Non-Conventional Energy Systems

Wind & Tidal Energy

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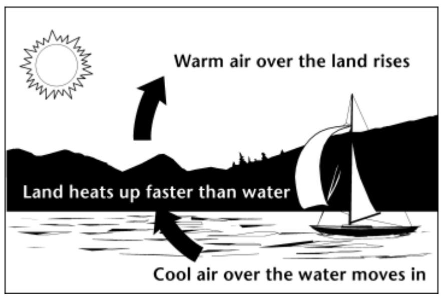
Wind Energy

Wind is simple air in motion. It is caused by the uneven heating of the earth's surface by the sun. Since the earth's surface is made of very different types of land and water, it absorbs the sun's heat at different rates.

During the day, the air above the land heats up more quickly than the air over water. The warm air over the land expands and rises, and the heavier, cooler air rushes in to take its place, creating winds. At night, the winds are reversed because the air cools more rapidly over land than over water.



In the same way, the large atmospheric winds that circle the earth are created because the land near the earth's equator is heated more by the sun than the land near the North and South Poles.

Today, wind energy is mainly used to generate electricity. Wind is called a renewable energy source because the wind will blow as long as the sun shines.

Like old fashioned windmills, today's wind machines use blades to collect the wind's kinetic energy. Windmills work because they slow down the speed of the wind. The wind flows over the airfoil shaped blades causing lift, like the effect on airplane wings, causing them to turn. The blades are connected to a drive shaft that turns an electric generator to produce electricity.

There are two types of wind machines (turbines) used today based on the direction of the rotating shaft (axis): horizontal–axis wind machines and vertical-axis wind machines. Small turbines used to power a single home or business may have a capacity of less than 100 kilowatts. Some large commercial sized turbines may have a capacity of 5 million kilowatts, or 5 megawatts. Larger turbines are often grouped together into wind farms that provide power to the electrical grid.

BENEFITS OF WIND ENERGY

- Wind energy is an ideal renewable energy because:
    - it is a pollution-free, infinitely sustainable form of energy

- it doesn't require fuel
- it doesn't create greenhouse gasses
- it doesn't produce toxic or radioactive waste.

- Wind energy is quiet and does not present any significant hazard to birds or other wildlife.
- When large arrays of wind turbines are installed on farmland, only about 2% of the land area is required for the wind turbines. The rest is available for farming, livestock, and other uses.
- Landowners often receive payment for the use of their land, which enhances their income and increases the value of the land.
- Ownership of wind turbine generators by individuals and the community allows people to participate directly in the preservation of our environment.
- Each megawatt-hour of electricity that is generated by wind energy helps to reduce the 0.8 to 0.9 tonnes of greenhouse gas emissions that are produced by coal or diesel fuel generation each year.

WIND ENERGY PROGRAMME IN INDIA

The Wind power programme in India was initiated towards the end of the Sixth Plan, in 1983-84. A market-oriented strategy was adopted from inception, which has led to the successful commercial development of the technology. The broad based National programme includes wind resource assessment activities research and development support, implementation of demonstration projects to create awareness and opening up of new sites; involvement of utilities and industry; development of infrastructure capability and capacity for manufacture installation, operation and maintenance of wind electric generators; and policy support. The programme aims at catalyzing commercialization of wind power generation in the country. The Wind Resources Assessment Programme is being implemented through the State Nodal Agencies, Field Research Unit of Indian Institute of Tropical Meteorology (IITM-FRU) and Center for Wind Energy Technology (C-WET).

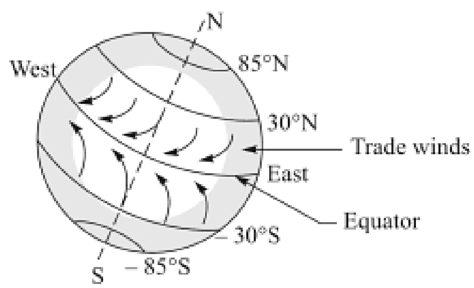
Wind resources in India are influenced by the strong south-west summer monsoon, which starts in May-June, when cool, humid air moves towards the land and the weaker north-east winter monsoon, which starts in October, when cool, dry sir moves towards the ocean. During the period March to August, the winds are uniformly strong over the whole Indian Peninsula, except the eastern peninsular coast. Wind speeds during the period November to March are relatively weak, though higher winds are available during a part of the period on the Tamil Nadu coastline.

A notable feature of the Indian programme has been the interest among private investors/developers in setting up of commercial wind power projects. The gross potential is 45,000 MW (Source MNRE) and a total of a little over 7082 MW of commercial projects have been established until March 2007.

TYPES OF WINDS

Global Winds

The primary force for global winds is produced due lo differential healing of the earth surface at equator (0° longitudes) and polar regions (about ± 90° longitude). More healing lakes place near the regions of equator and less healing occurs at polar regions, and so cold winds move from polar to equatorial regions. The air in touch with ocean water is much colder than air in the plain areas, and so cold winds generated from ocean areas move towards plain areas. The rotation of the earth on its axis produces Coriolis force and this force is responsible for forcing the global winds towards westernly direction. These air currents arc also called trade winds as sailing ships in the past used these air currents for ship movement and trading. The global winds and circulations are shown in following figure.



