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سازمان انتشارات

Technical English

for the Students of

Power Engineering

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In the Name of God

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To:

Sepideh and Ali Reza

May faith, wisdom and knowledge always guide them through their lives, and may they always fulfill their duties towards their country, in particular, and towards the human society, in general.

Mohammad R. and Farideh

تقدیم به:

سپیده و علیرضا

بدان امید که ایمان ، خرد و دانایی همواره راهنمای ایشان در مسیر زندگی باشد و بدین آرزو که همواره در ایفای وظایف خویش نسبت به میهنشان ، به طور خاص ، و نسبت به جامعه بشری ، به طور عام ، پیشگام و پیروز باشند.

محمدرضا و فریده

Preface

This book is the result of many years of teaching technical English to the students of power engineering at University of Birjand. The main motivation behind writing this book was the lack of a suitable book specifically written for power engineering students in Iran. Of course, a good number of valuable and well-written books in this subject can be found in the market, but most of them suffer from at least one (or more) of the following shortcomings:

- Most of the existing books are written by authors whose main area of expertise is English, and not power engineering. This, in some cases, has resulted in poor technical quality of the book, while the English content is quite defensible. In some rare cases, even wrong and misleading content is observable.
- In some books, the texts chosen are so outdated that some of the ideas presented in them are not acceptable anymore.
- Most, if not all, of the books are written for electrical engineering, as a general and wide field including: power, electronics, communications, control and even computer engineering, and the student has to pay for a book from which only 20% or so is useful for him/her.
- We believe that the students who select Technical English have, or at least are expected to have, sufficient grammatical proficiency from their previous English courses, and so, a course on Technical English must be primarily focused on reading comprehension and technical vocabulary. Some of the books present too much English grammar, and thus, are somehow unable to achieve their main expected goal.

The present book, to us, has a number of advantages over similar books, the most significant of which can be listed as follows:

- It is written solely for power engineering students, and so, it helps the student focus on his/her area of interest/studies.
- The book follows a historical course, from the History of Energy, the Industrial Revolution and the History of Power Engineering all the way to the most modern and challenging issues and subjects currently being followed in power engineering's most advanced research and teaching centers, such as: Renewable Energy Resources, Distributed Generation, Smart Grids, Restructuring and Deregulation, Energy Storage Systems and Electric Vehicles.
- The book follows a logical course from Generating Electric Power to Power Transmitting over long distances and to Distributing Electric Power between the end users. It also covers most of the main sub-areas of power engineering, including: Electric Machines, Power Transformers and Power Electronics.
- Throughout the book, numerous references have been made to environmental issues, and to the necessity of preserving the environment while following the path of a sustainable development. Renewable energy resources, too, have assumed a deserving place throughout the book.

The book contains thirteen Units, each of which designed in eight pages and believed to be suitable and adequate for teaching in one 100-minutes class time. Therefore, the book can be conveniently covered by a 2 credit hours course. It is proposed that the lecturer reads and translates each Unit's main text in the class first, and in the next class, the students having read the Unit beforehand, read and answer its exercises.

During the course of preparing this book, Mr. Ali Reza Aghaebrahimi has been very active and helpful in preparing some of the figures used in the book, and in making modifications and/or improvements in some others. For this, the authors are sincerely thankful to him.

Before getting published, the book's materials have been taught for two semesters in 2011-2012 at University of Birjand, and their shortcomings and errors have been tried to be found and corrected.

Thus, the students who helped this process are to be thankfully acknowledged.

Like any other human product, nevertheless, the book may contain some errors or mistakes. The authors will be grateful if such cases are kindly reported to: aghaebrahimi@birjand.ac.ir. All other suggestions and/or questions about exercises, too, are more than welcome by the authors.

At the end, the authors hope that this book can play its expected role in enhancing the Iranian power engineering students' knowledge and proficiency in Technical English, while having them ponder about the other worthy issues mentioned in the text and within the exercises.

M. R. Aghaebrahimi
F. Farhadi

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Unit One

The History of Energy

Energy plays a fundamental role in shaping the human condition. People's need for energy is essential for survival. So, energy production and consumption are some of the most important activities of human life. Many experts believe that energy is the key to the progress of civilization. To them, the evolution of human societies is dependent on the conversion of energy for human use.

Throughout history, humans have tried to control the energy stores and flows that are part of nature. For thousands of years, people relied solely on the chemical energy gained from food. This energy produces the mechanical energy of working muscles. That includes their own muscles and the muscles of domesticated animals, such as horses and oxen. But thanks to human intellect, people were able to overcome physical limits imposed on their own muscle power by using tools and harnessing the energies outside their own bodies.

Fig. 1.1 – Oxen with cart

The earliest energy tools were those used to hunt animals, harvest plants, catch fish and birds, and process and transport food. Most of the family structures, social groups, and political and economic institutions created over thousands of years focused primarily on the extraction, processing, exchange, and marketing of food and fossil and organic energy sources, such as wood and coal. These energy supplies were used for heating, cooking, lighting, or for firing the ovens and furnaces used in melting different metals.

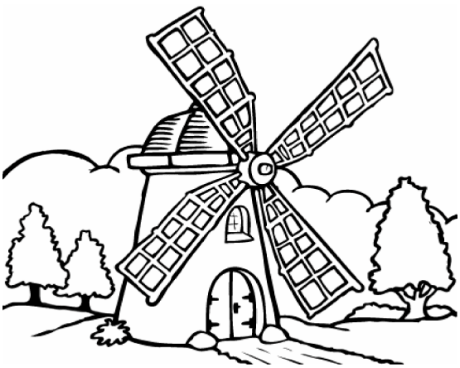

Fig. 1.2 – A windmill

Age of Water and Wind Power

Before the modern age, people relied for power on their muscles, their animals' muscles, and on water and wind. Persians have been the first people to develop windmills between 500 and 900 A.D. Sails had long been used to move ships at sea, but Persians converted the wind for use in pumping water and grinding grain. These were vertical style mills with the sails spinning the shaft directly connected to a pump or grind-stone. Windmills first appeared in Europe about the time of the Crusades (1096-1270). As their design was considerably different from the Persian model, there is some doubt about whether they were developed independently or were borrowed by some Crusaders returning home who might have seen them in operation. The first known windmill in China is documented in 1219 A.D.

Fig. 1.3 – Watermill machinery

Europe, which possessed many areas of water-power potential, particularly benefited from harnessing the energy produced by moving water. The vertical waterwheel, invented perhaps two centuries before the time of Christ, spread across Europe within a few hundred years. By the end of the Roman era, waterwheels powered mills to crush grain, melt and shape iron, saw wood, and carry out a variety of other early industrial

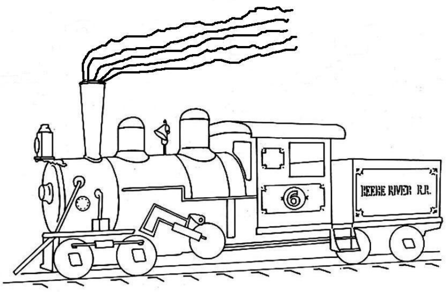

Fig. 1.4 – A steam locomotive

tasks. So, productivity increased, dependence on human and animal muscle power gradually declined, and locations with good water-power resources became centers of economic and industrial complexes.

During the Middle Ages, hydraulic engineers mounted mills on boats and bridges, and from these, hydropower dams evolved to store and develop water pressure and to divert water into power canals, and then to wheels.

Meanwhile, the harnessing of wind power to propel sailing ships across oceans opened up the Americas to Europe. Colonists brought with them water-powered mills, which appeared from Latin America to Canada. By the time of the Industrial Revolution, Euro-American industry depended for energy almost entirely on water power.

Age of Steam

The modern era began with the 18^{th} century introduction of steam power to English coal mines by Thomas Savery and Thomas Newcomen. The relationship between coal mining, the iron industry, and steam power led to advances in steam technology. By 1800, steam engines joined waterwheels in powering English textile mills. Although water power continued to be the dominant energy resource for manufacturing through much of the 19^{th} century, steam power ultimately proved more flexible and economically efficient.

During the 19^{th} century, steam engines improved enormously. The steam engine permanently established the link between fossil energy resources and industrialization. European users turned to coal for steam fuel before 1800, and by the mid-nineteenth century coal succeeded wood as steam fuel. The scarcity and high cost of good coal, combined with discoveries of petroleum in southern California resulted in the development of oil as steam fuel. Eventually, petroleum replaced coal as steam fuel during the first half of the 20^{th} century. The extensive use of fossil fuels such as coal and petroleum, however, has had many negative effects on the environment, which will be addressed later in Unit Five.

The Electrical Age

Fig. 1.5 – Electrical age

Among the technological challenges in using non-living energy resources is the transmission of power. Toward the end of the 18th century, many people became interested in phenomenon of electricity. A number of developments ultimately revolutionized the transmission of power. Those developments included the production of electricity with primary batteries and later with electromagnetic induction, the transmission of electricity through copper wires, and the development of electric motors. By the end of the 19th century, restrictive and inflexible direct connection of manufacturing machines to waterwheels, windmills, and steam engines, which was achieved by gears, drive shafts and belts, was replaced by electrically powered machinery. These machines get their power through wires coming from far away hydroelectric and steam-turbine power plants. The shape and character of factories changed dramatically during the 20th century, as machines powered by electric motors could be located almost anywhere. Additionally, electric power replaced gas for outdoor lighting. It also replaced kerosene lights and wood and coal stoves and heaters in many homes.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. The role energy plays in human survival is not very important.

___2. During early ages of human history, their main source of mechanical energy has been the energy found in food.

___3. The use of hydraulic energy did not start until Christ's birth.

___4. Using water energy did not have any effects on the level of production.

___5. The flexibility and economic efficiency of steam power was found to be more than that of water power.

___6. The existing link between fossil fuels and industrialization was created by steam engines.

___7. The energy found in non-living resources has always been easy to transfer.

___8. Using electric energy to run machinery has more restrictions than steam, water and wind energy.

___9. The improvements in steam turbines increased the efficiency, so less fuel was needed to generate the same amount of electric power.

___10. The extensive use of fossil fuels during the past decades did not have any negative impacts on the environment.

II. Reading comprehension. Fill in the blanks with appropriate words given.

achieved	decades	led	prominent
applications	field	particularly	reaction
bombarding	fission	physicists	stage

In the 19th century, research in physics had ………… to the discovery of nuclear radiation. Most ………… in this discovery was Marie Curie, whose work "on the radiation emitted by uranium compounds" set the ………… for subsequent discoveries on atomic structure and the internal power of the atom. The early ………… of the 20th century brought sustained scientific research in atomic physics, ………… in Europe. Italian physicist Enrico Fermi at the University of Rome was prominent among scientists working in this exciting …………, and during the 1930s he focused on producing artificial radiation by ………… uranium atoms with neutrons. As the world went to war in the 1940s, Fermi and other ………… in Europe and America came to understand that a uranium atom split by a neutron would cause a chain ………… of atom splitting that would release enormous energy. This process, called nuclear …………, suggested possible military …………, and Fermi and his colleagues at Columbia University joined with Albert Einstein to persuade the U.S. Government to study the idea. Meanwhile, at Columbia University, Fermi tried to develop a controlled nuclear fission chain reaction. In December of 1942, he and his team ………… the first controlled nuclear chain reaction.

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	achieve	achievement	achievable	-----
2	determine	determination	determined	determinedly
3	environ	environment	environmental	environmentally
4	evolve	evolution	evolutional	evolutionally
5	found	foundation	foundational	foundationally
6	possess	possession	possessive	possessively

1. The invention of steam engine was a huge ………… for humanity.
2. Marie Curie ………… radium's radioactive properties and atomic weight.
3. The wind energy is an ………… acceptable source of energy. It does not have much negative impact on the …………
4. ………… biology studies the theory of ………… in human beings and animals.
5. There are ………… differences between past and present.
6. Uranium ………… radioactive properties which are dangerous for living things.

IV. Vocabulary expansion: word forms. Choose the right word form for each sentence below.

1. Create

a. The Statue of David was not ………… by Michelangelo. He only finished the incomplete work of Agostino di Duccio.

b. Fermi's ………… mind was instrumental in his success.

c. The structure of human being's brain is one of the most complicated secrets of ………… .

d. To build a better future, one needs to have enough ………… .

2. Economize

a. In …………, inflation, employment rate and economic growth rate are important indicators of a nation's ………… conditions.

b. During the past decades, oil products have not been consumed ………… in our country.

c. The fuel consumption was ………… as the machinery's efficiency was improved.

d. Many ………… insist that development in the society must be sustainable.

3. Produce

a. The ………… of steel is a necessity for industrialization.

b. To be more …………, one must make the best use of the resources available to him/her, especially the time.

c. Steel is ………… through combining iron ore, coke and limestone.

d. Iran is one of the world's largest oil ………… countries.

4. Rely

a. They proved to be ………… machines after years of service.

b. In modern power systems, ………… is a very important issue.

c. Soldiers ………… on a few pieces of bread during the siege.

d. Our country must reduce its ………… on oil revenues and ………… more on non-oil exports.

5. Transport

a. In many countries, people use railways as the main method of ………… .

b. The workers were ………… to the factory by two buses.

c. In Canada, where no roads are available, they ………… large pieces of wood through rivers.

V. Vocabulary: write the Persian equivalent of the following words.

accessible		grain	
alternative		harness	
attribute		hydroelectric	
belt		impact	
benefit		impose	
challenge		induction	
character		intellect	
climb		lighting	
compete		marketing	
complex		mount	
consumption		muscle	
conversion		oven	
copper		overcome	
crush		permanent	
decline		petroleum	
dependence		phenomenon	
discovery		possess	
divert		primary	
domesticate		processing	
dominant		productivity	
dramatically		progress	
efficiency		propel	
environment		restrictive	
essential		revolutionize	
establish		scarcity	
eventually		shaping	
evolution		solely	
exchange		spread	
expert		steadily	
exploitation		stimulate	
extraction		survival	
flexible		transmission	
fundamental		transport	
furnace		variety	
gain		vertical	

Unit Two

The Industrial Revolution

The huge volume of knowledge and technology we enjoy and employ today is the result of relentless efforts of so many great scholars and scientists throughout the history. From ancient and contemporary mathematicians who have founded the basis of our everyday analyses and calculations, to physicists and chemists who have spent much of their lives in laboratories to uncover the secrets of our universe and to find the laws and rules governing its different aspects, all have played pivotal roles in gathering the existing scientific and technological heritage. This process has been going on for millennia.

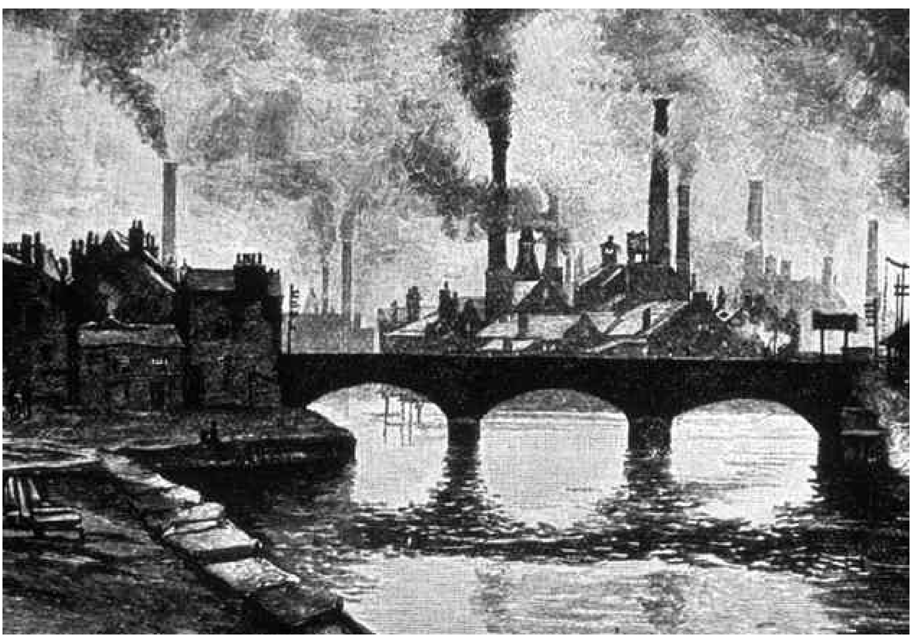

Fig. 2.1 – The Industrial Revolution dramatically changed the face of human societies

The engineering systems, however, are much younger, compared to many human inventions, and date back only to about three centuries ago. The beginning of modern engineering systems can be attributed to what is known as the Industrial Revolution. The major outcome of the Industrial Revolution was the widespread replacement of human labor by new inventions or machinery.

In general, it is believed that the Industrial Revolution began by the invention of Steam Engine by the Scottish inventor and mechanical engineer James Watt in the 18th century. Iron was the key metal of the Industrial Revolution, and the steam engine was perhaps the most important machine technology. However, contrary to the popular belief, there was not just a single inventor involved in the creation of the first steam engine. Inventions and improvements in the use of steam for power began prior to the 18th century, as it was the case with iron.

The first known steam engine, used as a toy for entertainment, was made by a Greek/Egyptian mathematician and engineer called Heron of Alexandria in the 1st Century A.D. A sketch of this invention, called Heron's Aeolipile, is shown in Fig. 2.2.

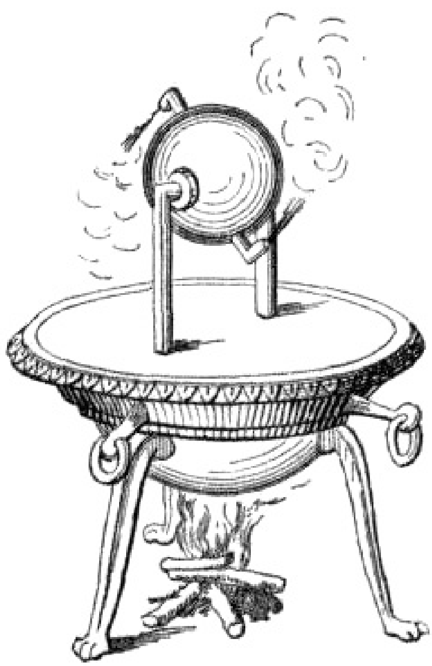

Fig. 2.2 – Heron's Aeolipile

As early as 1689, English engineer Thomas Savery created a steam engine to pump water from mines. Thomas Newcomen, another English engineer, developed an improved version of it by 1712. About fifty years later, between 1763 and 1775, James Watt made the most significant improvements, allowing the steam engine to be used in many industrial applications, not just in mining. The misconception that Watt was the actual inventor of the steam engine arose from the

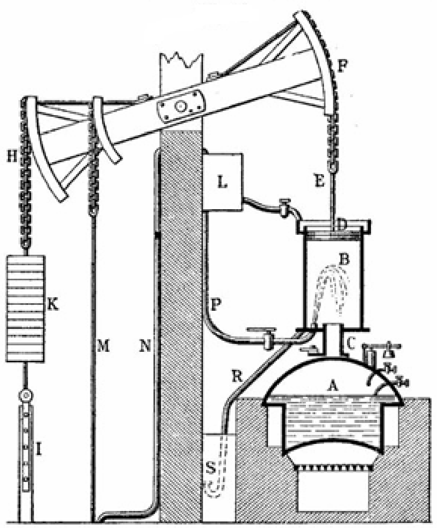

Fig. 2.3 – Early Watt pumping engine

fundamental nature of his contributions to its development. Early mills had run successfully with water power, but the advancement of using the steam engine meant that a factory could be located anywhere, not just close to water. Fig. 2.3 shows a sketch of an early Watt pumping engine.

