atmosphere. This implies the fact that the earth receives the peak irradiance as about 1020 watts per square meter (W/m^2) at the equator. Although the diffused radiation cannot be concentrated, yet they may be useful like the direct radiations. (Please refer to Unit 1 of the course REEM002 Solar Energy for details).



Basically two types of collectors are used to harness solar energy. The thermal collectors of different types (*viz.*, flat plate collector, concentrating collector) are used to heat air, water or other organic fluids for different purposes and photovoltaic collectors are used to convert the solar radiation into electricity.

Wind energy

The wind energy conversion systems extract the energy contained in the blowing wind and convert it into mechanical or electrical power. Wind is a promising source of clean energy although it's wide variations, for example, day to day or seasonal variations or even from time to time in a day has made wind energy a somewhat intermittent resource (Please refer to the Unit 1 of the course REEM 004 Wind and Hydro Energy for details).

Ocean energy

The oceans can be a major source of energy as it covers around 70 % of the surface of the earth. The exploitable energy in oceans can be in the form of tides, wave or the thermal energy stored in water. Thus, three basic types of conversion technologies are utilized to extract energy from oceans. These are named as tidal energy, wave energy or ocean thermal energy conversion systems.

Hydrogen and fuel cell

Hydrogen is a fascinating source of energy as its combustion produces little pollution and leads to no green house gas emission. It can be readily converted into heat or power. The only problem is that hydrogen does not exist freely in nature for direct application. Hydrogen isolated from various sources can be fed to fuel cells. Fuel cells are the devices which are used to convert chemical energy into electricity in a very efficient way. This area is also gaining momentum among the current areas of research. Fuel cells can be used to power passenger vehicles as well as domestic utilities. Fuel cell is one of the most promising alternatives of fossil fuel in near future.

Geothermal

Another important source of energy is the large pool of geothermal resources. The technology basically involves the utilization of the heat of the inside earth for thermal application as well as electricity generation. Geothermal resources play a very important role in the volcanically active regions in particular.

Energy from Biomass (Bio-energy)

Energy from biomass has also significant role in the field of renewable energy. Biomass basically refers to the biological material derived from living organisms such as wood, crops, and waste. With reference to energy studies, biomass often means the materials derived from plants as well as materials derived from animal and vegetables. Out of all the resources, wood is considered to be the largest resource for biomass and over thousands of years people have been using this resource for cooking and heating purposes. Besides, bio-fuels derived from biomass offer enough potential for cheap and secure energy supplies. Some common forms of bio-fuels are Bio-ethanol, Bio-diesel and Bio-gas. (Please refer to Units 1 & 4 of the course REEM003 Biomass Energy).

Common Bio-fuels	Application	Major Source
• **Bioethanol**	Substitute for petrol (gasoline).	Cereal based crops • Wheat • Sugar beet, • Maize (corn), • Soyabeans and • Sugarcane
• **Biodiesel**	Substitute for diesel	Oilseed based crops • Oilseed rape (OSR) • Palmoil
• **Biogas**	Substitute for natural gas	Organic waste materials - • Animal waste • Waste generated from municipal, commercial and industrial sources

1.3 ADDRESSING ENVIRONMENTAL CONCERN

The environment and the use of energy are closely related. Energy from various sources is utilized to perform various activities for the need of human civilization. By doing so, we inflict some kind of direct or indirect affect upon the environment. These effects are often found to be adverse to the human society as well as other living beings on the earth. In particular, the use of huge amount of fossil fuel resources by various industries has already caused great damages to the environment. The atmospheric pollutions created by such usage have been a great concern in the world.

1.3.1 AIR POLLUTION

Basically the presence of various substances like particulate matters including chemicals and biological materials in the atmospheric air can be referred to as air pollution. The substances may exist in any form; they may exist as either solid particles or as liquid droplets or even in gaseous form. The increased level of such undesired materials causes several health hazards to the human being as well as other living organisms along with the environment.

The effect of air pollution on human health has been a major issue in the present day world. The adverse effect of air pollution on human health may be in the form of short term diseases like bronchitis, chest problem, irritations in different organs of human body etc or may be chronic type like lung cancer, cardiopulmonary diseases etc.

1.3.2 PRIMARY AND SECONDARY POLLUTANTS

Generally air pollutants refer to those substances which result in air pollution causing harm to man and enviroment. Pollutants which are directly emitted from some process are known as primary pollutants. Besides, some of the primary pollutants react or combine with one another to form another substance or compound in the air which is again harmful to the man and environment. These are known as the secondary pollutants. Moreover, there are some pollutants which can be resulted either directly from the emissions of some processes or may be formed by the interaction of other primary pollutants as well. These pollutants therefore can have their places in both the groups of pollutants, namely, primary and secondary pollutants.

Some of the major primary pollutants are Sulphur dioxide, Nitrogen oxides (Nox), Carbon monoxide, Carbon dioxide, Volatile organic compoundes (VOC), Particulate matters, Ammonia, Radioactive pollutants and Chlorofluorocarbons (CFC). The secondary pollutants include particulate matters resulting from interactions of gaseous pollutants and photochemical smog and ground level ozone.

These pollutants are formed or emitted due to both natural as well as man made activities. For example the sulphur dioxide is manly poroduced by volcanos and combustion of fuels like coal during various industrial processes. One of the severe consequences of Sulpuhur dioxide is that it can also lead to acid rain by forming H_2SO_4 through oxidation in presennce of a catalyst.

1.3.3 CURRENT SCENARIO IN ENVIRONMENTAL ISSUES

The use of energy from fossil fuels increased significantly following the industrial revolution which has led to the increased level of atmospheric pollution and subsequent environmental effects. Sulphur dioxide, nitrogen oxides, carbon dioxide etc are some examples of the pollutants resulting from the emissions from using energy. Another point is to be noted that the air pollutants created at a site does not reside in that site only, but they can travel from few hundred kilometers to even thousands of kilometers affecting the environment in a global way.

In view to safeguard the public health from severe effect of atmoshpeheric pollution, many countries have set up the stadards about the permissible level of various pollutants stemming from emissions due to energy use. The World health Organization also monitors and reviews the scenario through various mechanism and frames air quality guidelines from time to time.

The power generation plants running on fossil fuel are one of the major contributors of producing sulphur dioxide, nitrogen oxide or carbon dioxide emmissions. These emissions may cause the formation of smog, acid rain etc along with the climate change. The urban air quality has been continuous degrading even though various norms have been set up by the concerned authorities in order to maintain the standards. This is due to mainly the population growth, rapid industrialization and increasing number of on road traffic running on fossil fuel.

The use of renewable energy sources has gained the importance in this aspect. The level of emissions stemming from the use of renewable energy sources is significanly less when compared with the emission level of the conventional power plants. There has been a constant effort to use the renewable sources in a more efficient manner across the world.

1.4 SUITABILITY AS CDM

The Clean Development Mechanism (CDM) is a kind of mechanism to stimulate stimulates sustainable development while allowing some flexibility to the industrialized countries in meeting their emission reduction targets. There are certain major environmental issues leading to climate change, in particular the global warming, which have received global significance currently. The main reasons for these issues claming the global importance are that they affect all the mankind on a global scale and their effects are neither confined to any particular country nor influenced by any race or religion.

1.4.1 GLOBAL WARMING

Global warming basically refers to the increase in temperature of the earth's surface based on the documented records across the world. Both the natural and manmade activities, for example, changes in solar irradiance and anthropogenic green house gas emissions, can be held responsible for global warming. However the human contribution towards global warming is far more than the natural cause. The green house gases like carbon dioxide, methane etc emitted from different human activities used to form a layer over the earth. This layer then traps the heat waves which are supposed to escape to the atmosphere in absences of this layer. Carbon dioxide, usually emitted from combustion of fossil fuels like coal, oil and natural gas, has the largest share among the green house gases.

Global warming has major effects on the weather causing changes in temperature and frequency of heat waves. It has also adverse effects on other components like Arctic sea ice extent which shares the climate system and thereby causes the climate change. Some other impacts of global warming include rising sea levels, glacier retreat, changes in pattern of agriculture, extreme weather conditions leading to disasters, food shortage etc. The mitigation of global warming is being addressed by reducing the energy use or adopting energy conservation measures in various ways, for example, by using fuel efficient vehicles, changing life style and promoting new and renewable energy technologies like fuel cell, solar, wind, geothermal, ocean thermal energy conversion etc.

1.4.2 ADDRESSING CLIMATE CHANGE ISSUE

In the year 1992, a number of countries joined an international treaty, namely, the United Nations Framework Convention on Climate Change in order to tackle the problem of climate change as well as the global warming issue. The treaty was signed by more than 150 nations in June, in Rio de Janerio. The UNFCC had a focus on anthropogenic activities resulting in supplementing the natural greenhouse effect and emphasized on stabilizing the greenhouse gas emissions by the year 2000 at 1990's levels. Its objectives also included the adoption of policies to mitigate the climate change and preparation of green house gas inventories at national level. The Conference of Parties (COP) is the apex body of the convention which is responsible for examining the parties' obligations, redefining objectives and subsequent implementation.

The Kyoto Protocol, initially adopted in 1997 in Kyoto, Japan and enforced in 2005 is an addition to this treaty which has more powerful and legally binding measures to fight the global warming. Under this protocol 37 countries (Annex I Countries) agreed to reduce major greenhouse gases including carbon dioxide (CO_2) and methane (CH_4). The protocol also allowed the concerned countries to fulfil their commitment through Emission Trading, Joint Implementation (JI) and Clean Development Mechanism (CDM).

1.4.3 CLEAN DEVELOPMENT MECHANISM (CDM)

The purpose of the CDM is to facilitate sustainable development in developing countries and to help Annex I countries to fulfill their target. This mechanism facilitates investments related to emission- reduction projects in developing countries by the industrialized ones. By implementing such projects the industrialized countries are entitled to earn certified emission reduction (CER) credits which can then be traded to meet their targets for emission reduction under the Kyoto Protocol. To qualify to be a CDM project, projects have to demonstrate evidences of achieving higher emission reductions as compared to the emission reductions which could be achieved otherwise. Besides promoting sustainable development as well as emission reduction, CDM provides a flexible means to industrialized nations to fulfill their emission reduction requirement.

Renewable energy technologies (RET) have many advantages which have made them vital instruments for securing sustainable energy. The primary advantage of Renewable energy technologies over the conventional energy sources is that the supply of energy from renewable sources is apparently infinite as well as free of cost. Though initial costs of installations are still high at present, the operating costs are very low. Many countries have already taken up RET projects, the number of which is becoming competitive to the projects based on conventional energy sources. It is also observed that there exist many barriers which retard the growth of renewable energy technologies in many other countries even though the number of countries promoting these technologies has been continuously increasing across the world. The reasons for unsatisfactory progress may be of a wide range of factors including financial, institutional, technological and lack of awareness or inefficient information dissemination mechanism, thus leaving only a few countries to have clear cut renewable energy policies.

The Clean Development Mechanism (CDM) under the Kyoto protocol provides the opportunity to the project developers, who may be private or public, to generate and sell certified emission reductions (CERs) from the projects intended to reduce the green house gas emission in the developing countries. These projects can also be renewable energy projects. The project developers thus get the financial incentives through this mechanism by promoting the new and renewable energy technologies which in turn reduces the green house gas emissions.

SUMMING UP

In this unit, the various forms of energy and the different sources of energy are discussed. A brief overview of various renewable energy sources including some basic definitions of different types of energy sources is presented here. The global primary energy consumption and the proven reserves of fossil fuels have also been compared. Some important environmental issues, namely, air pollution, global warming as well as the Clean Development Mechanism (CDM) have also been briefly discussed.

The new energy sources have enough potential to improve the current energy scenario. Besides, these are equally effective to safeguard the environment from potential damages resulting from anthropogenic green house gas emissions. The appropriate steps would be to formulate and adopt suitable policies, both in government and private sectors, to promote the applications of renewable energy sources. Mass awareness campaigns, effective information dissemination mechanism, installation and demonstrations of some pilot projects are also expected to boost up the growth of renewable energy applications particularly in the regions which are yet to show satisfactory trends in this regard.

PROBABLE QUESTIONS

1) Describe the various classifications of energy sources with appropriate examples.

2) Discuss the current energy scenario based on the demand and supply across the globe as well as in the Indian context.

3) What do you understand by energy conservation?

4) What are the roles of renewable energy sources in energy conservation efforts?

5) Discuss the current issues on environment which can be influenced by applications of new energy sources.

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UNIT-2: HYDROGEN ENERGY

UNIT STRUCTURE

OBJECTIVE

The objective of this chapter is to discuss the hydrogen energy. In includes some basics of hydrogen energy along with production methods and storage and transportation issues. It highlights some applications associated with hydrogen energy.

INTRODUCTION

Hydrogen can be treated as a nearly ideal fuel. It is a kind of fuel that produces little pollution on combustion, as well as leads to no greenhouse gas emission. When burnt in a pure oxygen environment, hydrogen produces only water, whereas in air (78% nitrogen and 21% oxygen) hydrogen produces oxides of nitrogen on combustion similar to that of fossil fuel combustion. Hydrogen does not produce carbon dioxide no matter whether it is a burning process or a reaction in the fuel cell. Because of these features, hydrogen finds a distinctive place in the field of energy.

2.1 BASICS OF HYDROGEN ENERGY

One of the most fascinating carriers of energy is the hydrogen. Hydrogen can be converted into heat or power in a much simpler as well as cleaner way. It forms water on combustion with oxygen and no pollutants are coming out of the process. However, it does not exist freely for direct utilization.

Hydrogen is basically a secondary source of energy. Hydrogen has to be extracted first from hydrocarbons or water. Then only it can be used running applications. The separation of hydrogen from its sources again involves energy. This energy can be supplied from other renewable energy sources as well in a environment friendly way. Renewable energy sources like solar, wind etc usually cannot provide a constant source of energy. However a fraction of the electricity produced from such sources can be utilized to supply the energy requirement for hydrogen production which can be stored for future use. In other way by sacrificing a portion of energy produced from other renewable energy sources for hydrogen production, a continuous supply of energy to the society may be possible. However storage of hydrogen is another critical issue and is of much importance in the area of economic viability. Besides these, the hydrogen economy encompasses also the issues related to packaging, delivery, transfer etc. – the important components of an energy market. In order to achieve a sustainable market, the energy inevitably consumed in these components, should be smaller than the energy actually delivered to the customer.

2.1.1 PROPERTIES OF HYDROGEN

The energy contained in hydrogen is more than other substances on a weight for weight basis. Hydrogen has well known physical properties. It is the smallest of all atoms and also the lightest gas as well. It has a very low energy per unit volume. At ordinary temperature and pressure density of hydrogen is about 1/14th that of air and 1/9th that of natural gas. As compared to methane, the gravimetric heating values of hydrogen are as follows:

	Higher Heating Value (HHV)	Lower Heating Value (LHV)
Hydrogen -	142 MJ/kg	120 MJ/kg
Methane -	55 MJ/kg	50 MJ/kg

The volumetric heating values at pressure and temperature of 1 bar and 25 deg C respectively are as follows

	Higher Heating Value (HHV)	Lower Heating Value (LHV)
Hydrogen -	11.7 kJ/litre	9.9 kJ/litre
Methane -	36.5 kJ/litre	32.9 kJ/litre

2.2 PRODUCTION METHODS

The method of production of hydrogen depends basically on its source, namely, water, hydrocarbon fuels or other hydrogen carriers. For example, electrolysis can be used to produce hydrogen from water; reforming or thermal cracking can be employed to produce hydrogen from hydrocarbon fuels etc. Broadly, the processes used for producing hydrogen may be categorized as chemical, electrolytic, thermolytic, photolytic and biological processes.

Earlier hydrogen was produced by passing steam over red hot iron filings. Iron reacts with water liberating hydrogen which is then washed by bubbling it through water. The gas is used to fill the hot air balloons. Later, hydrogen is produced from the reaction of iron with sulphuric acid which was a costly process. In modern processes, aluminium chips are made to react with the caustic soda to produce hydrogen. By employing the processes like partial oxidation, steam reforming or the thermal decomposition, hydrogen can be produced from hydrocarbons and alcohols. As a result of these processes, syngas, which is a mixture of carbon monoxide and hydrogen, is formed.

The typical sequence for the large scale production of hydrogen from fossil fuel used for ammonia production involves desulphurization of the feedstock as the sulphur has a negative effect on the catalysts associated with the processes. After that, by means of steam reforming sysngas is produced. In the final step, the carbon monoxide is removed to get the hydrogen. The process of electrolysis for production of hydrogen is usually employed for production of hydrogen in small quantities

2.3 STORAGE AND TRANSPORTATION

Because of its low volumetric energy density, hydrogen storage is not a simple task. It may be noted that, though hydrogen has a higher gravimetric heating values, it is the lightest element which demands more volume for storing as compared to other fuels. For this reason the gravimetric heating value of hydrogen is of little or no importance when we want to tackle the issue of storing and transporting hydrogen. The volume requirement is the prime factor in the area of storage and transportation since, for example we cannot increase size of the fuel tank of an automobile or the diameter of pipelines as much we wish. Therefore there is an urgent need to compress hydrogen so that it can be stored in an optimum volume as well as it can be efficiently transported. For this purpose we have to be much more concerned with the volumetric heating values of hydrogen depending upon type of its application or use. hydrogen has to be made more energy dense in order to affect useful and effective transportation.