Local Winds

Local winds arc generated due to uneven heating. Uneven heating occurs on land surface and water bodies due lo solar radiation. As a result, cool and heavy air currents move from water bodies to land surface. At night, the direction of wind is reversed as land surface cools more rapidly than water bodies. The same conditions also prevail in hilly areas where hill slope heats up during the day and cools down during the night more rapidly than the low land. This temperature difference causes air currents to move lo the hill slope during the day and to the low-lying land during night.

ENERGY IN WIND

The wind has kinetic on account of its motion. This kinetic energy can be given by the following equation:

$$KE = P_0 = \frac{1}{2} m u_0^2$$

where m is mass of air, A = area and u_0 is speed of free air.

$$m = \rho A u_0$$

$$P_0 = \frac{1}{2}(\rho A u_0) u_0^2$$

or $$\frac{P_0}{A} = \frac{1}{2}\rho u_0^3$$

The above relation indicates that the power available in wind per unit area is proportional to the cubic power of its speed.

HOW WIND TURBINES WORK

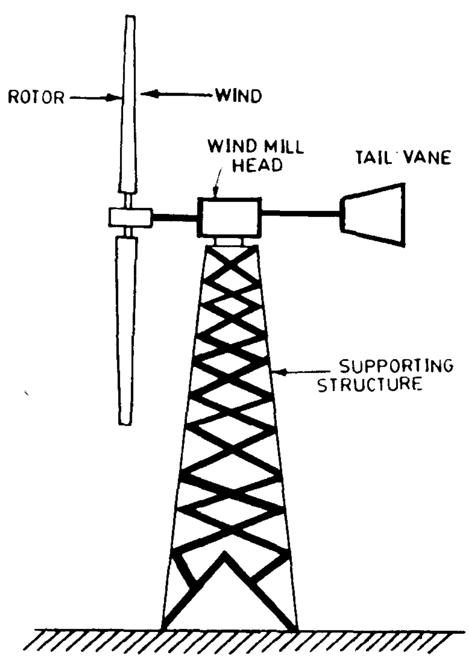
Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity.

So how do wind turbines make electricity? Simply stated, a wind turbine works the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity. The electricity is sent through transmission and distribution lines to homes, businesses, schools, and so on.

TYPES OF WIND TURBINES

Horizontal Axis

Most wind machines being used today are the horizontal-axis type. Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable for generating electricity.



SCHEMATIC OF A HORIZANTAL AXIS TYPE WIND MILLS

Advantages of horizontal wind turbines

- Blades are to the side of the turbine's center of gravity, helping stability.
- Ability to wing warp, which gives the turbine blades the best angle of attack. Allowing the angle of attack to be remotely adjusted gives greater control, so the turbine collects the maximum amount of wind energy for the time of day and season.
- Ability to pitch the rotor blades in a storm, to minimize damage.
- Tall tower allows access to stronger wind in sites with wind shear. In some wind shear sites, every ten meters up, the wind speed can increase by 20% and the power output by 34%.
- Tall tower allows placement on uneven land or in offshore locations.
- Can be sited in forests above the treeline. .
- Most are self-starting.
- Can be cheaper because of higher production volume, larger sizes and, in general higher capacity factors and efficiencies.

Disadvantages of horizontal wind turbines

- HAWTs have difficulty operating in near ground, turbulent winds because their yaw and blade bearing need smoother, more laminar wind flows.
- The tall towers and long blades (up to 180 feet long) are difficult to transport on the sea and on land. Transportation can now cost 20% of equipment costs.
- Tall HAWTs are difficult to install, needing very tall and expensive cranes and skilled operators.
- Their height can be create local opposition based on impacts to viewsheds.
- Offshore tower can be a navigation problem and must be installed in shallow seas. HAWTs can't be floated on barges.
- Downwind variants suffer from fatigue and structural failure caused by turbulence.

Vertical Axis

Vertical–axis wind machines have blades that go from top to bottom and the most common type (Darrieus wind turbine) looks like a giant two-bladed egg beaters. The type of vertical wind machine typically stands 100 feet tall and 50 feet wide. Vertical-axis wind machines make up only a very small percent of the wind machines used today.

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft running vertically. Key advantages of this arrangement are that the generator and/or gearbox can be placed at the bottom, near the ground, so the tower doesn't need to support it, and that the turbine doesn't need to be pointed into the wind. Drawbacks are usually the pulsating torque that can be produced during each revolution and the drag created when the blade rotates into the wind. It is also difficult to mount vertical-axis turbines on towers, meaning they must operate in the often slower, more turbulent air flow near the ground, with resulting lower energy extraction efficiency.