Watt worked as a mathematical-instrument maker from the age of 19 and soon became interested in improving the steam engines. He determined the properties of steam, especially the relation of its density to its temperature and pressure, and designed a separate condensing chamber for the steam engine. This condensing chamber prevented enormous losses of steam in the cylinder and enhanced the vacuum conditions. Watt's first patent, in 1769, was issued for this device and other improvements on Newcomen's engine. These improvements included steam-jacketing[1], oil lubrication, and insulation of the cylinder in order to maintain the high temperatures necessary for maximum efficiency.

In 1775 Watt and his partner Matthew Boulton began the manufacture of steam engines. Watt continued his research and patented several other important inventions, including the rotary engine for driving various types of machinery; the double-action engine, in which steam is admitted alternately into both ends of the cylinder; and the steam indicator, which records the steam pressure in the engine.

The centrifugal or flyball governor, which was invented by Watt in 1788, is of particular interest today. It includes the basic concept of automation and control systems; the feedback concept. A feedback links a system's output to its input. The flyball governor is connected mechanically to the output shaft of a steam engine, as is

[1] A jacket, or outer covering, containing steam that surrounds and heats a cylinder.

shown in Fig. 2.4, so that the ball mechanism rotates at the speed of the engine. If the load on the engine decreases, speed will tend to increase which, through centrifugal action, forces the balls outward. Through the linkage, this will proportionately close off the steam supply to the engine. If the engine tends to lose speed, the mechanism increases the steam supply accordingly. Therefore, the flyball governor maintains engine speed at a preset value without human intervention.

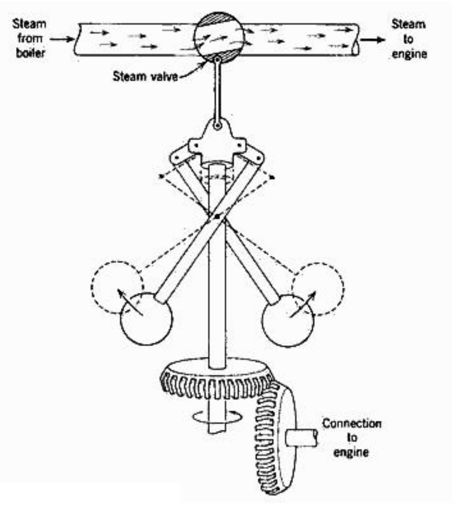

Fig. 2.4 – Flyball governor

The Industrial Revolution prepared necessary grounds for humanity to employ the huge forces of the nature for his comfort and to explore territories which were unthinkable before. The invention of automobiles, aviation, space travel, and generating electricity, used along with various electrical devices for different purposes, are some of these historic achievements.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. Before industrial revolution, the main source of power was human labor.

___2. The industrial revolution began before the steam engine was invented.

___3. Compared to other metals, iron had very little role in the industrial revolution.

___4. The first use of steam as a source of power was before the 18^{th} century.

___5. Heron’s Aeolipile was used as an industrial instrument in ancient Alexandria.

___6. Contrary to the popular belief, James Watt was not the first scientist to invent the steam engine.

___7. Water power was not used to run mills before the industrial revolution.

___8. The relationship between different properties of steam was considered in Watt’s innovations.

___9. The flyball governor needs human intervention to keep a constant engine speed.

___10. In modern control systems, feedback plays an important role.

II. Reading comprehension. Fill in the blanks with appropriate words given.

all-metal	construction	income	period
began	effect	influenced	spread
capacity	fuelled	notably	turning point

The Industrial Revolution was a ………… from the 18th to the 19th century where major changes in agriculture, manufacturing, mining, transportation, and technology had a profound ………… on the social, economical and cultural conditions of the times. It ………… in the United Kingdom and subsequently ………… throughout Europe, North America, and eventually the world. The Industrial Revolution marks a major ………… in human history. Almost every aspect of daily life was ………… in some way. Most ………… , the average income and population began to exhibit unprecedented sustained growth. In the two centuries following 1800, the world's average per capita ………… increased more than 10 times, while the world's population increased over 6 times. Trade expansion was enabled by the ………… of canals, improved roads and railways. The introduction of steam power ………… primarily by coal, wider utilization of water wheels and powered machinery made a dramatic increase in production ………… . The development of ………… machine tools in the first two decades of the 19th century facilitated the manufacture of more production machines for manufacturing in other industries.

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	agree	agreement	agreeable	agreeably
2	comfort	comfort	comfortable	comfortably
3	develop	development	developed	-----
4	differ	difference	different	differently
5	implement	implementation	implementable	-----
6	vary	variation	various	variously

1. Economic historians are in ………… that the Industrial Revolution was the most important event in the history of humanity since the domestication of animals and plants.

2. They lived ………… together in their newly built house for many years.

3. The technological and economic progress was accelerated with the ………… of steam-powered ships and railways.

4. ………… methods of coal mining were employed in various parts of the world.

5. The ………… of internal combustions engines and electrical power generators in 19^{th} century greatly improved the efficiency of different industries.

6. The period of time covered by the Industrial Revolution ………… with different historians.

IV. Vocabulary expansion: word forms. Choose the right word form for each sentence below.

1. Bring

a. Last week, the visitors ………… lots of books to donate to the public library.

b. The teacher is ………… a big box with him to put the books and video tapes in it.

c. Please ………… only a pen and a calculator to the exam room.

d. The Industrial Revolution has ………… many changes to people's lives and ways of doing things.

2. Construct

a. One of the best ways to improve the situation and reduce mistakes is to encourage and accept ………… criticism.

b. The ………… project will begin right after the end of the cold season.

c. Ancient Iranians ………… Persepolis with primitive tools and materials.

d. The government will ………… a new bridge across the river.

3. Invent

a. René Descartes was a French philosopher and mathematician with a very ………… mind.

b. The ………… of Internet and the Information Technology have made the Global Village a reality.

c. Even today nobody knows who ………… the first wheel.

4. Lubricate

a. One way to keep the engine cool is through ………… .

b. The broken part of the engine was not ………… properly.

c. In order to reduce losses, make sure to ………… the pump every week.

5. Make

a. Before the invention of tools and instruments, people had to ………… their needs by their hands.

b. Modern tools are mostly ………… of different metals, but non-metallic materials are used too.

c. The company is ………… many products, from pencils to huge construction machinery.

d. James Watt ………… a lot of efforts to improve the steam engine's performance and efficiency.

V. Vocabulary: write the Persian equivalent of the following words.

achievement		instrument	
advancement		insulation	
alternately		intervention	
ancient		invention	
application		losses	
aspect		lubrication	
automation		machinery	
aviation		maintain	
basis		manufacture	
centrifugal		mill	
chamber		mine	
concept		necessary	
condense		outcome	
contemporary		patent	
contrary		pivotal	
contribution		prepare	
cylinder		preset	
density		pressure	
determine		prevent	
develop		properties	
device		proportionately	
element		record	
employ		replacement	
enhanced		rotary	
enormous		separate	
explore		shaft	
feedback		significant	
flow		supply	
gathering		temperature	
governor		territory	
huge		uncover	
human labor		universe	
improvement		vacuum	
indicator		volume	
industrial		widespread	

Unit Three

The History of Power Engineering

The word electricity comes from the Greek word "electron", for amber. The bases of the modern concepts of electricity can be traced to the Greeks, who discovered the fact that certain rocks - magnetite - attracted each other. Later it was learned that certain substances, when rubbed, would attract small objects. Thus, static electricity was produced when a piece of amber was rubbed with a cloth.

In 1600, an English physicist and astronomer, William Gilbert, published his pioneer work "De Magnete", presenting the results of nearly 20 years of experimentation with substances known to possess electrical properties.

In 1660, Otto von Guericke invented the first electric machine - a rotating globe of sulfur which, when electrified, attracted substances such as feathers. Most important, he observed small sparks and heard their noises, and noted the repulsion of what now are called "similarly charged bodies".

During the 18th and 19th centuries, new principles of electricity and their applications were discovered. In 1752, Benjamin Franklin proved that lightning is a form of electricity. About 1790, the Italian physicist Luigi Galvani discovered the existence of a current of electricity. Another Italian physicist, Alessandro Volta, developed the first electric battery about ten years later, and in 1820, Hans Ørsted of Denmark, discovered the magnetic effect of an electric current. The names of Andre Ampere, George Ohm, Karl Friedrich Gauss, Michael Faraday, Joseph Henry, and James Clerk Maxwell are equally significant to that era of research and theorizing about electricity.

The Advent of the Electric Age

When Thomas Davenport of Vermont invented the electric motor in the late 1830s, he called it a "toy" because it could not do any useful work. Although the electric motor eventually would extend the uses of this new energy source, for the next half-century electricity remained little more than a laboratory curiosity. It remained for others to make electricity practical - others such as Thomas Alva Edison, who perfected incandescent electric lamp (1879) and built the Pearl Street Power Station (1882); Charles Parsons, inventor of the turbine-generator (1884); Nikola Tesla, inventor of an alternating current (AC) system (1888) which used the first AC motor, a generator, and transformers; and George Westinghouse, who, shortly after Tesla's discovery of how to generate alternating current, developed high-voltage AC electrical systems more suitable for commercial use.

The world's first company organized to produce and sell electricity was the California Electric Light Company, established in San Francisco on June 30, 1879.

Thomas Edison was especially important in the development of electricity. Pearl Street Station, built by the Edison Illuminating Company, which was headed by Edison, was the first central power plant in the United States. It was located at Pearl Street in Manhattan, New York. It began with one 27-ton direct current (DC) generator, at that time called a "dynamo", and it started generating electricity on

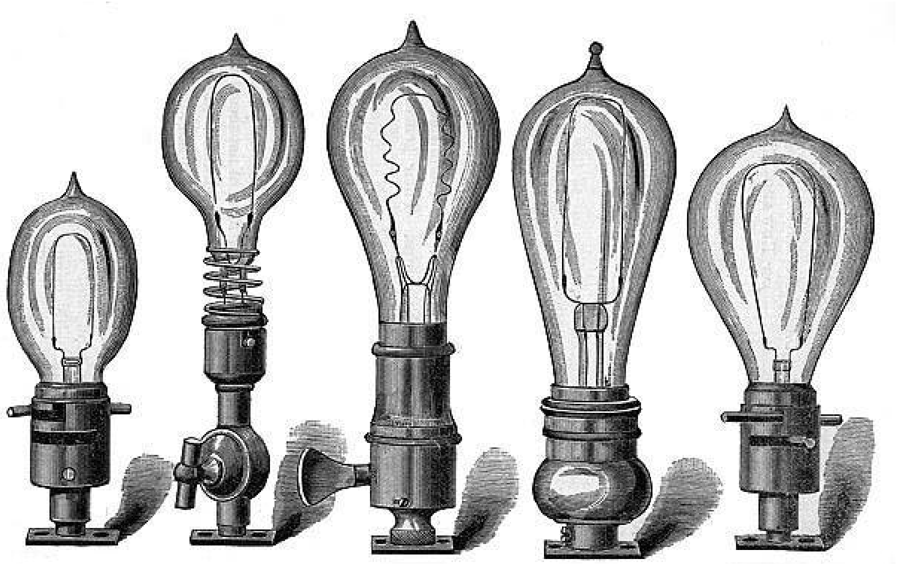

Fig. 3.1 – Early incandescent lamps

September 4, 1882. It initially served a load of 400 lamps at 85 customers. By 1884, Pearl Street Station was serving 508 customers with 10,164 lamps using six dynamos, each producing about 1,100 kilowatts. The station burnt down in 1890, destroying all but one dynamo that is now kept in the Greenfield Village Museum in Dearborn, Michigan.

Despite its limitations, Pearl Street Station's interconnected grid became a model for power generation and distribution systems nationwide. But for Edison, the question of how to distribute the power was perhaps more challenging than producing the electricity to light the bulbs. For safety reasons, Edison insisted on installing his power lines underground – a costly practice that required Edison to convince the mayor of New York City to allow him to dig up the streets to install 100,000 feet of wiring to connect customers to the power plant. To use with his power system, Edison developed other necessary items, including a meter to measure a customer's electricity usage. Edison also built manufacturing plants for light bulbs, generators and other power system components.

Equally significant, Edison educated a number of other

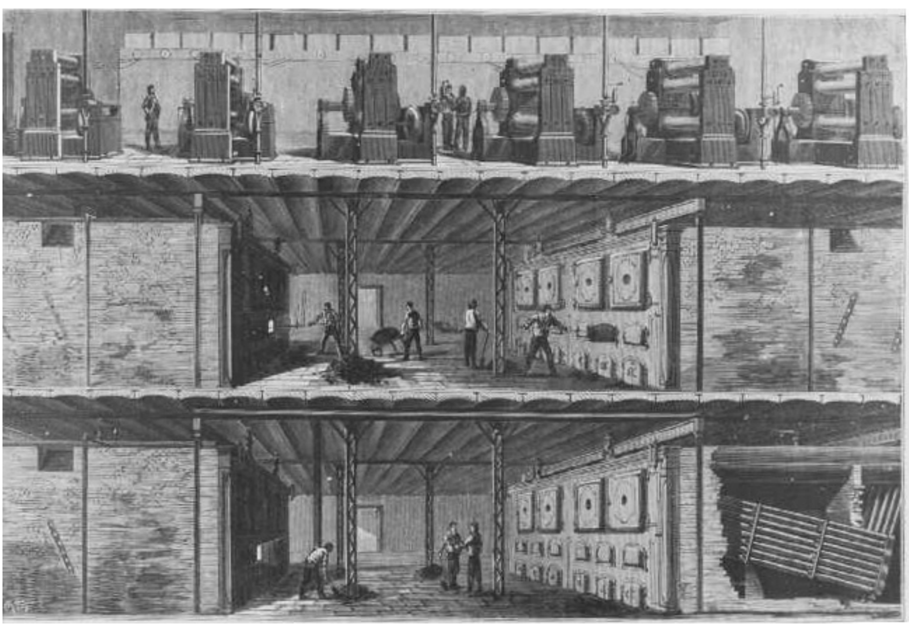

Fig. 3.2 – Interior of Pearl Street Station, New York

important contributors to electric power technology, among them Nicola Tesla who developed AC power generation.

Edison's DC power system became the initial standard for distributed electricity, powering electric railways and manufacturing motors as well as lighting. Unfortunately, its power could not be easily transmitted over long distances, a task which Tesla's AC power system achieved. Implemented by Edison's competitor in electric power, the Westinghouse Company, AC power replaced DC power and made possible the development of large electrical generating plants located long distances from customers. Although Westinghouse's harnessing of hydropower at Niagara Falls with Tesla's polyphase system is perhaps better remembered, developments in AC power transmission from distant Sierra Nevada power sites in California to the coastal cities of San Francisco and Los Angeles established the standard in long-distance polyphase electric-power transmission. By the early 20th century, electricity had become the favored method for transmitting energy.

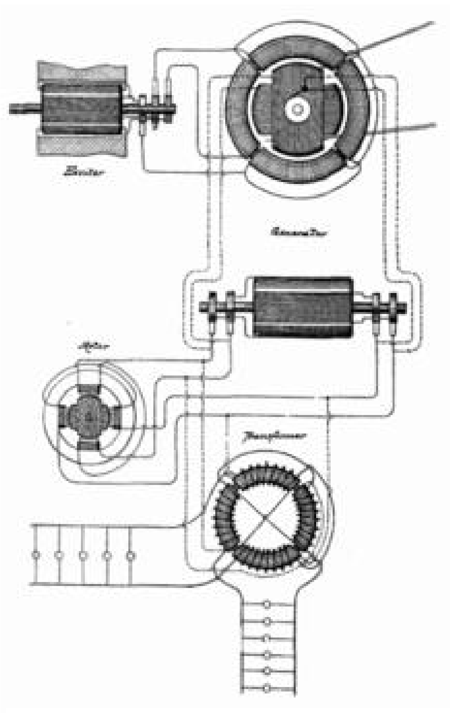

Fig. 3.3 – Tesla's AC dynamo

Today, nearly 130 years after the first electric systems came into existence, power systems are the largest systems ever built by human beings. Tens of thousands of huge generators are connected together through millions of kilometers of high-voltage transmission lines and bring light, heat, refrigeration, and numerous other domestic, commercial, industrial and agricultural services to nearly 6 billion people worldwide. Perhaps Tomas Edison and his colleagues never thought of such huge systems, but they certainly had enough foresight to try to build such a future for their children and grandchildren.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. Static electricity can be produced by rubbing a piece of amber with a cloth.

___2. In 17th century it was discovered that similarly charged bodies repel each other.

___3. Ancient Greek scientists knew that lightning is a form of electricity.

___4. Alessandro Volta developed the first electric battery in 16th century.

___5. Nikola Tesla was the first person to invent alternating current motors, generators, and transformers.

___6. The world's first company organized to produce and sell electricity was established before Pearl Street Station.

___7. The main advantage of Edison's system in Pearl Street was the fact that it could transmit power over very long distances.

___8. It was before the invention of alternating current that building large power stations located far from load centers became possible.

___9. The first standard for long-distance polyphase electric-power transmission was set by the transmission system from Sierra Nevada power sites in California to the coastal cities of San Francisco and Los Angeles.

___10. During the first decades of 20th century, electricity was not regarded as a proper means for transmitting energy

II. Reading comprehension. Fill in the blanks with appropriate words given.

brilliant	customers	electrodes	nearly
commercial	developed	engine	plant
curiosity	during	housed	scale

The first electric arc lamp was ………… in 1809 by the English chemist, Sir Humphrey Davey. It produced a ………… light when electricity was discharged between two ………… . At that time, however, there were no generators or other economical sources of electric power, so it was merely a scientific ………… .

Pearl Street was America's first central electrical power …………, i.e., all components for generating electricity were ………… in one building. When it began ………… generation, DC power for incandescent lamps was produced and distributed on a large ………… It had one ………… which generated enough power for 800 electric light bulbs. ………… the first year of operation, the number of ………… increased to ………… 500.

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	attract	attraction	attractive	attractively
2	destroy	destruction	destructive	destructively
3	exist	existence	existing	-----
4	experiment	experiment	experimental	experimentally
5	extend	extension	extensive	extensively
6	repulse	repulsion	repulsive	repulsively

1. Similar magnetic poles repel each other, while dissimilar poles ………… each other.
2. The whole city of Bam was seriously damaged by ………… forces of the earthquake in 2003.
3. Unfortunately, only a few ancient buildings are in ………… today, all of which must be preserved carefully.
4. The presence of electric charges in a place can be shown by ………… tests.
5. Before the discovery of petroleum, coal and wood were used ………… as main sources of thermal energy.
6. Magnetic ………… can be used to move objects from one place to another.

IV. Vocabulary expansion: word forms. Choose the right word form for each sentence below.

1. Compete

a. Edison and Westinghouse both ………… for a larger share in the electricity market.

b. There is a big ………… between multinational companies to get more contracts in developing countries.

c. Iran's main ………… in the Organization of Petroleum Exporting Countries (OPEC) is Saudi Arabia.

d. In order to win the Noble Prize in physics and chemistry, many scientists ………… with each other.

2. Install

a. Workers are ………… new electrical equipment in the factory.

b. Electrical ………… are among main targets in modern wars.

c. The generator was ………… after the building was built.

3. Measure

a. Electrical ………… is a major branch in electrical engineering.

b. Electrical current is ………… in terms of Amperes.

c. A wattmeter is continuously ………… the motor's consumed power.

4. Observe

a. Last night, the students ………… the moon by a large telescope.

b. Soldiers on both sides are ………… the borderline 24 hours a day.

c. Many ………… gathered in the street to see the event directly.

d. An ………… is a place where different objects are exhibited.