The method for storing hydrogen is decided by several factors like, volume to be stored, restrictions on the weight of the storage system, time, space, end use etc. Regarding the type of the end use, for example, some end users may like to purchase hydrogen in the liquid form so that it can be vaporized whenever required rather than preferring onsite hydrogen production. Also there may be several restrictions on storage like time, space etc. For efficient transportation and storage all such factors have to be appropriately considered. There are basically three methods for tackling such issues. Hydrogen can be compressed, liquefied, or chemically combined (Solid-State Storage of Hydrogen) for the purpose.

A number of factors are associated with the design of a hydrogen storage system. Some of these factors are gravimetric concentration, volumetric concentration, turnaround efficiency, dormancy, safety etc. The gravimetric concentration (GC) is defined as the ratio of the stored hydrogen to the overall mass of the loaded storage and retrieval system while the volumetric concentration (VC) is the ratio of the stored hydrogen to the total volume of storage and retrieval system. The gravimetric concentration is a unit less parameter while the volumetric concentration may be expressed as kg per cum (kg/ m^3). The turnaround efficiency is the ratio of the retrieved hydrogen to the amount of input hydrogen. The parameter dormancy describes the ability of the system to retain its hydrogen over a long duration of time.

2.3.1 COMPRESSED HYDROGEN

For many applications, hydrogen is stored in high pressure cylinders. But due to its distinguished physical properties, hydrogen is very difficult to be compressed among all the gasses. Also, there is a requirement of intensive amount of energy for this compression to take place effectively.

The large scale use of compressed hydrogen started in the early 1880's. By this process the British troops used to transport hydrogen in wrought iron welded vessels for using in war balloons. If a vehicle is to carry hydrogen in place of gasoline, the energy density of hydrogen must match to that of gasoline which requires hydrogen to be compressed to a much higher pressure. For the same energy, hydrogen compressed to 800 atmospheres, still requires 3 times more volume than gasoline. A lightweight tank can hardly contain such pressures safely. Again, if a tank is made of high strength steel to safely bear this pressure, the weight of the tank becomes much higher than the hydrogen it contains. This implies that a truck or an automobile using a steel tank would not be practical as the weight of the tank may be as much as that of the vehicle. Occasionally, an alternative may be the high pressure tanks made from carbon fibre.

2.3.2 SOLID-STATE STORAGE OF HYDROGEN

Solid state storage of hydrogen involves the use of a reversible chemical reaction. In his process a metal is made to react with hydrogen to create a metal hydride. Usually metal hydride is formed by the reaction at higher pressure while the reaction reverses to metal and hydrogen at lower pressures. Such systems can operate at room temperature under relatively low pressures. This is an efficient system of storage while speaking in terms of volume but its weight increases due to the mass of metal hydride. The solid state hydrogen storage can be achieved through three generic routes, namely, adsorption, absorption and chemical reaction. Adsorption is associated with carbon and zeolite materials, absorption to form simple metal hydrides and chemical reactions are involved with the formation of complex metal hydrides or chemical hydrides.

There are some alkali metal hydrides which are capable of releasing hydrogen when exposed to water. Although these hydrides can hold enough hydrogen facilitating useful transportation, about 70 % of the energy is consumed for creation of these hydrides. This factor limits their widespread use. Some other metals (platinum, zirconium, lanthanum) can be formed into sponges which can store hydrogen. These are very expensive and storage capacity is very less as compared to their weight. Also, the storage tank required in both the cases should be very heavy.

2.3.3 LIQUID HYDROGEN

In order to achieve the highest density and to match the optimum storage space requirement hydrogen must be liquefied. The density of liquid hydrogen is about 71 kg/m^3. Basically liquefaction of hydrogen is achieved by cooling the gas which changes its form from gaseous to liquid. This is a multi-stage process and uses several refrigerants and compression/ expansion loops at various stages to produce the extreme cold. Liquefaction involves a combination of compressors, heat exchangers, expansion engines, throttle valves etc which acts together to facilitate the desired cooling. Typically in industrial liquefaction of hydrogen, liquid nitrogen is used to cool hydrogen initially. It is then fed through several multi-stage heat exchangers, where turbo expanders supply the necessary cooling power. Finally liquefaction of hydrogen is achieved by throttling in a Joule-Thomson valve.

The first liquefaction of hydrogen was achieved more than 100 years ago. The temperature at which hydrogen liquefies is -253°C. This fact demands for a special equipment for its storage. The challenges in liquid hydrogen storage lie with the energy efficiency of the liquefaction process and the thermal insulation of the storage tank. In order to minimize the thermal losses in liquid hydrogen storage tanks three basic mechanisms of heat transfer, namely, thermal conduction, convection and radiation are required to be considered appropriately. Typically, thermal radiation losses can be reduced by using multilayer insulation which incorporates layers of metallic foils with glass wool. To reduce the thermal convection losses, two vessels are used similar to a thermos flask. The insulated inner vessel is inserted in the outer vessel and the space between the two vessels is evacuated. The thermal conduction losses can be substantially reduced by proper tank design as well as appropriate selection of materials.

The volume occupied by liquid or cryogenic hydrogen is also about three times more than the volume occupied by gasoline for the same energy. But the advantage of cryogenic hydrogen is that the tank required for its storage is much lighter.

2.4 APPLICATIONS

Hydrogen gas can be suitably used in variety of applications in various areas. Its use may spread from residential to industrial application, from surface transport to aircraft or rocket engines. Furthermore, electricity can be generated by using hydrogen through fuel cell for lighting purpose or to run other domestic appliances. In industry, hydrogen is used either as a fuel or as a chemical agent. The use of hydrogen for running the engines of automobiles or motor transports is getting more importance in the context of fossil fuel conservation. Also, hydrogen fuel engines can have higher efficiencies and the carbon monoxide emission, stemming from engine lubricating oil only, would be very small. In rocket engines, liquid hydrogen serves as a coolant for engine nozzle and other parts before it is mixed with oxidizer and burnt. The exhaust coming out of such engine is clean water along with some traces of ozone and hydrogen peroxide.

SUMMING UP

Hydrogen is often treated as the energy source of the future. It is expected that hydrogen can be a solution to the scarce energy scenario prevailing worldwide. The most appealing factor about hydrogen is that it does not lead to green house gas emission. On the contrary, it is not available in the nature in a free gaseous state. It has to be derived from some compounds, e.g. water. Also, this separation of hydrogen always associated with some primary energy sources like oils, natural gas etc. This implies that hydrogen is basically an energy vector or energy carrier transmitting and distributing energy and at the same time, this energy carrier is not a convenient one. For using hydrogen in automobiles, motor transports and in other similar uses, the energy density has to be sufficiently increased and the processes like liquefaction or compression, becomes inevitable for the purpose.

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UNIT-3: FUEL CELL

UNIT STRUCTURE

OBJECTIVE

In this chapter, fuel cell is discussed. It includes principle of working, basic thermodynamic and electrochemical principles, classifications and applications for power generations.

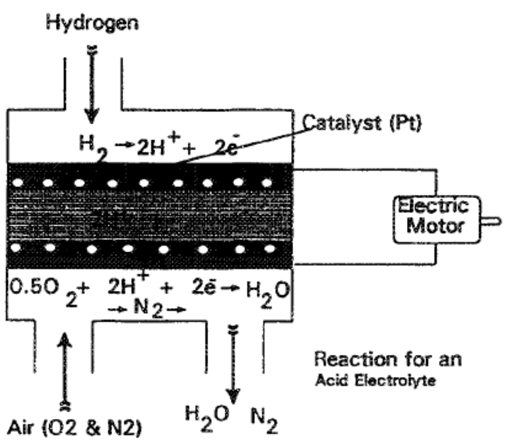
INTRODUCTION

Fuel cell is a device which converts chemical energy directly into electricity. It uses two electrodes immersed in an electrolyte similar to a battery. However the conversion of power in fuel cell is very efficient, non-polluting as well as flexible. Also, while supplying electricity, depletion of the electrode material does not occur in fuel cell unlike the battery. Fuel cells are being developed to power passenger vehicles, domestic utilities and also for small devices like laptop computers etc. It is also expected that fuel cell may be the one of the major alternatives for fossil fuel, especially in the transport sector, because of their cleanliness and high reliability.

3.1 PRINCIPLE OF WORKING

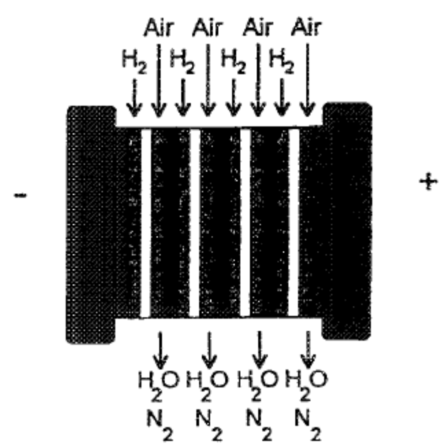
Usually a fuel cell combines a fuel, namely, natural gas or hydrogen, to produce electricity. An electrochemical process is involved in this method of electricity generation.

Basically, all the oxidation rations which produce energy are of similar nature. Chemical energy is released in these reactions through the transfer of electrons. In the process of combustion of hydrogen and oxygen transfer of electrons takes place immediately. As a result of the process heat is released along with the formation of water. However, in the case of fuel cell electrolyte has a role to play between the hydrogen and oxygen. Here hydrogen and the oxygen does not come into contact immediately, rather they are separated by an electrolyte. Initially, with the help of a catalyst, electrons are separated from the hydrogen molecule which gives rise to the formation of hydrogen ions. These ions then move towards the oxygen side through the electrolyte. On the other hand, the electrons which can pass through the electrolyte move through the external electrical circuit towards the oxygen side. This movement of electrons results in the flow of electric current through the external circuit doing the useful work. On reaching the oxygen side, the electrons combine with the hydrogen ion to form water. In this process, a direct energy conversion can be achieved at low temperature by forcing the electrons through the external circuit.



Schematic of fuel cell operation

Fig. - 1



Schematic of fuel cell stack

Fig.- 2

Using the fuel cell, electrical power can be generated in a continuous manner. Moreover, the absence of moving parts in fuel cells makes them a choice for quite, clean as well as a reliable source of power. Hydrogen is typically used as fuel in the fuel cell and the oxygen, usually taken from the air, serves as the oxidant. The basic by products of the associated reactions are water and heat along with electricity production.

The primary feature of fuel cell is that it converts a fuel directly into electricity. For this reason, fuel cells can be operated at much higher efficiencies than the internal combustion engines and it can produce more electricity from the same amount of fuel.

A number of fuel cells can be combined together to form a fuel cell stack. The power generated from the stack is dependent on the number of individual cell along with the surface area of each cell. The total output voltage is decided by the number of individual cells used in the stack and the current is determined by the surface area of each individual cell.

3.2 BASIC THERMODYNAMIC AND ELECTROCHEMICAL PRINCIPLES

The fuel cell reaction resembles a very slow hydrogen gas combustion process. At the anode or positive electrode, electrons are separated from the hydrogen atoms and they flow through the external electrical circuit driving the load. On the other hand, at the cathode or negative electrode, the combination of hydrogen ions with oxygen atoms and electrons takes place, thus resulting in the formation of water and heat. The combination of hydrogen with oxygen to produce water along with heat and electricity can be represented as,

$$H_2 + 0.5\ O_2 = H_2O + \text{Heat} + \text{Electricity}$$

This implies that 1 kilo mole of hydrogen combines with 0.5 kilo mole of oxygen to form 1 kilo mole of water and the by-products as heat and electricity. The free energy of the overall fuel cell reaction decides the amount of electricity generated. The difference between the heating value of the fuel and its entropy at the temperature and pressure of conversion gives the value of free energy of formation. For the reaction, the free energy change can be expressed as

$$\Delta G = \Delta H - T\,\Delta S$$

Where, ΔG = free energy change

ΔS = change in entropy for the reaction

T = absolute temperature in Kelvin

Typically, the theoretical conversion efficiency in a hydrogen oxygen fuel cell for converting heat into electricity is about 83 % at atmospheric pressure and at 25 deg C.

The electrochemical principle of fuel cell can be better understood through the reactions which take place during the power conversion mechanism. Basically, the type of the fuel used in a fuel cell along with the electrolyte, decides the nature of the chemical reactions taking place in the process.

Although, as in laboratory demonstration, the simplest fuel that can be used in fuel cell is hydrogen, the difficulty in hydrogen storage limits its use in fuel cell applications. Other fuels for fuel cell include methanol or a combination of hydrazine (NH_2NH_2) with hydrogen peroxide (H_2O_2) as oxidant etc. The electrolytes used in fuel cell can also be of different chemical nature. For example, they may be either alkaline or acid or there may be a molten carbonate or ceramic electrolyte used in the fuel cell. The chemical reactions involved in some of the fuel cells are given below.

Considering hydrogen – oxygen fuel cell with KOH as alkaline electrolyte, the OH^- is used as current carrying ions. The reactions are as follows:

KOH dissociates hydroxyl ion as,	KOH	$K^+ + OH^-$
At anode,	$2\ H_2 + 4\ OH^-$	$4\ H_2O + 4\ e^-$
At cathode,	$4\ e^- + O_2 + 2\ H_2O$	$4\ OH^-$
The overall reaction is,	$2\ H_2 + O_2$	$2\ H_2O$

In case of acid electrolyte, the H^+ ions can come either from the hydrogen ionization or from the dissociation of the acid. In both the cases H^+ ions are replenished at the anode. For example a phosphoric acid (H_3PO_4) electrolyte may dissociate as -

	H_3PO_4	$3\ H^+ + PO_4^{---}$
At anode,	$2\ H_2$	$4\ H^+ + 4\ e^-$

At cathode, $4H^+ + 4e^- + O_2$ $2H_2O$

The overall reaction is, $2H_2 + O_2$ $2H_2O$

In case of molten carbonate electrolyte, when hydrogen is used as fuel, the reactions are–

At anode, $H_2 + CO_3^{--}$ $H_2O + CO_2 + 2e^-$

At cathode, $CO_2 + 2e^- + 0.5\ O_2$ CO_3^{--}

When CO is used as fuel,

At anode, $CO + CO_3^{--}$ $2CO_2 + 2e^-$

At cathode, $CO_2 + 2e^- + 0.5\ O_2$ CO_3^{--}

When ceramic electrolytes are used,

At cathode, $O_2 + 4e^-$ $2O^{--}$

At anode, with hydrogen as fuel $2H_2 + 2O^{--}$ $2H_2O + 4e^-$

With CO as fuel $2CO + 2O^{--}$ $2CO_2 + 4e^-$

If the fuel is methanol, then the reactions can be expressed as,

At anode, $CH_3OH + H_2O$ $CO_2 + 6\ H^+ + 6\ e^-$

At cathode, $6\ H^+ + 6\ e^- + 1.5\ O_2$ $3\ H_2O$

The overall reaction is, $CH_3OH + 1.5\ O_2$ $CO_2 + 2\ H_2O$

3.3 CLASSIFICATIONS

Fuel cells are basically classified based on the type of electrolyte being used. They can also be classified based on the type of fuel used as well as on the basis of the operating temperature.

There are different types of electrolytes used in fuel cell. They can be acid, alkaline, molten carbonate or solid oxide (ceramic) or they can be differentiated as aqueous, non-aqueous, molten or solid. The range includes the proton exchange membrane (a solid polymer material), phosphoric acid (a liquid), alkaline (a liquid), molten carbonate (a liquid) and solid oxide ceramic). Similarly the fuels used in fuel cell may also be of different type – gas, liquid or solid. For example, the fuel used in a fuel cell may be hydrogen, fossil fuel, hydrocarbon, alcohol or hydrazine (NH_2NH_2) fuel. Also depending on the working temperature a fuel cell can be categorized as a low temperature (25 – 100 deg C), medium temperature (100 – 500 deg C), high temperature (500 – 1000 deg C) or very high temperature (above 1000 deg C) fuel cell. The variety of fuel cells includes the following types:

Proton Exchange Membrane or Polymer Electrolyte Membrane Fuel Cell (PEMFC)
Molten Carbonate Fuel Cell (MCFC)
Solid Oxide Fuel Cell (SOFC)
Phosphoric Acid Fuel Cell (PAFC)
Alkaline Fuel Cell (AFC)
Direct Methanol Fuel Cell (DMFC)
Solid Acid Fuel Cell (SAFC)
Solid Polymer Fuel Cell (SPFC)

The phosphoric acid cell (PAFC) can also be referred as the first generation of fuel cells. They are the first kind of fuel cell to be applied for commercial use. Its primary use is in stationary power generation although it can be used for large vehicles as well. The efficiency is around 85 percent in case of co-generation of heat and electricity and around 37 to 42 percent in case of electricity generation alone.

