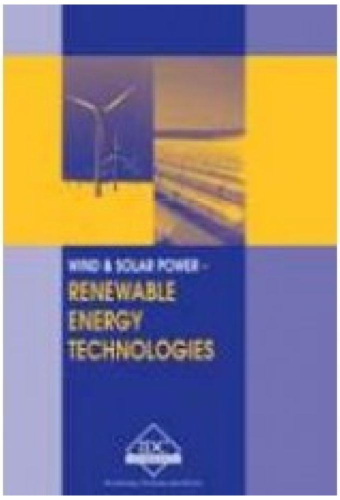
RE-E - Wind & Solar Power - Renewable Energy



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Short Description

The past ten years has seen a significant increase in applying wind and solar power technologies from the domestic user to the corporate market. There has been a dramatic improvement in the efficiencies in these technologies and this has helped make the applications economical. Specific energy yields from wind turbines have increased by 60% and installation costs have dropped significantly (up to 50% in many cases). Global wind generating capacity has reached 100,000 MW capacity in March 2008 with almost 20,000 MW installed during 2007 alone.

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Applications of photovoltaic (PV) systems are growing rapidly worldwide with worldwide installation of PV modules skyrocketing to 2,826 MW in 2007 (= 62% growth from 2006). Many countries are passing legislation to enforce greater use of PV systems and this is helping to drive up the production of these systems. All of these technologies are interdisciplinary requiring a knowledge of topics as varied as aerodynamics, electricity and wind statistics for wind power and mechanical engineering, electronic and electrical engineering for solar power.

This manual will outline the step by step process of designing, installing and commissioning photovoltaic and wind powered systems. It should be emphasised that this is not an advanced in-depth manual but one covering the important issues enabling you to do simple designs and then to investigate the design and installation issues in more detail either by further study or in conjunction with experts in the field.

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1 Introduction to Renewable Energy

Objectives

After reading this chapter, the student will be able to:

- Understand the various sources of energy
- Understand the laws of thermodynamics
- Understand the meaning of renewable energy
- Know the various applications of renewable energy
- Work out the economics of converting the renewable energy source into usable energy
- Know the various forces driving the development of renewable technologies

1.1 Overview

On earth, mankind currently largely relies on the various nonrenewable energy resources such as coal, oil and natural gas. These fossil fuels draw energy from finite resources which eventually will either get depleted or their extraction will become environmentally and economically nonviable.

On the other hand renewable energy resources such as wind energy and solar energy are nonperishable and are replenished constantly. Also from the point of view of environment renewable energy scores quite a few points over the conventional energy resources as it has a much lower impact on the environment. The combustion of fossil fuels has caused serious damage to the environment because of the localized release of the harmful gases and waste heat generated from power plants. This has resulted in a phenomenon called global warming which is a matter of great concern. Also the radioactive waste material released from the nuclear plants into the atmosphere is a cause for worry in the long term.

In recent years, there has been a significant increase in applying wind and solar power technologies, from the domestic user to the corporate market. There has been a dramatic improvement in the efficiencies in these technologies and this has helped to make the applications economical.

All of these technologies are interdisciplinary. They require knowledge of topics as diverse as aerodynamics, electricity and wind statistics for wind power and mechanical engineering, electronic and electrical engineering for solar power.

In this manual we will outline the step-by-step process for designing, installing and commissioning photovoltaic and wind powered systems, which form a major part of energy usage of all the renewable energies. This manual aims at giving practical inputs to engineers and technicians enabling them to do simple designs and then to investigate the design and installation issues in more detail.

1.2 Sources of energy

The various sources of energy available on earth are:

The sun

Solar energy is the ultimate source of most of the energy used today. Solar energy exists in different forms, both direct and indirect. Solar energy arrives directly on earth in the form of light. This energy can be converted into various other forms of energy such as wind energy, hydro energy, wave energy and biomass. Let us see how.

Solar energy, in the form of light, heats the different parts of the planet by different amounts. This temperature difference gives rise to a pressure difference in the atmosphere, resulting in wind. The heat from the sun causes water to evaporate, which forms clouds and again falls on earth in the form of rainwater. This flowing water can be used to generate hydro energy. The sun also provides energy to the plants to grow and create biomass fuels in various forms such as wood, agricultural waste etc. Thus we have seen how important is solar energy to produce the various sources of energy.

These energy sources are widely utilized to produce electricity. They are used in many thermal systems and for mechanical power.