5. Organize

a. UNICEF is an ………… helping needy children worldwide.

b. The field trip to the power station was ………… very well.

c. The government is the ………… of Tehran International Book Fair (TIBF), which is held every Spring.

V. Vocabulary: write the Persian equivalent of the following words.

agricultural		interconnected	
amber		lightning	
astronomer		limitation	
attract		measure	
certain		meter	
charged		noise	
cloth		note	
coastal		numerous	
colleague		object	
commercial		observe	
competition		organize	
component		perfect	
convince		pioneer	
curiosity		polyphase	
destroy		practical	
dig		present	
distance		principle	
domestic		prove	
earn		publish	
electrify		refrigeration	
emerge		remain	
existence		repulsion	
expensive		respect	
experimentation		rub	
extend		safety	
favor		similar	
filament		spark	
foresight		static	
globe		substance	
grid		task	
illumination		theorize	
implement		trace	
incandescent		underground	
insist		usage	
install		X-ray tube	

Unit Four

Generating Electric Power

Electric power is a secondary form of energy, i.e. it does not exist primarily in nature and must be derived from other sources of energy found in nature. This process is called electricity generation, or power generation.

The fundamental principles of electricity generation were discovered during the 1820s and early 1830s by the British scientist Michael Faraday. His basic method is still used today: electricity is generated by the movement of a loop of wire, or disc of copper between the poles of a magnet.

For power systems, it is the first step in the delivery of electricity to consumers. There are other important steps too, namely transmission and distribution.

Electricity is most often generated at a power station by electromechanical generators. In thermal power stations, generators are primarily driven by heat engines fueled by chemical combustion or nuclear fission. However, other means such as the kinetic energy of flowing water and wind are also used to drive generators.

In addition, in modern power systems there are some newer technologies that can be used to generate electricity such as solar photovoltaic and geothermal power.

Centralized power generation became possible when it was recognized that AC power transmission lines can transport electricity at very low costs across great distances by taking advantage of the ability to raise and lower the voltage using power transformers.

Electricity has been generated at central stations since 1881 and the first power plants were run on water power or coal. Today, we mainly use petroleum, natural gas, hydroelectric, coal and nuclear energy with a small amount of solar energy and wind generators, as well as geothermal sources.

Methods of Generating Electricity

There are seven main methods of directly transforming other forms of energy into electrical energy:

1. *Static electricity*, from the physical separation and transport of charge (example: lightning).
2. *Electromagnetic induction*, where an electrical generator, dynamo or alternator transforms kinetic energy into electricity.
3. *Electrochemistry*, the direct transformation of chemical energy into electricity, as in a battery, fuel cell or nerve impulse.
4. *Photoelectric effect*, the transformation of light into electrical energy, as in solar cells.
5. *Thermoelectric effect*, direct conversion of temperature difference to electricity, as in thermocouples.
6. *Piezoelectric effect*, from the mechanical strain of electrically anisotropic[1] molecules or crystals.
7. *Nuclear transformation*, the creation and acceleration of charged particles.

Static electricity was the first form discovered and investigated, and the electrostatic generator is still used even in modern devices such as MHD[2] generators. Electrons are mechanically separated and transported to increase their electric potential.

Almost all commercial electrical generation is done using electromagnetic induction, in which mechanical energy from a driver, or prime mover, forces an electrical generator to rotate. There are many different methods of developing the mechanical energy, including heat engines, hydro, wind and tidal power.

In a nuclear power plant, the heat of a nuclear reaction is used to run a heat engine. This drives a generator, which converts mechanical energy into electricity by magnetic induction.

Most electric generation is driven by heat engines. The combustion of fossil fuels supplies most of the heat to these engines, with a smaller fraction from nuclear fission and a much smaller from renewable sources. The modern steam turbine, invented by Sir Charles Parsons in 1884, today generates about 80 percent of the electric power in the world using a variety of heat sources.

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1 A substance which has different properties in different directions.
2 Magneto hydrodynamic.

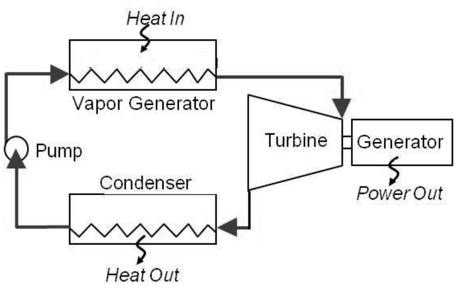

Fig. 4.1 – Rankine cycle

Turbines

All turbines are driven by a fluid acting as an intermediate energy carrier. Many of the heat engines just mentioned are turbines. Other types of turbines can be driven by wind or falling water. Conventional methods include:

Steam – Most steam power plants generate electrical power by using fuels like coal, oil or natural gas. A simple steam power plant consists of a boiler, turbine, condenser and a pump. Fuel, burned in the boiler and superheater, heats the water to generate steam. The steam is then heated to a superheated state in the superheater. This steam is used to rotate the turbine which powers the generator. Electrical energy is generated when the generator windings rotate in a strong magnetic field. After the steam leaves the turbine it is cooled to its liquid state in the condenser. The liquid is pressurized by the pump prior to going back to the boiler. Steam power plants are based on Rankine cycle, shown in Fig. 4.1.

Existing nuclear power plants, too, are steam plants. The difference is that they get the thermal energy needed to generate steam from a nuclear reaction called nuclear fission, instead of burning fossil fuels.

Hot Gas - The gas turbine is used in a wide range of applications. Common uses include power generation plants and military and commercial aircrafts.

In a simple gas turbine cycle, which works based on Brayton cycle shown in Fig.4.2, low pressure air is drawn into a compressor (state 1) where it is compressed to a higher pressure (state 2). Fuel is added to the compressed air and the mixture

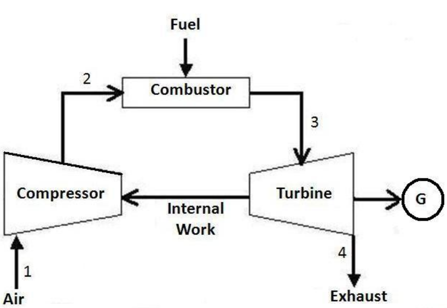

Fig. 4.2 – Brayton cycle

is burnt in a combustion chamber. The resulting hot products enter the turbine (state 3) and expand to state 4. Most of the work produced in the turbine is used to run the compressor and the rest is used to run auxiliary equipment and produce power.

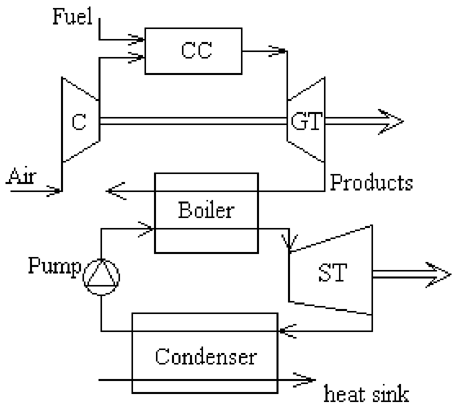

Fig. 4.3 – Combined cycle

Combined Cycle - Combined cycle plants are driven by both steam and hot gas, as shown in Fig. 4.3. They first generate power in a hot gas turbine by burning natural gas and then use residual heat to generate additional electricity from steam. These plants offer efficiencies of up to 60%.

Water (hydroelectric) - Turbine blades are acted upon by flowing water, produced by hydroelectric dams or tidal forces. The power extracted from the water depends on the volume of flowing water (usually measured in cubic meters per second) and on the difference in height between the source and dam's outlet. This height difference is called the head. The amount of potential energy in water is proportional to the head. To deliver water to a turbine while maintaining pressure caused by the head, a large pipe called a penstock may be used. See Fig. 4.4.

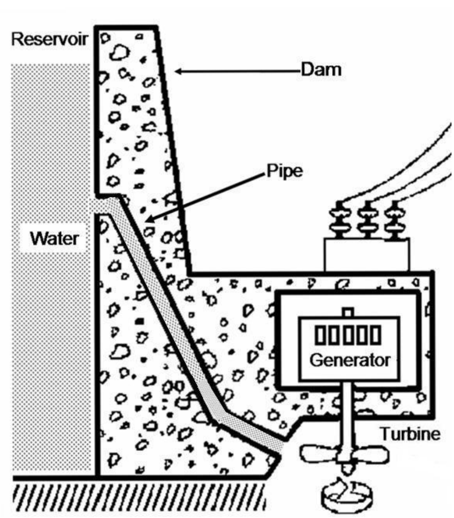

Fig. 4.4 – A hydropower station

Reciprocating Engines

Small electricity generators are often powered by reciprocating engines burning diesel, biogas or natural gas. Diesel engines are often used for back up generation, usually at low voltages. However, most large power grids also use diesel generators, originally provided as emergency back up for a specific facility such as a hospital or to feed power into the grid during certain circumstances. Biogas is often combusted where it is produced, such as a landfill or wastewater treatment plant, with a reciprocating engine or a microturbine, which is a small gas turbine.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. Without some kind of energy conversion method, electric energy will not be accessible.
___2. To generate electricity, it is enough to put a loop of wire inside a magnet's poles.
___3. AC transformers and AC transmission lines did not have any effects on building centralized power stations.
___4. It is possible to convert chemical energy to electric energy, without the need to a mechanical mover.
___5. Electrostatic generation is not used anymore, as it is an old method.
___6. The steam turbine has a little share in today's electricity production.
___7. Steam power stations have four main parts, namely: a boiler, a turbine, a condenser and a pump.
___8. In Brayton cycle, the heat exhausted from the gas turbine is re-used to generate electricity.
___9. Combined cycle power plants have a lower efficiency, compared to power stations using Rankine and Brayton cycles.
___10. If the flow of water is not large enough, a higher dam is needed to generate more power.

II. Reading comprehension. Fill in the blanks with appropriate words given.

blades	considerably	produced	reduces
bodies	drop	proportional	required
condenses	pressure	purposes	surrounding

Steam is ……….. in a boiler, where thermal energy is added to liquid water until its molecules separate into a dense, high-pressure gas. The hotter the steam, the higher its ………… and the more effective it is at spinning the turbine. As the steam flows through the turbine and does work on the rotating …………, its pressure and temperature ………… . By the time the steam leaves the turbine, it has cooled ………… and its pressure is only slightly above atmospheric. Now, it is time to return it to the boiler for reuse. But the steam must first be converted back into water because the work ………… to pump steam into the boiler is ………… to its volume. Turning the steam into dense liquid water ………… that work enormously. The low-pressure steam flows through a cooling tower, where it gives up heat to the ………… air. Once the steam has given up enough heat, it ………… into water and can be returned to the boiler. Many power plants are built near large ………… of water, which also receive some of the steam's waste heat. And a few modern power plants use this waste heat for other industrial or commercial ………… such as heating buildings.

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	accelerate	acceleration	accelerating	-----
2	combine	combination	combined	combinedly
3	combust	combustion	combustible	-----
4	depend	dependence	dependent	dependently
5	expand	expansion	expansive	expansively
6	induce	induction	inductive	inductively

1. ………… is the rate at which an object's speed changes.

2. The ………… of Sodium and Chlorine results in table salt.

3. Internal ………… engines rely on special ………… materials for their operation.

4. In order to survive, human beings ………… on energy originated from sun.

5. In today's competitive business environment, managers should think more ………… about how to run their institution.

6. In an ……….. motor, electric current is ……….. by magnetic field.

IV. Vocabulary expansion: word forms. Choose the right word form for each sentence below.

1. Extract

a. Different minerals are ……….. from mines in different ways.

b. The ……….. of oil in sea is a very complicated process.

c. A number of countries are ……….. natural gas in Persian Gulf.

2. Move

a. The electrons' ……….. in a conductor creates electric current.

b. Most electric machines have ……….. parts, called rotors.

c. An object can be ……….. if enough force is exerted on it.

3. Process

a. The main "thinking" part of each computer is called a ……….. .

b. Crude oil must be ……….. in a refinery before it can be used by ordinary consumers.

c. Under normal circumstances, ……….. an application for connecting a residential building to the existing electric network takes less than a week.

4. Recognize

a. After many inspections, the engineers ……….. the reason why the generator was not working properly.

b. The building was not ……….. at all, after such a horrible fire.

c. The medal was given to him in ……….. of his valuable service.

5. Separate

a. In enrichment process, a centrifuge ……….. Uranium 235 from Uranium 238.

b. ETA is a paramilitary ……….. movement in Basque, Spain.

c. The ………..of Church and State is applied in some countries.

V. Vocabulary: write the Persian equivalent of the following words.

acceleration		lower	
advantage		mention	
auxiliary		microturbine	
back up		military	
blade		mixture	
boiler		movement	
carrier		nature	
centralized		nerve impulse	
circumstances		nuclear fission	
combined		original	
combustion		outlet	
common		particles	
compress		photovoltaic	
conventional		pipe	
creation		pressurize	
cubic		process	
cycle		product	
dam		proportional	
deliver		provide	
derive		raise	
distribution		reciprocating	
emergency		recognize	
equipment		renewable	
expand		residual	
facility		secondary	
field		solar	
fraction		strain	
fuel cell		superheat	
hunt		supply	
intermediate		thermal	
investigate		thermocouple	
kinetic energy		tidal	
landfill		tool	
liquid		treatment plant	
loop		wastewater	

Unit Five

Renewable Energy Resources

Although the industrial revolution brought so many improvements to the human life, it was not without negative impacts. One of the most serious problems created by the increased use of fossil fuels during the past 2-3 centuries is the global warming.

Global warming is the increase in the average temperature of Earth's near-surface air and oceans. According to a report by the Intergovernmental Panel on Climate Change (IPCC) in 2007, global surface temperature increased 0.74 ± 0.18 °C during the 20th century. Most of the observed temperature increase since the middle of the 20th century has been caused by increasing concentrations of greenhouse gases (GHG), including water vapor, carbon dioxide, methane, and nitrous oxide. These are gases which result from human activities such as the burning of fossil fuels and deforestation. Climate model projections shown in the latest IPCC report indicate that the global surface temperature is likely to rise a further 1.1 to 6.4 °C during the 21st century. The increase in global temperature will cause sea levels to rise and will change the amount and pattern of raining, probably including expansion of deserts. Warming is expected to be strongest in the Arctic and would be responsible for continuing reduction of glaciers, permafrost and sea ice. Other likely effects include more frequent and extreme weather events, species extinctions, and changes in agricultural yields. As a result of contemporary

Fig. 5.1 – Global warming

increases in atmospheric carbon dioxide, the oceans have become more acidic, a result that is predicted to continue.

Global warming and its related changes will vary from region to region around the globe, but everybody is going to be affected by its negative impacts somehow. Proposed measures to decrease climate change include reduction of GHG emissions and more use of renewable energy resources to generate electricity. These resources include: hydro, wind, solar, geothermal, wave and tidal, and biomass.

Wind Power

Wind energy is one of the most available sources of renewable energy throughout the world. Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. This wind flow, when harvested by modern wind turbines, can be used to generate electricity. The terms "wind energy" or "wind power" describe the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity.

Wind turbines, like aircraft propeller blades, turn in the moving air and power an electric generator that supplies an electric current. Simply stated, a wind turbine is the opposite of a fan. Instead of using electricity to make wind like a fan, wind turbines use wind to make electricity.

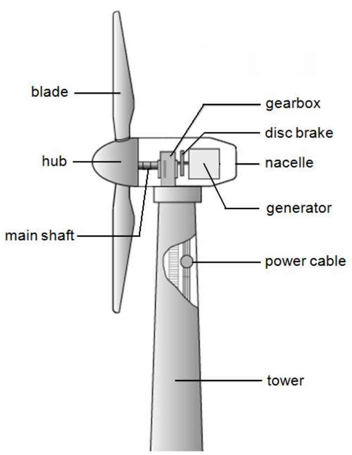

Fig. 5.2 – A wind turbine

Modern wind turbines fall into two basic groups; the horizontal-axis, and the vertical-axis. Most large modern wind turbines are horizontal-axis turbines. Horizontal-axis turbine components include:

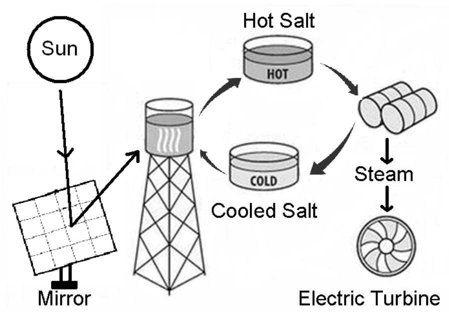

Fig. 5.3 – A CSP system

- blade or rotor, which converts the energy in the wind to rotational shaft energy;
- hub, which is the center part of the rotor;
- a drive train, usually including a gearbox and a generator;
- nacelle, an enclosure housing the generator and other equipment;
- a tower that supports the rotor and the nacelle; and,
- other equipment, including brake, controls, electrical cables, ground support equipment, and interconnection equipment.

Wind turbines are often grouped together into a single wind power plant, also known as a wind farm. Wind farms generate bulk electrical power and the electricity from these farms is fed into a utility grid and distributed to customers, just as with conventional power plants.

Solar Power

Solar technologies are characterized as either passive solar or active solar depending on the way they capture, convert and distribute solar energy. Active solar techniques include the use of solar thermal collectors and photovoltaic panels to harness the energy. Passive solar techniques include orienting a building to the sun, selecting materials with good thermal characteristics or light dispersing properties, and designing spaces that naturally circulate air.

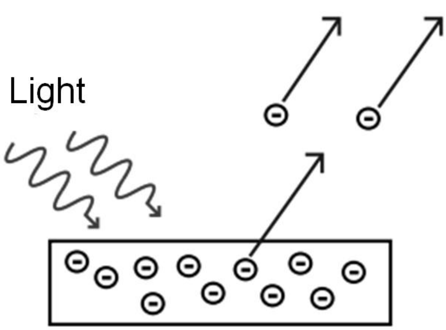

Fig. 5.4 – The photoelectric effect

Solar energy can be harnessed in different levels around the world. Depending on the geographical location, the closer to the equator the more "potential" solar energy is available.

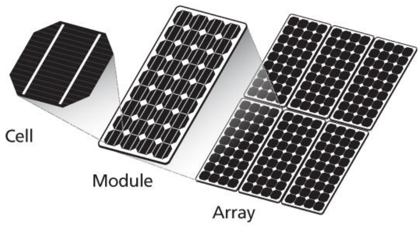

Fig. 5.5 - The components of a solar panel

Solar thermal technologies can be used for water heating, space heating, space cooling and also for electricity generation. Concentrated Solar Power (CSP) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The captured energy is then used to create steam and the steam is used to turn a turbine driving a generator.

Photovoltaics (PV) is a method of generating electrical power by directly converting solar radiation into DC current using semiconductors that exhibit the photoelectric effect. In the photoelectric effect, electrons are emitted from matter (metals and non-metallic solids, liquids or gases) as a consequence of their absorption of energy from light. Photovoltaic power generation employs solar panels composed of a number of cells containing a photovoltaic material.