The proton exchange membrane (PEM), the molten carbonate cell ($NaCO_3$), and solid-oxide ceramic cells are all demonstrated well. The proton exchange membrane or Polymer electrolyte membrane (PEM) fuel cells are capable of delivering high power density. They are usually lower in weight as compared to other types of fuel cell. The electrolyte used in PEM fuel cells is a solid polymer and the electrodes are porous carbon electrodes containing a platinum catalyst. They usually operate at low temperature of around 80 deg C which minimizes the wear and tear of system components. They can be suitably used in passenger vehicles. However, since they require hydrogen as fuel, the storage problem of hydrogen may restrict their use in this arena.

The electrolyte used in alkaline fuel cells (AFC) is a solution of potassium hydroxide in water and the catalysts used at the electrodes are coming from various metals. They are marked for their applications in spacecrafts with an efficiency of around 60 percent. Both the gases, hydrogen and oxygen, should be free from carbon dioxide for their appropriate functioning.

The molten metal carbonate fuel cells as well as the solid oxide fuel cells are more suitable for stationary functions. In case of molten metal carbonate fuel cells, a mixture of molten carbonate salt suspended in porous, chemically inert ceramic lithium aluminium oxide ($LiAlO_2$), form the electrolyte. These are high temperature fuel cells with efficiencies up to around 60 percent and they are not susceptible to carbon dioxide poisoning. On the other hand, in solid oxide fuel cells (SOFCs), a hard, nonporous ceramic compound forms the electrolyte which enables a solid construction. These are also high temperature fuel cells, but they require appropriate heat shielding for retaining the operational temperature. The solid oxide fuel cells are free from carbon dioxide or sulphur poisoning.

3.4 APPLICATIONS FOR POWER GENERATIONS

The fuel cells have the potential for diverse use, right form power generation to automotive applications, or from domestic to space applications. The average voltage of a fuel cell is around 0.75 volt. Since the fuel cell provides direct current, inverters may be required for driving AC loads. By suitable series parallel combination of a number of fuel cells, it is possible to produce the desired amount of voltage and current corresponding to the electrical load. Presently, the thrust areas of fuel cell application have been considered as their use in stationary power plants as well as in automotive power plants.

3.4.1 STATIONARY POWER PLANTS:

The stationary power plants using fuel cells may be of large capacity centralised plant, dispersed utility operated plants of say, tens of MW size, or onsite power plants ranging from say 10 to 100kW size.

The advantages of using fuel cell over the conventional heat engines are that these plants create little pollution and they do not produce noise. Fuel cells can be made in the form of modules having different size which makes their transportation easier. These modules can be readily assembled on the site to meet the desired voltage and power requirement. The modular construction makes the expansion easier. In some typical plants, there may be scope for co-generation using the high temperature exhaust gases.

Fuel cell based power plants are expected to be highly reliable with low maintenance cost. They can operate at a reasonable good efficiency even at a fraction of the rated power. Their overload characteristics are also very good. The efficiency for fuel utilization in a central power plant, where coal is gasified and the gas is fed to the fuel cell for electricity generation, is expected to be much higher than in conventional steam power plant. Solid oxide fuel cells may be the future choice for this type of applications. In case of portable generators, low temperature fuel cell using methanol as fuel may be preferred. Fuel cells may be a good option for remote areas for providing mobile and emergency power.

3.4.2 AUTOMOTIVE POWER PLANTS:

Fuel cells have the potential for automotive power plant applications. The advantages include the extremely low pollution, high efficiency along with high power density. With the use of fuel cells, electric vehicles may run through a longer travel ranges compared to the conventional batteries. However we may have to sacrifice the specific power which implies the reduction in acceleration and speed. Compact solid polymer electrolyte fuel cell (SPFC) may be suitable for small and medium sized vehicles. Their low operating temperature also enables rapid start ups. Among the other applications, fuel cells are also used in submarines motivated mainly by their cleanliness of operation.

SUMMING UP

Fuel cell may be treated as an ideal device for electricity generation. Due to its operational cleanliness along with absence of noise, it may be a favourable choice for electricity generation in urban areas. In order to fulfil the hydrogen requirement of the fuel cell, additional process or method has to be incorporated. The method of steam reforming of either naphtha or natural gas can serve the purpose satisfactorily. Different types of fuel cells are being developed to suit specific applications.

PROBABLE QUESTIONS

- What is fuel cell? Explain its basic working principle.
- Name some common types of fuel cell. What are the parameters used to classify fuel cell?
- Write the chemical reactions involved in some commonly referred fuel cells.
- What are the different types of application of fuel cell?
- Mention some features of fuel cell which justify its use in different applications.

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UNIT-4: OCEAN ENERGY

UNIT STRUCTRE

4.1 OCEAN ENERGY RESOURCES

Oceans can be a major source of energy provided it can be appropriately exploited for the use of human society. Around 70 % of the earth's surface area is covered by oceans and seas and hence they represent a large pool of energy. These exploitable energies from oceans are stored in the tides, waves or as thermal energy. However the thermal energy hidden in the oceans can be a major focus for exploitation. This thermal energy comes from the exposure of the water surface to the solar radiation. Since the major portion of the earth is covered by water, so we can have a large volume of thermal energy storage. With the property of high specific heat capacity of water, oceans can be treated as large reservoir of solar thermal energy which can be suitably exploited for our use. Thus the oceans can provide us enormous opportunity for fulfilling our energy need in the field of renewable energy sources.

4.2 OCEAN ENERGY ROUTES

The energy routes from oceans can be categorized in three major categories, namely, ocean thermal energy conversion, wave energy conversion and tidal energy conversion. These energies basically come from the solar radiation and the rotation of the Earth.

Solar radiation is absorbed by the vast water surface of the oceans and thereby causes a temperature gradient towards downward from the water surface of the oceans. This temperature gradient is used in the ocean thermal energy conversion technology.

The waves in the oceans are caused by the blowing of the wind on the surface of the oceans. The fast moving waves have a lot of kinetic energy hidden in them. The wave energy conversion technology attempts to exploit this hidden energy from the surface of the oceans.

The rotation of the earth as well as the action of sun and moon on the water surface of the oceans and seas causes the water surface to rise or fall periodically. These movements of water surface above and below the normal water level are known as tides. There is an enormous movement of water between each rise (high tide) and fall (low tide) of water level and thus becomes a huge source of energy. The tidal energy conversion technology makes use of this movement of water to convert it into a useable form of energy.

However a fourth category can also be added which can be termed as hydrological cycle. This is a kind of secondary conversion of ocean energy. This energy comes from the mechanism of surface water evaporation by solar heating. The cycle results in rain fall, causing rivers to inundate. Further, the rivers can then be used as a source of water by constructing dams or by applying other suitable technology for running a typical hydroelectric power plant.

4.3 OCEAN THERMAL ENERGY CONVERSION (OTEC)

The ocean thermal energy is an indirect form of solar thermal energy. A great amount of thermal energy (heat) is stored in the world's oceans. Each day, the oceans absorb enough heat from the sun to equal the thermal energy contained in 250 billion barrels of oil. OTEC systems convert this thermal energy into electricity.

The ocean thermal energy concept was proposed as early as 1881 by the French physicist Jacques d' Arsonval. The heat contained in ocean which is solar in origin can be converted into work out put (or electricity) by making use of the temperature difference between the warm surface and the colder deep water (which is about 20 – 25 deg K) in a suitable heat engine. The facilities proposed for achieving this conversion are commonly referred to as Ocean Thermal Energy Conversion (OTEC) plants or sometimes as Solar Sea Power Plants (SSPP).

4.3.1 WORKING PRINCIPLE OF OCEAN THERMAL ENERGY CONVERSION (OTEC):

The principle of OTEC plant is based on a well established physical (Thermodynamic) principle. If a heat source is available at higher temperature and a heat sink at a lower temperature, it is possible in principle to utilize the temperature difference in machine or prime mover (e g turbine) that can covert part of the heat taken up from the source into mechanical energy and hence into electrical energy. The residual heat is discharged to the sink at lower temperature. In the OTEC system, the warm ocean surface water is the heat source and the deep colder water provides the sink. OTEC utilizes the temperature difference existing between warm surface water of around 27 – 29 deg C and the cold deep sea water of around 5 – 7 deg C, which is available at a depth of 800 – 1000m. The process of OTEC requires that the warm surface water and cold water from depth (about 1000 – 1500 m) be brought into proximity as they act as the heat source and the heat sink, respectively for a heat engine.

Though the primary objective of an ocean thermal energy conversion system is to generate electricity some secondary benefits can also be achieved from this conversion. Some of these may be mentioned as below.

1. OTEC systems can also have other benefits like enhanced aquaculture, desalination or even air conditioning, which might reduce the cost of electricity generated.
2. Potable water
3. Hydrogen production: One suggestion is to use direct electric current to decompose sea water by the process of electrolysis; the main products would be hydrogen and oxygen. The hydrogen could be liquefied and transported by tanker to a point where it could be used as fuel.
4. Produce ammonia for use as fertilizer: Alternatively the hydrogen could be combined with atmospheric nitrogen to form ammonia for use as fertilizer, thereby saving natural gas which is presently the main source of hydrogen for this purpose.

4.3.2 CLASSIFICATION

The ocean thermal energy conversion system may be classified either by the type of installation or by the cycle of operation. According to the type installation it may be a land based type which is installed on shore or it may a floating type which is installed off shore. The classification by the cycle of operation includes basically an open cycle or a closed cycle system. Another cycle termed as hybrid cycle system includes the features of both open and closed cycle. The open cycle is also known as Claude cycle and the closed cycle is also known as Anderson Cycle.

4.3.2.1 OPEN CYCLE SYSTEM:

In the open cycle system, water is the working fluid. The warm surface water is caused to boil by lowering the pressure without supplying any additional heat. The low pressure steam produced then drives a turbine and exhaust steam is condensed by the deep colder water and is discarded. A heat exchanger is not required in the evaporator and direct contact between the exhaust steam and a cold water spray makes a heat exchanger as necessary in the condenser. On the other hand because of the low energy content of low pressure steam, very large turbines or several smaller units operating in parallel would be required to achieve a useful electric power output. (Ref. Fig. – 1 in Appendix).

4.3.2.1.1 FEATURES OF OPEN CYCLE SYSTEM:

- Because of the need in the open cycle to harness the energy in low pressure steam, extremely large turbines (compared to wind turbine) must be utilized. For example, 1 MW OTEC plant requires a steam turbine of 12 m in diameter. To maintain vacuum in the flash evaporator, massive vacuum pumps will be required.

- Degasifiers (deaerators) must be used to remove the gases dissolved in the sea water unless one is willing to accept large losses in efficiency.
- On the other hand since there are no heat transfer problems in the evaporator, the problem of bio fouling control is minimized.
- The most obvious advantage of the open cycle is that warm sea water is flash evaporated and the need for having a surface heat exchanger is eliminated.
- The cost of an open cycle system providing substantial number of MW is presently regarded by most OTEC workers as being significantly greater than for a closed cycle system. The turbine constituted almost half the cost of power system, but may be amenable to reductions that could result from design innovations.
- The other major advantage is that potable water is obtained when the exhaust steam from the turbine is condensed,

4.3.2.2 CLOSED CYCLE SYSTEM

In the closed cycle system a liquid working fluid, such as ammonia or propane, is vaporized in a an evaporator (or boiler); the heat required for evaporation is transferred from the warm ocean surface to the liquid by means of a heat exchanger. The high pressure vapour leaving the evaporator drives as expansion turbine, similar to that of a steam turbine that is designed to operate at lower inlet pressure. The turbine is connected to as electric generator in the usual manner. The low pressure exhaust from the turbine is cooled and converted back into liquid in the condenser. The cooling is achieved by passing cold, deep ocean water from a depth of 700 – 900 m or more, through a heat exchanger. The liquid working fluid is then pumped back as high pressure liquid to the evaporator thus closing the cycle.

4.3.2.2.1 FEATURES OF CLOSED CYCLE SYSTEM:

- Turbines in closed cycle are much smaller and hence less costly than that use the low pressure steam of open cycle For example for 1 MW plant, the ammonia turbine will have a diameter of about 1.1 m only. The fabrication of such turbine is technically easier than fabrication of very large steam turbines for open cycle. The pressure at the ammonia turbine will be of the order of 9 – 6 bar resulting in compact turbines
- The closed cycle also avoids the problem of the evaporator
- It however requires the use of very large heat exchangers (boiler and condenser) because for an efficiency of about 2 % the amounts of heat added and rejected are about 50 times the output of the plant.
- The closed cycle systems require expensive working fluids like Freon or ammonia.

- Closed cycle systems offer the most promise for near future.

4.3.2.3 HYBRID CYCLE

There are several variations on standard OTEC open cycle systems. One variation is the hybrid cycle which is an attempt to combine the best features and avoid the worst features of open and closed cycles. Here sea water is first flash evaporated to steam as in open cycle. The heat in the resulting steam is then transferred to ammonia in an otherwise conventional closed Rankine cycle system.

4.3.3 FACTORS DECIDING A VIABLE OTEC:

1. **Temperature gradient**

The temperature gradient is the difference between surface water temperature and deep water temperature. The surface temperatures (and temperature differences) vary both with latitude and season, both being maximum in tropical, subtropical, and equatorial waters, i. e., between the two tropics, making these waters most suitable for OTEC systems

In the tropics, the ocean surface temperature often exceeds 25 deg C while 1 km below, the temperature is usually not higher than 10 deg C. These are two essentially infinite heat reservoirs, a heat source at the surface at about 27 deg C and a heat sink some 1 km directly below at about 4 deg C, both reservoirs are maintained annually by solar incidence.

In general,

a) A significant temperature difference – at least about 20 deg C – between surface and deep ocean waters (for 700 – 900 m depth or more) that will permit year round operation the greater the difference the lower will be the cost of generating electricity.
b) The best sites are in the tropical belt between about 20 deg N and 20 deg S latitude.
c) Choosing a site consideration should be given to the potential for biofouling effects

2. **Site Consideration:**

A viable OTEC plant must satisfy the following simultaneously:

a) Coastal zone land must be available.
b) Sea floor must descend sufficiently rapidly from the shore based plant location
c) The seasonal availability of warm and cold water without undue gradation by the warm and cold water effluents from the otec plant must meet certain criteria.

4.3.4 FACTORS AFFECTING THE PERFORMANCE OF AN OTEC SYSTEM:

There are three main factors affecting the performance of an OTEC system. These are -

1. Heat exchanger (evaporator and condenser).
2. Working fluid
3. Biofouling

1. Heat exchangers:

Heat exchangers are important constituents because of the fact that –

1) The electric power that can be generated depends in the first place on the rate of heat transfer from the warm ocean water to the working fluid in the evaporator.
2) Furthermore the conversion of this heat into electrical energy with maximum efficiency requires that the temp of the working fluid entering the turbine should be as high as possible and that of the fluid leaving the turbine as low as possible.

Heat exchangers known as evaporators and condensers are a key ingredient, since extensive areas of material are needed to transfer significant amounts of low quality heat of the low temperature difference being exploited. In other words large volumes of water must be circulated through the plant requiring commensurately large heat exchangers.

In an OTEC system departure from ideal behaviour in the turbine and allowance for the energy required to pump the cold water from great depths would reduce the net efficiency for electric power generation to 2 to 2.5 %. This may be compared with the almost 40 % efficiency of modern coal fired power plant. The low conversion efficiency would be compensated by the enormous amounts of heat available in ocean surface water. But in order to utilize this heat to generate electricity economically, water must be pumped through the heat exchangers in both evaporator and condenser at very high rates. In a facility designed to produce 100 MW electrical power for example the total flow of water might be more than 500 million gallons (2.2 million cu m; 1892.6 million liter; 1gallon = 3.7 liter) per hour. The areas of the heat exchanger surfaces for both evaporator and condenser would be about 1 million sq. m (note that 100 MW is only 1 /10 th of the electrical power generated by single modern coal fired or nuclear plant.

The maximum or ideal efficiency for conversion of heat in to mechanical work (or electricity) in a turbine depends on the drop in temperature of the working fluid in its passage through the turbine and the turbine inlet temp. If temp drop in the turbine is 10 deg C (10 K) and the inlet temp. is 20 deg C (20+273 = 293 K), hence the maximum thermal efficiency is 10/293 = 0.034 or 3.4 %.