Solar energy is the most abundantly available energy source on the earth. The amount of solar energy received by the earth in a year is approximately 300 X 10^{13} kWh. The annual world energy demand for the year 2000 was estimated at about 50 X 10^{12} kWh/year which is 60 times lesser than the total solar energy received . Thus there is an enormous potential to harness this energy in the future.

Gravity

The earth's force that attracts everything towards itself is known as gravitational force. This gravitational force can be used as a source of tidal energy. Tides are generated primarily by the gravitational attraction between the earth and the moon. This energy is largely used in the generation of electricity and mechanical power. However, tidal energy can be effectively used only on certain suitable sites since there is a certain minimum difference of level of high tide and low tide that is required . Also the location needs to be suitable for the civil construction of tidal power stations. For this reason tidal energy is only used at a small scale and its supply is limited to certain localised regions only.

Fossil fuels

The earth's crust has enormous amounts of fossil fuels like coal, oil and gas. These are widely used sources of energy to generate electricity, mechanical power and thermal systems. These resources comprise nearly 90% of the world's total energy consumption. This heavy dependence on fossil fuels is a cause of concern, since these resources are fast depleting. This is particularly true for oil and natural gas.

Nuclear Energy

Nuclear energy is the energy generated by the fission reaction in nuclear reactors. Nuclear energy is exclusively used for the generation of the electricity. At present all the reactors use Uranium isotope. However world uranium resources are estimated to last only for the next 35 years. So it is evident that unless new technologies are used , their will be difficulties in harnessing nuclear energy in the near future. Apart from this , the issue of radioactive waste disposal and the release of harmful radioactive materials into the environment in case of an accident in the power plant, is of great concern.

Geothermal Energy

Geothermal Energy is the energy which emerges in the form of heat from the molten interiors of the earth. This type of energy is highly localised for the reason that the earth's crust is non-homogeneous in nature. At certain spots below the earth's surface, the temperature is much higher than the average, which causes the formation of dry or wet steam at these locations. This energy can be utilized for the generation of electricity or space heating.

1.2.1 Power

Power is the rate at which energy is produced or consumed. When we refer to an electricity bill, we call it as a power bill, which actually is the electrical energy consumption.

Power is measured in watts. One watt is defined as the usage of energy at the rate of one joule per second. Thus, we see here that electricity is commonly measured as watt-hours or kilowatt-hours. These are represented by the symbol Wh or kWh.

1.2.2 Conversion of energy units

We have seen that different forms of energy have different measuring units. For designing a system, it is very important that a common measure of unit is used. Different forms of energy should be converted into one unit before performing any calculations for a design. As an example, let us see a conversion between joules and kilowatt-hours.

Convert 1000 kilojoules into kilowatt-hours

1 kilojoule = 1 kilowatt-second

= 1 / 3600 kilowatt-hour

= 2.7×10^{-4} kilowatt-hour

1000 kJ = $(2.7 \times 10^{-4}) \times 1000$

= 0.278 kWh

Often, conversions may not be as simple as this. Hence, conversion tables are used. For the benefit of delegates attending this course we have provided some conversion software, which is very easy and fast to use.

1.3 Laws of thermodynamics

Energy is constantly being converted from one form to another. For example, when we switch on a bulb, electricity is converted into light, which is the used energy; evaporation of water on earth is caused by converting the solar energy into heat, which evaporates the water. The laws of thermodynamics describe this energy conversion process more scientifically.

1.3.1 First law of thermodynamics

This is also known as the law of conservation of energy. The law states that,

“Energy can neither be created nor destroyed. Whenever energy is transformed from one form to another, the total quantity of energy remains the same”.

Let us see this with an example.

Figure 1.1

Energy conversion process of a light bulb

The input energy shown here is the electricity. The output is in the form of light energy, which is also called useful work. While doing the useful work, the bulb also looses energy in the form of heat.

However, the input energy will always be equal to the sum of output energy and the energy loss. This can be represented by the following equation

$$\mathbf{E_i = E_o + E_l}$$

Where

E_i input energy in joules or watt-hours

E_o output energy in joules or watt-hours

E_l energy loss in joules or watt-hours

1.3.2 Second law of thermodynamics

The second law of thermodynamics can be stated in a number of ways as follows based on the observations.

- Heat flows from a body at higher temperature to a body at lower temperature irrespective of the mass and material of the body participating in the heat transfer. This heat flow is possible without the addition of external work
- Work has the tendency to convert into work but the heat cannot be converted into work
- Every engine rejects heat to the surrounding

The second law of thermodynamics implies that energy can always be converted from its high quality form (e.g. electricity) into lower quality energy (e.g. heat). However the reverse is not true.