Advantages of vertical wind turbines

- Easier to maintain because most of their moving parts are located near the ground. This is due to the vertical wind turbine's shape. The airfoils or rotor blades are connected by arms to a shaft that sits on a bearing and drives a generator below, usually by first connecting to a gearbox.
- As the rotor blades are vertical, a yaw device is not needed, reducing the need for this bearing and its cost.
- Vertical wind turbines have a higher airfoil pitch angle, giving improved aerodynamics while decreasing drag at low and high pressures.
- Low height useful where laws do not permit structures to be placed high.
- Smaller VAWTs can be much easier to transport and install.
- Does not need a free standing tower so is much less expensive and stronger in high winds that are close to the ground.
- Usually have a lower Tip-Speed ratio so less likely to break in high winds.

Disadvantages of vertical wind turbines

- Most VAWTs produce energy at only 50% of the efficiency of HAWTs in large part because of the additional drag that they have as their blades rotate into the wind.
- There may be a height limitation to how tall a vertical wind turbine can be built and how much sweep area it can have.
- Most VAWTS need to be installed on a relatively flat piece of land and some sites could be too steep for them but are still usable by HAWTs.
- Most VAWT's have low starting torque.
- A VAWT that uses guyed wires to hold it in place puts stress on the bottom bearing as all the weight of the rotor is on the bearing. Guyed wires attached to the top bearing increase downward thrust in wind gusts.

TURBINES

Utility-scale turbines range in size from 100 kilowatts to as large as several megawatts. Larger turbines are grouped together into wind farms, which provide bulk power to the electrical grid.

Single small turbines, below 100 kilowatts, are used for homes, telecommunications dishes, or water pumping. Small turbines are sometimes used in connection with diesel generators, batteries, and photovoltaic systems. These systems are called hybrid wind systems and are typically used in remote, off-grid locations, where a connection to the utility grid is not available.

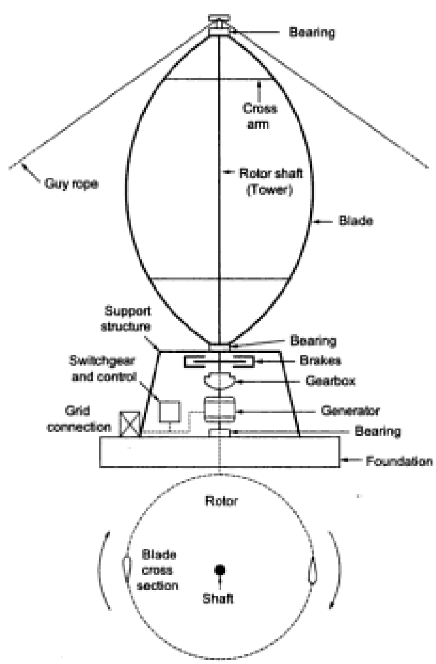
Savonius Wind Turbines

Savonius wind turbines are a type of *vertical-axis wind turbine* (VAWT), used for converting the power of the wind into torque on a rotating shaft. Savonius turbines are one of the simplest turbines. Aerodynamically, they are drag-type devices, consisting of two or three scoops. Looking down on the rotor from above, a two-scoop machine would look like an "S" shape in cross section. Because of the curvature, the scoops experience less drag when moving against the wind than when moving with the wind. The differential drag causes the Savonius turbine to spin. Because they are drag-type devices, Savonius turbines extract much less of the wind's power than other similarly-sized lift-type turbines. Much of the swept area of a Savonius rotor is near the ground, making the overall energy extraction less effective due to lower wind speed at lower heights.

Savonius turbines are used whenever cost or reliability is much more important than efficiency. For example, most anemometers are Savonius turbines, because efficiency is completely irrelevant for that application. Much larger Savonius turbines have been used to generate electric power on deep-water buoys, which need small amounts of power and get very little maintenance. Design is simplified because, unlike horizontal-axis turbines, no pointing mechanism is required to allow for shifting wind direction and the turbine is self-starting. Savonius and other vertical-axis machines are not usually connected to electric power grids. They can sometimes have long helical scoops, to give smooth torque.

Darrieus Wind Turbines

The constructional details of a vertical axis wind turbine (Darrieus-type rotor) are shown in following figure.



The details of the main components are as follows:

Tower (or Rotor Shaft). The tower is a hollow vertical rotor shaft, which rotates freely about the vertical axis between the top and bottom bearings. It is installed above a support structure. In the absence of any load at the top, a very strong tower is not required, which greatly simplifies its design. The upper part of the tower is supported by guy ropes. The height of the tower of a large turbine is around 100 m.