All these requirements can be met only if there is effective heat transfer in the heat exchangers. Special efforts are being made to improve the engineering design of heat exchangers suitable for OTEC use. Also the constructional materials must have good heat conductivity and resistance to corrosion and erosion by rapidly flowing ocean water. Among the materials being considered prime candidates are –

1) Titanium,
2) Aluminium (or an alloy)
3) An alloy of copper
4) Plastic

2. Biofouling:

The deposition and growth of micro-organisms, called biological fouling or bio fouling, on the cooling water side of the condenser heat exchanger is a problem encountered in most power plants. It would also be expected to arise in both the evaporator and condenser heat exchangers of an OTEC plant. Bio fouling is important because it reduces the heat transfer efficiency. Bio fouling effect and ways of dealing with them are being studied in connection with the design and location of OTEC plants. Such effects are expected to be especially significant for the evaporator heat exchangers where the warmer water would be conductive to the growth of marine organism.

To maintain a viable OTEC heat exchangers provisions must be made to inhibit the formation of fouling layers and to remove any significant fouling that forms. Bio fouling is less with copper (or copper alloy) heat exchangers because traces of dissolved copper act as biocide.

Bio fouling is usually dealt with by

1) Chemical (chlorination)
2) Mechanical (brushes or rubber balls) means.
3) Increasing the flow rate of water is advantageous because the organisms are less likely to become attached to the heat exchanger surfaces. However the flow rate must not be high enough to cause erosion.

3. Working fluid:

The selection of working fluid should be based on considering its cost, safety and environmental impact. Each of possible working fluid (ammonia and propane) has advantages and disadvantages. Ammonia has better operating characteristics than propane and it is much less flammable. On the other hand ammonia forms a noxious vapour and probably could not be used with copper heat exchanger. Propane is compatible with most heat exchanger materials, but it is highly flammable and forms an explosive mixture with air. Ammonia has been used as the working fluid in successful tests of OTEC concept with closed cycle systems.

4.3.5 ADVANTAGES

Solar energy collected and stored as heat by the world's major oceans, can be converted into electricity through a generation process similar to that of conventional power plants, except that in the case of OTEC, no depletable fuel is required. only the requirement to pay for circulating much more warm and cold water than is normally associated with conventional power generation**.** Although there is some seasonal variation in the ocean thermal resource at a given OTEC power plant location, there is little diurnal variation. So, they smooth out the diurnal intermittence of the solar radiation in contrast to other electric power options. Unlike direct solar energy the ocean energy is available continuously rather that only in day time. Since the ocean waters are heated by the sun they constitute a virtually inexhaustible source of energy, OTEC power plants provide a potentially substantial renewable source of base load electricity**.**

4.3.6 DISADVANTAGES

OTEC power generation gives less efficiency.- the achievable net conversion efficiency is only about 2.5 % (Carnot efficiency 7 %) compared to 30 to 40 % associated with conventional power plants because of the OTEC requirement for parasitic power (such as pumping up cold water supply) and other losses. This energy form has very low efficiency and has very high capital cost, because the temperature difference is small even in tropics. It has High capital cost; and there are limitations in bringing the warm and cold water onto shore via aqueducts (artificial cannel/ conduit). Also, there has been a limited market potential for OTEC electricity at OTEC sites.

4.3.7 POTENTIAL PROSPECTS IN INDIA:

India is geographically well placed as far as potential is concerned with a ΔT above 20 deg c between see surface water and 1000 m depth throughout the year. Attractive locations suitable for land based as well as floating OTEC plants are available on the Indian coast and in the island groups in Indian Ocean.

4.4 WAVE ENERGY CONVERSION

Waves can be considered as one of the major offshore energy resources. The enormous power of oceanic waves has been realized by human folks thousands of years ago through the mighty slam into ships and cliffs. The appropriate transformation of this power in to a usable form can lead to a major relief to the energy starved human society.

A number of factors have been associated with the creation of waves in the oceans and seas. These may be wind, gravitational pull from the sun and moon, changes in atmospheric pressure, earthquakes etc. However the most common waves are ones which have been created by the wind and have been considered primarily for wave energy conversion. The frictional effect between the wind and the surface water of the seas and oceans create a rolling circular motion under the water surface. This leads to a forward motion of surface water as waves having a huge amount of kinetic energy as well as raising the surface water level accumulating a huge amount of potential energy. In fact waves store the energy of the wind. The various designs of wave energy converters explore the possibilities of utilizing both the kinetic and potential energy stored the ocean wave.

The waves, once generated by the wind, normally follow a random pattern in which some of them tend to cancel each other and dissipate quickly; whereas others form a regular train of long waves. The focus of interest as a source of energy has been remained often in the regular and powerful waves. Like other renewable energy sources, the wave energy potential is also dependent on the geographical location as well as subject to seasonal variations including diurnal variations in a particular location. Normally, locations having energy densities of about 50 kW per metre of wave front on the average are considered to be good sites for wave energy conversion, e.g. around 100 miles off the north west of Scotland. The performance of a wave energy conversion system has been decided by a variety of factors such as intensity of the storms, wave size, wave length, period and direction of the waves and so on.

4.4 .1 WAVE POWER CALCULATIONS

Energy contained in an ideal wave is proportional to the square of the wave height. The height of the wave (H) is defined as the vertical distance between the through and the crest of a wave. The horizontal distance between two successive crests, measured along the direction of propagation is known as wavelength (λ). The term fetch means the distance over which the wind blows and the duration is the length of time during which the wind blows. The period T is the time interval between two successive wave crests at a fixed point. The number of wave crest which pass a fixed point in a given time is called the wave frequency. The phase velocity (v) of the wave is the ratio between the wavelength and the period and the group velocity (v_g) is defined as the velocity of wave energy propagation.

The energy density of an ocean wave is approximately,

$$W = g \rho (H/2)^2 \text{ J/m}^2$$

Where, ρ is the density of water (roughly 1000 kg/m^3), H is the height of

The power associated with a wave is

$$P = v_g W \text{ W/m}$$

Where, v_g is the group velocity of the wave, that is, the velocity of wave

If the depth of water is denoted by d, in case of deep water where d >> λ, the wave velocity can be expressed by,

$$v = \sqrt{g} (\lambda / 2\Pi)^{1/2} \text{ and } v_g = v / 2$$

In case of shallow water where λ >> d , the wave velocity can be expressed as

$$v = \sqrt{g}\, d^{1/2} \text{ and group velocity, } v_g = v.$$

4.4.2 TYPES OF WAVE ENERGY CONVERTERS:

The primary requirement for designing a wave power plant is the statistical distribution of wave amplitude, wave period and wave direction. The wave activity can be monitored by a installing a wave rider buoy. The buoy monitors wave height and period, energy flux, vertical acceleration, time and buoy location etc through its inbuilt sensors. In order to characterize the wave pattern at a particular location, wave data for a numbers of years are required for higher accuracy.

The wave energy converters can be either an offshore type or a shoreline type. There are various devices which have been designed on trial basis to extract the wave energy in a sustainable way. However a consistent design is yet to be established due to the wide variation of input as well as due to the variations of the associated environmental and geographical parameters.

The offshore wave energy converters may be categorized as Heaving buoys, Hinged contour or Overtopping type. The Tapered channel type is a kind of shoreline wave energy converter. The Oscillating water column category converters can be suitably used for both offshore and shoreline energy conversion.

In the overtopping converters waves are directed connected to a reservoir through a ramp. The intensity of the waves is increased by incorporating a couple of reflector arms along the way the reservoir. The water then moves along the ramp, spills in to the reservoir and flows back to the ocean from the reservoir after driving an appropriate turbine which in turn drives the generator to produce electricity

The heaving buoy converters use the vertical oscillation of water to drive a piston lever mechanism. A wave operated pump can be an example of using this principle. Here the oscillation of water is used to operate a pump which forces water to drive a turbine coupled to generator.

The hinged contour category uses the wave profile for energy conversion. Here cylindrical sections are hinged together and made to float on or near the sea surface which moves according to the shape of the wave. The action of the waves on the sections is used to pump high pressure oil through hydraulic motors which in turn drive electrical generators. Suitable mooring systems are used to keep each cylindrical section in proper position.

In the tapered channel system, an artificial bay or lake is created which is connected to oceans by means of tapered canal. The canal is constructed by means of heavy concrete structure in order to resist the force of reasonable storms and the walls are rising far above the ocean level. The tapering of the canal helps the wave to raise its height progressively and thereby spills over the canal walls into the lake. Thus there is great difference in height between the wave and the ocean level and this differential height is used to generate electricity through hydraulic turbines.

In the oscillating water column type converters, wave are used create an oscillating column of water in a duct like structure whose one end is submerged in the oceans while the other end is connected to an air turbine. The duct is constructed in a slanted position. Wave causes water to fill in the submerged duct and oscillates up and down inside the duct. This oscillating water column in turn gives an effect of suction and compression to the air column inside the duct above the water level. Further this back and forth movement of air column is fed to a special turbine, namely Wells turbine, for generating electricity. The specialty of the Wells turbine lies with the fact that it rotates in the same direction no matter in which direction the air stream flows.

4.4.3 ADVANTAGES

Waves can produce a great deal of energy and this energy is a free one - no fuel needed, no waste produced. Most designs are inexpensive to operate and maintain. There are minimal environmental impacts. Onshore wave energy systems can be incorporated into harbor walls and coastal protection thus providing dual use.

4.4.4 DISADVANTAGES

Since the wave energy depends on the waves - sometimes we may get lots of energy, sometimes nothing. It needs a suitable site, where waves are consistently strong. The devices must be able to withstand very rough weather. It may create disturbance or destruction of marine life and possible threat to navigation from collisions because the wave energy devices rise only a few feet above the water. Waves harness a lot of the sun's power, but they are better for surfing than generating electricity. It also requires high capital investment for initial construction as well as for power transmission cables to the shore.

4.5 TIDAL ENERGY

Harnessing of tidal energy involves the utilization of the head created by tidal movements of ocean water. Basically tides are the effects of the gravitational attraction of the sun and the moon on the earth though the moon has much higher influence on this effect. Because of this effect surface water is pulled up from the earth creating high tides. Also, due to the rotation of the earth, its relative position with respect to the moon changes causing the change of the tidal location as well. In this process a periodic succession of high and low tides takes place. The difference between the high and low tide is called as tidal range. This differential head can be utilized for generating electricity through a hydraulic turbine. The first tidal power plant was commissioned by General De-Gaulle at La Rance in 1966. The feasibility of generating electricity from oceanic tides depends on the tidal range. A minimum average tidal range of 5 to5.5 metres is necessary for harnessing tidal power.

4.5.1 MAJOR COMPONENTS OF A TIDAL POWER PLANT:

The major components of a tidal power plant can be named as the power house, dam and the sluice ways. The dam, which is also termed as a barrage, forms a pool or basin for storing water. It acts as a barrier between a basin and the sea or another basin, when multiple basins are used. The sluice ways are used to direct the water flow into to basins or out of the basins as per requirements for operating the plant.

4.5.2 TYPES OF TIDAL POWER PLANTS:

Depending on the number of basins used, a tidal plant may be a single basin or a multi basin type.

Only one basin is used in case of a single basin type tidal plant. The basin and the sea are separated by the barrage and the sluice ways are suitably located along the dam to direct the water flow between them. The arrangement lets the water to be trapped in the basin after a high tide and during low tide, allows to flow the water from the basin through a turbine thus producing electricity. It is also possible to generate electricity when an emptied basin is being filled up by water during the high tide. Typically the barrage consists of a number of sluice ways and low head turbines.

A multi basin system generally comprises of two basins- one is termed as upper basin, while the other is termed as lower basin. The powerhouse is typically located between the two basins. By controlled operations of the sluice gates, water is made to flow from the upper basin to the lower basin continuously thereby power generation can be made continuous. However since the head of water between the two basins varies from time to time and cycle to cycle the power generated from this arrangement also varies as well.

There are different types of turbines under study for tidal power plant. A bulb type turbine is an axial flow turbine. It is placed in a horizontal hydraulic duct and entirely surrounded by water; a shaft provides communication with the engine room of the power plant. Some other commonly referred turbines are shaft turbines, rim type turbines or straight flow turbines.

4.5.3 FEATURES

The amount of power available from a tidal power system depends on the tidal range and the basin area. Apart from the locations, various other factors cause the head to vary widely in tidal power systems. Also there is a requirement of huge capital investments for construction works as well as power transmission to distant load centres and may require a long time for completion of the project. Sufficient tidal range should be available to override these factors in order to justify a tidal power plant.

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UNIT-5: GEOTHERMAL ENERGY

UNIT STUCTURE

5.1 ORIGIN

The energy which is exploited from the heat of earth's interior can be termed as geothermal energy. This is basically derived from the thermal energy stored inside the earth. Some of the physical phenomena resulting from the internal thermal energy of the earth are the volcanoes, geysers, hot springs etc. Primarily the decay of radioactive materials within the earth's interior leads to the production of this thermal energy. For this reason, the geothermal energy is also referred as a form of fossil nuclear energy. Although there is an enormous amount of thermal energy within the earth, only a portion of this energy can be favourably exploited. The amount of energy which can be feasibly exploited is restricted to certain locations on the earth.

The source of the geothermal energy is the molten core of the earth where the temperature is around 4000 deg C. The central molten core is surrounded by a semi-fluidic material termed as the mantle. The mantle is further covered by the crust. The thickness of the crust ranges from 30 to 90 cm. The crust has a varying temperature at different depth. As the depth increases, so does the temperature. The rate of rise of temperature with respect the depth is around 30 deg C per kilometre. The temperature at the base of the crust is around 1000 deg C which increases proportionally with the depth inside the core.

The most likely sites for geothermal energy are the regions subjected to earthquakes and volcanic eruptions. Magmas, the hot molten rock of the mantle, escaping through the faults or cracks close to the surface create hot spots on the surface spreading from 2 to 3 kilometres around the fault. Geysers, bubbling mud holes etc are examples of such phenomena. The favourable locations for these phenomena are the junction of tectonic plates. The tectonic plates make up the earth's crust and they used to move continuously. During motion, when they collide, a very strong force is developed which causes build up of mountains, tidal waves or earthquakes. There are many geothermal sites located near the edges of Pacific plate.

The first electricity generation using naturally occurring steam was done in Italy in 1904. The following table shows a comparison of power generation from geothermal resources for two years, viz. 1990 and 2003, for some select countries which are known to have substantial potential for geothermal energy.

GEOTHERMAL POWER PLANTS		
Site	**Installed Capacity (MWe)**	
	1990	**2003**
United States	2775	2200
Philippines	890	1931
Mexico	700	953
Italy	545	790
Indonesia	145	807
Japan	215	561
New Zealand	283	421
Iceland	45	200
El Salvador	95	162
Costa Rica	0	161
Kenya	45	127

Source: International Geothermal Association

Apart from electricity generation, geothermal energy can also be favourably used for other thermal applications. The hot underground water can suitably be used for direct heating purposes like in green houses storing vegetables or flowers throughout the year, space heating etc.

As per estimation, the size of geothermal resources is very high. According to the U.S. Geological Survey, the thermal energy within the crust is estimated to be more than 2 x 10^{22} Btu. Though the estimated energy is very high, geothermal energy is considered to be a low grade one since the temperature of the steam or hot water used is only usually low. Also geothermal hot spots are usually scattered and located away from the prospective consumers. Transporting thermal energy over a great distance scarifies the efficiency to a great extent. This implies that the point of use should be closer to the source as far as possible.

5.2 TYPES OF GEOTHERMAL ENERGY SITES

Geothermal energy is appropriately extracted from the hot spots located in certain regions of the earth. The most common extraction system is the hydrothermal system. In this system the thermal energy of the magma is stored in water or steam that fills the pores and fractures in the rock and thus forms the geothermal reservoir. These reservoirs can be classified into wet steam and dry steam systems depending on the type of steams generated. The wet steam system is basically a hot water one. These systems are more abundantly available but have been utilized occasionally because of the technical inconveniences associated with them. On the other hand the dry steam systems, though limited in nature, are often used for electricity generation for similar reason.

Apart from the hydrothermal resources, geothermal resources can be categorized into two other types, namely, geo-pressurized reservoirs and hot dry rocks. The geo-pressurized reservoirs consist of hot, liquid brines. These brines lie in large, deep areas and are usually subjected to high pressures. The energy stored in it is a combination of thermal, mechanical as well as chemical.

The hot dry rocks are the type of geothermal resources which do not have aquifers or fractures (cracks) facilitating fluid to the surface unlike hydrothermal reservoirs. In order to exploit this type of resources water is to be circulated through cracks. The circulating water extracts the heat of the hot dry rocks which can be utilized appropriately. Artificial reservoirs can be made for the purpose by hydraulically fracturing these rocks and creating cracks for water circulation.