As of 2010, solar photovoltaic electricity is being generated in more than 100 countries of the world. At present, it comprises a tiny fraction of the total global power-generating capacity from all sources, yet it is the fastest growing power-generation technology in the world. Between 2004 and 2009, grid-connected PV capacity increased at an annual average rate of 60 percent, to about 21 Gigawatts (GW). Such installations may be ground-mounted (and sometimes integrated with farming and grazing) or built into the roof or walls of a building, which is known as Building Integrated

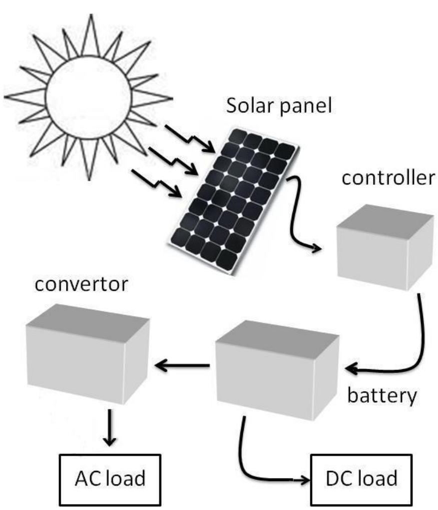

Fig. 5.6 – An off-grid photovoltaic system

Photovoltaics (BIPV). Off-grid PV produces an additional 3–4 GW.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. The increased use of fossil fuels since the industrial revolution has increased the volume of greenhouse gases in the Earth's atmosphere.
___2. Greenhouse gases make the Earth's atmosphere cooler.
___3. Global warming has created favorable conditions for all animals to live and to increase their numbers.
___4. At least some of the natural disasters during the past 50 years, like floods and storms, can be attributed to global warming.
___5. The negative impact of global warming is limited to the Arctic.
___6. Radiations from sun have no role, direct or indirect, in creating winds on the Earth's surface.
___7. A wind turbine generator is designed to harness the kinetic energy in wind and change it to electric power, to be fed into a grid.
___8. Some of the passive solar techniques have been used in Iranian architecture for many centuries.
___9. A CSP system converts sun's radiation directly to electric current.
___10. The best materials for making photovoltaic cells are those with very high levels of conductivity.

II. Reading comprehension. Fill in the blanks with appropriate words given.

affect	generate	organisms	processes
biodegradable	made of	origin	ranging
conventional	numerous	petroleum	source

Biomass, a renewable energy …………, is biological material from living, or recently living …………, such as wood, waste, gas, and alcohol fuels. Biomass is plant matter used to ………… electricity or produce heat. The most ………… way in which biomass is used relies on direct burning. Forest residues, such as dead trees and branches, and wood chips and garbage are often used for this. However, biomass also includes plant or animal matter used for production of fibers or chemicals. Biomass may also include ………… wastes that can be burnt as fuel. It excludes such organic materials as fossil fuels, which have been transformed by geological ………… into substances such as coal or ………… . Industrial biomass can be grown from ………… types of plants, including a variety of tree species, ………… from eucalyptus to oil palm. The particular plant used is usually not important to the end products, but it does ………… the processing of the raw material. Although fossil fuels have their ………… in ancient biomass, they are not considered biomass by the generally accepted definition because they contain carbon that has been "out" of the carbon cycle for a very long time. Biomass is ………… carbon, hydrogen and oxygen.

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	absorb	absorption	absorbing	absorbingly
2	characterize	characterization	characteristic	characteristically
3	circulate	circulation	circulating	-----
4	collect	collection	collective	collectively
5	concentrate	concentration	concentrating	-----
6	convert	conversion	convertible	convertibly

1. Normally, dry soil ………… water better than wet soil.

2. Allowing electric current to flow is ………… of metals like copper and iron.

3. Electric fans are used for forced ………… of air in buildings and tunnels.

4. They tried to harvest the farm's yield ………… .

5. In a thermal solar plant, sun's light is ………… in a small point by mirrors or lenses.

6. The kinetic energy of water is ………… to electricity, if a proper dam is built on the river.

IV. Vocabulary expansion: word forms. Choose the right word form for each sentence below.

1. Contain

a. The generator is safely kept in a ………… during transportation.

b. This box ………… some transmission line equipment and tools.

c. PVC pipes ………… electric cables are used in some buildings.

2. Exhibit

a. Many modern electric equipment were shown in the ………… .

b. Copper ………… very good electric characteristics.

c. The effects of lightning on towers were ………… by pictures.

3. Expect

a. The power generated by a wind turbine is ………… to increase when wind blows faster.

b. The utility is ………… its first solar power plant next year.

c. Increased use of renewable energy sources in recent years has risen the ………… about a cleaner environment in the future.

4. Indicate

a. All data are ………… a horrible future if the current trend of global warming is going to continue.

b. The number of birds in a city is a good ………… of the environmental situation there.

c. Voltage level and frequency are two major ………… in any power system.

5. Predict

a. The system's future load is ………… by computational methods and artificial intelligence techniques, like artificial neural networks.

b. Wind speed is not exactly ………… for long durations.

c. To ………… the sun's level of radiation, measured data from previous years is analyzed carefully.

V. Vocabulary: write the Persian equivalent of the following words.

absorb		horizontal	
active		housing	
aircraft		hub	
annual		installation	
axis		integrate	
beam		interconnect	
brake		irregularity	
bulk		nacelle	
capture		orient	
characterize		panel	
circulate		passive	
climate		pattern	
collect		permafrost	
composed of		predict	
concentration		projection	
consequence		radiation	
contain		region	
deforestation		response	
desert		result	
disperse		rise	
drive train		roof	
emission		sail	
enclosure		semiconductor	
equator		species	
exhibit		specific	
extinction		state	
extreme		support	
feed		tower	
focus		track	
frequent		uneven	
glacier		utility	
governmental		warming	
grazing		wind farm	
grind		windmill	
harvest		yield	

Unit Six

Power Transmission Lines

After electric power is generated in a power plant, it must be transmitted to load centers, where most industrial and commercial consumers and homes and offices are located.

Transmission lines, also known as Extra High Voltage (EHV) lines, carry power from one point to another in a power system. They can carry alternating current or direct current, or a system can be a combination of both AC and DC. Also, electric current can be carried by either overhead or underground lines. Besides transmission lines, two other groups of lines are found in a power system. Those groups are called subtransmission and distribution line. The main characteristics that distinguish transmission lines from the other two groups of lines are: 1) Transmission lines are operated at relatively high voltages, 2) They transmit large quantities of power, and; 3) They transmit power over large distances. The reason why high voltages are used in transmission lines is as follows: Power, P, is the product of voltage, v, by electric current, i, i.e., $P = v \times i$. Also, power losses, P_L, in a transmission line with an ohmic resistance of R is: $P_L = R \times i^2$. When the voltage is increased in a transmission system, the current decreases and consequently, larger amounts of power can be transmitted with less loss of energy. Transmission voltages vary according to the particular grid system they

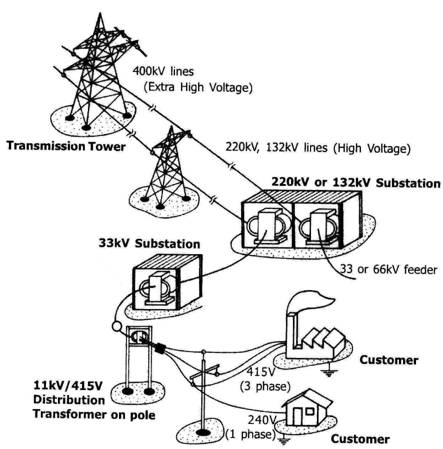

Fig. 6.1 – Part of a power system

belong to. Modern transmission voltages vary from 110 kV up to 765 kV.

Fig. 6.2 shows some examples of different overhead transmission line structures and Table 6.1 shows different levels of voltage employed in Iran's power system.

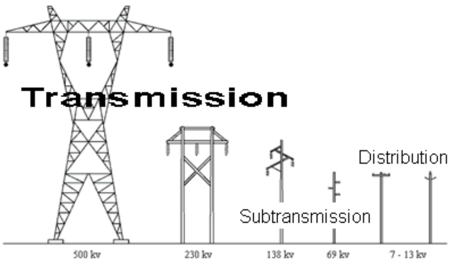

Fig. 6.2 – Transmission line structures

Table 6.1 – Different voltage levels in Iran's power system

Line Group	Distribution	Subtransmission	Transmission
Voltages (kV)	0.4, 11, 20 and 33	63 and 132	230 and 400

Overhead AC Transmission Lines

Overhead AC transmission lines share one characteristic; they carry 3-phase current. Transmission lines are designed in such a way that the power carrying conductors are supported on steel structures installed along the route. The power conductors are insulated from the transmission line structure through necessary insulation devices, or insulators. Fig. 6.3 shows a typical steel tower with its different components.

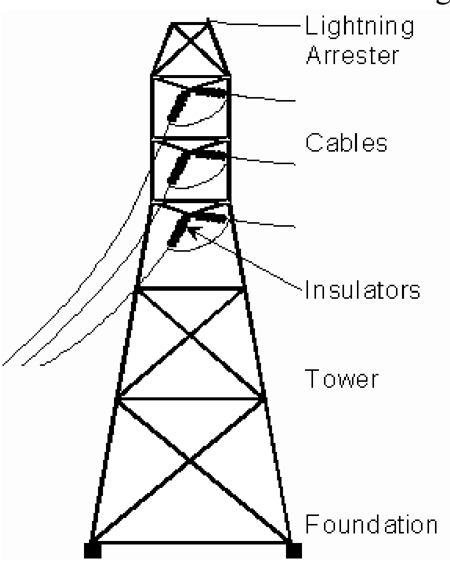

Fig. 6.3 – A typical steel tower

The DC voltage transmission tower has pairs of lines rather than triple lines as in AC lines. In a DC transmission line, one line is the positive current line and the other is the negative current line.

Lightning Arresters

At the top of the transmission towers, lightning arrester wires are connected directly to the steel tower so that

Fig. 6.4 – Typical ACSR conductors

lightning strikes will be grounded. Without the arresters, lightning could cause spikes, i.e. sudden sharp increases in the voltage, which can damage power transformers connected to the two ends of the line.

Conductors

To carry electric power, Aluminum Conductor Steel Reinforced (ACSR) conductors, or cables, are often used. ACSR conductors consist of a solid or stranded steel core surrounded by strands of aluminum. The principal advantage of these conductors is their high tensile strength so that they are used for longer spans with less supports. ACSR conductors are available in a wide range of steel, containing carbon from 0.5% to 0.85 %. The higher strength ACSR conductors are used for river crossings, overhead ground wires, installations involving extra long spans, etc. Aluminum is a good conductor and is much lighter than copper. With lighter wires, the towers can be spaced more widely so that fewer towers are needed. Fig. 6.4 shows the cross section of two typical ACSR conductors.

Insulators

An insulator, also called a dielectric, is a material that resists the flow of electric charge. These materials are used in electrical equipment as insulators or insulation. Their function is to support or separate electrical conductors without allowing current through

Fig. 6.5 – Polyethylene insulators

themselves. To increase the insulation level of an insulator, its length is increased proportionately.

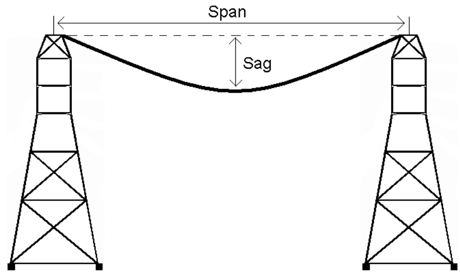

Fig. 6.6 – Transmission line's span and sag

The uninsulated cables can not be connected directly to the steel towers. Steel is also a good conductor and provides a path to the ground for the electricity. The wires have to be hung from long stacks of insulators to keep them insulated from the towers. Glass insulators were first produced in the 1850's for use with telegraph lines. As technology developed, insulators were needed for telephone lines, electric power lines, and other applications. Most modern insulators are made of glass, porcelain, plastic, rubber, and polyethylene.

Line Clearance

The clearances from the line conductor to the ground as well as to adjacent objects are ruled by the sag (or flash) of the conductor. Sag increases with the span length between two adjacent transmission line structures. The atmospheric conditions like ambient temperature, solar radiation, wind velocity as well as power flow influences the sag. The conductor also swings under heavy wind and it is required to maintain clearances under such conditions.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. This can be said that transmission stage is the intermediate stage between electric generation and consumption.
___2. A transmission system can not carry both AC and DC voltages at the same time.
___3. Distribution lines usually carry very large quantities of electric energy.
___4. For a given amount of electric power and for a given line, if voltage is increased 10 times power losses will decrease 10 times.

___5. Both AC and DC transmission lines need three conductors to carry electric power.
___6. Lightning arresters discharge the electric charge to ground and protect the power system and its components from excessive voltages caused by lightning.
___7. The steel strands in an ACSR cable are used to provide higher degrees of electric conductivity.
___8. In transmission systems aluminum is used because it is lighter than copper, yet is a good conductor for electric current.
___9. In order to achieve maximum strength, ACSR conductors are directly connected to steel towers.
___10. Atmospheric conditions do not have any effects on the way a conductor is hung from the towers at its two ends.

II. Reading comprehension. Fill in the blanks with appropriate words given.

classes	increased	installed	restricted
early	inefficient	lecture	revolutionized
essential	influential	located	transformer

In the ………… days of commercial electric power, transmission of electric power at the same voltage as used by lighting and mechanical loads ………… the distance between generating plant and consumers. In 1882, generation was with direct current (DC), which could not easily be ………… in voltage for long-distance transmission. Different ………… of loads (for example, lighting, motors, and railway systems) required different voltages, and so used different generators and circuits. Due to this specialization of lines and because transmission was so ………… that generators needed to be near their loads, it seemed at the time that the industry would develop into what is now known as a distributed generation system with large numbers of small generators ………… nearby their loads. In 1886 a 1 kV AC distribution system was ………… in Massachusetts. That same year, AC power at 2 kV, transmitted 30 km, was installed in Italy. At an AIEE meeting on May 16, 1888, Nikola Tesla delivered a ………… entitled "A New System of Alternating Current Motors and Transformers", describing the equipment which allowed efficient generation and use of polyphase alternating currents. The …………, and Tesla's polyphase and single-phase induction motors, were ………… for a combined AC distribution system for both lighting and machinery. Tesla's polyphase innovations ………… transmission. Regarded as one of the most ………… electrical innovations, it used transformers to increase voltage from generators to high-voltage transmission lines, and then to decrease voltage to local distribution circuits or industrial customers.

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	distinguish	distinction	distinguishable	distinguishably
2	distribute	distribution	distributable	-----
3	influence	influence	influential	influentially
4	insulate	insulation	insulating	-----
5	resist	resistance	resistive	resistively
6	transmit	transmission	transmissible	-----

1. Electric components were not ………… after the huge fire burnt down the whole power station.

2. Not all the electric power generated in an electric network is ………… between consumers. The ………… power is the total generation minus power losses in the system.

3. The power transmission capacity of overhead transmission lines is ………… by a number of factors, including the ambient temperature.

4. In order to ………… electric conductors, materials with very good dielectric properties are usually employed.

5. Some objects can be ………… heated by allowing a high current to flow in an adjacent ………….

6. Some ………… diseases can not be cured now, but they can easily be avoided through education and personal care.

IV. Vocabulary expansion: word forms. Choose the right word form for each sentence below.

1. Consume

a. In hot season, power ………… rises as more cooling devices are used.

b. Crude oil can not be ………… directly. It must be changed to different oil products in a refinery.

c. When ………… electric power, one must be careful no to be hurt by electricity.

2. Involve

a. Many workers and engineers are ………… in production and distribution of electric power.

b. Any job ………… electricity requires appropriate training and safety tools.

c. You should seriously………… your classmates in the discussion.

3. Provide

a. This year, the university ………… rooms for about 60% of the students, but food is ………… for anybody who asks for it.

b. To ………… enough power for the customers, enough generating capacity must be installed in the power system.

c. You can receive your university degree soon, ………… all the requirements of the degree are fulfilled.

4. Reinforce

a. Concrete is ………… properly, if enough steel bars are put in it.

b. Soldiers asked for ………… after the enemy's heavy attack.

c. To ………… people's faith and beliefs, good actions are needed much more than good words.

5. Surround

a. ACSR conductors are usually ………… by air as insulation.

b. A transmission system must have the minimum negative impact on its ………… environment.

c. In order to keep the energy consumption down, please ………… the boiler and hot water pipes with good thermal insulation.

V. Vocabulary: write the Persian equivalent of the following words.

according to		path	
adjacent		polyethylene	
ambient		porcelain	
arc current		principal	
arrester		range	
belong to		reinforce	
cable armor		relatively	
clearance		resistance	
conduct		route	
consequently		rubber	
consist		rule	
consumer		sag	
core		serious	
corona		share	
cross section		sharp	
crossing		shield	
damage		solid	
design		spaced	
dielectric		span	
discharge		spike	
distinguish		stack	
existing		steel	
flashover		strand	
geothermal		strength	
glass		strike	
global		structure	
ground		subtransmission	
hang		sudden	
influence		surround	
involving		swing	
light		tensile	
outage		triple	
overhead		typical	
pair		vary	
particular		velocity	

Unit Seven

Power Distribution Systems

The third stage in supplying electricity, after generation and transmission, is distribution.

A distribution system's network carries electricity from the transmission system and delivers it to the consumers. Typically, the network would include medium-voltage (less than 50 kV) power lines, called primary feeder mains, electrical substations, pad-mounted and/or pole-mounted distribution transformers, low-voltage (less than 1 kV) distribution wiring, called secondary main, and sometimes electricity meters. Distribution substations transform power from transmission or subtransmission voltages to the lower voltage used for local distribution to homes and businesses.

The modern distribution system begins as the primary feeder leaves the substation. It ends as the secondary main enters the customer's metering device through services or drops. A variety of methods, materials, and equipment are used among the various utility companies, but the end result is similar.

First, the energy leaves the substation in a primary circuit, usually with all three phases. The actual attachment to a building (electrical service or drop) varies in different parts of the world. Electrical service can be provided directly from the utility company's transformer or through service laterals.

Most areas provide three phase industrial service. There is no substitute for three-phase service to run heavy industrial equipment. To keep electric current away from equipment and people, a ground wire is normally provided and connected to conductive cases and other safety equipment. Distribution voltages vary depending on customer need, equipment and availability.

Some of the main components found in most distribution systems are as follows:

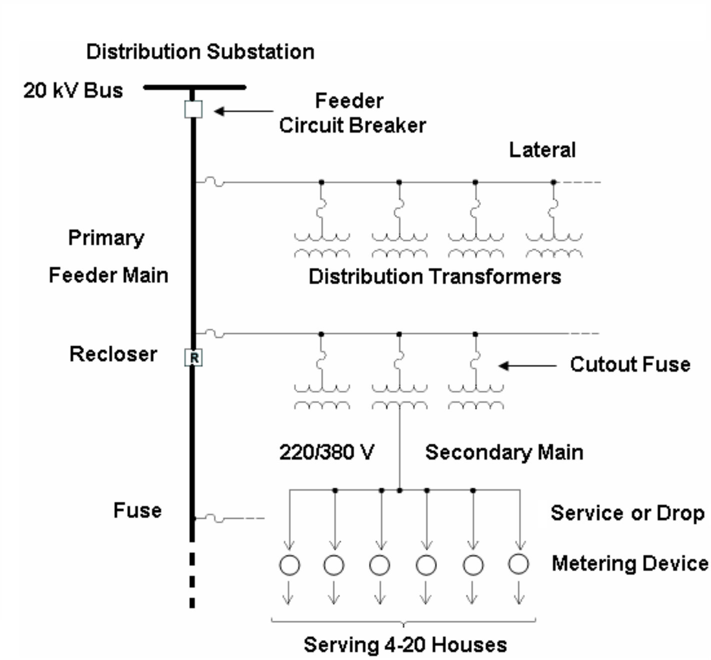

Fig. 7.1 – A power distribution system

Pad-Mounted Transformer: A pad-mounted transformer is a large metal cabinet located on the ground in a neighborhood or business area that is served by underground electrical lines.