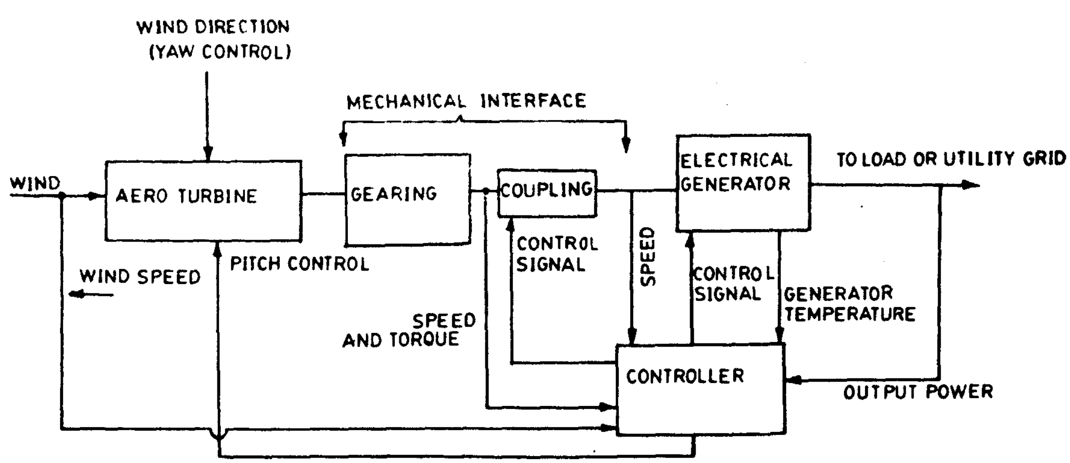
Blades. It has two or three thin, curved blades shaped like an eggbeater in a profile, with blades curved in a form that minimizes the bending stress caused by centrifugal forces—the so called Troposkein profile. The blades have an airfoil cross section with constant chord length. The pitch of the blades cannot be changed. The diameter of the rotor is slightly less than the tower height. The first large (3.8 MW), Darrieus type, Canadian machine has a rotor height as 94 m and the diameter as 65 m with a chord of 2.4 m.

Support Structure. The support structure is provided at the ground to support the weight of the rotor. Gearbox, generator, brakes, electrical switchgear and controls are housed within this structure.

Rotor. The Darrieus rotor is used for large-scale power generation. Its power coefficient is considerably better than that of an S-rotor. It runs at a large tip-speed ratio. The aerodynamic force on the blade reverses in even- revolution, causing fatigue. This, along with centrifugal force, complicates the design of the blade. One of the drawbacks of this rotor is that it is usually not self-starting. Movement may be initiated by using electrical generator as motor. As the pitch of the blade cannot change, the rotor frequency and, thus, the output power cannot be controlled. Rotor frequency increases with wind speed and power output keeps on increasing till the blades stall. Hence, at high wind speed it becomes difficult to control the output. For better performance and safety of the blades, gearbox and generator, it is desirable to limit the output to a level much below its maximum possible value.

PARTS OF TURBINE/WECS(WIND ENERGY CONVERSION SYSTEM)

The main components of a WECS are shown in following block diagram.



Following is the sketch of a wind turbine.