5.3 GEOTHERMAL POWER PLANTS

5.3.1 WET STEAM SYSTEM

The temperature of water can reach as high as 370^0C (700^0F) without boiling. This happens in the case wet steam systems. The water trapped in an underground reservoir is heated by the surrounding rocks and comes under very high pressures. This results the water temperature to rise to such a high value without boiling. The hot water thus produced escapes to the surface in some locations. Since the external pressure is lower than necessary to keep the water in liquid form, the hot water flash into steam thus forming a hot spring or a geyser. The locations in which the steam escapes through cracks in the surface are known as fumaroles and tapping of these wet steam fields are done in geothermal wells. When the hot water rises in the well, it flashes into a mixture of hot water and steam in a ratio of about 4:1. From this mixture, the steam is separated and utilized to run turbines for electricity generation while the hot water can be used for direct heating applications or for a desalination plant etc.

5.3.2 DRY STEAM SYSTEMS:

In some geothermal locations the underground pressure is not much higher than the atmospheric pressure though the temperature is high. These locations form the dry steam fields. Here the underground water under pressure boils by the heat of the surrounding rock and generates steam at about 165 deg C and 100 psi pressure. The steam thus generated is tapped through geothermal wells and can be used directly to drive a turbine for electricity generation.

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UNIT-6:MAGNETOHYDRODYNAMIC00.(MHD)

ENERGY CONVERSION

UNIT STRUCTURE

OBJECTIVE

In this chapter the principle of operation along with classifications and features of Magneto hydro dynamic (MHD) energy conversion are discussed.

INTRODUCTION

Magneto hydrodynamics (MHD) is one of the most promising fossil fuel technologies for reducing air pollution. Direct conversion of thermal energy of fossil fuel into electricity is possible with the help of this technology. Thus it eliminates the intermediate phases of converting thermal energy into mechanical energy which is done in case of conventional thermal power plants before electricity is generated by the alternator.

6.1 NEED OF MHD SYSTEMS

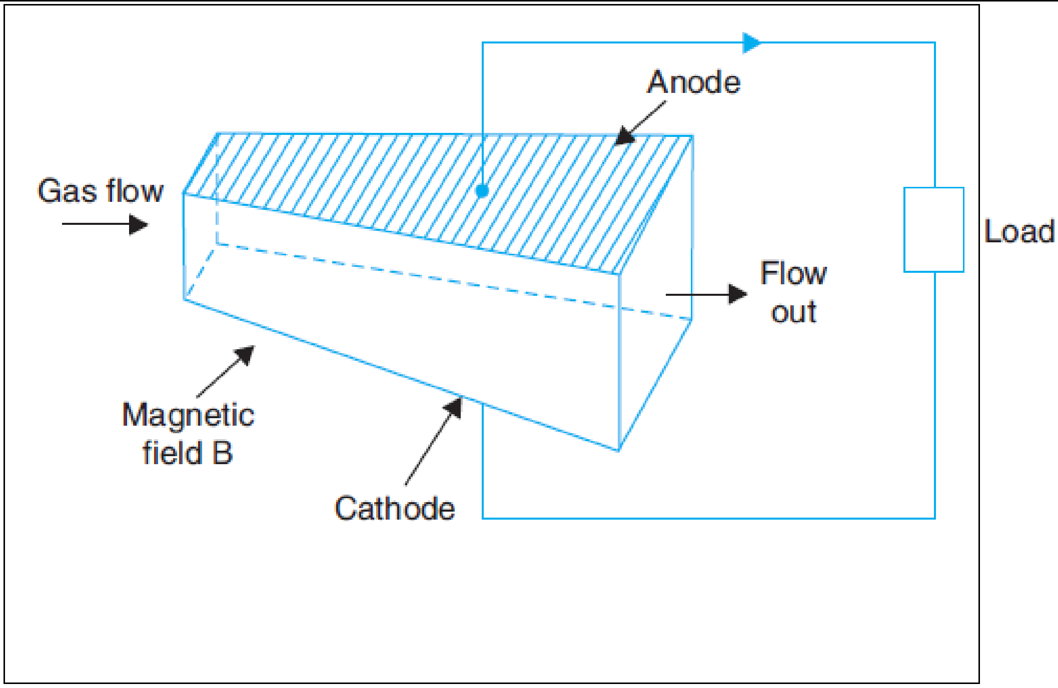
The exponential increase in the energy demand day by day is creating a global concern. The conventional sources of energy are apparently inadequate to meet the present demand for energy that stem from mainly industrial as well as agricultural growth. In order to reduce the gap between the demand and supply, continued efforts have been made which include the development of existing conventional technology and harnessing of renewable and non-conventional energy sources. In this effort, reduction of pollution to the environment as well as improved efficiency of the system is getting higher priority and the MHD power generating systems appear to be more appealing in this context.

6.2 PRINCIPLE OF OPERATION OF MHD

The MHD concept employs the classical thermodynamic principles for electricity generation. The thermodynamic cycle used in MHD is comparable to those of combustion turbine.

Here heat is directly converted into electrical energy. MHD employs the same principle like the conventional electrical generator which involves the movement of conductor in a magnetic field to induce an e.m.f. in the coil. In case of steam power plant, energy conversion takes place basically in two stages. In the first stage the heat energy generated from the fuel is converted into mechanical energy which is then used to drive the generator to produce electricity in the second stage. In case of MHD, there is no moving part. The hot gases produced by the combustion of the fuel directly produce the electrical energy. An MHD directly converts the internal energy of the gas into electrical energy without a conventional electric generator which gives it a distinctive place in power generation.

An MHD employs very high temperature electrically conducting gas. These gases are then are made to flow through a strong magnetic field at a very high velocity. The electrical energy thus produced is collected from the stationary electrode. MHD basically produces d.c. which has to be converted into a.c. through inverters.



Source: http://www.newagepublishers.com

Fig. 1- Basic Principle of MHD Generator

The ionization of the gas is achieved through heating the gas to very high temperature. The high temperature drives out the outer electrons from the atoms or gas molecules. Thus the particles become electrically charged and the gases move into the plasma state. The temperature range of thermal ionization of air is around 5000 deg C to 6000 deg C. In case of products of fossil fuel combustion or inert gases extremely high temperatures are required for thermal ionization.

The Faraday's law of electromagnetic induction states that a relative motion between a conductor and a magnetic field induces a voltage in the conductor. The principle of operation of an MHD system is based on this same law. The conductor referred to in the Faraday's law may be in solid, liquid or gaseous form. The MHD generators make use of hot ionized gas at around 3000 deg C as conductors. This ionized gas is made to flow through a duct where it is exposed to a strong magnetic field at right angles. Since the gas is in electrically conducting state and is moving in a magnetic field, a voltage is generated. An MHD generator supplies direct current (d.c.) which can be extracted by placing the electrodes in suitable positions.

6.3 CLASSIFICATION OF MHD SYSTEMS:

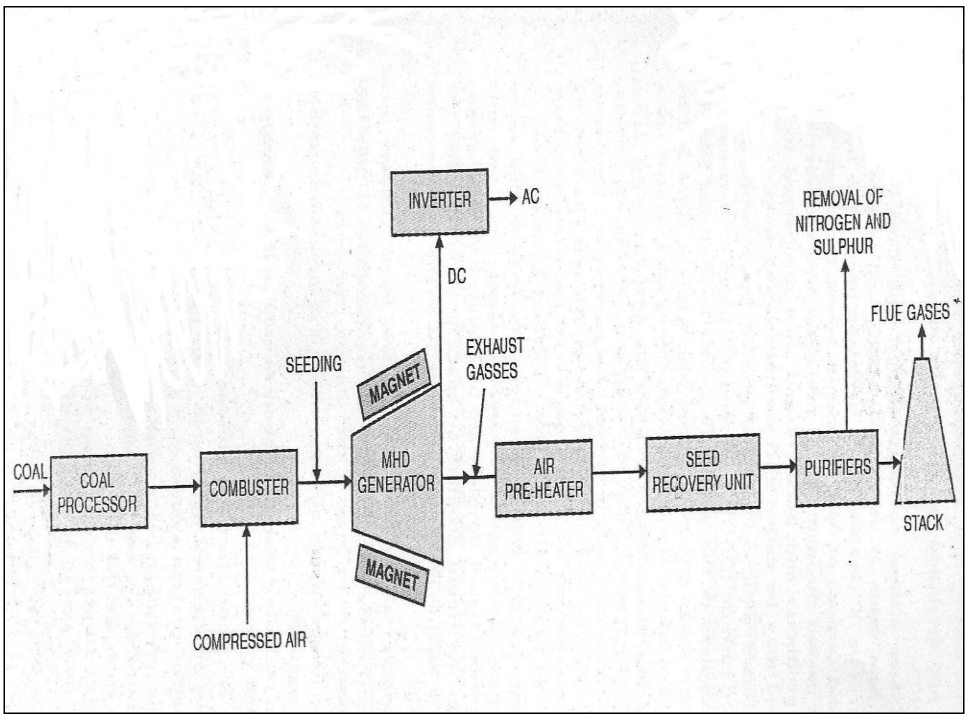
Based on the cycle of operations, an MHD system can be classified in two categories. These are -

1. Open cycle systems
2. Closed cycle systems

The working fluid in an open cycle system is usually discharged to the atmosphere after the electricity generation whereas in the closed cycle system the fluid is recycled to heat source for repetitive use. Typically, an open cycle MHD system runs on combustion products with air as the working fluid and a closed cycle system uses helium or argon as the working fluid.

6.3.1 OPEN CYCLE MHD SYSTEM

An elementary coal based open cycle MHD system is shown in the figure where combustion gas is passed through a magnetic field at high temperature and pressure. Here the processed coal is burnt in a combustor with preheated air. The temperature in the combustor is very high, typically around 2600 deg C and pressure is around 12 atmospheres. Under such conditions the combustion products enter into the plasma state. A seeding material, namely, potassium carbonate is used which increases the electrical conductivity of the resulting mixtures up to about 10 Siemens /m. The mixture is then allowed to expand through a nozzle and is passed through a strong magnetic field of about 5 to 7 Tesla at a very high velocity. During the expansion of hot ionized gas, movements of ions towards suitable electrodes take place, thus causing the flow of an electric current. The electric current thus produced is d.c. form and requires an inverter to convert it in to alternating current. The exhaust gas from the MHD



Source: Non-Conventional Energy Resources, Saeed, S.H.& Sharma, D.K.

Fig. 2 – Block diagram of an open cycle MHD system

generator is still having a high temperature. This heat is used to preheat the air before feeding it into the combustor. Seed materials are also recovered from the exhaust for reuse by employing appropriate processes and after removing the harmful elements, the gas is discharged in the atmosphere.

In MHD power generation any fossil fuel, coal, oil or natural gas can be used. Typically, graphite electrodes and duct made of boron nitride are used. The open cycle system is however not suitable for commercial purpose. When the MHD unit is operated in combination with a steam power generating unit, the efficiency of the process gets improved. In such combined system, the heat from the exhaust of the MHD generator is used to generate steam which drives a steam turbine for electricity generation.

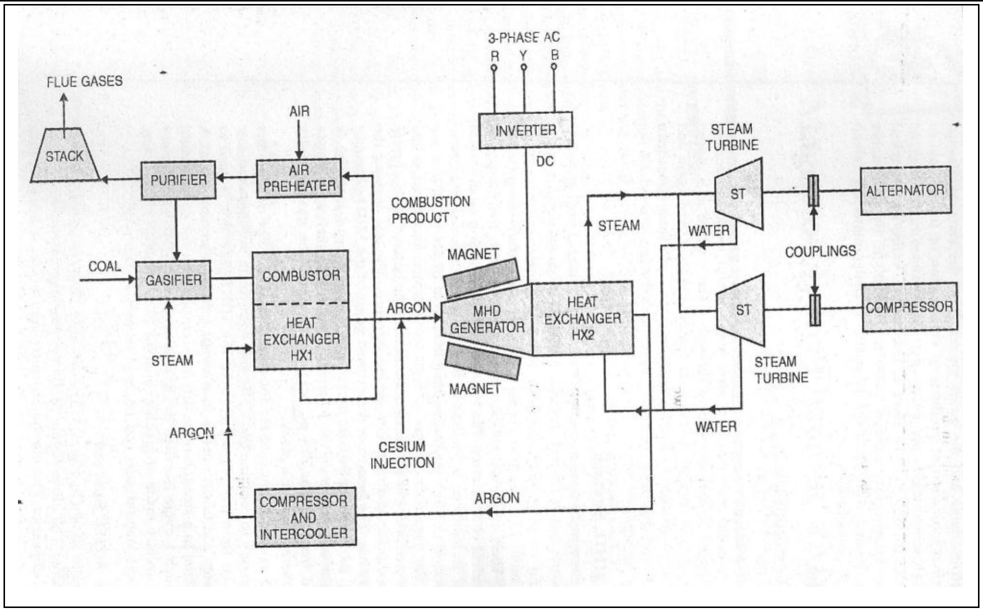
6.3.2 CLOSED CYCLE MHD SYSTEM:

In a closed cycle, working fluid is re-circulated in a closed loop. A closed cycle MHD system may of two types. One type is plasma converter. Here an ionized gas, namely, helium or argon, is used and cesium is typically used as seeding material. The other type may be a liquid metal converter. In this type of converter, vapour of metal or metal in liquid form is used.

The complete system can be apparently divided into three loops or sections which are interlinked by two heat exchangers. The first loop involves the gasification of coal where by hot gas of around 520 deg C and heating value of about 5.35 MJ/kg is produced. This gas when burnt in the combustor generates heat which is then transferred to the working fluid of the MHD generator with the help of the first heat exchanger (HX1). The products of the combustion are diverted through the air pre-heater and after purification they are released to the atmosphere. This first loop may also be termed as the external heating loop.

In the second loop, the hot working fluid, namely, the hot argon gas, is seeded with cesium and is made to flow through the MHD generator to produce direct current (d.c). in order to connect the output of the MHD generator to supply grid, the d.c. output needs to be converter into a.c. by means of inverter.

The third loop, which may also be termed as steam loop, is associated with the recovery of the heat of the working fluid with the help of a second heat exchanger (HX2). The heat of the

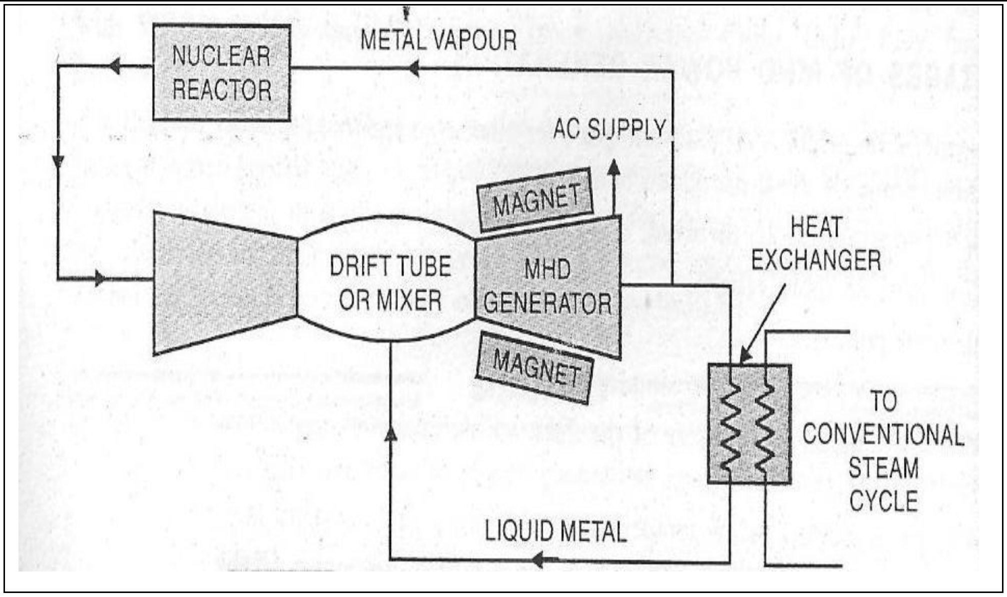


Source: Non-Conventional Energy Resources, Saeed, S.H.& Sharma, D.K.

Fig. 3 - Closed Cycle Plasma MHD system

hot working fluid is extracted and transferred to water to produce steam. This steam is used to drive a steam turbine – alternator set for generating three phase power. A part of the steam generated is also used to drive the compressor. On the other hand, the working fluid is fed back to the first heat exchanger through the intercooler and compressor.

In a liquid metal closed cycle MHD system, super heated metallic vapour expands through a supersonic nozzle into a drift tube or mixer. The vapour accelerates the atomized sub-cooled liquid droplets as well as also condenses the liquid droplets so that the fluid in the liquid state enters the MHD generator.



Source: Non-Conventional Energy Resources, Saeed, S.H.& Sharma, D.K.

Fig. 4 - Closed Cycle Liquid Metal MHD system

Although a closed cycle system can be used to generate more useful power at lower temperature, for example, around 1600 deg C, various critical issues like heat exchanger design, purity of working fluid etc should be appropriately handled beforehand for such a system.