Pole-Mounted Transformer: A pole-mounted transformer is a transformer mounted on a utility pole, usually made of reinforced concrete, steel or wood.

Bus: An electrical bus is a common electrical connection between multiple electrical devices. Buses are used for distribution of electrical power to components of a system. The (usually) thick conductor used is called a busbar.

Circuit breaker: A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by overload or short circuit. Its basic function is to detect a fault condition and, by interrupting continuity of current, to immediately discontinue electrical flow. Unlike a fuse, which operates once and then has to be replaced, a circuit breaker can be reset (either manually or automatically) to resume normal operation. Circuit

Fig. 7.2 – 145 kV SF6 gas circuit breaker

breakers are made in varying sizes, from small devices that protect an individual household appliance up to large switchgears designed to protect high voltage circuits feeding an entire city.

Autorecloser: An autorecloser is a circuit breaker equipped with a mechanism that can automatically close the breaker after it has been opened due to a fault. They are used in coordinated protection systems for overhead distribution lines. Distribution lines are exposed to transient faults such as lightning strikes, pieces of junk flying by wind, birds, squirrels climbing insulators, etc. With a conventional circuit breaker or fuse, a transient fault would open the breaker or blow the fuse, disabling the line until a technician could manually reclose the circuit breaker or replace the blown fuse. But an autorecloser will make several pre-programmed attempts to re-energize the line. If the transient fault has cleared, the autorecloser's circuit breaker will remain closed and normal operation of the power line will resume. If the fault is a permanent fault (downed wires, tree branches lying on the wires, etc.) the autorecloser will finish its pre-programmed attempts to re-energize the line and remain tripped off until manually commanded to try again. Autoreclosers are made in single-phase and three-phase

Fig. 7.3 – A cut-out fuse

versions, and use either oil or vacuum interrupters.

Cut-out fuse: In distribution systems, a cut-out fuse (or fuse cutout) is a combination of a fuse and a switch, used in primary overhead feeder lines to protect distribution transformers from current surges and overloads. An overcurrent caused by a fault in the transformer or customer circuit will cause the fuse to melt, disconnecting the transformer from the line. It can also be opened manually by utility linemen standing on the ground and using a long insulating stick called a hot stick.


Fig. 7.4 – 1-phase distribution transformer

Sectionalizer: The sectionalizer is a circuit-opening device used in conjunction with source-side protective devices, such as reclosers or circuit breakers. It automatically isolates faulted sections of electrical distribution systems. Power to operate the control circuitry and the mechanism is obtained from the line through current transformers (CT's). No auxiliary power supply, external connections, or external equipment is required. The sectionalizer senses current flow above a preset level, and when the source-side protective device opens to de-energize the circuit, the sectionalizer counts the overcurrent interruption. Sectionalizers are an economical method of further improving service on distribution lines equipped with reclosers or reclosing circuit breakers. They isolate permanent faults and confine outages to smaller sections of line.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. Only low-voltage and medium-voltage equipment can be found in a distribution system.

___2. Distribution substations can only be fed from transmission systems.
___3. The output from a distribution substation is called primary feeder, while the wiring feeding consumers is called secondary mains.
___4. Service laterals can be used to transfer electric power from the utility's transformer to the consumer.
___5. The best way to run heavy industrial equipment is to use single-phase or double-phase voltages.
___6. A ground wire diverts the electric current to ground when a short circuit happens between live wires and a conductive case.
___7. A circuit breaker can not interrupt the electric current flowing in the system it is connected to.
__8. It can be said that an autorecloser tries to minimize the interruption in the supply of electricity by trying several times to keep the power line working.
___9. A cut-out fuse is a protective device that can be opened only if the current in a distribution line exceeds a certain level.
___10. The power needed to operate the control circuitry and the mechanical parts of a sectionalizer is usually provided by a set of batteries.

II. Reading comprehension. Fill in the blanks with appropriate words given.

citizens	generated	restricted	terminate
connected	long	stepped-down	transformer
divided	overhead	stepped-up	transmit

Electric power is normally ………… at 11-39 kV in a power station. To ………… over long distances, it is then ………… to 132 kV, 230 kV or 400 kV as necessary. Power is carried through a transmission network of high voltage lines. Usually, these lines are hundreds of kilometers ………… and deliver the power into a grid. The grid is ………… to load centers, or cities, through a sub-transmission network of 63 kV or 132 kV lines. These lines ………… into a 63 kV or 132 kV substation, where the voltage is ………… to 20 kV for power distribution to load points. This is done through a distribution network of lines at 20 kV and lower. The power network which concerns the ordinary ………… is the distribution network of 20 kV lines or feeders coming out of the 63 kV substations. Each 20 kV feeder which exits from the 63 kV substations is .... into several auxiliary 20 kV feeders to carry power close to the load points. At these load points, a .... further reduces the voltage from 20 kV to 380 V to provide the final connection through 380 V feeders to individual customers, either at 220 V (as single-phase supply) or at 380 V (as three-phase supply). A feeder could be either an .... line or an underground cable. In urban areas, because of the density of customers, the length of a 20 kV feeder is generally up to 3 km. On the other hand, in rural areas, the feeder length is much larger (up to 20 km). A 380 V feeder should normally be ....to about 0.5-1.0 km. Very long feeders will cause low voltages at the consumer end.

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	conduct	conduction	conductive	conductively
2	disable	disability	disabled	-----
3	equip	equipment	equipped	-----
4	interrupt	interruption	interruptive	-----
5	require	requirement	required	-----
6	substitute	substitution	substitutive	-----

1. The .... of a wire is inversely proportional to its length.

2. A protective device can be .... by internal or external faults.

3. The linemen are .... with safety and live line operation tools.

4. The .... nature of lightning to electric power transmission can be balanced by using surge arresters in transmission systems.

5. Being aware of safety rules is a major .... in working with electric devices and networks.

6. To ensure the continuity of power generation, there must be enough spare parts in a power station to .... damaged items.

IV. Vocabulary expansion: word forms. Choose the right word form for each sentence below.

1. Attach

a. HV conductors are ………… to the tower through insulators.

b. Technicians must ………… an earth wire to any off-line medium-voltage or high-voltage device before trying to repair it.

c. Documents ………… to a letter are called ………… .

2. Carry

a. The major part of consumed power is ………… by ACSR cables.

b. Please ………… the acid batteries with extreme caution.

c. A ………… transformer put on a truck can be used temporarily when a power transformer is out of service due to repairs or faults.

3. Deliver

a. In order to increase the maximum ………… power of a transmission system, its voltage must be increased properly.

b. The ………… of power is usually done by distribution companies serving a specific region or district.

c. The power is ………… to the customer after it goes through a metering device.

4. Detect

a. The ………… of damaged parts is the first step in a repair plan.

b. Electric faults in a device are ………… by tools called relays.

c. A police officer trained to investigate crimes and collect information is called a ………… .

5. Replace

a. Trained technicians know how to ………… a blown fuse without any harm to themselves or to others.

b. A ………… fuse is combined with a switch to form a cut-out fuse.

c. Electric lamps used in airport runways are checked and ………… regularly to ensure maximum security and visibility day and night.

V. Vocabulary: write the Persian equivalent of the following words.

appliance		lateral	
attachment		lineman	
attempt		mains	
autorecloser		manual	
availability		mechanism	
branch		melt	
bus		metal	
cabinet		multiple	
case		neighborhood	
circuit breaker		obtain	
circuitry		overcurrent	
concrete		overload	
conductive		pad-mounted	
confine		pole-mounted	
conjunction		pre-programmed	
continuity		preset level	
coordinate		re-energize	
count		require	
detect		reset	
disable		resume	
disconnect		sectionalizer	
discontinue		sense	
downed wire		short circuit	
drop		stage	
entire		stick	
exposed to		substation	
external		substitute	
fault		surge	
feeder		switchgear	
ground wire		technician	
household		thick	
immediately		transient	
increase		tree	
interrupt		trip	
junk		wiring	

Unit Eight

Distribution Network Configurations

Distribution networks are designed in a variety of configurations. Some of the factors which affect the selection of the configuration are: the nature of loads to be supplied, the population density in the area to be supplied, the level of security and reliability needed for the electricity supply, the budget allocated to the network construction, the percentage of power losses allowed in the network, the voltage profile needed in the network, etc.

Network Types

Distribution networks are of three basic types: a) Radial, b) Loop, and; c) Interconnected. A radial network, which is the simplest and most commonly used type, leaves the station and passes through the network area with no normal connection to any other supply. This is typical of long rural lines with isolated load areas, or a large load with a devoted feeder. A radial feeder is shown in Fig. 8.1.

A loop network provides a two-way primary feed for important loads, so that if one current path is out of service because of faults or repairs, the second path continues to feed the load. Obviously, a loop network is more reliable than a radial one. Fig. 8.2 shows a loop network.

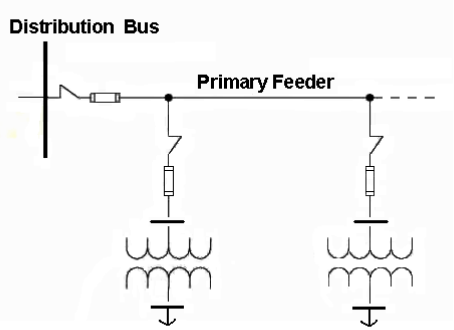

Fig. 8.1 – A single-source radial feeder

An interconnected network is generally found in more urban areas and will have multiple connections to other points of supply. These points of connection are normally open but allow various configurations by the operating utility by closing and opening switches. Operation of these switches may be by remote control from a control center or by a lineman. The benefit of the interconnected model is that in the event of a fault or required maintenance a small area of network can be isolated and the remainder kept on supply. Fig. 8.3 shows an interconnected distribution network.

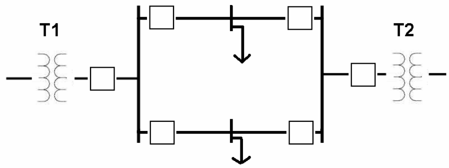

Fig. 8.2 – A loop network

Design Considerations

Within these networks there may be a mixture of overhead line construction utilizing traditional utility poles and wires and, increasingly, underground construction with cables and indoor or cabinet substations. However, underground distribution is significantly more expensive than overhead construction. In order to reduce this cost, underground power lines are sometimes co-located with other utility lines in what are called common utility ducts.

Distribution feeders exiting from a substation are generally controlled by a circuit breaker which will open when a fault is detected. Automatic circuit reclosers may be installed to further isolate the feeder thus minimizing the impact of faults.

Long feeders experience voltage drop, so they usually require capacitors or voltage regulators to be installed at the end of the line, or somewhere in the middle, to compensate the voltage drop. These auxiliary devices are helpful in reducing power losses in the distribution network too.

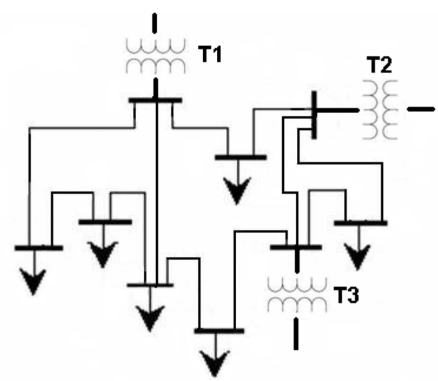

Fig. 8.3 – An interconnected network

Polyphase Systems

In most parts of the world, three phase service is often a Y (wye) in which the neutral is directly connected to the center of the transformer windings. Wye service is recognizable when a line has four conductors, one of which is lightly insulated. Three-phase wye service is excellent for motors and other heavy industrial use. In a three-phase system, the power flows to the load in a steady and uniform way. In single-phase systems, however, the power fluctuates in time with a frequency twice than that of the power system.

Many areas in the world use single-phase 220 V to 240 V for residential and light industrial services. In this system, a high voltage distribution network supplies a few substations per city, and the 220 V power from each substation is directly distributed. A hot wire and neutral are connected to the building from one phase of three phase service.

In the U.S. and parts of Canada and Latin America, split phase service is the most common. Split phase provides both 120 V and 240 V service with only three wires. The house voltages are provided by neighborhood transformers that lower the voltage of a phase of the distributed three-phase. The neutral is directly connected to the three-phase neutral. Socket voltages are 120 V, but 240 V is also available for heavy appliances, like refrigerators and washers, because the two halves of a phase oppose each other.

Rural services normally try to minimize the number of poles and wires. Single-Wire Earth Return (SWER) is the least expensive, with one wire. It uses high voltages, which in turn permit the use of galvanized steel wire. The strong steel wire permits inexpensive wide pole spacings. Other areas use high voltage split-phase or three phase service at higher costs.

Supply Characteristics

Characteristics of the supply given to customers are generally given by a contract between the supplier and the customer. Variables of the supply include:

- AC or DC - Virtually all public electricity supplies are AC today. Users of large amounts of DC power, such as some electric railways, telephone companies and industrial processes such as aluminum smelting, either have their own DC generators or use rectifiers to get DC from the public AC supply,

- Voltage, including tolerance (usually +10 or -15 percent),
- Frequency, commonly 50 or 60 Hz, 16.6 Hz for some railways and, in a few older industrial and mining locations, 25 Hz,
- Phase configuration (single phase, polyphase including two phase and three phase),
- Maximum demand (usually measured as the largest amount of power delivered within a 15 or 30 minute period during a billing period),
- Load factor, expressed as the ratio of average load to peak load over a period of time. Load factor indicates the degree of effective utilization of equipment (and capital investment) of distribution line or system,
- Power factor of connected load,
- Earthing arrangements.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. Economic considerations do not play any role in selecting a distribution system's configuration.

___2. Electric power can flow in both directions in a radial distribution network.

___3. In order to feed a rural load located far away from the distribution bus, loop configuration is preferred over the radial configuration.

___4. Considering system's security and reliability, a loop configuration is better than a radial one, but not as good as an interconnected network.

___5. Not all the switches in an interconnected network are always closed. Rather, they are closed or opened based on the distribution system's conditions and requirements.

___6. System faults have the least negative impact on radial networks, then on loop networks, and have the most negative impact on interconnected networks.

___7. Both overhead and underground cables can be used in distribution systems, but the costs of overhead cables are significantly more than underground cables.
___8. The length of a feeder line does not have any effect on the voltage fed to the load at the end of the line.
___9. To reduce the impact of faults on the power supply, autoreclosers are usually used in distribution systems.
___10. Single-phase wiring is used to feed residential customers because it is cheaper and easier to handle.
___11. Under some conditions, the Earth can be used as a return path for the electric current to reduce the construction costs.

II. Reading comprehension. Fill in the blanks with appropriate words given.

building	cover	hard	sealed
classified	existing	installed	smaller
completely	fluid	maintenance	urban

The ……….. power distribution substations can be ……….. into three categories. The first category of existing substations includes "exterior" substations, where the equipment and connections are ……….. outside, on a specific site. These substations generally ……….. a large surface area and do not have a pleasant appearance. Considering their design, these substations require a lot of ……….., as the equipment is subject to the climatic conditions of the site, which can be ……….. . The second category of existing substations includes the "metal-clad" substations, where the equipment is located in ……….. enclosures and insulated by a pressurized ……….. . These metal-clad substations are much ……….. than the exterior substations and have their equipment ……….. protected. However, their fabrication and maintenance costs are very high. The third category of existing substations includes the "interior" substations. These substations include a partitioned ……….. in which the equipment is located and insulated by ambient air. Considering their structure, these substations are often used in ……….. centers, as they are relatively compact and have a much more pleasant appearance compared to exterior substations.

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	devote	devotion	devoted	devotedly
2	isolate	isolation	isolated	isolatedly
3	mix	mixture	mixed	mixedly
4	permit	permission	permissible	permissibly
5	relate	relation	relating	-----
6	select	selection	selective	selectively

1. Good engineers show extreme ………… to their duties and tasks under any circumstances.

2. Before being connected to the electric network, the generator was tested ………… .

3. The fuel basket in Iranian thermal power plants is mainly a ………… of residual oil, natural gas and diesel fuel.

4. Maximum ………… voltage for residential customers throughout the world is under 400 V.

5. The breakdown of most refrigerator compressors can be ………… to the voltage fluctuations in distribution networks.

6. A good protective system, when designed and implemented properly, deals with faults and abnormal situations ………… .

IV. Vocabulary expansion: word forms. Choose the right word form for each sentence below.

1. Allocate

a. According to the law, the ………… of annual budget must be approved by the parliament first.

b. In order to be successful, one must ………… his/her time and resources properly and wisely.

c. Unfortunately, the horses ………… to Captain Scott's mission to the South Pole were not able to withstand the extreme cold weather in the Antarctica.

2. Compensate

a. In some long distribution networks, capacitors are used to ………… the voltage drop.

b. Besides capacitors, other power system devices are available for voltage ………… too.

c. The use of renewable energy resources is ………… some of the environmental wrong-doings by humans, such as too much carbon emissions.

3. Maintain

a. Generators are ………… according to a regular and precise plan to keep their ability to work properly.

b. The ………… of electric devices must be done by properly trained technicians.

c. Power plants work day and night ………… a steady flow of electric power to the consumers.

4. Tolerate

a. The voltage ………… is usually about ±10% of the rated voltage.

b. An insulator usually can ………… voltages higher than its rated voltage for a very short time.

c. The weight of conductors and insulators is better ………… by steel towers than wooden poles.

5. Utilize

a. Proper ………… of energy resources requires understanding and education for citizens, as well as the managers and decision-makers in all sections of the society.

b. In order to ………… electric power easily, indoor wirings are spread throughout buildings, offices and industrial units, with enough sockets installed where necessary.

c. The first people who ………… wind power for grinding grains are said to have been Persians.

V. Vocabulary: write the Persian equivalent of the following words.

actual		percentage	
affect		permit	
allocate		polarization	
arrangement		population	
billing		profile	
breakdown		public	
budget		radial	
by-pass		ratio	
capacitor		rectifier	
capital		regulator	
coefficient		reliability	
co-locate		remainder	
compensate		remote	
configuration		repair	
contract		residential	
coupling		rural	
damping		security	
demand		selection	
devote		self-supporting	
diversity		sleeve	
duct		smelting	
fluctuation		socket	
flux		spacer	
indicate		spacing	
indoor		split	
instantaneous		spur	
interruption		tie-line	
investment		tolerance	
isolate		traditional	
lightly		trunk	
maintenance		urban	
middle		utilize	
neutral		variable	
obvious		virtually	
peak		winding	

Unit Nine

Electric Machines

An electric machine is the generic name for a device that converts one form of energy to another, or changes alternating current from one voltage level to a different voltage level.

Based on how they convert energy or change the voltage, electric machines are divided into three main categories, i.e., generators, motors and transformers.

Currently, more than 99% of the electric power is being generated by conventional generators. Also, more than 60% of the generated power is consumed by electric motors, from giant MW motors used in the industry, to fractional horsepower motors used in homes and offices.