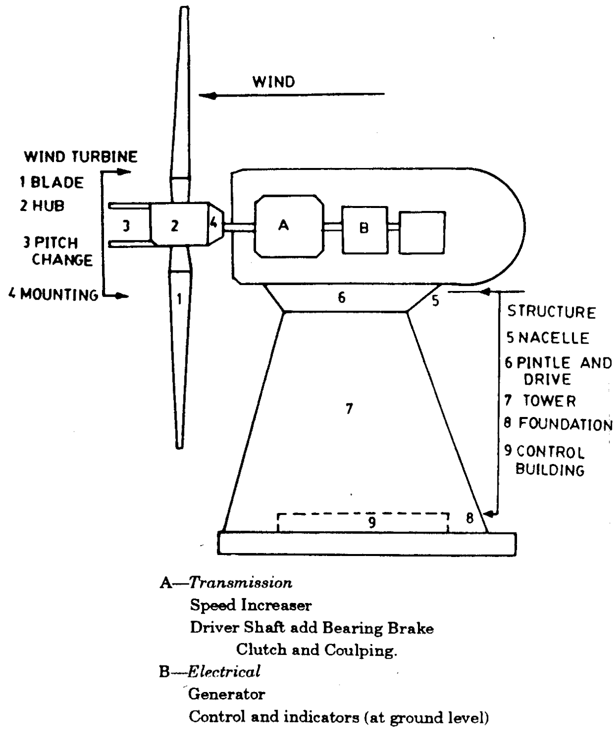


Diagram-1

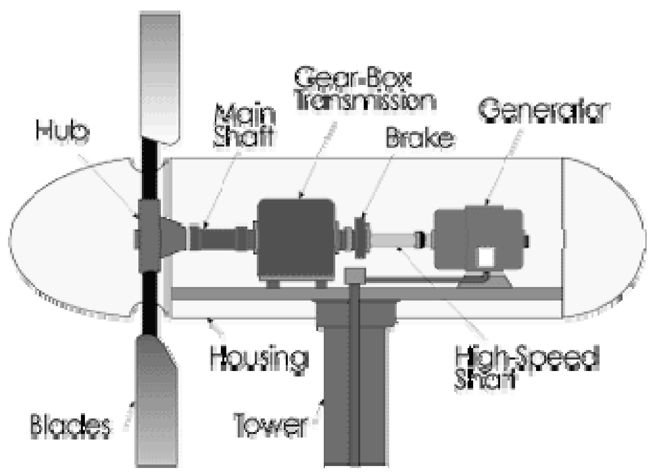


Diagram-2

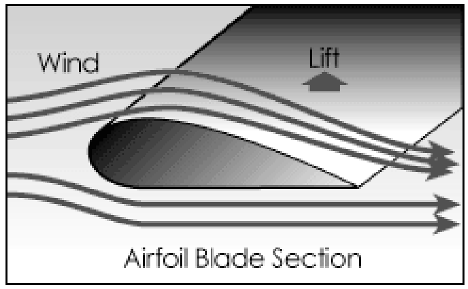
The *blades* of the turbine are attached to a *hub* that is mounted on a turning *shaft*. The shaft goes through a *gear transmission box* where the turning speed is increased. The transmission is attached to a *high speed shaft* which turns a generator that makes electricity.

If the wind gets too high, the turbine has a *brake* that will keep the blades from turning too fast and being damaged.

Various parts are

- **Anemometer**: Measures the wind speed and transmits wind speed data to the controller.

- **Blades**: Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate. The lift blade design employs the same principle that enables airplanes, kites and birds to fly.



The blade is essentially an airfoil, or wing. When air flows past the blade, a wind speed and pressure differential is created between the upper and lower blade surfaces. The pressure at the lower surface is greater and thus acts to "lift" the blade. When blades are attached to a central axis, like a wind turbine rotor, the lift is translated into rotational motion. Lift-powered wind turbines have much higher rotational speeds than drag types and therefore well suited for electricity generation.

- **Brake**: A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.

- **Controller**: The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because they might be damaged by the high winds.

- **Gear box**: Gears connect the low-speed shaft to the high-speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

- **Generator**: The generator is what converts the turning motion of a wind turbine's blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity. Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The generator's rating, or size, is dependent on the length of the wind turbine's blades because more energy is captured by longer blades.

  Generators that produce AC are generally equipped with features to produce the correct voltage (120 or 240 V) and constant frequency (50 Hz) of electricity, even when the wind speed is fluctuating.

DC generators are normally used in battery charging applications and for operating DC appliances and machinery. They also can be used to produce AC electricity with the use of an inverter, which converts DC to AC.

- **High-speed shaft**: Drives the generator.
- **Low-speed shaft:** The rotor turns the low-speed shaft at about 30 to 60 rotations per minute.
- **Nacelle**: The nacelle sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.
- **Pitch**: Blades are turned, or pitched, out of the wind to control the rotor speed and keep the rotor from turning in winds that are too high or too low to produce electricity.
- **Rotor**: The portion of the wind turbine that collects energy from the wind is called the rotor. The rotor usually consists of two or more wooden, fiberglass or metal blades which rotate about an axis (horizontal or vertical) at a rate determined by the wind speed and the shape of the blades. The blades are attached to the hub, which in turn is attached to the main shaft.
- **Tower**: Towers are made from tubular steel (shown here), concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity. The tower on which a wind turbine is mounted is not just a support structure. It also raises the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations. Maximum tower height is optional in most cases, except where zoning restrictions apply. The decision of what height tower to use will be based on the cost of taller towers versus the value of the increase in energy production resulting from their use. Studies have shown that the added cost of increasing tower height is often justified by the added power generated from the stronger winds. Larger wind turbines are usually mounted on towers ranging from 40 to 70 meters tall.
- **Wind direction**: This is an "upwind" turbine, so-called because it operates facing into the wind. Other turbines are designed to run "downwind," facing away from the wind.
- **Wind vane:** Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.
- **Yaw drive/control:** Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive, the wind blows the rotor downwind.
- **Yaw motor:** Powers the yaw drive.

OPERATING CHARACTERISTICS

All wind machines share certain operating characteristics, such as cut-in, rated and cut-out wind speeds.

Cut-in Speed

Cut-in speed is the minimum wind speed at which the wind turbine will generate usable power. This wind speed is typically between 7 and 10 mph.

Rated Speed

The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. For example, a "10 kilowatt" wind turbine may not generate 10 kilowatts until wind speeds reach 25 mph. Rated speed for most machines is in the range of 25 to 35 mph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases. The output of most machines levels off above the rated speed. Most manufacturers provide graphs, called "power curves," showing how their wind turbine output varies with wind speed.

Cut-out Speed

At very high wind speeds, typically between 45 and 80 mph, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called the cut-out speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage. Shut down may occur in one of several ways. In some machines an automatic brake is activated by a wind speed sensor. Some machines twist or "pitch" the blades to spill the wind. Still others use "spoilers," drag flaps mounted on the blades or the hub which are automatically activated by high rotor rpm's, or mechanically activated by a spring loaded device which turns the machine sideways to the wind stream. Normal wind turbine operation usually resumes when the wind drops back to a safe level.