6.4 FEATURES OF MHD SYSTEMS

The MHD power generation basically does not require any moving parts. This feature makes them more reliable as compared to other conventional methods. Also its high temperature operation assures higher efficiency. The MHD power generation reduces the thermal pollution. The MHD generators typically have low specific weight and high power density and are capable of rapid start. They are simpler in concept and allow higher capacity due to flexibility in the size of the duct. Above all, apparently, all heat sources like coal, oil, gas, solar and nuclear can be suitably used in MHD power generations.

Although the MHD power generation offer a number of advantages as compared to the conventional methods, their commercial applications are restricted due to the problems associated with the use of high temperature as well as corrosive and abrasive environment.

SUMMING UP

The repeated conversion of one form of energy into another form reduces the overall efficiency due to the cumulative losses in different conversion stages. For example, heat of the fuel is used to generate steam. The energy in the steam is transformed into mechanical energy which drives to generator to produce electrical energy. The typical range of overall efficiency of a thermal power plant thus varies from 37 to 40 %. On the other hand the MHD power generation facilitates the direct conversion of heat into electricity. This eliminates the intermediate energy conversion stages and therefore can lead to better overall efficiency. With further development of new and sophisticated technologies, MHD can be expected to be suitable for wider commercial applications.

PROBABLE QUESTIONS

1. What are the advantages of magneto-hydro-dynamic power generation over the conventional methods?
2. Explain the basic principle of a MHD generator.
3. How do you distinguish between Open cycle MHD system and Closed cycle MHD system?
4. Explain the operation of an Open cycle MHD system.
5. Describe the operating principles of closed cycle plasma and closed cycle liquid metal MHD systems.

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UNIT-7: ELECTROCHEMICAL ENERGY STORAGE SYSTEM

UNIT STRUCTURE

OBJECTIVE

In this unit, basic electrochemical energy storage systems, namely, batteries, their types and working principles as well as the role of carbon nano-tube in electrodes are discussed.

INTRODUCTION

The ability to convert easily and efficiently into different forms has made electricity a versatile form of energy. For example electricity can be efficiently converted into heat energy. Also the efficiency by which electricity can be converted into heat energy is usually higher than the efficiency of conversion of heat energy into electricity due to that fact that heat represents a disordered form of energy in atoms, whereas, the electricity is a highly ordered form of energy. Typical overall conversion efficiency of a thermal power plant operating on fossil fuel is below 40 %. However, the major drawback lies with the electricity is its large scale storage.

In general, almost all the electrical energy generated by the conventional methods is being consumed simultaneously with the generation. There is little scope for large scale storage of generated electricity. Also, large scale storage of electricity may not be essential for conventional power plants as the generation can be varied according to the requirement of load. Ideally if the demand is more, generation of electricity can be increased and if the demand is less, the generation of electricity can be reduced. This may only be an issue of variation of fuel consumption in case of fossil fuel power plant.

But the situation is not identical for non-conventional or renewable energy sources. Most of these sources are erratic or unpredictable in nature. Besides, demand and availability in such cases often mismatch. In many situations when we need the power, theses sources may not be adequate to meet the demand. On the other hand, they may be abundantly available when there is very little requirement of electricity. For example, solar photovoltaics or wind power can not meet the load demand all the time throughout the year. The energy storage systems thus become inevitable for such cases in order to supply the power as per requirement. The electrochemical energy storage systems are the most common and widely used in various applications.

7.1 BATTERIES

Batteries used to store energy in electrochemical form. They are used to generate electricity by chemical reaction to meet the power requirement. Batteries can be found in many applications ranging from toys to satellites. The growth rate of batteries is estimated to be 6 % per annum.

A battery makes use of electro-chemical oxidation reduction reaction (redox) in order to convert the chemical energy of its active material into the electrical energy. Its one way conversion efficiency ranges from 85 to 90 %. The electrochemical energy may be categorized as an intermediate form, namely the, semi ordered form which is neither completely ordered as electrical form of energy nor completely disordered like the heat energy.

For recharging the battery in case of rechargeable ones, a reverse process is used where electrons are transferred form one material to another with the help of electric circuit. Direct electron transfer takes place in case of non-electrochemical redox reaction involving only heat like in rusting or burning. Batteries can provide higher conversion efficiencies as they convert chemical energy into electrical energy through electrochemical reactions and thus they are free from the limitations imposed by thermodynamic laws in Carnot cycle as in case of heat engines.

7.1.1 BASIC COMPONENTS

The basic electrochemical unit is usually termed as a cell. A battery typically comprises of a number of cells. These cells may be connected in series or parallel depending on the output voltage and current requirement.

A cell basically comprises two electrodes termed as anode and cathode and an electrolyte. An electrode either gives up electrons or accepts electrons through the external circuit depending on its types, namely, anode or cathode during the electrochemical reaction. The electrolyte which is the ionic conductor serves as the medium for transfer of ions between the electrodes inside the cell. Typical electrolyte is in the liquid form like water or other solvents. They are added with salt, acid or alkalis to increase the ionic conductivity. However, solid electrolytes are also used in some batteries. The selection of anode and cathode materials is usually governed by the weight and capacity of the cell. The materials which results in reduced weight as well as higher cell capacity are normally preferred although, such combinations may not be feasible all the time due to various problems such as reactions with other cell components, polarization, high cost and so on.

7.2 CLASSIFICATION OF BATTERIES

Based on their recharging capability, the electrochemical batteries can be classified into the following types:

1. Primary battery and
2. Secondary battery

The primary batteries are those batteries which convert the chemical energy into the electrical energy through electrochemical reaction in an irreversible manner. This implies that these batteries can not be recharged again and they need to be discarded after they are completely discharged. They are typically used in applications requiring high energy density for a single time.

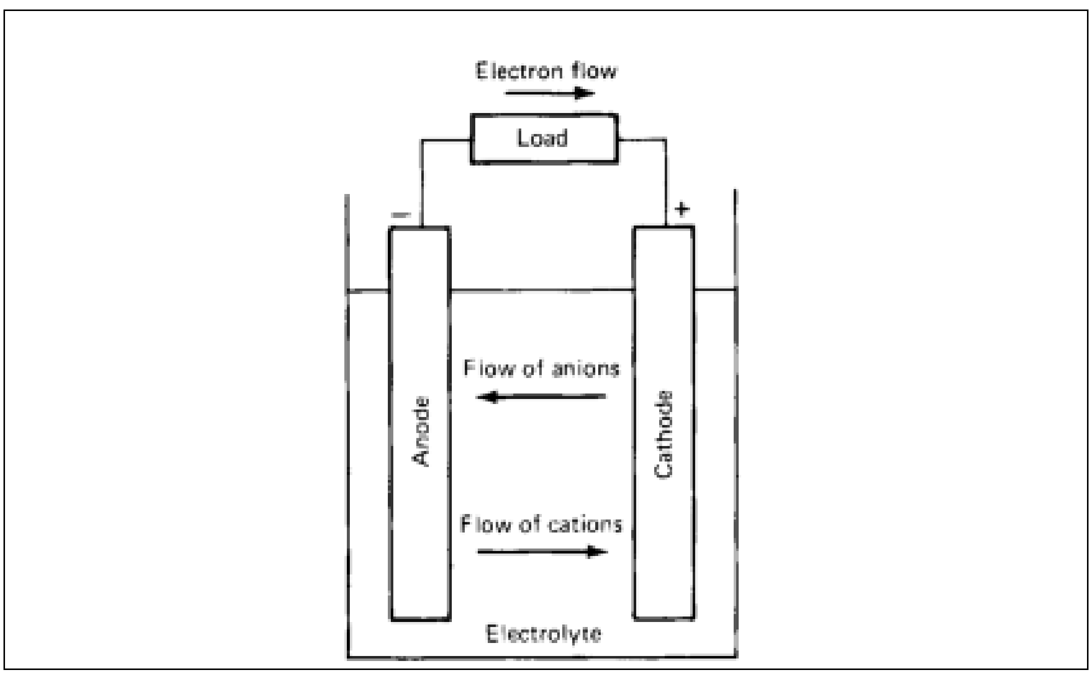
The secondary batteries are also called as the rechargeable batteries. In such batteries, the electrochemical reactions are reversible. Therefore, once they are discharged, they can be recharged again by an external power source. While discharging, such batteries convert chemical energy into electrical energy. On the other hand, during charging, they convert the electrical energy back into the chemical energy to be stored in the battery for future use. In each process, whether charging or discharging, a fraction of the energy is dissipated to the surroundings in the form of heat and the overall conversion efficiency ranges from 70 to 80 %.

The reserve batteries are usually used for specific applications where the other batteries can not meet the requirement. They are supposed to withstand severe environmental conditions. These batteries are capable of delivering high power for relatively small durations. Missiles and other weapon systems can be cited as examples of applications of such batteries.

7.3 OPERATION OF BATTERIES

7.3.1 DISCHARGE MODE

In the figure a cell is connected across an external load. During the discharging operation, electrons will flow from the anode to the cathode through the external load. On the other hand, the cations or positively ions will flow to the cathode and the anions or negative ions will flow to the anode through the electrolyte thus completing the electrical circuit.



Source: Handbook of Batteries, Linden & Reddy, 2002

Fig. 1 - Electrochemical operation of a cell (discharge).

Considering the anode and cathode material as zinc (Zn) and chlorine (Cl_2) the reactions during discharging operations can be summarised as below.

At the negative electrode, oxidation or anodic reaction takes place by which loss of electron occurs:

$$Zn \rightarrow Zn^{2+} + 2e$$

At the positive electrode, reduction or cathodic reaction takes place by which gain of electron occurs:

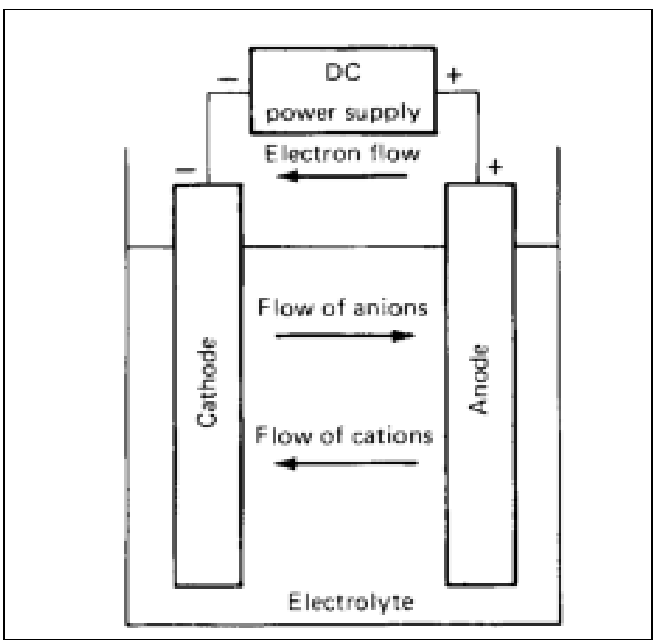
$$Cl_2 + 2e \rightarrow 2Cl^-$$

The overall reaction for discharge operation thus can be written as:

$$Zn + Cl_2 \rightarrow Zn^{2+} + 2Cl^-(ZnCl_2)$$

7.3.2 CHARGE MODE

In case of charging operations of a rechargeable battery, the current flows in the reversed direction as compared to the discharging. The oxidation reaction occurs at the positive electrode whereas the reduction takes place at the negative electrode. Since, oxidation occurs at the anode and reduction takes place at the cathode, by definition, the anode now becomes the positive electrode while the cathode becomes the negative electrode.



Source: Handbook of Batteries, Linden & Reddy, 2002

Fig. 2 - Electrochemical operation of a cell (charge).

Considering the similar cell (Zn/Cl_2) as in discharging operation above, the reactions during charging operation can be expressed as follows.

At the negative electrode, reduction or cathodic reaction takes place by which gain of electron occurs:

$$Zn^{2+} + 2e \rightarrow Zn$$

At the positive electrode, oxidation or anodic reaction takes place by which loss of electron occurs:

$$2Cl^{-} \rightarrow Cl_2 + 2e$$

The overall reaction for charge operation thus can be written as:

$$Zn^{2+} + 2Cl^{-} \rightarrow Zn + Cl_2$$

7.4 TYPES OF BATTERIES

Some major types of commonly used batteries can be named as below:

- Lead-acid (Pb-acid) battery
- Nickel-cadmium (NiCd) battery
- Nickel-metal hydride (NiMH) battery
- Lithium-ion (Li-ion) battery
- Lithium-polymer (Li-poly) battery
- Zinc-air battery

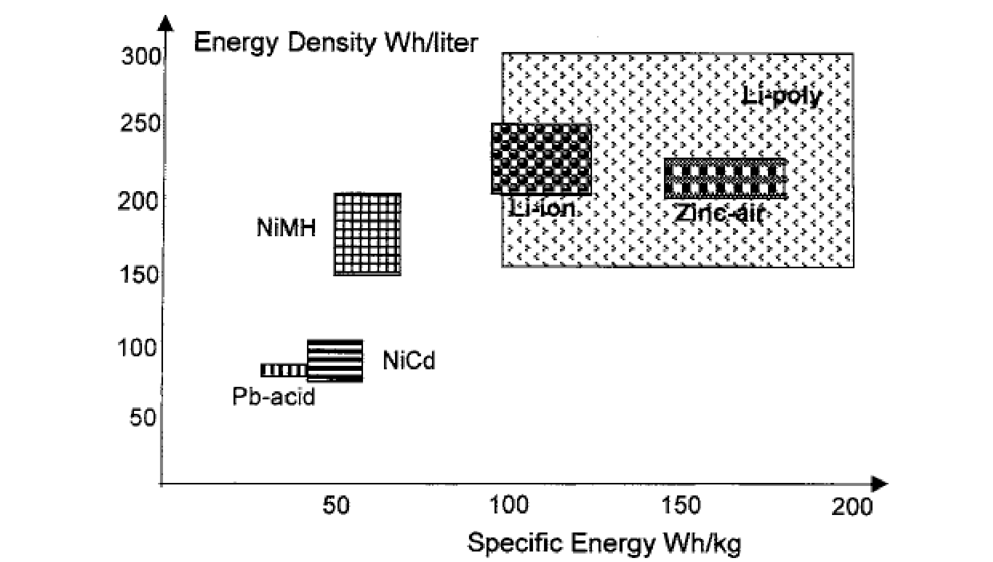
There are various novel types of batteries which are being developed for specific applications like electric vehicles, spacecraft and utility load levelling etc including for applications in renewable power systems.

The average voltage in different types of batteries varies during discharge which is decided by the electrochemistry. The selection of the type of battery for a specific application is usually done through optimization of performance and the cost. Typical cell voltage during discharge in some of the batteries can be found in the table.

Electrochemistry	Cell Voltage	Remark
Lead-acid	2.0	Least cost technology
Nickel-cadmium	1.2	Exhibits memory effect
Nickel-metal hydride	1.2	Temperature sensitive
Lithium-ion	3.4	Safe, contains no metallic lithium
Lithium-polymer	3.0	Contains metallic lithium
Zinc-air	1.2	Requires good air management to limit self-discharge rate

Source: Wind and Solar Power Systems, Patel, M.R., 2000.

Table 1 - Average Cell Voltage During Discharge in Various Rechargeable Batteries.



Source: Wind and Solar Power Systems, Patel, M.R., 2000.

Fig. 3 - Specific energy and energy density of various electro-chemistries.

7.4.1 LEAD-ACID BATTERY

The most common type of rechargeable battery is the Lead-Acid battery. This type is commonly preferred due to its maturity as well as higher performance to cost ratio. However the energy density by weight and volume is the least in this type of battery. Here, water and lead sulfate are formed during discharge and the sulphuric acid electrolyte gets diluted by the water. This results in the decrease in specific gravity of the electrolyte along with the decrease in the state of charge. During recharging, the reaction is reversed forming lead and lead dioxide at the negative and positive plates respectively. The battery gets revived ideally into its original state of charge.

There are various versions available with the lead-acid battery. They may be shallow-cycle, deep-cycle or sealed gel-cell version. The shallow-cycle versions are suitable for short burst of energy and are typically found in automobile applications. When the applications require repeated full charge and discharge operations, the deep-cycle versions are preferred. The deep-cycle versions are found in a wide range of applications. Another version of lead acid battery, namely the sealed gel–cell version uses electrolyte in a non-spillable gel form. This makes the battery capable to be mounted sideways or upside down. However, since this version of lead acid battery is kind of costly one, they are used in specific applications only, for example in military avionics.

7.4.2 NICKEL CADMIUM BATTERY

The Nickel Cadmium (NiCd) cells consist of positive electrodes made of cadmium whereas the negative electrodes made of nickel hydroxide. Separation of electrodes is accomplished by a nylon separator and potassium hydroxide electrolyte in a casing made of stainless steel. These batteries are used in most of the applications requiring repeated charging – discharging operations.