Energy Conversion

Energy conversion in electric machines takes place in an electromagnetic field. In order to create and shape the electromagnetic field, ferromagnetic alloys with good magnetic properties are used. The part of the machine which conducts the magnetic flux is called "magnetic core". With appropriate design, a magnetic circuit is formed within the machine which acts very similar to an electric circuit. In electric circuits, the driving force is the

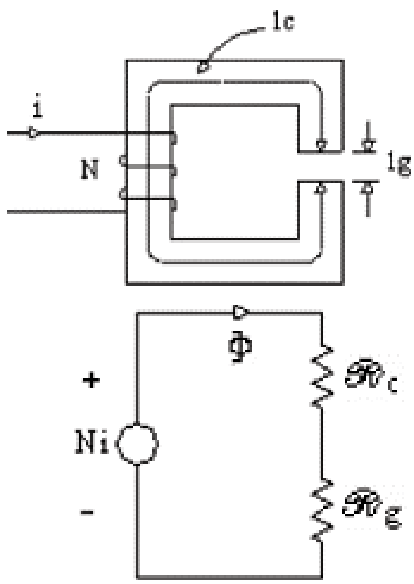

Fig. 9.1 – Magnetic core and circuit

voltage or the electromotive force (EMF), the moving particles, or electrons, form the electric current, and, the ohmic resistance of the circuit regulates the electric current. In magnetic circuits, similarly, the driving force is magnetomotive force (MMF), the magnetic flux circulates in the circuit, and the magnetic resistance, also called "reluctance", regulates the magnetic flux. Because of the physical separation between the stator and the rotor, magnetic fields in motors and generators always experience one or more air gaps in their path.

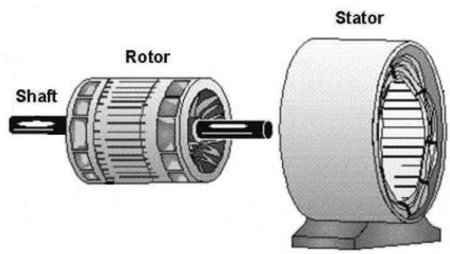

Fig. 9.2 – Main parts of a machine

Generator

An electric generator is a device that converts mechanical energy to electrical energy. The sources of mechanical energy, the prime mover, can be any of the types introduced in Unit Four and Unit Five.

There are two main parts of a generator which can be described in either mechanical or electrical terms. In mechanical terms the rotor is the rotating part of an electrical machine, and the stator is the stationary part of an electrical machine. In electrical terms the armature is the power-producing component, or winding, of an electrical machine and the field is the magnetic field component of an electrical machine. The armature can be on either the rotor or the stator. The magnetic field can be provided by either electromagnets or permanent magnets mounted on either the rotor or the stator. Windings on the stator and rotor are tightly put in grooves, or slots. Generators are classified into


Fig. 9.3 – 3-phase windings in stator slots

two types, AC generators and DC generators.

AC Generator

An AC generator converts mechanical energy into alternating current electricity. Because power transferred into the field circuit is much less than power transferred into the armature circuit, AC generators almost always have the field winding on the rotor and the armature winding on the stator.

AC generators are classified into several types. The first is asynchronous or induction generators, in which stator flux induces currents in the rotor. The prime mover then drives the rotor above the synchronous speed, causing the opposing rotor flux to cut the stator coils producing active current in the stator coils. The second type is synchronous generator or alternator, in which the current for the magnetic field is provided by a separate DC current source.

DC Generator

A DC generator produces direct current electrical power from mechanical energy. A DC generator can operate at any speed within mechanical limits and always delivers a direct current waveform. Direct current generators known as dynamos work on exactly the same principles as alternators, but have a commutator on the rotating shaft which converts the alternating current produced by the armature to direct current. There are several ways in which the magnetic field is created in a DC generator, i.e., series, shunt and compound fields.

Motor

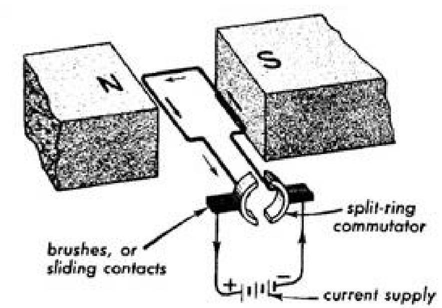

Fig. 9.4 – DC commutation

An electric motor converts electrical energy into mechanical energy. The reverse process of electrical generators, most electric motors operate through interacting magnetic fields and current-carrying conductors to generate rotational force. Motors and generators have many similarities and many types of electric motors can be run as generators, and vice versa.

Electric motors are found in applications as diverse as industrial fans, blowers and pumps, machine tools, household appliances, power tools, and disk drives. They may be powered by direct current or by alternating current which leads to the two main classifications: AC motors and DC motors.

AC Motor

An AC motor converts alternating current into mechanical energy. It commonly consists of two basic parts, an outside stationary stator having coils supplied with alternating current to produce a rotating magnetic field, and an inside rotor attached to the output shaft that is given a torque by the rotating field.

There are two main types of AC motors, depending on the type of rotor used. The first type is the induction motor, which only runs slightly slower or faster than the supply frequency. The magnetic field on the rotor of this motor is created by an induced current. The second type is the synchronous motor, which does not rely on induction and as a result, can rotate exactly at the supply frequency. The magnetic field on the rotor is either generated by current delivered through slip rings or by a permanent magnet.

DC Motor

The brushed DC electric motor generates torque directly from DC power supplied to the motor by using internal commutation, stationary permanent magnets, and rotating electrical magnets. Brushes carry the electric current from the commutator to the spinning wire windings of the rotor inside the motor. Brushless DC motors use a rotating permanent magnet in the rotor, and stationary electrical magnets on the motor housing. A motor controller converts DC to AC. This design is simpler than that of brushed motors because it eliminates the complication of transferring power from outside the motor to the spinning rotor.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. In all categories of electric machines, some kind of conversion between electric and mechanical energy takes place.
___2. The magnetic field in an electric machine acts similar to the catalyst in an electrochemical process, because it facilitates the conversion between two types of energy.
___3. The analogy between magnetic circuits and electric circuits make the analysis of electric machines easier.
___4. All prime movers in modern power stations are steam turbines.
___5. In all generators, the armature winding is always located on the rotating part, i.e. on the rotor.
___6. In an induction generator, the rotor's magnetic flux is generated independently from the stator's magnetic flux.
___7. A main difference between an AC generator and a DC generator is that the latter has a commutator mounted on its shaft.
___8. The operation of electric motors is based on the fact that if a current-carrying conductor is put inside a magnetic field, a mechanical force will be exerted on it.
___9. There are basic differences between the structure and the operation principles of DC generators and DC motors.
___10. Synchronous machine is called by this name, because its rotor and its stator magnetic field rotate exactly at the same speed.

II. Reading comprehension. Fill in the blanks with appropriate words given.

ability	contrast	negative	shaft
caused	damaged	produced	sources
characteristics	desirable	range	windings

The universal motor is a series DC motor which has been designed to operate on both AC and DC power. The ………… to operate on AC is because the current in both the field and the armature ………… (and hence the resultant magnetic fields) will alternate in synchronism, and so the resulting mechanical force will be ………… in a constant direction. Operating at normal power line frequencies, universal motors are often found in a ………… rarely larger than 1000 watt. An advantage of the universal motor is that AC ………… may be used on motors which have some good ………… of DC motors, such as high starting torque and very compact design. The ………… aspect is the maintenance and short life. These are the problems ………… by the commutator. Induction motors can not turn a ………… faster than allowed by the power line frequency. By …………, universal motors generally run at high speeds, making them useful for appliances such as blenders, vacuum cleaners, and hair dryers where high speed and light weight is ………… They are also commonly used in portable power tools, such as drills. The motor may be ………… from over-speeding, if it is operated without enough mechanical load on its shaft.

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	apply	application	applicable	applicably
2	complicate	complication	complicated	complicatedly
3	describe	description	describable	----
4	interact	interaction	interactive	interactively
5	oppose	opposition	opposite	oppositely
6	rotate	rotation	rotational	rotationally

1. Electromagnetic laws are ………… to all electric machines.

2. The relationship between stator and rotor magnetic fields in an induction machine is not very ………… .

3. To ………… how a generator works, one needs to know Faraday's Law of Induction.

4. Modern computer programs work more ………… than older ones.

5. In terms of electric charge, an electron is the ………… of a proton.

6. The ………… of motor's shaft in ball bearings generates heat, which must be ventilated properly.

IV. Vocabulary expansion: word forms. Choose the right word form for each sentence below.

1. Alternate

a. Most home appliances need 110V or 220V ………… current.

b. Soldiers ………… their posts every two hours.

c. Renewable energy resources are very good ………… for fossil fuels.

2. Eliminate

a. Using some kind of local generation in rural areas may ………… the need to a long network connection.

b. Urban underground cables have …………. overhead LV and MV distribution lines in many cities.

c. The ………… of negative environmental effects is not possible with the old trend of fossil fuel consumption.

3. Regulate

a. The relationship between voltage and current in a circuit is ………… by Ohm's Law.

b. Safety ………… do not allow a HV transmission line to pass through a densely populated area.

c. A voltage ………… tries to keep the voltage at the end of a radial feeder within acceptable limits.

4. Reverse

a. The rotation of a 3-phase motor can be ………… by interchanging two phases.

b. Electric conductance is the ………… of electric resistance.

c. Some of the damage done by man to the environment is …………, if proper action is taken on time.

5. Spin

a. Electrons ………… around the nucleus steadily and continuously.

b. The ………… force of the Earth is cancelled by the Sun's gravitational force.

c. A power station operating in the system with less than its full capacity is called the system's ………… reserve.

V. Vocabulary: write the Persian equivalent of the following words.

alloy		magnetomotive	
alternating		opposing	
alternator		power factor	
armature		rated voltage	
asynchronous		regulate	
benefit		reluctance	
blower		rely	
brush		repulsion	
category		reverse	
commutation		rotating	
complication		salient pole	
compound		separation	
compressed		several	
cylindrical		shape	
damper bar		shunt field	
describe		similarity	
diverse		slightly	
eliminate		slip ring	
event		slot	
exciter		somewhat	
experience		spin	
fan		squirrel cage	
ferromagnetic		stability	
gap		starting current	
generic		stationary	
giant		steady state	
groove		stepper motor	
horsepower		tightly	
hysteresis		torque	
interaction		transient	
lagging		universal	
leading		vice versa	
leakage flux		voltage drop	
load factor		waterwheel	
magnetization		winding pitch	

Unit Ten

Power Transformers

Power transformers are the third category of electric machines. Their difference with electric motors and generators is that they just change the voltage level of an AC system and are not involved in energy conversion. As it was mentioned in Unit Six, power losses in a transmission system are reduced significantly by increasing the system's voltage. Increasing the voltage at the generation end of a transmission system, and decreasing it at the load end, is done by power transformers. Therefore, power transformers are vital elements in an efficient and reliable power system.

Power transformers installed in transmission systems usually have very large rated capacities, perhaps up to several hundreds of MVA. In distribution systems, to the contrary, the rating is much less and capacities as low as a few KVA are common. However, the principles on which these transformers work are exactly the same.

Constructing a Transformer

If a conductor carrying a changing current is brought near a second conductor, then the changing magnetic flux surrounding the first conductor will be linked to the second conductor and will induce a voltage in it. Such a basic transformer is shown in Fig. 10.1. An AC voltage is connected to a primary conductor, shown as the left-hand solid bar in Fig. 10.1. In response to the voltage, an AC current flows, setting up a time-varying magnetic field

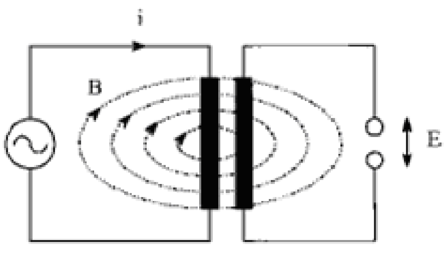

Fig. 10.1 – A basic transformer

surrounding the primary conductor.

A secondary conductor, shown as the right-hand solid bar in Fig. 10.1, is located in proximity to the primary conductor so that the magnetic flux surrounding the primary conductor links the secondary circuit. According to the law of induction, there will be an induced voltage E around the path surrounding the time-varying flux.

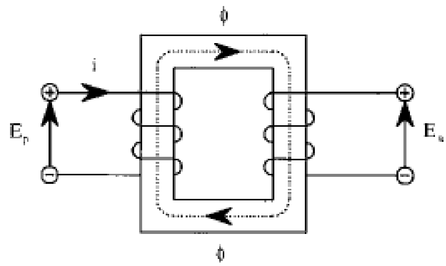

Fig. 10.2 – A more efficient transformer

The configuration shown in Fig. 10.1 is not very efficient in transferring energy because only a small portion of the total magnetic flux surrounding the primary conductor will be linked to the secondary circuit. In order to improve the efficiency of the transformer, the magnetic field needs to be channeled in such a way that most of the flux produced by the primary conductor is linked to the secondary circuit. This is accomplished by surrounding the primary and secondary conductors with a magnetic core material having an affinity for magnetic flux. This modification is shown in Fig. 10.2. By adding the magnetic core, essentially all of the magnetic flux produced in the primary conductor is linked to the secondary conductor. Therefore, the efficiency of the transformer is greatly increased.

Core Structure

There is no moving part in a transformer, thus there is no significant air gap in their magnetic circuit either. Similar to AC motors and generators, transformer magnetic cores are subject to time-varying magnetic flux. Time-varying magnetic flux induces an AC voltage in the magnetic core, which in turn, creates an electric current in the body of the core, known as eddy current. Because of the ohmic


Fig. 10.3 – A 3-phase laminated core

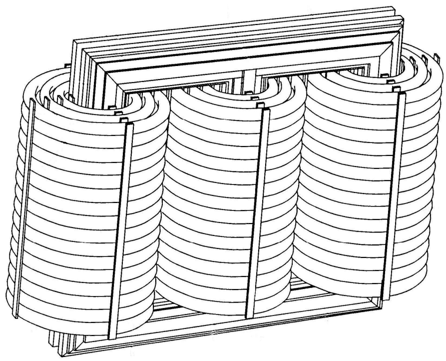

Fig. 10.4 – 3-phase core and coils

resistance of the core, some power is lost in the core. These loses, known as eddy current losses, generate additional heat in the core which can be harmful to the core, as well as to the coils wound on it. To keep eddy current losses at the minimum, magnetic cores which experience time-varying magnetic flux are constructed from thin steel laminations which are electrically isolated from each other, but have very good magnetic conductance. This increases the ohmic resistance significantly, and therefore, eddy current losses are reduced drastically.

Three-phase Transformers

As conventional AC systems have three phases, so do power transformers. A three-phase transformer can be constructed by the combination of three single-phase transformers. Alternatively, three sets of primary and secondary windings can be wound on a single magnetic core to form a three-phase unit. Fig. 10.4 shows the core and coils of a three-phase transformer.

The most obvious way of transforming voltages and currents in a three-phase electrical system is to operate each phase as a separate single-phase system. This requires a four-wire system comprised of three phase wires plus a common neutral wire that is shared among the three phases. Each phase is transformed through a set of primary and secondary windings connected phase-to-neutral. This is commonly referred to as the Y-Y connection. Each primary winding is magnetically linked to one secondary winding through a common core leg. In the Y-Y connection, each primary and secondary winding is connected

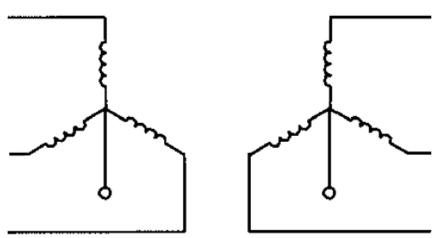

Fig. 10.5 – The Y-Y connection

to a neutral point. The neutral point may or may not be brought out to an external physical connection and the neutral may or may not be grounded.

A winding connected phase-to-phase is called a delta-connected winding because of its resemblance to the Greek letter Δ when it is depicted in a vector diagram. Since a Δ winding has no connection to its neutral point, it is usually left ungrounded. The Δ-Y connection is shown in Fig. 10.6. For technical and protection reasons, the Δ-Y connection transformer is used universally for connecting AC generators to transmission systems.

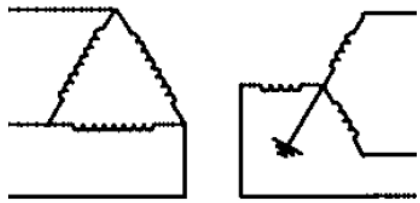

Fig. 10.6 – The Δ-Y connection

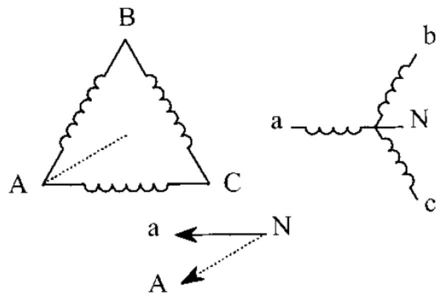

Fig. 10.7 – Phase angle displacement

A careful examination of the primary and secondary voltages in a three-phase Δ-Y transformer reveals that the primary voltage of any given phase is displaced electrically by 30° from the secondary voltage of the corresponding phase. The 30° phase angle displacement may either be positive or negative; i.e., the primary voltage may either lead the secondary voltage by 30° or lag the secondary voltage by 30° depending on how the transformer is connected. The property of a Δ-Y transformer that causes the primary and secondary voltages to be out of phase with each other is referred to as the phase angle displacement of the transformer. Fig. 10.7 shows this phenomenon, in which the primary voltage a-N is measured with respect to the real neutral point N, and the secondary voltage A-N is measured with respect to a virtual neutral point.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. All electric machines are used for transferring energy, but only some of them convert the form of the transferred energy too.
___2. The employment of power transformers has made the economic operation of large power systems possible.
___3. Unlike transmission transformers, distribution transformers can convert both direct current and alternating current.
___4. Air-core transformers are as efficient as iron-core transformers.
___5. A magnetic core improves the magnetic linkage between primary and secondary windings.
___6. This can be said that some extremely small air gaps exist in a transformer's magnetic core because of its laminated structure.
___7. Eddy currents in a non-laminated core are much smaller than eddy currents in a properly laminated core.
___8. A bank of three single-phase transformers acts similar to one three-phase unit, but may need a larger space for installation.
___9. A coil in a Δ winding experiences a lower voltage, compared to a coil in a Y winding.
___10. The secondary voltage in a Δ-Y transformer is always 30° ahead of its primary voltage.

II. Reading comprehension. Fill in the blanks with appropriate words given.

associated	coupled	extensively	regulate
boosting	distribution	involving	relationship
capacity	electrically	narrow	special

The autotransformer is the simplest and the most interesting of the connections ………… two windings. It is used quite ………… in bulk power transmission systems because of its ability to multiply the effective KVA ………… of a transformer. An autotransformer has two windings, a common winding and a series winding. Besides being magnetically …………, and unlike transformers, the two windings in an autotransformer are ………… connected too. An autotransformer is called a ………… autotransformer if the series winding boosts the output voltage. Care must be exercised when discussing ''primary'' and ''secondary'' voltages in ………… to windings in an autotransformer. In two-winding transformers, the primary voltage is ………… with the primary winding and the secondary voltage is associated with the secondary winding. In the case of a boosting autotransformer, however, the primary (or high) voltage is associated with the series winding, and the secondary (or low) voltage is associated with the common winding. Autotransformers are also used on radial ……….. feeder circuits as voltage regulators. A voltage regulator is a ……….. type of autotransformer that is designed specifically to ……….. line voltage over a relatively ……….. output range, typically around ±10% of the incoming voltage.

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	associate	association	associated	-----
2	clear	clearance	clear	clearly
3	convince	conviction	convincing	convincingly
4	locate	location	located	-----
5	multiply	multiplication	multiplied	-----
6	transform	transformation	transformable	-----

1. The magnetic field around a current-carrying conductor is ……….. with the movement of electrons in it.

2. For safety reasons, enough ……….. must be observed around MV and HV equipment.

3. The engineers talked about the usefulness of the new solar power plant quite …………

4. A wind farm must be ……….. where enough wind energy exists.

5. The wind turbine's output is a ……….. of the wind speed and the area swept by the rotor.

6. Crude oil is ……….. to many valuable products and derivatives.

IV. Vocabulary expansion: word forms. Choose the right word form for each sentence below.

1. Accomplish

a. Receiving an engineering degree is a major ……….. for anybody.

b. The huge task of constructing the power station was ………… only through team work by all engineers, technicians and workers.

c. To ………… maximum efficiency, careful design and manufacturing are necessary.