For example, energy in the form of high-pressure steam is converted into mechanical energy in a turbine and further converted into electrical energy. Here the high quality energy is transforming a part of its energy into more high quality energy and the remaining is being transformed into low quality energy in the form of low-pressure steam or hot water.

Figure 1.2

Applying second law of thermodynamics

The sun's energy, for example, is of a very high quality. Most of this energy is directly converted into heat, which is not used by mankind. Heating up the earth's surface is simply wasting the high quality energy.

The use of a renewable energy system can help to get some useful work done by converting the sun’s energy into heat.

1.4 Renewable and non-renewable energy

Energy can also be generalized into two categories:

- Renewable
- Non-renewable

Any form of energy which is replaced by nature, with or without human assistance within a relatively short span of time is termed renewable energy. The time frame can be 24 hours, a week, or a year. Solar energy, wind and hydro energy are the most common forms of renewable energy. The sun offers energy in the form of heat and light. This energy is renewed everyday. Due to the heat of the sun water on the earth evaporates to form clouds. This results in rain, which is used to generate hydro energy. Wind keeps blowing on earth irrespective of time.

All these three natural processes on earth are continuous and cannot be stopped. Renewable energy is also sometimes called clean or green energy, since it is generated from non polluting sources of energy.

Both human and environmental health is affected by air quality and renewable energy provides clean, reliable energy. Biopower plants reduce the amount of emissions into the air from controlled agricultural burning—converting agricultural residues, urban wood waste, and even landfill gas into power. Wind and solar photovoltaic systems installed at homes and businesses reduce the need for power from polluting fuels, especially during peak hours of energy usage. Solar thermal and geothermal heating technologies reduce the amount of energy needed to heat water and drive industrial processes, again reducing the use of polluting fuels.

Wind farms can produce clean energy on a large scale. Small wind turbine systems are already used widely in farms and ranches. Solar photovoltaics can often be applied to unused spaces such as roofs and the tops of parking structures.

While renewable energy sources do not have the same negative impact on natural ecosystems that conventional power sources do, there are environmental concerns associated with each renewable technology. Fortunately, each of these concerns is being addressed.

Non-renewable energy resources are those with finite reserves that cannot be renewed within our lifetimes. Renewal of these resources may take millions of years. Such energy sources exist in the form of fossil fuels such as oil, gas, and coal. Nuclear fuels like uranium also cannot be renewed.

Most of the energy in the world today is generated using nonrenewable resources. For example the electricity which we use everyday is generated by large power plants using fossil fuels. These power plants pollute the environment which is the cause of serious health problems. Large dams built to generate hydro electricity destroy the ecosystems and wild life.

However, non-renewable energy is extensively used today on earth due to its higher calorific value. The biggest advantage of non-renewable energy is that it can be stored.

1.4.1 Applications of the technology

Wind

It captures the energy of air currents using turbine blades. As the blades rotate, electricity is generated. Wind turbines can be used as stand-alone applications, or they can be connected to a utility power grid or even combined with an alternative power generating system like photovoltaic (solar cell) system. For utility-scale sources of wind energy, a large number of wind turbines are usually built close together to form a *wind plant*. Several electricity providers today use wind plants to supply power to their customers.

Solar

There are many ways in which solar energy is effectively used today. Solar energy is used in solar heating, solar refrigeration, solar electricity to power traffic lights etc. Solar technologies include: photovoltaic cells, which convert sunlight directly into useable energy. The solar concentrators use mirrors to focus the sun’s light and generate intense heat. This turns water to steam and generates electricity in the process. Solar thermal heating devices such as solar water heaters and even solar ovens are used for smaller applications.

Hydro

It captures the energy generated by water movement and converts it into electricity. While hydro is the largest source of renewable energy in California and the U.S, it can be controversial. In the context of renewable energy, low impact, small hydro, and micro hydro (those installations producing less than 20 megawatts of electricity) projects are considered by some as more environmentally sensitive and appropriate than traditional large-scale projects.

Biopower

It releases the energy trapped in organic material or biomass. Biopower uses biomass energy to generate electricity. Biopower has diverse applications from diverse sources: from creating gas that is used to fire electric plants, to recycling cooking oil and using it to power buses and cars. Biopower applications include co-firing with coal, collecting methane and landfill gases and burning urban wood waste to generate electricity.

1.5 Economics of renewable energy

Since renewable energy offers many advantages in terms of environmental aspects, there are efforts made by various states to promote and subsidize the use of renewable energy resources. In spite of this, there are certain economical barriers because of which the use of renewable energy is not comparable to the fossil fuels. But there are certain locations and applications where the use of renewable energy is as cost effective as the fossil fuels. For example in remote locations where the cost transportation of conventional fuels or the transmission of electrical power is very high. Alternative energy sources like wind power and photovoltaic systems are not yet competitive with conventional energy sources except in very special energy markets. Rapid developments are occurring in various renewable technologies to make them an economically viable option.