As compared to the conventional lead-acid batteries, the NiCd batteries have usually lesser weight, longer deep cycle life and are more temperature tolerant. On the other hand, these batteries suffer from a memory effect which causes degradation of the capacity while left unused for a long time. Besides, cadmium is also being currently reviewed in the context of environmental regulations. For such reasons, NiMH and Li-ion batteries are replacing the NiCd batteries as found in laptop computers and other similar products.

7.4.3 NICKEL-METAL HYDRIDE BATTERY

The NiMH batteries possess an improvement in energy density as compared to NiCd ones. Here in order to eliminate the scrutiny of cadmium in respect of environmental concerns, metal hydride is used for the anode. Also these types of batteries have negligible memory effect on their performance. However, their major drawbacks include lower ability to deliver high peak power, high self-discharge rate, greater scope for damage caused by overcharging and high cost as well.

7.4.4 LITHIUM-ION BATTERY

Lithium-ion batteries usually have around three times the energy density as compared to lead-acid batteries. This is due to the fact that lithium’s atomic weight is low, namely, 6.9 against 207 of lead. Since these cells give higher cell voltages of around 3.5 Volts, lesser number of cells than the lead acid batteries (cell voltages around 2.0 Volts) is required to be connected in series for producing a given voltage. This in turn reduces the manufacturing cost of the battery for a given output voltage. These batteries require appropriate charging circuitry for providing protection against overcharging.

7.4.5 LITHIUM-POLYMER BATTERY

Lithium-Polymer is basically a lithium battery with solid polymers as electrolytes. It consists of a lithium film bonded to a thin layer of solid polymer electrolyte. This solid polymers help in increasing the cell's specific energy.

7.4.6 ZINC-AIR BATTERY

These batteries comprise of zinc as negative electrode, potassium hydroxide as electrolyte and carbon as positive electrode exposed to the air. The carbon electrode, which can also be termed as air- cathode, facilitates reduction reaction during discharge whereas the zinc electrode is oxidized during this operation. Oxygen from the air is absorbed during discharge and is converted to oxygen ions for transporting to zinc anode. During charging operations, oxygen is generated in the reverse way. The Zinc-Air batteries require proper management of air for satisfactory performance.

7.5 EQUIVALENT ELECTRICAL CIRCUIT

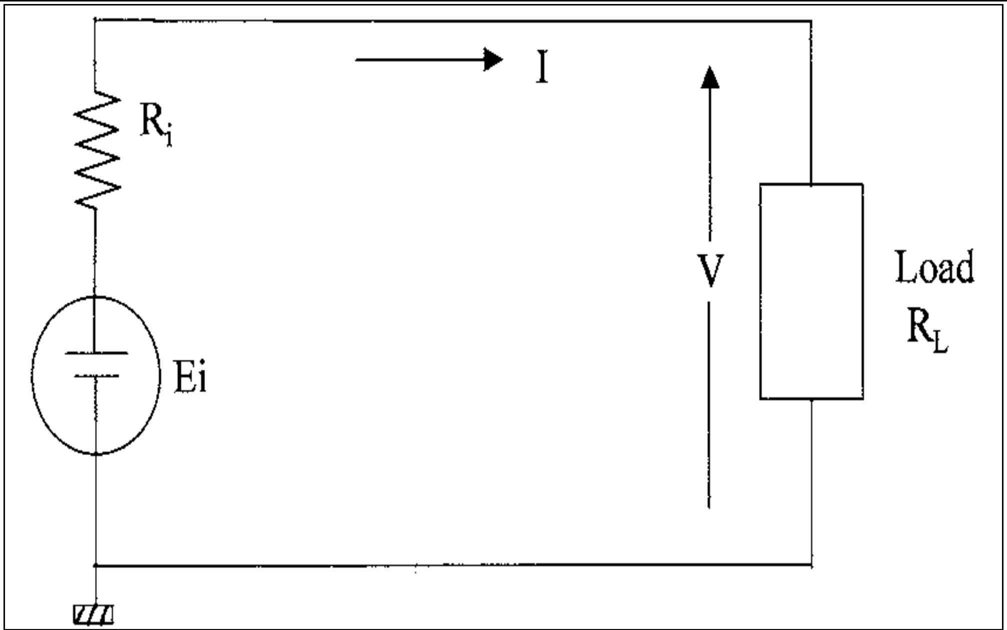
The equivalent circuit of a battery can be seen in the figure. A battery can be represented by a constant voltage source in series with small internal resistance. In general, the open-circuit or electrochemical voltage of the battery decreases while the internal resistance increases, both in a linear way with the Ah of discharge. This indicates that a partially discharged battery has a lower open-circuit voltage and higher internal resistance as compared to the fully charged state. This can be expressed mathematically as follows.

$$E_i = E_o - K_1 Q_d$$

$$R_i = R_o + K_2 Q_d$$

Where,

E_i , R_i	=	open-circuit or electrochemical voltage and internal resistance of the battery respectively at the instant i
E_o , R_o	=	Voltage and internal resistance of the battery respectively under fully charged condition
Q_d	=	Ah of discharge of the battery
K_1 , K_2	=	constants to be found by curve-fitting the test data



Source: Wind and Solar Power Systems, Patel, M.R., 2000.

Fig. 4 - Equivalent electrical circuit of battery showing internal voltage and resistance.

The terminal voltage decreases drops with increasing load (R_L) and the power (P) delivered to the external load is given by,

$$P = I^2 R_L$$

Where,

I = Current through the load and

R_L = Resistance of the load

In certain applications, a battery may be required to supply maximum possible power over a short duration as the case may be in a heavily loaded motor. The maximum power that can be delivered by a battery can be determined with the help of maximum power transfer theorem. According to this theorem, the condition for delivering maximum power from the source to load is that the internal impedance of the source must be equal to the conjugate of the load impedance. This implies that for delivering maximum power to a DC load the necessary condition is as follows.

$$R_L = R_i$$

Where, R_L = resistance of the load

R_i = internal resistance of the battery

This implies,

$$P_{max} = E_i^2/4R_i$$

The maximum power P_{max} also varies with the state of charge since E_i and R_i depend on the state of charge. As the battery is being discharged, the efficiency decreases resulting in more heat generation. The internal loss is given by I^2R_i while the efficiency (η) at any state of charge can be expressed as,

$$\eta = R_L/(R_L+R_i)$$

7.6 ROLE OF CNT IN ELECTRODES

With the growth of portable electronics along with alternative energy demands, the advanced energy storage systems are gaining much more importance. Batteries with Higher power and energy densities are of great demand in various applications. To meet the various requirements, batteries should have increased storage capacity, greater rate capabilities as well as good cyclability. In this context, the Carbon nanotubes (CNTs) have a considerable impact in electrochemistry. The use of Carbon nanotubes in electrodes of an electrochemical system is found to be beneficial in a number of ways. In particular, such electrodes offer enhanced rates of electron transfer along with reduced surface fouling.

Carbon nanotubes can serve as the cathode in lithium-ion batteries. The lithium storage reaction on the surface of carbon nanotubes can be much faster and thus can deliver high power. In the context of performance of lithium-ion batteries, typical CNT based electrodes can produce very high power outputs in short bursts and steady, lower power for long periods. The energy output for a given weight can be over five times more than for conventional electrochemical capacitors and the total power delivery capability may be around 10 times that of lithium-ion batteries.

7.7. SUMMING UP

The electrochemical storage systems can play an important role in the arena of energy demand and supply. They can certainly help a lot in meeting energy requirement in case of portable or mobile applications. In particular, they can be very much useful in harvesting the intermittent or unpredictable sources of energy such as solar, wind or most of the similar renewable energy sources, from the point of storing energy which can be used later on as per requirement. Besides, with the advent of newer technologies, energy densities, power handling capabilities etc. of such systems are expected to be enhanced a lot in near future and they can have a major role in reducing the gap between energy demand and supply in various applications.

PROBABLE QUESTIONS

1. Justify the need for an energy storage device.
2. What are the types of battery? Define with suitable example.
3. Distinguish the features of NiCd, NiMH and Li-ion batteries.
4. Explain the charging and discharging operations of a battery.
5. Explain the condition for maximum power transfer from a battery with the help of its equivalent circuit.

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UNIT-8: MAGNETIC AND ELECTRIC STORAGE SYSTEM

UNIT STRUCTURE

OBJECTIVE

In this unit, modern energy storage devices, namely, super conducting magnetic energy storage (SMES) systems and super capacitor energy storage systems (SCES) are discussed.

Introduction:

With continuous increase in consumption of energy, the quest for new and renewable energy sources have also been gaining more and more focus. However, along with the exploration and exploitation of new energy resources, finding an efficient device to store this energy is also equally important. Batteries, capacitors and Superconductive Magnetic Energy Storage (SMES) coils can be named as three important types of energy storage devices. These devices are used to store energy in various forms (e.g. chemical, electrical and magnetic). Batteries can be found in a wide range of applications. The conventional capacitors have lower energy densities making them suitable for low to medium power applications whereas the Super Capacitor Energy Storage (SCES) systems much higher energy densities. SMES systems can be used economically in high power applications.

8.1 SUPER CONDUCTING MAGNETIC ENERGY STORAGE (SMES) SYSTEMS

With the advances of modern society as well as the technological development, an uninterrupted supply of power is becoming an urgent need of the current situation. In order to avoid the negative impacts such as interruption of a production process or to avoid the damage of a system or utility caused by the fluctuating power for example, a reliable source of power is becoming very much essential nowadays. This situation urges the researchers to go beyond the conventional energy storage devices. The SMES is kind of device which is expected to serve as one of the better energy storage systems in the present day crisis.

It is also often seen or observed that though the problems of the industries, namely manufacturing or others have been tackled by various ways at varying degrees, the sufferings the domestic sectors as well as non manufacturing industries due to poor quality of power are still in need to be appropriately addressed in most of the cases. There is a range of electronic products and domestic utilities which are very much sensitive to fluctuation or interruption of the main voltage and thus most likely to be suffered in a worst manner by the poor power quality. An appropriate and efficient energy storage device can compensate for such problems to a reasonable extent.

The superconducting magnetic energy storage system (SMES) is one of the most advanced techniques used for storing energy. SMES can demonstrate enough potential for their use in distribution grid.

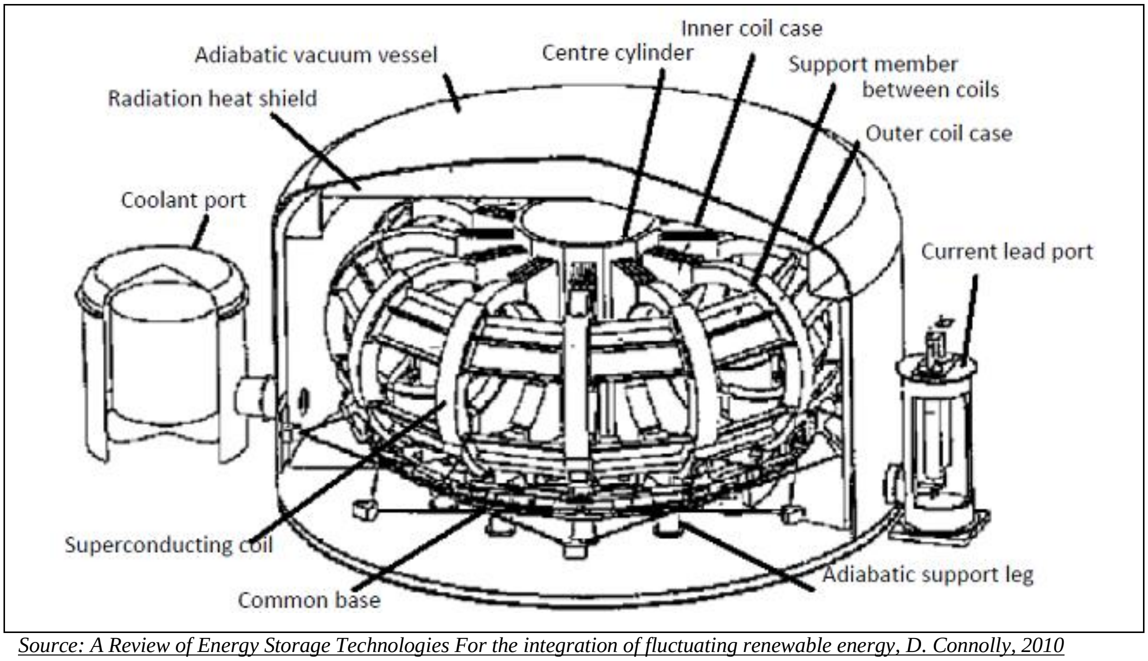
8.1.1 WORKING PRINCIPLE OF SMES

The storage capacity of a device made of certain materials can be enhanced by replacing the materials with superconducting ones. The electrical resistance of a low temperature superconducting material is almost zero. These superconductors can be categorized into two types, namely, low-temperature superconductors and high-temperature superconductors. The low-temperature superconductors need to be cooled in the range of 0 K to 7.2 K while for the high-temperature types, temperature ranges from 10 K to 150 K.

- Superconductivity, first discovered by H. K. Onnes in 1911, is a phenomenon characterised by complete absence of electrical resistance that occurs in certain materials at low temperatures
- A superconductor is an element or metallic alloy, which lose all electrical resistance when cooled to near absolute zero (-273.15 degrees Celsius)
- Electric current can flow through superconductors without any energy loss (very difficult to produce ideal superconductor practically)

In SMES, energy is stored in a magnetic field. The magnetic field is created by flowing DC through a coil. The coil consists of super conducting material and needs to be cryogenically cooled. The direct current flowing through the coil creates a magnetic field that stores energy. In case of conventional coils, for example, the coils made of copper wires, heat dissipation will occur due the resistance offered by the wire to the flow of current. On the other hand, in case of super conducting materials which offer zero resistance to the direct current at low temperature, dissipation of energy as heat does not occur. Thus by using superconducting materials in the coil, energy can apparently be stored for an indefinite period which can be extracted back whenever required. The difficulty lies in maintaining these characteristics of the materials without making the systems too cold. A cooling device is necessary for maintaining the low temperature in SMES system.

A SMES with different components are shown in Fig. 8.1. The different components of a SMES are discussed later.



Source: A Review of Energy Storage Technologies For the integration of fluctuating renewable energy, D. Connolly, 2010

Fig. 8.1- Components of a superconducting magnetic energy storage device

The main feature of SMES is that they can be recharged very quickly and the charging and discharging cycle can go on thousands of times without any significant damage to the magnet. The expected life time is more than 20 years. Usually the time taken by SMES for discharging completely is less than one minute. The complete discharge may also be achieved in the range of milliseconds with appropriate PCS (power conversion/conditioning system) support. Also the recharge time can be suitably adjusted according to the specific requirement and system capacity.

8.1.2 ESTIMATION OF ENERGY STORAGE IN SMES:

The temperature and the local magnetic field determine the current carrying capacity of the wire in the coil. The material properties of the wire also play an important role (strain tolerance, thermal contraction upon cooling etc) in SMES design. Typically, 50.77 K is considered as the operating temperature.

The induced energy stored in the coil and the rated power can be expressed as follows:

Energy stored in the coil, $$E = \frac{1}{2} LI^2$$

where, L = inductance of the coil and

I = current flowing through the coil

Rated power of the coil, $$P = V I$$

where, V = Voltage across the coil and

I = current flowing through the coil

The energy to be stored by the SMES device decides the size of the SMES coil. Storage capacities for SMES can range even up to 2 MW.