2. Emerge

a. Countries like India and Brazil are considered ………… economic powers.

b. The ………… of electric power made huge improvements in the human's life.

c. Tesla ………… as the winner in his dispute with Edison over the advantages of AC over DC systems.

3. Improve

a. The operation of an electric machine can be ………… through the use of better ferromagnetic materials.

b. The ………… in electric power generation and consumption is the result of many people's hard work during the past century.

c. To ………… the voltage profile, capacitors or voltage regulators are usually used.

4. Response

a. A motor's ………… to changes in its load depends on its inertia.

b. An engineer is ………… for what s/he designs and implements.

c. When necessary, the power station ………… to load fluctuations very quickly.

5. Theorize

a. Maxwell ………… electromagnetic phenomena with mathematics.

b. The ………… capacity of a transmission line may be more than its actual capacity.

c. In …………, a motor can always be used as a generator, but in actual world, there may be some minor differences.

V. Vocabulary: write the Persian equivalent of the following words.

ability		lamination	
accomplish		link	
affinity		located	
associated		mismatch	
bank		multiply	
bar		narrow	
boost		out of phase	
brought		perhaps	
care		phase shifter	
channel		portion	
coil		property	
combination		proximity	
comprised of		quite	
conductance		rated capacity	
core leg		referred to	
corresponding		reliable	
coupled		resemblance	
depicted		resonance	
diagram		reveal	
displacement		set up	
drastic		skin effect	
eddy current		specifically	
efficient		subject to	
employment		tank	
essentially		tap changer	
examination		tertiary	
extensive		thin	
extremely		turns ratio	
grounded		typically	
harmful		vector	
impedance		virtual	
incoming		vital	
inrush current		within	
interesting		with respect to	
involve		wound	

Unit Eleven

Power Electronic Circuits

Although electric energy is generated either in AC or DC form, it can easily be converted from one form to another, using power electronic devices and circuits. There are numerous power electronic circuits in operation, each one with specific applications, advantages and limitations. However, the most commonly used power electronic circuits are rectifiers (AC to DC) and inverters (DC to AC). Other power electronic circuits, too, are employed which can convert DC to DC at different voltages, or AC to AC at different voltages and/or frequencies.

Rectifying Devices

The operation of most power electronic circuits is based on rectifying devices. The simplest rectifying device is diode. Diode is a two-terminal electronic component with asymmetric transfer characteristic. It has low (ideally zero) resistance to current flow in one direction, and high (ideally infinite) resistance in the other. A semiconductor diode, the most common type today, is a crystalline piece of semiconductor material with a p-n junction connected to two electrical terminals. The most common function of a diode is to allow an electric current to pass in one direction, called the diode's forward direction, while blocking current in the opposite direction, or the reverse direction. This unidirectional behavior is called rectification, and is used to convert alternating current to direct current. Diodes are non-controlled switches, as there is no external control over their operation. Today most diodes are made of silicon, but

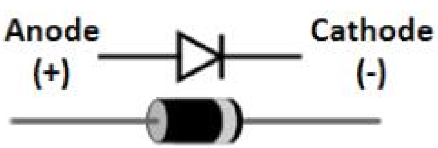

Fig. 11.1 – A diode

other semiconductor materials such as germanium are used too.

Besides diodes, other rectifying devices with more complicated structures and characteristics are made and utilized too. The most common is thyristor. A thyristor is a solid-state semiconductor device with four layers of alternating N and P-type material. They act as controlled switches, conducting when their gate receives a current trigger, and continue to conduct while they are forward biased, that is, while the voltage across the device is not reversed.

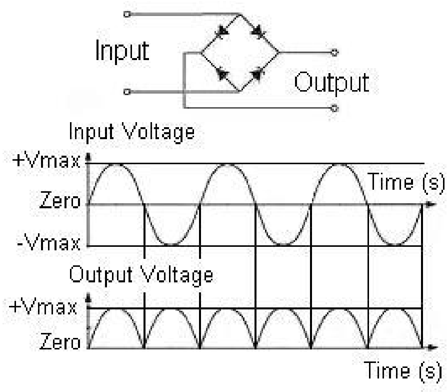

Fig. 11.2 – A full-wave diode rectifier

Rectifier Circuits

A rectifier circuit is one which converts AC current to DC. The AC source can be a single-phase, a three-phase, or in general, a polyphase source. The DC output of the circuit depends on the type of rectifying switches used and the way they are connected. In general, rectifiers can be categorized as the following two groups:

Half-wave circuits: A half-wave circuit has one rectifying device in each line of the AC supply. All cathodes of the devices are connected to a common connection to feed the DC load. The return from the load is connected to the AC supply's neutral.

Full-wave circuits: These circuits are in fact two half-wave circuits connected in series, one feeding into the load and the other returning load current directly to the AC lines, thus eliminating the need to use AC supply's neutral. Full-wave circuits are more commonly called bridge circuits.

The control characteristics of various circuits can be placed broadly in one of the following three groups:

Uncontrolled circuits: In these circuits, only diodes are used and the DC output has a fixed mean value. This value is a function of the applied AC voltage and can not be adjusted, unless the AC voltage is adjusted.

Fully-controlled circuits: In these circuits, all rectifying elements are thyristors (or similar devices, such as power transistors). By suitable control of the phase angle at which thyristors are turned on, it is possible to control the mean value of the DC voltage, and even to reverse the DC load voltage.

Half-controlled circuits: These circuits contain a mixture of thyristors and diodes. This mixture permits the adjustment of the DC voltage's mean value, but prevents the reversal of the load voltage.

Inverter Circuits

A power inverter, or inverter, is an electrical circuit that changes direct current to alternating current. The converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching devices, and control circuits. Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high voltage direct current (HVDC) systems that transport bulk power over very long distances. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries. The inverter performs the opposite function of a rectifier.

The output of inverter circuits can be categorized in a number of groups, the most common of which are as follows:

Square wave: The square wave output has a high harmonic content, not suitable for certain AC loads such as motors or transformers. Square wave units were the pioneers of inverter development, but other units were designed later to improve the power quality.

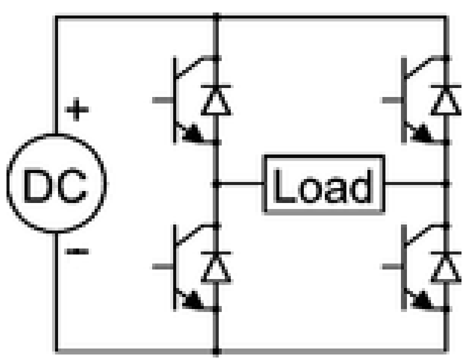

Fig. 11.3 – An H-bridge inverter

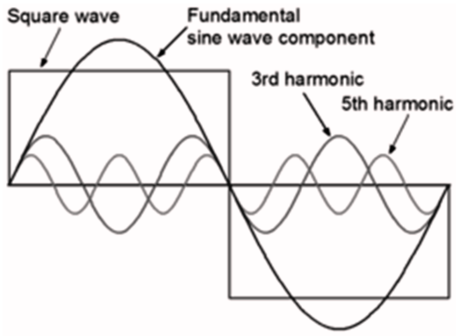

Fig. 11.4 – Square wave output

Modified sine wave: The output of a modified square wave, or modified sine wave inverter, is similar to a square wave output except that the output goes to zero volts for a time before switching positive or negative. It is simple and low cost and is compatible with most electronic devices, except for sensitive or specialized equipment, for example certain laser printers, fluorescent lighting and audio equipment. Most AC motors will run with this power source, but at a reduction in efficiency of approximately 20%.

Multilevel: Multilevel inverter is a power electronic circuit that synthesizes a desired AC voltage from several levels of direct current voltage as inputs. The advantages of using multilevel topology include reduction of power ratings of power devices and lower cost.

The H-bridge inverter circuit shown in Fig. 11.3, which supplies a single-phase AC load, uses power transistors as main switches with anti-parallel diodes. An anti-parallel diode's task is to transfer the load current away from the main switch, thereby allowing it to regain its blocking (off) state. Fig. 11.4 shows the square wave output of an inverter, with its fundamental sine wave component and 3rd and 5th harmonics.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. Power electronic circuits provide a wide range of DC and AC sources with different levels of voltage and variable frequencies.

___2. Power electronic converters have created the possibility of using many electric appliances and tools in different parts of the world which have different electric network characteristics.

___3. If controlled properly, a diode can conduct electric current in both directions.
___4. The direction at which electric current flows in a diode does not have any impact on its impedance.
___5. The main difference between a diode and a thyristor is the fact that thyristor will not conduct current in forward-biased state, unless it receives a firing signal at its gate.
___6. A half-wave rectifier can be used to feed a DC load, even if the neutral point of the AC source is not accessible.
___7. With a fully-controlled rectifier, the DC load can be supplied both with positive and negative voltage polarities.
___8. In order to connect photovoltaic generation units to AC grids, appropriate inverters must be designed and employed.
___9. A square wave inverter output is the closest inverter output to sinusoidal waveforms.
___10. The existence of harmonics in the output of a modified sine wave inverter increases power losses in AC motors.

II. Reading comprehension. Fill in the blanks with appropriate words given.

contain	different	method	partially
converters	electronic	mobile	releasing
declines	level	output	space

DC to DC ………… are important in portable electronic devices such as ………… phones and laptop computers, which are primarily supplied with power from batteries. Such ………… devices often ………… several sub-circuits, each with its own voltage level requirement ………… from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage). Additionally, the battery voltage ………… as its stored power is discharged. Switched DC to DC converters offer a ………… to increase voltage from a ………… lowered battery voltage thereby saving ………… instead of using multiple batteries to accomplish the same task. Most DC to DC converters also regulate the …………voltage. Electronic switch-mode DC to DC converters convert one DC voltage ………… to another, by storing the input energy temporarily and then ………… that energy to the output at a different voltage. The storage may be in either magnetic field storage components (inductors, transformers) or electric field storage components (capacitors).

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	adjust	adjustment	adjustable	adjustably
2	operate	operation	operating	-----
3	renew	renewal	renewable	renewably
4	resume	resumption	resumed	-----
5	specialize	specialization	specialized	-----
6	store	storage	storable	-----

1. When a power system's load changes, the generation level must be ………… to preserve the balance between generation and consumption.

2. Besides the capital cost of building a new power station, the ………… costs, too, must be considered in the planning stage.

3. It takes millions of years for fossil fuels in the nature to ………….

4. The ………… of substation's work depends on the repair plan.

5. A ………… technician is responsible for the operation of MV and HV tools and instruments.

6. Electric Energy ………… Systems (ESS's) are becoming more popular in power systems around the world.

IV. Vocabulary expansion: word forms. Choose the right word form for each sentence below.

1. Continue

a. The supply of load can not be ………… if a permanent fault occurs in the system and remains un-cleared.

b. The ………… of power supply during peak hours requires enough generation capacity installed in the system.

c. The ……….. service to customers is a major goal of a well-managed utility.

2. Coordinate

a. Protective devices in a power system must be properly ……….. to ensure the system's normal operation all the time.

b. Every group needs a ……….. to ……….. the activities of all members, and to prevent interference between their specific tasks.

c. To use a computer mouse, good hand and eye ……….. is necessary.

3. Invert

a. Temperature ……….. , when combined with pollution, is a very dangerous environmental situation, which usually happens in winter and is one of the results of too much fossil fuel consumption.

b. Both voltage and frequency of an AC source are ……….. with proper devices.

c. The occupation of Iran in World War II ……….. the pace of war against Nazis.

4. Modify

a. Installing Static VAR Compensators (SVC's) can ……….. the problem of too much voltage fluctuations in power systems.

b. The ……….. of a load's power factor is possible with synchronous machines and capacitors.

c. The new transmission line's proposed route was ……….. to protect the National Wildlife Park.

5. Synthesize

a. To ……….. is the process of creating new materials through combining different elements.

b. In modern industries, more ……….. materials are being used to improve product characteristics.

c. A sound ……….. is an electronic device which combines artificial sounds to create music pieces.

V. Vocabulary: write the Persian equivalent of the following words.

additionally		inverter	
adjust		junction	
anti-parallel		layer	
approximately		mean value	
asymmetric		modification	
audio		multilevel	
behavior		non-controlled	
bias		operation	
bidirectional		opposite	
block		partial	
bridge circuit		phase angle	
broadly		polarity	
categorize		portable	
cathode		power rating	
cellular phone		primarily	
compatible		reactance	
complicated		regain	
content		release	
converter		requirement	
crystalline		reversal	
desired		sensitive	
diode		sine wave	
exception		solid-state	
firing signal		specialized	
fixed		square wave	
fluorescent		storage	
forward		sub-circuit	
full-wave		synthesize	
function		temporarily	
gate		terminal	
half-controlled		thyristor	
half-wave		topology	
harmonic		transfer	
ideally		trigger	
inductor		unidirectional	

Unit Twelve

Power Systems in 21^{st} Century
Part I

Today's alternating current power grids evolved in late 1890s, based partly on Nikola Tesla's design. At that time, the grid was developed as a centralized unidirectional system of electric power transmission, electricity distribution, and demand-driven control.

In the 20^{th} century power grids originated as local grids that grew over time, and were eventually interconnected for economic and reliability reasons. By the 1960s, the electric grids of developed countries had become very large. These systems were highly interconnected, with thousands of central power stations delivering power to major load centers via high capacity power lines.

Although the beginning of electric systems in western countries was initially made possible through investment by the private sector, in many countries large power stations, transmission systems, and distribution networks belonged, and still belong, to governments.

All these aspects have experienced significant changes during the past few decades and will certainly continue to change dramatically in the 21^{st} century. Some main areas of future change and development in power systems are introduced in this Unit, as well as in Unit Thirteen.

Distributed Generation

Distributed generation (DG), also called dispersed generation, generates electricity from many small energy sources. Most countries generate electricity in large centralized facilities, such as fossil fuel, nuclear, hydropower or large solar power plants. These plants have excellent economic advantages, but usually transmit electricity over long distances and negatively affect the environment. Distributed generation allows collection of energy from many different sources and may give lower environmental impacts and improved security of supply.

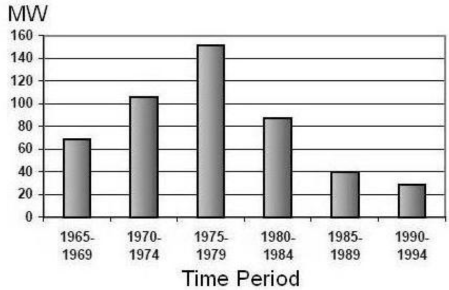

Fig. 12.1 – Optimum generation capacity

Historically, central power plants have been an integral part of the electric grid, in which large generating facilities are located either close to primary energy resources or located far from populated load centers. These power plants, then, supply the traditional transmission and distribution grids which distribute bulk power to load centers and consumers.

The economic advantages of central power plants began to decrease in the late 1970s, and by the start of the 21st century many central plants could no longer deliver competitively cheap and reliable electricity to remote customers through the grid. Fig. 12.1 shows the economically optimum generating capacity in the US. In recent decades, therefore, economic benefits no longer come from increasing generating capacity, but from smaller units located closer to sites of demand.

Distributed generation plants are mass-produced, small, and less site-specific. In addition, they reduce the amount of energy lost in transmitting electricity because the electricity is generated very near where it is used, perhaps even in the same building. This also reduces the size and number of power lines that must be constructed.

Distributed Energy Resource (DER) systems are small-scale power generation technologies, typically in the range of 3 kW to 10 MW. One popular source is solar panels on the roofs of buildings. Another source is small wind turbines. These units need low maintenance, and have low pollution. Many distributed generation sites combine wind power and solar power.

For reasons of reliability, distributed generation resources are usually interconnected to the same transmission grid to which the central stations are connected. Various technical and economic issues occur in the integration of these resources into a grid. Technical problems arise in the areas of power quality, voltage stability, harmonics, reliability, protection, and control. A large scale

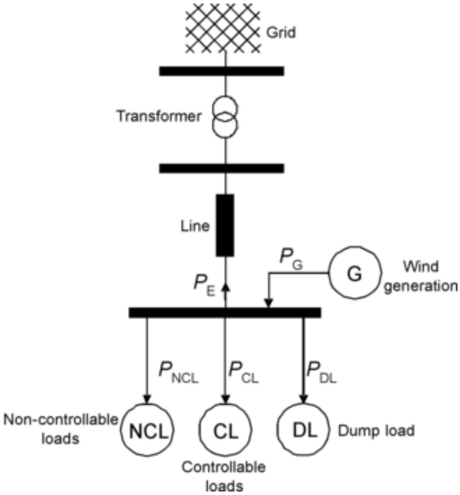

Fig. 12.2 – Wind DG connected to the grid

deployment of distributed generation may affect grid-wide functions such as frequency control and allocation of reserves. Fig. 12.2 shows the connection of a wind generation unit to the existing grid. Since the wind power is not controllable, a dump load has been added to the local controllable and non-controllable loads to keep the balance between the generation and the consumption all the time. A dump load, usually an electric heating system, is a device to which wind generator power flows when the system can not accept more power.

Smart Grids

A smart grid is a digitally enabled electrical grid that gathers, distributes, and acts on information about the behavior of all participants, i.e. suppliers and consumers. The main goal is to improve the efficiency, reliability, economics, and sustainability of electricity services. Application of smart grid technology implies a fundamental re-engineering of the electricity services industry.

In conventional power systems, metering of electricity consumption was necessary on a per-user basis in order to allow appropriate billing according to the level of consumption of different users. Because of limited data collection and processing capability, fixed-tariff arrangements were commonly used. Also, dual-tariff arrangements, where night-time power was charged at a lower rate than daytime power, were used in some systems. The metering capabilities of the 1960s imposed technological limitations on the degree to which price signals could be propagated through the system.

Through the 1970s to the 1990s, growing demand led to increasing numbers of power stations. In some areas, supply of

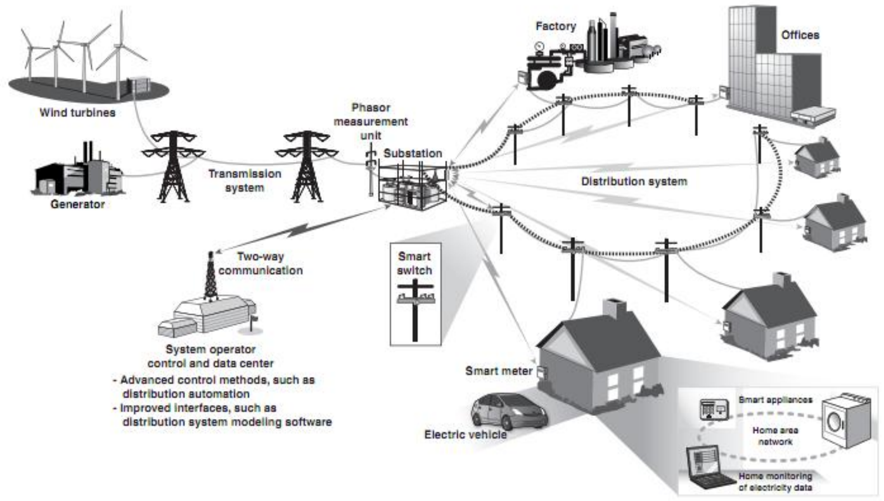

Fig. 12.3 – A Smart Grid consisting of smart control, measurement and consumption

electricity, especially at peak times, could not keep up with this demand, resulting in poor power quality. The resulted decrease in power quality included blackouts, power cuts, and brownouts. A brownout is a reduction of the system's voltage and/or frequency to reduce the consumption. At the same time, people depended more and more on electricity for industry, heating, communication, lighting, and entertainment, and consumers demanded higher levels of reliability.