In case of small scale system used by farms or homes, renewable energy can still be a cost effective option. Wind energy systems are by far the most commercially viable option compared to the conventional energy. The surge in fossil fuel rates is making the renewable energy more competitive in today's power market. Let us analyze the wind energy system installation and the factors that need to be considered before deciding on this option

1.5.1 Cost

The generation cost of wind energy is calculated based on the following parameters:

- Total project cost
- Operation and maintenance cost
- Average annual wind speed at the site

- Wind turbine efficiency
- Amortization period and interest rate

Total project cost

The total project cost includes

- Cost of the wind energy system
- Transportation and erection cost
- Project preparation cost (permit etc)
- Cost of land and infrastructure

The total project cost can be expressed as a function of the wind system's rated electrical capacity. A grid-connected residential-scale system (1-10 kW) generally costs between $2,400 and $3,000 per installed kilowatt. That is $24,000-$30,000 for a 10 kW system. A medium-scale, commercial system (10-100 kW) is more cost-effective, costing between $1,500 and $2,500 per kilowatt. Large-scale systems of greater than l00 kW cost in the range of $1,000 to $2,000 per kilowatt, with the lowest costs achieved when multiple units are installed at one location. In general, cost rates decrease as machine capacity increases.

Remote systems with operating battery storage typically cost more, averaging between $4,000 and $5,000 per kilowatt. Individual batteries cost from $150 to $300 for a heavy-duty, 12 volt, 220 amp-hour. Larger capacity batteries, those with higher amp-hour ratings, cost more. A 110-volt, 220 amp-hour battery storage system, which includes a charge controller, costs at least $2,000.

Operation and maintenance cost

The operation and maintenance cost include the servicing and repair of the equipment, insurance and other operating expenses.. As a rule of thumb, one can estimate annual operating expenses of about 2% to 3% of the initial system cost. Another estimate is based on the system's energy production and is equivalent 1 to 2 cents per kWh of output.

Average annual wind speed

The average annual wind speed on the site is of paramount importance to the cost of energy. As a rule of thumb the annual energy output of modern wind turbines can be estimated by means of the expression

$$e = 0.625V^3XA \text{ (kWh/m}^2\text{ swept rotor area)}$$

where V (m/s) is the annual average wind speed at the hub height and A is the rotor swept area

Wind turbine efficiency

The efficiency is defined as the ability to operate when the wind speed is higher than the wind turbine's cut-in wind speed and lower than its cut-out speed, is typically higher than 98% for modern wind farms.

Amortization period

The amortization period or economic life time depends upon the technical life time of the wind energy system. The technical lifetime for modern wind systems is typically 20 years. As a rule amortization period is taken to be equal to the technical life time of the system. Interest rate again depends upon the type of loan and the amortization period. Lending institutions base their interest charges upon a number of factors, including the amount of risk involved in a particular loan and current economic conditions. For this example we will assume that the interest rate is 5%.

The cost of wind energy in $/kwh can now be calculated as follows:
$c = (a.I_{tot}/ E.e) + m$

where,

c cost of the wind energy in $ / kwh

a annuity factor

Itot total project cost per m2 rotor area

E wind turbine efficiency

e annual energy output (kwh/m2)

m operation and maintenance cost

The annuity factor a is calculated as follows:

$a = i(1+i)^n / (1+n)^i-1$

where

i is rate of interest

n is amortization period

$$\mathbf{e = 0.625 \times pi/4 \times D^2 V^3}\ \text{W}$$

where

V (m/s) is the annual average wind speed at the hub height and

D is rotor diameter in meters.

For this example lets consider a domestic wind energy system which has a installed power capacity of 10 kw . The wind energy system cost for such a system would be approximately US$ 30000.

The total project cost is approx. 125 % of the wind energy system cost . The cost per kw will be $3000

Itot = 3000x 1.25 = 3750 $ / kw

E = 98%

m = 1 US cent/ kwh

i = 5%

n = 20 years

Assuming a wind speed of 7.5 m/s at a 50 m hub height and the rotor diameter to be 5 m let us calculate the annual energy output

$e = 0.625X\ pi/4 \times 5^2 X\ 7.5^3\ X24X365 = 45352$ kwh/year

$a = 0.05 \times (0.05+1)^{20}/\{(1+20)^{.05} -1\} = 0.808$

c = (0.808X 3750/.98X 45352) + .01) = 0.070 $/kwh

From this example we can see that compared to the cost of conventional power which is about 20 cents /kwh, wind energy is very cost effective.