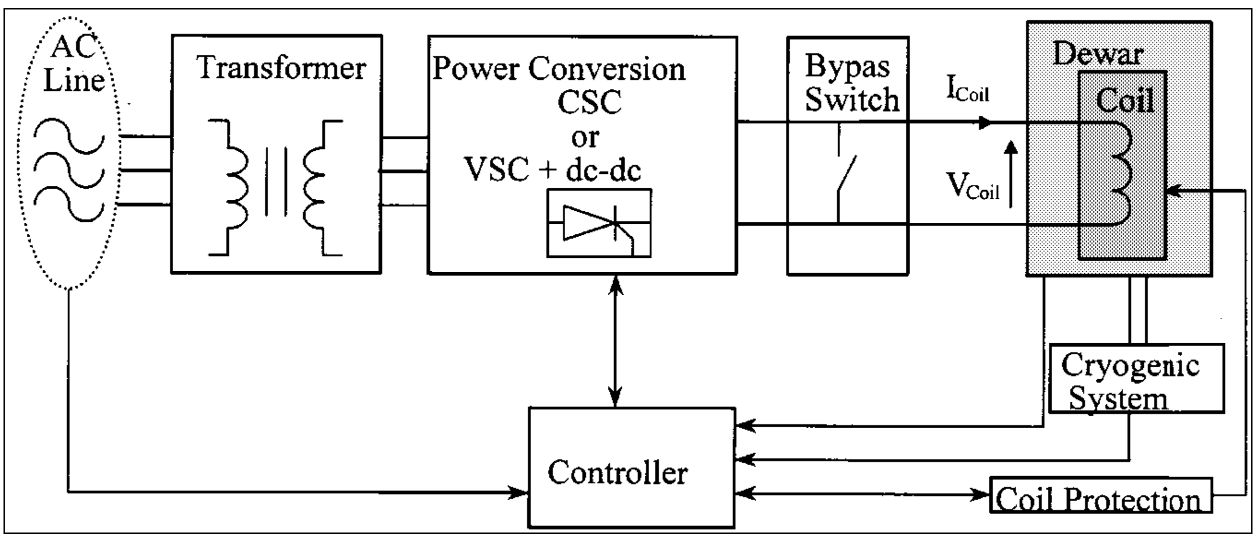
8.1.3 SMES SYSTEM COMPONENTS:

The major components of an SMES system are the superconducting coil, a power conversion/conditioning system (PCS), cryogenically cooled refrigerator and a cryostat or vacuum vessel (Figs. 8.1 and 8.2). The superconducting coil is maintained at the cryogenic temperature by a cryostat containing helium or nitrogen liquid vessels. The power conversion/conditioning system serves as the interconnection between the SMES and AC power system. It also controls the charging and discharging of the coil.

SMES system consists of four major subsystems

- Conductor coil ➢ carries the circulating current
- Power electronics system ➢ controls the flow of current into and out of the coil to charge and discharge the SMES
- Cooling equipment ➢ maintains the coil at a low enough temperature to maintain superconductivity
- Physical structure ➢ supports the coil against magnetic forces during SMES operation.

The power conversion/conditioning system (PCS) serves as the interface between SMES coil and power system. Two types of PCS are generally used. These are current source converter (CSC) and voltage source converter (VSC). The power conversion system can use either a current source converter (CSC) or a voltage source converter (VSC). Typically, CSC is used for mini or medium sized SMES system while VSC is used in a large sized SMES system. In the first case, the current source converter acts as an interface to the AC system in order to charge and discharge the coil where as in the second case, the voltage source converter is used with a dc - dc chopper to serve the purpose. The voltage applied across the super conducting coil, whether positive or negative, dictates accordingly the charging or discharging of the coil. The SMES attains the standby mode when the average voltage across the coil (V_{coil}) is zero causing a constant average current (I_{coil}) through the coil. The current source converter is simple and offers easier control as compared to voltage source converter. The response of power exchange with CSC is much faster than with VSC.



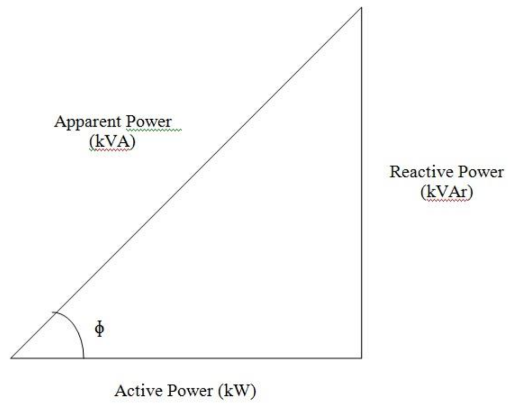
Source: Energy Storage Systems for Advanced Power Applications, Paulo F. Ribeiro et al, IEEE, 2001

Fig. 8.2 - Components of a typical SMES system

SMES are accepted as highly efficient energy storing device and are considered as suitable for both real and reactive power. These devices are being used for stabilizing the distribution grid as well as for enhancing the power quality in ultra-clean power consuming sectors like microchip fabrication facilities.

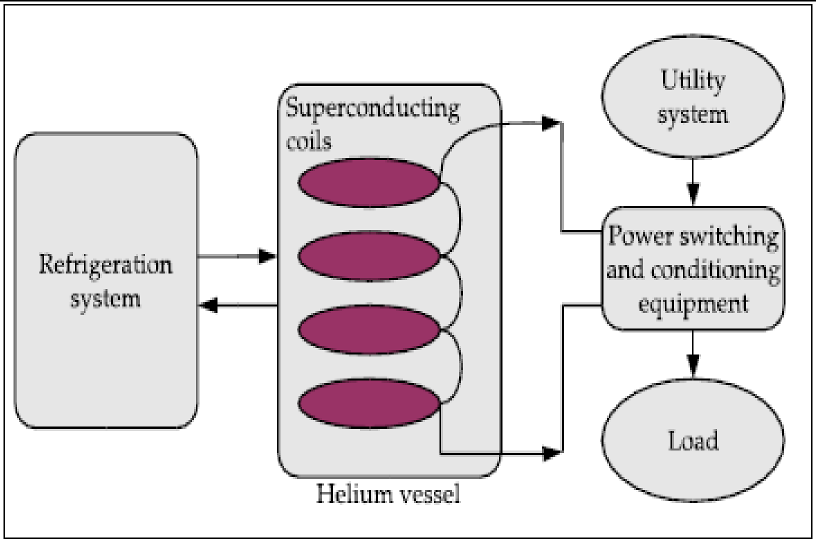
Apparent power (kVA)	• Measures the electrical load on a circuit or system • Product of Voltage (kV) kilovolts and current (kVA)
Real or Active Power (kW)	• Portion of apparent power that produces work • Measured in watt (W) or Kilowatt (kW)
Reactive power (kVAr)	• Portion of apparent power that does no work • Must be supplied to all types of magnetic equipment, e.g. motors, transformers etc

Power Factor (cos ϕ) is the ratio between active power (kW) and apparent power (kVA)



8.1.4 SMES OPERATION:

The operation of an SMES system involves stepping down of the AC transmission voltage in the first phase with the help of a step-down transformer (Fig. 8.2 & Fig. 8.3). This stepped down AC voltage in the appropriate range is then converted into DC and fed to the coil of superconducting material. Energy is then stored in the magnetic field created by the DC flowing through the coil. The maximum energy that can be stored in the coil is determined by the design of the device. When the AC network suffers from voltage or frequency instability, sags etc, the coil discharges power to the network to provide the required boost and thus behaves as a source of energy. The conversion of DC to Ac is done through the converter.



Source: Newest Electrical Energy Storage Systems: SMES and SCES, Patel et al

Fig. 8.3 - Operation of a superconducting magnetic energy storage system

The electrical losses existing in AC applications are possible to be reduced with the help of proper design of the device as well as through appropriate wire architecture. It may be assured that, whatever may be the applications, either AC or DC, a significant energy saving can be achieved through the SMES systems.

8.1.5 FEATURES OF SMES:

The most significant characteristic of the SMES device is that it is a very quick response device. It has the potential for handling high power, for example multi-MW systems. It is about 97- 98% efficient energy storage device. The SMES exhibits better dynamic performance as compared to most of the other storage devices.

However sensitivity to the temperature is considered as the major drawback of SMES systems. An extremely low temperature is essential for the coil to exhibit as a superconductor and even a small variation in temperature can lead to instability in the performance of the coil causing loss of energy. Besides, parasitic losses are also induced in the system due to the incorporation of the cooling device. Though the rapid discharge rates have made SMES suitable for certain applications, the same characteristics have made them inappropriate in some other applications reducing their flexibility in use as compared to other devices such as batteries.

8.1.6 APPLICATIONS OF SMES:

SMES can directly store electrical energy. It can be readily installed, a feature, which makes them more attractive in applications. Various factors like low transition temperature, critical magnetic field and critical current density, often impose restrictions in the applications of superconductors. An SMES basically consists of a high inductance coil. These systems can store both active and reactive power from the power system or distribution grid. It can also deliver power, both active and reactive, to the power system as well depending on the requirement. The controlling of the active and reactive power injected to the system can be achieved by different techniques. For example, the controlling of the active power can be done by variations in duty cycle of the switches in a dc-dc chopper while the magnitude of the output voltage of the converter can be used for controlling the reactive power.

SMES is considered to be ideal for industrial power market for improving power quality because of its instantaneous discharge rates along with high power capacity. Protection of the equipments and component from any undue fluctuation in the network, for example, due to variation in customer demand, sudden voltage sags, lightening strikes etc, can be assured as SMES stabilizes such fluctuations. Therefore, SMES is a useful tool in network up-gradation which can improve the power handling capacity of the network. Typical applications

Source: Study of Electricity Storage Technologies and Their Potential to Address Wind Energy Intermittency in Ireland, A. Gonzalez et al, 2004

Fig. 8.4 Distributed SMES at a substation

Source: Outlook Of Energy Storage Technologies, C. Naish et al, 2008

Fig. 8.5 Two MJ SMES developed by ACCEL

of SMES may include load leveling, frequency support (spinning reserve) in case of generation loss, dynamic voltage support (VAR compensation), improving transient and dynamic stability and overall reliability of power systems. An SMES can instantaneously follow the load changes in the system enabling the conventional generating units to operate at constant output. It is capable of damping out low frequency oscillations due to system transients and stabilizes the system frequency. Spinning reserve refers to the amount of generation which is kept unloaded and ready to take load as required, e.g. in case a major generating unit or transmission line is forced out of service. In charged mode, SMES can provide a tremendous amount of spinning reserve capacity at lower cost over comparable values and methods of maintaining spinning reserve. It increases stability and power carrying capacity of a transmission system by reactive volt-ampere (VAr) control and power factor correction. Also, in the event of major loss of generation or heavily loaded transmission line, which results in dynamic voltage instability, SMES has demonstrated its effectiveness in mitigating dynamic voltage instability by supplying real and reactive power simultaneously.

8.2 CAPACITORS AND SUPER CAPACITOR:

Energy is stored in capacitors through accumulation of charges (positive and negative). A capacitor basically consists of two parallel plates. These plates are separated by a dielectric material. When the plates are oppositely charged an electric field is induced which can store energy.

The energy stored in a capacitor can be expressed as follows.

Energy stored in the capacitor, $$E = \frac{1}{2} CV^2$$

where, C = capacitance of the capacitor and

V = voltage applied across the capacitor

The capacitance C can be determined from the following expression.

Capacitance of the capacitor, $$C = \frac{1}{d} \varepsilon_o \varepsilon_r A$$

where, d = distance between the two plates

ε_o = permittivity of free space (8.854×10^{-12} F/m)

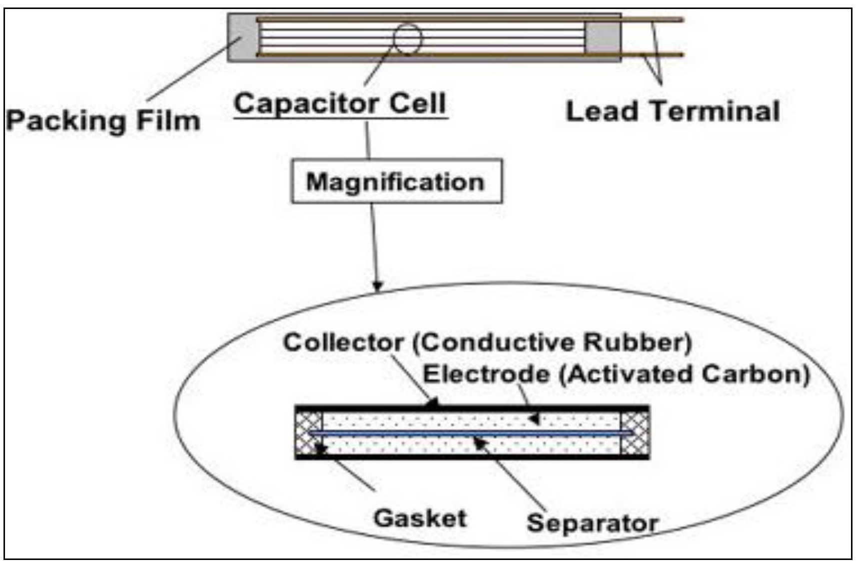
ε_r = relative permittivity or dielectric constant

A = area of the parallel plates

It can be seen from the above expressions that the energy stored by a capacitor can be increased either by increasing the capacitance and/ or increasing the applied voltage. However, increase of the capacitance or the applied voltage cannot be done infinitely. If we gradually increase the applied voltage, at certain stage, the dielectric material will break down and conduction will start. Similarly, the increase of capacitance is also limited by the dielectric constant of the material.

8.2.1 SUPER CAPACITOR ENERGY STORAGE (SCES):

A new type capacitor, known as super capacitor, usually consists of carbon nano-tube electrodes along with thin film polymers as dielectric layer. It is also known as ultra capacitor or electrochemical double layer capacitor having two electrodes along with an electrolyte. Like conventional capacitor, an electric field is generated in super capacitor by two conductors and a dielectric where energy is stored. The electrodes are separated by a membrane separator. Polarized liquid layers are used as interfaces between the conducting electrolytes and the conducting electrodes which increase the capacitance. A charge separation occurs at the interface between the solid electrode and the electrolyte forming two charge layers- one with excess of electrons on one side while the other having excess of positive ions. The polar molecules residing in between form the dielectric. The electrode materials may be of metal oxides, carbons or conducting polymers. Depending on applications, solid, organic or aqueous type electrolytes may be used. Like conventional capacitors, super capacitors can also be connected in series or parallel mode. Typically, they have the energy densities in the range of 20 MJ/m^3 to 70 MJ/m^3 and they are about 95% efficient. From environmental point of view, carbon based super capacitors are much favoured for industrial applications as there is no use of heavy metals. The layout of a super capacitor energy storage device is presented in Fig. 8.6 along with its components.



Source: A Review of Energy Storage Technologies For the integration of fluctuating renewable energy, D. Connolly, 2010

Fig. 8.6 Components of a super capacitor energy storage device

Like SMES, electrical energy can be directly stored in SCES also. SCES can be built in modular way having the characteristics between conventional capacitors and batteries. They can provide a large amount of power during a short time.

Power Density (W/m^3)	➢	Rated output power divided by volume of the storage device
Energy Density (Wh/m^3)	➢	Stored energy divided by the volume of the storage device

8.2.2 SUPER CAPACITOR ENERGY STORAGE (SCES) VS. BATTERIES:

Super capacitors may be a good replacement for batteries in many applications ranging from smaller ones like in cellular phones to lager ones like in cars. Super capacitors rank lower than batteries in the pretext of energy density. Due to the lower energy density, SCES are usually bulkier than conventional batteries. However, they can appropriately eliminate many disadvantages of the batteries as mentioned below:

(a) The number of cycles up to which a battery can be charged or discharged is limited in nature. These cycles can not go on and on and sufficient time should be allowed to charge/ discharge due to the involvement of chemical reactions.

(b) Heating effect is observed in batteries due to the chemical reactions involved and hazards to the environment due to the use of acidic batteries is also causing a great concern for the society.

(c) There is also a growing concern for environmental hazards created by the use of acidic batteries.

Charging and discharging of super capacitor can be done almost for unlimited times. It possesses the rapid charge/discharge characteristics which makes it suitable for applications like load levelling or others requiring sudden power boost. Besides, while discharging, SCES does not produce heat.

The life time of super capacitor is very high. It requires little maintenance cost. The performance of super capacitor is not degraded with respect to time or cycles of operation. Unlike batteries it does not result in environmental hazards and can be safely stored.

8.2.3 APPLICATIONS OF SCES:

SCES is considered as attractive choice for many power quality applications, particularly in the small scale range, say, about less than 250 kW. It is not economical for large scale applications. The most appealing feature of SCES is its rapid charge/discharge characteristics. The expected life of SCES is extremely long, that is, about $1x10^6$ cycles, which gives added advantage in its application. Since it is susceptible to minimum degradation due to deep discharge and offer no significant hazard to the environment during their extremely long life cycle, SCES can be considered suitable for applications like hybrid cars, cellular phones along with load levelling. A combination of super capacitors and conventional batteries has also been tried in many applications.

SUMMING UP:

Energy storage is an essential component in power systems in order to compensate for the sudden fluctuation or interruption of power caused by various factors. Efficient Energy storage systems can play a major role in improving the condition of intermittent energy supply including energy extracted from renewable sources. The SMES systems possess a great deal of commercial potential, particularly in the context of transmission upgrades and industrial power quality.

Various research works are going on to reduce the cost of high temperature SMES devices including capital as well as operating costs. With the advent of more mature technology, SMES is expected to contribute a lot in the power scenario in an economical way.

Super capacitors may be proved very useful in specific application with their extremely long life span and fast response characteristics although their low energy densities may restrict their use in some applications. Combinations of super capacitors and batteries are expected to produce much better results in the field of power quality improvement.

Questions:

1. State the needs of advanced energy storage systems.
2. What is superconducting magnetic storage system (SMES)?
3. Describe the functions of SMES components.
4. Explain the operation of SMES and SCES.
5. Compare the distinctive features of SCES with conventional batteries.

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