Towards the end of the 20th century, electricity demand patterns were established as follows: domestic lighting, heating and air-conditioning led to daily peaks in demand that were met by a group of "peaking power generators". These generators would be turned on for short periods of time each day. Usually, gas turbines were used due to their relatively lower capital cost and faster start-up times. The relatively low utilization of these peaking generators, together with the necessary redundancy in the electricity grid, resulted in high costs to the electricity companies. These high costs, consequently, were passed to the customers in the form of increased tariffs.

Since the early 21st century, opportunities to take advantage of improvements in electronic communication technology to resolve the limitations and costs of the electrical grid have become apparent. Technological limitations on metering no longer force peak power prices to be averaged and passed on to all consumers equally. In addition, different energy prices during the day and night can be sent to the consumers to help them manage their consumption and minimize their power bills. This means that at peak times, when the energy is more expensive, consumers limit their usage only to necessary appliances. Less important loads, thus, can be fed off-peak, when the energy is cheaper. The overall result is a reduced peak for power producers and less costs for consumers.

In parallel, growing concern over environmental damages caused by fossil-fired power stations has led to a desire to use large amounts of renewable energy. Dominant forms of renewable energy, such as wind power and solar power, are highly variable. Therefore, to facilitate the connection of these sources to the existing grids, more sophisticated control and communication systems are needed.

A smart grid has the ability to fulfill all these new requirements, and more, by using the advances in the field of Communication and Information Technology (CIT).

Exercises

I. Reading comprehension. Put “T” for true statements and “F” for false statements.

___1. The first power systems were designed and built on a local basis, and not as large and widespread interconnected systems.

___2. The interconnection of power systems in the early 20th century resulted in less economic benefits and reduced the power system's reliability.

___3. The use of DG enables power system operators to use a wider range of energy resources to produce electric energy.

___4. Environmental concerns play no role in power system's orientation towards distributed generation.

___5. It is expected to generate cheaper electric energy in the future by larger centralized power plants.

___6. Distributed generation not only increases the security of electric energy supply, it also reduces transmission power losses.

___7. There is a very close correlation between the concept of distributed generation and the use of more renewable energy resources such as a wind and solar.

___8. A smart grid can be designed and built, even without the digital methods of gathering data and processing information.
___9. At the end of the last century, since the increased peak demand was not completely met by power suppliers, the number of blackouts and power cuts increased.
___10. To achieve higher efficiencies and more economic and environmental benefits in a smart grid, all control and operation techniques of the conventional power systems must be used without any changes.

II. Reading comprehension. Fill in the blanks with appropriate words given.

central	equipment	network	refers to
communication	improvements	options	remote
consumers	modernize	processing	workers

Smart Grid generally ……….. a class of technology being used to bring electricity delivery systems into the 21st century. This is done by using computer-based ……….. control and automation. These systems are made possible by two-way communication technology and computer ……….. that has been used for decades in other industries. They are beginning to be used on electricity networks, from the power plants and wind farms all the way to the ……….. of electricity in homes and businesses. They offer many benefits to utilities and consumers. These benefits are mostly seen as big ……….. in energy efficiency on the electricity grid and in the consumers' homes and offices.

For a century, utility companies have had to send out ……….. to gather much of the data needed to provide electricity. The workers, for example, read meters, look for broken ……….. and measure voltage. Most of the devices utilities use to deliver electricity have yet to be automated and computerized. Now, many ……….. and products are being made available to the electricity industry to ……….. it.

Much in the way that a "smart" phone these days means a phone with a computer in it, smart grid means "computerizing" the electric utility grid. It includes adding two-way digital ……….. technology to devices associated with the grid. Each device on the ……….. can be given sensors to gather data (power meters, voltage sensors, fault detectors, etc.), plus two-way digital communication between the device in the field and the utility's network operations center. A key feature of the smart grid is automation technology that lets the utility adjust and control each individual device or millions of devices from a ………… location.

III. Vocabulary expansion: word forms. Choose the right word form for each sentence below. Make necessary changes if required.

	Verb	Noun	Adjective	Adverb
1	correlate	correlation	correlative	correlatively
2	deploy	deployment	deployable	-----
3	disperse	dispersion	dispersive	dispersively
4	integrate	integration	integral	integrally
5	originate	origination	original	originally
6	sustain	sustainability	sustainable	sustainedly

1. There is a close ………… between the number of wild animals (such as wild birds) living in an area and the environmental conditions there.

2. Large amounts of wind energy are ………… in a power system, if appropriate control and protection strategies are designed and implemented.

3. To ………… the additional heat generated in a thermal power plant, after the steam exits the turbine, high cooling towers are usually used.

4. In mathematics, some domains are called ………… closed domains, if certain conditions are met.

5. Power transformer was ………… designed and used by Austrian scientists. Its design was perfected later by Westinghouse Company in the United States.

6. ………… development is a pattern of economic growth in which natural resources are used to meet human needs, while preserving the environment so that these needs can be met not only in the present, but also for the next generations.

IV. Vocabulary: write the Persian equivalent of the following words.

air-conditioning		intelligent	
apparent		issue	
arise		keep up	
blackout		large scale	
broken		mass-production	
brownout		metering	
capability		modernize	
capital cost		network	
charge		occur	
collection		opportunity	
computerize		optimum	
concern		option	
correlation		orientation	
data		originate	
demand-driven		overall	
deployment		participant	
desire		partly	
detector		pollution	
disadvantage		populated	
dispersed		power cut	
distributed		power quality	
dual-tariff		private	
dump load		processor	
enable		propagate	
entertainment		protection	
evolved		redundancy	
facilitate		re-engineering	
facilities		resolve	
fixed-tariff		sector	
fulfill		sensor	
gather		site-specific	
grid-wide		smart	
imply		sophisticated	
initially		start-up	
integral		sustainability	

Unit Thirteen

Power Systems in 21st Century
Part II

In Unit Twelve, two subjects of Distributed Generation and Smart Grids were discussed. In this Unit, two other important aspects of modern power systems will be introduced.

Power System Restructuring and Deregulation

Electric power systems around the world are currently undergoing substantial changes in their structure and rules of operation. This process is known as restructuring and deregulation.

Up to early 1990s most electricity in the U.S., for example, was supplied by vertically integrated utilities operating under a regulatory contract between them and the state authorities. Vertical integration is the structure of the business operation, in which the company controls all aspects related to its particular product, from production to transportation and distribution between the customers. Under the contract, the utilities agreed to provide an adequate supply of electricity for all users in return for receiving a fair rate for their production.

In contrast, over 50% of generating capacity in the U.S. is now operating under a centrally administered wholesale power

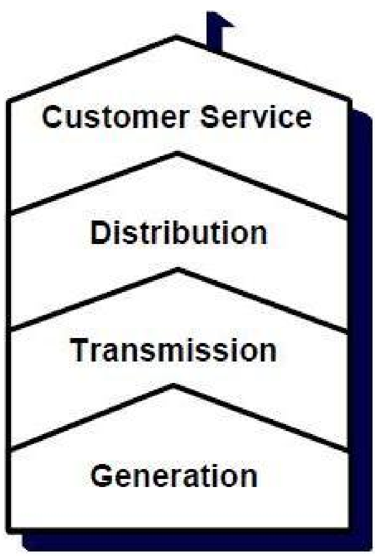

Fig. 13.1 – Vertically integrated structure

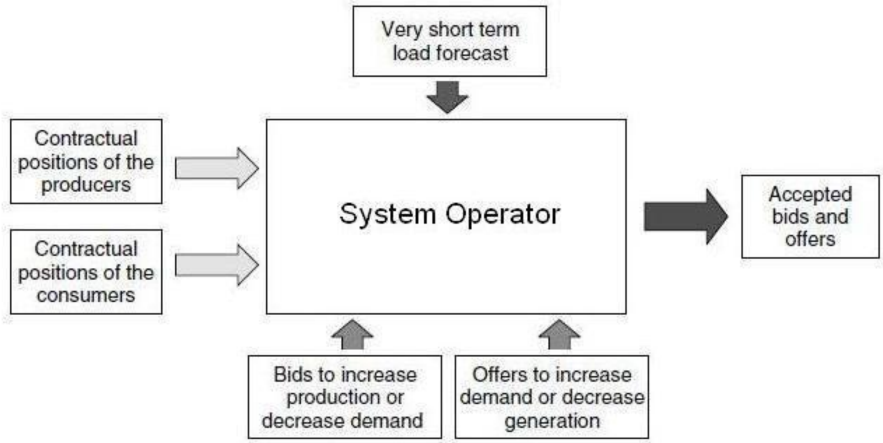

Fig. 13.2 – A restructured utility system

market in which electricity is priced in accordance with the location and timing of its injection into the transmission grid.

A restructured power system consists of five main players: GenCo's, or generation companies, TransCo's, or transmission companies, DisCo's, or distribution companies, Independent System Operator (ISO), and the Regulatory Body.

The Independent System Operator works at the heart of the power system connecting all participants, i.e. GenCo's, TransCo's, retailers that buy and sell electricity, industries and businesses that use electricity in large quantities, and local DisCo's that deliver electricity to people's homes.

Every few minutes the ISO forecasts consumption throughout the system's area. This forecast is usually performed using intelligent computational methods, such as Artificial Neural Networks (ANN). The input to this kind of computer programs usually includes information about power consumption in previous similar time periods, the time of the year and day, weather conditions, etc. It then collects the best offers from generators to provide the required amount of electricity. This allows customers to see prices fluctuate based on supply and demand. As a result, they can shift consumption away from peak time to times when the price is lower, or they can buy power from the GenCo which is offering the lowest price.

The regulatory body, which is a government authority, has the responsibility to make sure that the operation of the system does not present risks to the national security. It also ensures system's reliability and efficiency, as well as fairness for all players. In such an environment, companies, too, will continuously be developing new strategies for the purchase and sale of energy to enhance their net earnings, while protecting against financial and operational risks.

The restructuring and deregulation of the power utility industry is bringing about significant competitive, technological and regulatory changes. Independent power producers, power marketers and brokers have added a new and significant dimension to the task of maintaining a reliable electric system. Unlike other sectors of the economy, restructuring of the electricity industry requires a careful analysis because of the nature of the real-time operations.

The development of electricity markets is based on the premise that electrical energy can be treated as a commodity. There are, however, important differences between electrical energy and other commodities such as bushels[1] of wheat, barrels of oil or even cubic meters of gas. These differences have a profound effect on the organization and the rules of electricity markets.

The most fundamental difference is that electrical energy is directly linked with a physical system that functions much faster than any other market. In this physical power system, supply and demand – generation and load – must be balanced on a second-by-second basis. If this balance is not maintained, the system collapses with catastrophic consequences. Such a breakdown is intolerable because it is not only the trading system that stops working but also an entire region or country that may be without power for many hours. Restoring a power system to normal operation following a complete collapse is a very complex process that may take 24 hours or more in large, industrialized countries. The social and economic consequences of such a system-wide blackout are so severe that no sensible government would agree to the implementation of a market mechanism that significantly increases the likelihood of such an event.

Another significant, but less fundamental, difference between electrical energy and other commodities is that the energy produced by one generator cannot be directed to a specific consumer. Conversely, a consumer cannot take energy from only one generator.

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1 A bushel is a unit for dry volume in the US, equal to 35.24 liters or 8 gallons.

Instead, the power produced by all generators is pooled on its way to the loads. This pooling is possible because units of electrical energy produced by different generators are indistinguishable.

Finally, the demand for electrical energy exhibits predictable daily and weekly cyclical variations. However, it is not the only commodity for which the demand is cyclical. The consumption of coffee, to take a simple example, exhibits two or three sharp peaks every day, separated by periods of lower demand. Trading in coffee does not require special mechanisms because consumers can easily store it in solid or liquid form. On the other hand, electrical energy must be produced at the same time as it is consumed.

Energy Storage Systems

The addition of variable energy sources to power systems, such as wind and solar energy, has complicated the control methods used by system operators. As mentioned earlier, the balance between generation and consumption must be kept all the time. The uncontrollable variations in wind and solar energies, however, make this task very difficult. Wind blows intermittently and so some form of storage is required to compensate for calm periods. Solar energy is equally not available on cloudy days and during the nighttime, so stored energy must be available to compensate for the loss of sunlight.

To overcome this difficulty, one of the solutions is to use energy storage systems (ESS). In a system with sufficient ESS capacity, the surplus energy is stored when the generation is higher than the consumption, and it is returned to the system when the demand is higher than supply.

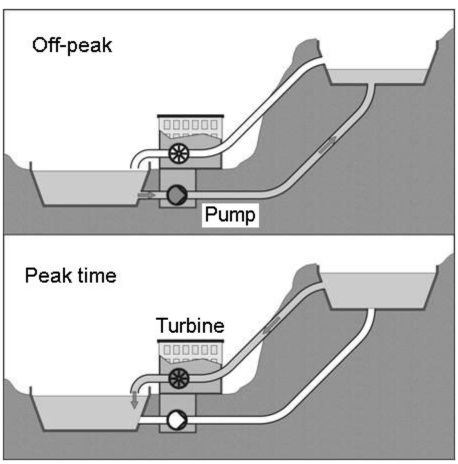

Fig. 13.3 – A pumped-storage system

Energy storage is accomplished by devices or physical media that store energy to perform useful operation at a later time. A device that stores energy is sometimes called an

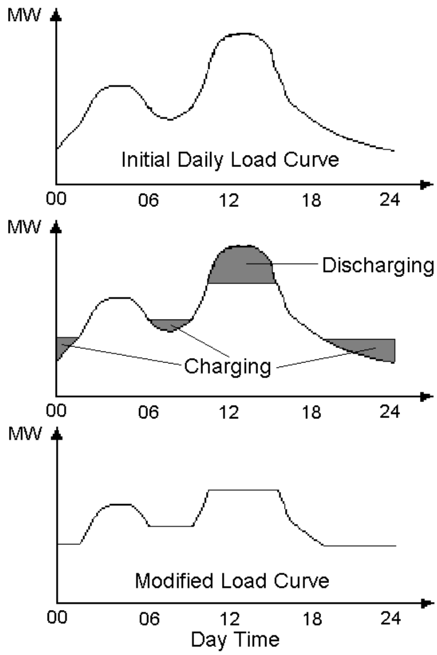

Fig. 13.4 – Modifying a load curve by ESS

accumulator.

Energy storage as a natural process is as old as the universe itself - the energy present at the initial formation of the universe has been stored in stars such as the Sun, and is now being used by humans directly (e.g. through solar heating), or indirectly (e.g. by growing crops or conversion into electricity in solar cells).

Electrical energy can be stored as a form of potential energy. For example, a battery stores convertible chemical energy to operate a mobile phone, and a hydroelectric dam stores energy in a reservoir as gravitational potential energy.

Energy storage systems in commercial use today can be broadly categorized as mechanical, electrical, chemical, biological and thermal.

Until recently electrical energy has not been converted and stored on a major scale, however new efforts to that effect began in the 21st century.

An early solution to the problem of storing energy for electrical purposes was the development of the battery as an electrochemical storage device. Batteries have previously been of limited use in electric power systems due to their relatively small capacity and high cost. However, since about the middle of the first decade of the 21st century, newer battery technologies have been developed that can provide significant large-scale load-leveling capabilities. A similar possible solution to deal with the intermittency issue of solar and wind energy is found in the capacitor. Other methods of storing energy currently being used or under study are: pumped-storage stations, compressed air storage, flywheels, superconductors, fuel cells working with hydrogen, molten salt, etc. A newly proposed method of grid energy storage is called Vehicle-to-Grid (V2G) energy storage system, where modern electric vehicles that are plugged into the electric grid can release the stored electrical energy in their batteries back into the grid when needed.

In dealing with energy storage systems for power system applications, two challenges must be addressed: the technical issue and the financial issue.

Technical issues of interest are: ESS energy and power ratings, the lifetime of the ESS, the ESS speed in responding to system's needs, energy losses, charging and discharging limitations, environmental problems, etc.

The financial challenge comes from the fact that most storage methods, when used in scales suitable for power system applications, are too expensive and their benefits may not cover their costs.

Many research projects are currently underway to overcome financial challenges, while improving the technical characteristics of ESS technologies.

Exercises

I. Reading comprehension. Put "T" for true statements and "F" for false statements.

___1. Before restructuring began in the US, the regulatory contract between utilities and government ensured the reliable supply of electricity to customers, while keeping prices fair for both sides.
___2. In a restructured system, the energy prices are set by the government and utilities play no role in price-setting.
___3. In a restructured system, small residential customers can buy their needed energy directly from any GenCo and independently from DisCo's.
___4. To facilitate the power system's normal operation, ISO must use some kind of short-term load forecasting technique.
___5. This can be said that a main object of restructuring power systems is to implement free market (supply and demand) rules.
___6. Implementing free market rules in a power system is done exactly through the same methods used in other businesses and markets.

___7. In a restructured power system, the pooling system is used because the power produced by a specific GenCo can not be directed to a specific customer.
___8. Control strategies used in a power system with a large amount of wind energy are exactly the same as the ones used in other systems.
___9. This can be said that fossil fuels are natural storage systems which have stored energy for thousands of years.
___10. At present, there are no obstacles in using very large-scale energy storage systems to solve power system problems.

II. Reading comprehension. Fill in the blanks with appropriate words given.

combustion	existence	interest	propulsion
consume	hydrogen	originally	remained
dominant	impact	prices	vehicle

An electric ………… (EV), also referred to as an electric drive vehicle, uses one or more electric motors for …………. Three main types of electric vehicles exist, those that are directly powered from an external power station, those that are powered by stored electricity ………… from an external power source, and those that are powered by an on-board electrical generator, such as an internal ………… engine (a hybrid electric vehicle) or a ………… fuel cell. Electric vehicles include electric cars, electric trains, electric airplanes, electric boats, electric motorcycles and electric spacecrafts.

Electric vehicles first came into ………… in the mid-19^{th} century, when electricity was among the preferred methods for motor vehicle propulsion. Currently, the internal combustion engine is the ………… propulsion method for motor vehicles, but electric power has ………… common in other vehicle types, such as trains and smaller vehicles of all types.

During the last few decades, environmental ………… of the petroleum-based transportation system, along with high oil …………, has led to renewed ………… in an electric transportation system. Electric vehicles differ from fossil fuel-powered vehicles in that the electricity they ………… can be generated from a wide range of sources, including fossil fuels, nuclear power, and renewable sources.

III. Vocabulary: write the Persian equivalent of the following words.

accumulator		load-leveling	
adequate		marketer	
administered		media	
artificial		molten	
authority		neural	
barrel		obstacle	
bid		on-board	
bring about		perform	
broker		plug	
bushel		pooling	
catastrophic		premise	
characteristics		price-setting	
collapse		profound	
commodity		propulsion	
computational		pumped-storage	
conversely		purchase	
cubic meter		real-time	
cyclical		regulatory	
deregulation		reservoir	
earning		responsibility	
fair		restore	
financial		restructuring	
flywheel		retailer	
forecast		sensible	
formation		severe	
gravitational		short-term	
hybrid		spacecraft	
independent		strategy	
indistinguishable		substantial	
industrialized		superconductor	
injection		surplus	
intermittent		trading	
intolerable		underway	
lifetime		vehicle	
likelihood		wholesale	

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