WIND POWER PLANTS

Wind power plants, or wind farms as they are sometimes called, are clusters of wind machines used to produce electricity. A wind farm usually has dozens of wind machines scattered over a large area. The world's largest wind farm, the Horse Hollow Wind Energy Center in Texas, has 421 wind turbines that generate enough electricity to power 230,000 homes per year.

As a rule, wind speed increases with altitude and over open areas with no windbreaks. Good sites for wind plants are the tops of smooth, rounded hills, open plains or shorelines, and mountain gaps that produce wind funneling.

SITE SELECTION FOR WIND TURBINE

General Comments

The ideal site is the top of a gently rounded hill rising from a flat plain covered with short grass or surrounded by water. The hilltop should have sufficient level area for all wind turbine foundations to be at the same height and the preferred soil type is sand, well bonded by short grass. Most sites fall short of this ideal and the following features should be taken into account.

Wind Access

Nearby obstructions or topographical features which could interfere with wind flow and/or cause excessive turbulence should be avoided. Examples of the former are trees and buildings. A good rule of thumb is to site the wind turbine a distance away from any obstruction, equal to ten times the height of that obstruction.

If a nearby obstruction upwind in the direction of the prevailing wind is unavoidable it is desirable for the hub height of the wind turbine to be 2.5 times the height of that obstruction and definitely not less than twice the height. If there is doubt on the height of tower required to raise the wind turbine above turbulent air, it is possible to get an indication of the degree of turbulence at different heights, by flying a kite in a wind speed typical of that experienced at the site.

If the site is subject to prevailing winds from one or two directions eg. regions subject to trade winds, then the prevailing wind directions are the ones which should be taken into particular account and obstacles to wind flow can be accepted in other directions.

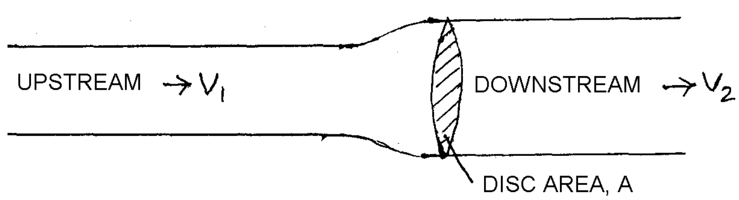
A location adjacent to steep cliffs should be avoided because they cause a high degree of turbulence. A final slope near the wind turbine of up to 1 in 3 is however acceptable

Site conditions

Sites with insufficient soil depth to allow full excavation of foundations should be avoided unless there is exposed sound rock. In this case the use of rock bolts for the guy anchors is satisfactory.

WIND TURBINE THEORY

The simplest model is based on a momentum theory developed over a century ago. A simple representation showing the overall control volume of air is given in following figure.



Application of momentum and energy relationship shows that the effective average axial velocity at the disc, V is given by

$$V = \frac{1}{2}(V_1 + V_2) \qquad (1)$$

The power output P from the disc can be expressed as the rate of extraction of kinetic energy from this flow, that is

$$P = \frac{1}{2}\rho AV\left(V_1^2 - V_2^2\right) \quad (2)$$

where ρAV is the mass flow rate through the disc.

(ρ being air density and A the swept area of the actuator disc). It is convenient to describe the retardation in the flow using an axial inference factor a, such that

$$V = V_1(1-a) \quad (3)$$

and therefore

$$V_2 = V_1(1-2a) \quad (4)$$

Substituting V and V_2 from equations (3) and (4) into (2) so that power is expressed in terms of the upstream velocity V_1, the power is given by

$$P = \frac{1}{2}\left[4a\left(1-a\right)^2\right]\rho AV_1^3 \quad (5)$$

The terms are grouped in this way because the $4a(1 - a)^2$ term is normally known as power coefficient C_p. This is the ratio of the actual power delivered by the disc to the free stream power flowing through a similar but uninterrupted area A. If the axial interference factor "a" is zero then C_p is zero and no power is developed; if "a" is 0.5 the downstream velocity V_2 is zero.

For maximum power,

$$\frac{dP}{da} = 0$$

From equation (5), this condition leads to

$$a = 1/3$$

that is $C_{pmax} = 16/27$ (6)

Putting a = 1/3 in equation (4), we get

$$V_2 = \frac{1}{3}V_1 \quad (7)$$

that is for maximum power, exit velocity = one third of entrance velocity.

Hence $$P_{max} = \frac{1}{2}\left(\frac{16}{27}\right)\left(\rho AV_1^3\right)$$

$$= 0.593\left(\frac{1}{2}\right)\left(\rho AV_1^3\right)$$

$$= 0.593.P_{total} \quad (8)$$

The axial thrust T on the disc can also be predicted

$$T = \frac{1}{2}\left[4a\left(1-a\right)\rho A V_1^2\right] \quad (9)$$

4a(1 – a) is known as thrust coefficient C_T. C_T has an obvious maximum when a = 0.5 and the downstream velocity is zero; for maximum power output (when a = 1/3) C_T still has 8/9 of its maximum value.