1.5.2 Payback period

The payback period is the period in which the initial investment is recovered through the energy cost savings. To calculate the payback period of a residential and commercial wind energy system we need to first calculate the annual energy cost savings and annual operating cost of the wind energy system.

Dividing total project cost by the difference between annual energy cost savings and annual operating costs gives the payback period:

For example, consider the total initial cost of a 15 kW residential system and a 100 kW commercial system: Generally the cost of wind energy system is approximately $3000 per KW. Hence following will be the total project costs :
Residential 15 kW system = $45,000
Commercial 100 kW system = $300,000

Annual electric savings is the retail value of electricity from the wind energy system that would otherwise have been bought from the utility company. It is determined by multiplying the retail cost of electricity by the number of kilowatt-hours the wind turbine is supposed to produce in a typical year. A manufacturer or dealer can provide an estimate of the wind system's annual output as a function of a specific location's average wind speed. Assume the cost of electricity to be 20 cents per kWh and the annual output from the residential and commercial systems at a 14 mph site to be 30,000 kWh and 300,000 kWh, respectively. The annual energy-cost savings from both systems would be:

Residential $ 0.20 / kWh x 30,000 kWh = $ 6000
Commercial $0.20/kWh x 300,000 kWh = $ 60,000

Annual operating costs are estimated by multiplying the wind system's energy output by a typical operations and maintenance cost, such as 5 cents per kWh. The annual operating costs are:
Residential $0.05/kWh x 30,000 kWh = $1500
Commercial $0.05/kWh x 300,000 kWh = $15,000
Now that all components of the payback equation are defined, the payback period can be calculated as.

Residential payback period:

$45,000/($6000 - $1500) = $45,000/$4500

= 10 years

Commercial payback period:

$300,000/($60,000 - $15,000) = $300,000/$45,000

= 6.6 years

You will see above, that the larger the system is, the lesser is the payback period.

1.5.3 Other economic factors

Apart from the energy cost savings, there could be other factors also which influence the cost savings. For example the costs of conventional electrical energy keep increasing over a period of time. This increase in energy cost can be seen as an additional cost saving in case of a wind energy system.

In many countries, if the wind energy system is connected to the grid, the excess energy produced by it, is bought out by the utility. However, the rate at which the utility companies buy back the excess power is generally very low compared to the rate of a KW of conventional energy. Therefore it is advised that the system capacity should be properly matched with the load demand. In case if the buy back rate is equal or more than the purchased power rate, the system can be designed for higher output.

In some states in the USA, the government offers several incentives in terms of tax benefits and low interest loans. This can further reduce the cost of the wind energy system.

Finally the resale value at the end of the technical design life time of a wind turbine also will contribute towards the return on investment. Typically the resale value of a wind turbine is assumed to be 10% of its initial cost.

1.6 Forces driving the technologies today

The main driving forces enabling the growth of renewable energy technologies are:

- Reduced environmental impact
- Energy independence and diversification
  - Inflation-proof fuel costs

- Modular design

The fossil fuel resources are dwindling worldwide. In addition to this, the environmental impact of fossil fuels has reached unacceptable limits. These factors make the development of renewable energy technologies inevitable. There is no doubt that the future energy resources will be primarily renewable energy resources. The distributed nature of renewable energy resources makes them inherently safer considering the potential for terrorist threats to centralized energy and power supplies. Major technological improvements in the past two decades have made renewable energy technologies cost effective in many applications. Governments around the world are reducing subsidies for fossil fuels, further improving their cost effectiveness.

Certain renewable energy technologies, especially wind and photovoltaic energy, have progressively become less expensive and more reliable. The renewable energy technologies used in 1980s were at the developmental stage and therefore not very reliable and cost effective. But today’s technologies are getting closer to being economically viable at least in some localized areas.

In some cases wind energy costs have come down dramatically. Some of the wind energy system suppliers are offering wind power at the rate as low as 4 cents/KWh. Even the costs of photovoltaic systems, which are considered as more expensive option, have seen a significant reduction over the last few years. It is now possible to generate PV power at the rate of 25 to 50 cents/KWh.

Geothermal and small-scale hydro plants can produce electricity for between 4.5 and 7 cents/kWh. Some renewable technologies are on the threshold of being fully competitive in the energy market. With continued technological developments and inevitable increases in fossil energy prices, renewable sources are favored to become the fastest growing source of power in the 21st century.