FORCES ON BLADES AND THRUST ON TURBINE

There are two factors which act on blades

1. **Circumferential force**: acting in the direction of wheel rotation that provides the torque
2. **Axial force**: acting in the direction of the wind stream

The circumferential force, or torque T can be obtained from

$$T = P/\omega = P/\pi DN \quad (10)$$

where T = torque kgf or Newton (N); ω = angular velocity of turbine wheel, m/s; D = diameter of turbine wheel = (√4/A).A m; N = wheel revolutions per unit time, s^{-1}

∴ The real efficiency $\eta = P/P_{total}$

or $$P = \eta.P_{total} = \eta.\frac{1}{2}.\left(\rho A V_1^3\right) \quad (11)$$

For a turbine operating at power P, the expression for torque becomes

$$T = \eta.\frac{1}{2}.\left(\rho A V_1^3/\pi DN\right)$$

$$= \eta.\frac{1}{2}.\frac{\rho\pi}{4}.\frac{D^2V_1^3}{\pi DN} = \eta.\frac{1}{8}.\frac{\rho D V_1^3}{N} = \eta.\frac{1}{8}.\left(\frac{\rho D V_1^3}{N}\right) \quad (12)$$

At maximum efficiency (η_{max} = 16/27), the torque has maximum value T_{max} which is equal to

$$T_{max} = \frac{2}{27}.\left(\frac{\rho D V_1^3}{N}\right)$$

The external force

$$F_x = \frac{1}{2}\left[\rho A\left(V_1^2 - V_2^2\right)\right] = \frac{\pi}{8}.\left[\rho D^2\left(V_1^2 - V_2^2\right)\right] \quad (13)$$

The axial force on a turbine wheel operating at maximum efficiency where $V_2 = (1/3)V_1$ is given by

$$F_{x,max} = \frac{4}{9}.\left[\rho A V_1^2\right] = \frac{\pi}{9}.\left[\rho A V_1^2\right] = \frac{\pi}{9}\left[\rho D^2 V_1^2\right] \quad (14)$$

Example

Wind at 1 standard atmospheric pressure and 15^0 C has velocity of 15 m/s, calculate

- *(i) the total power density in the wind stream*
- *(ii) the maximum obtainable power density*
- *(iii) a reasonably obtainable power density*
- *(iv) total power*
- *(v) torque and axial thrust*

Given: turbine diameter = 120 m, and turbine operating speed = 40 rpm at maximum efficiency. Propeller type wind turbine is considered.

Solution

For air, the value of gas constant is R = 0.287 kJ/kgK

1 atm = 1.01325×10^5 Pa

Air density $\rho = P/RT = (1.01325 \times 10^5)/287 \times 288 = 1.226$ kg/m^3

(i) Total power $P_{total} = \rho A V_1^3/2$

Power density will be $P_{total}/A = (1/2)\rho V_1^3 = (1/2) \times 1.226 \times 15^3 = 2068.87$ W/m^2

(ii) Maximum power density

$= P_{max}/A$

$= (8/27)\rho A V_1^3 = (8/27) \times 1.226 \times 15^3 = 1226$ W/m^2

(iii) Assuming efficiency = 35%

$P/A = n(P_{total}/A) = 0.35 \times 2068.87 = 724$ W/m^2

(iv) Total power

P = Power density x area

$= 724 \times (\pi/4)D^2$ watt

= 8184 kW

(v) Torque at maximum efficiency

$T_{max} = (2/27)(\rho D V_1^3/N)$

$= (2/27)(1.226 \times 120 \times 15^3/(40/60)$

= 55170 N

(vi) Maximum axial thrust

$F_{x,max} = (\pi/9)\rho D^2 V_1^2$

$= (\pi/9)(1.226 \times 120^2 \times 15^2)$

= 1385,870 N

Problem (AMIE Winter 1993)

Wind at 1 standard atmospheric pressure and 15^0C temperature has a velocity of 10 m/s. The turbine has diameter of 120 m and its operating speed is 40 rpm at maximum efficiency. Calculate

(a) total power density in the wind stream

(b) maximum obtainable power density assuming η = 40%

(c) total power produced (kW)

(d) torque and axial thrust

Answer: 613 W/m^2, 363 W/m^2, 245 W/m^2, 2270 kW, 16347 N, 616255 N

TIP SPEED RATIO

The tip-speed is the ratio of the rotational speed of the blade to the wind speed. The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed. Electricity generation requires high rotational speeds. Lift-type wind turbines have maximum tip-speed ratios of around 10, while drag-type ratios are approximately 1. Given the high rotational speed requirements of electrical generators, it is clear that the lift-type wind turbine is most practical for this application.

The number of blades that make up a rotor and the total area they cover affect wind turbine performance. For a lift-type rotor to function effectively, the wind must flow smoothly over the blades. To avoid turbulence, spacing between blades should be great enough so that one blade will not encounter the disturbed, weaker air flow caused by the blade which passed before it. It is because of this requirement that most wind turbines have only two or three blades on their rotors.

The tip speed ratio(TSR) is given by

$$TSR = V_{tip}/V$$

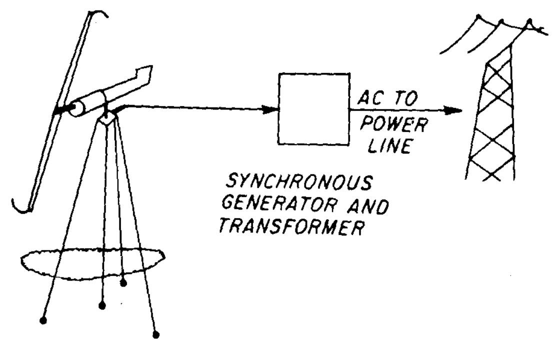
where V_{tip} = speed of the rotor tip

V = free wind speed

APPLICATIONS OF WIND ENERGY

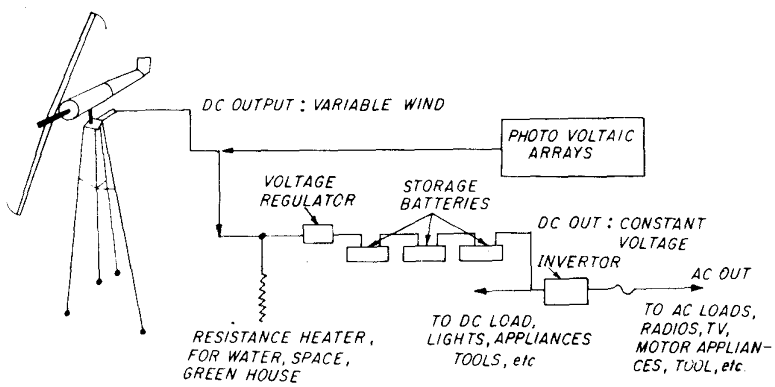
Direct Electricity generation

Wind power can be used in centralised utility applications to drive A.C. electrical generators. In such applications, the energy is fed directly into power networks through step-up transformers.



Electrical Storage

Batteries are the most common form of electrical storage. Where heat, rather than electricity, is the desired end product of a wind turbine application, hot water is the usual storage medium. However, the advantageous economics of other heating systems make wind-powered heating a less attractive option.



A system with battery storage

Batteries can store and deliver only DC power. Unless an inverter is used to convert DC to AC, only DC appliances can be operated from the stored power. The battery voltage must be the same as the voltage needed to run the appliance. Standard battery voltage is 6 or 12 volts. For an appliance requiring 24 volts, two 12-volt or four 6-volt batteries connected in series are required. For a 120-volt application, you will need a series of ten 12-volt batteries.

The least costly batteries for wind applications are deep cycle, heavy-duty, industrial type lead-acid batteries, such as those used in golf carts and forklifts designed for high reliability and long life. They can be fully charged and discharged, while standard lead-acid batteries (e.g., automobile type) cannot. Gel-cell lead acid batteries have improved the safety of the traditional liquid acid battery by containing the hydrogen that can be produced during charging, and by preventing the liquid acid from spilling.

Battery conversion efficiency is approximately 60% to 80%. A battery's capacity is rated in amp-hours, a measure of its ability to deliver a certain amperage for a certain number of hours. For example, for a rating of 60 amp-hours, 3 amps can be delivered for 20 hours. Batteries should be routinely inspected for fluid level and corrosion. The storage room should be well ventilated. If allowed to accumulate, the hydrogen gas produced by some batteries can explode.

Heat Storage

When heat is the desired end product, hot water is an alternate way to store energy. It is well suited to northern climates where the heating season coincides with the windy season. There are two basic ways to produce heat from a wind turbine. Electricity can be sent to resistance heaters immersed in water, or the wind turbine's rotor shaft can be mechanically coupled to a paddle or pump that agitates water, thereby heating it.

- **Resistance Heaters**. The first method of heat storage involves electrical resistance heaters which can be DC or AC powered with unregulated voltage and frequency levels. Thus, the buyer has considerable flexibility in choosing a machine without the need for additional complex and expensive control or conditioning devices. The conversion efficiency of a resistance heater is nearly 100%, and heat loss is minimized if the water storage tank is well-insulated. Resistance heaters can also be used directly to heat air, as with baseboard electric home heaters.
- **Mechanical Heating**. The second method of heating water is by mechanically agitating it, using either a pump or a paddle. The heat is produced by the large frictional losses that are produced by agitation. This method of heating does not require an electrical generator. Instead, the power from the rotating rotor shaft is used directly. Theoretical conversion efficiencies are nearly 100%, but practical considerations can reduce this considerably. As yet, only a few experimental models of this type of wind system have been tested.

Tidal Energy

Tidal power, sometimes called *tidal energy*, is a form of hydropower that exploits the rise and fall in sea levels due to the tides, or the movement of water caused by the tidal flow. Because the tidal forces are caused by interaction between the gravity of the Earth, Moon and Sun, tidal power is essentially inexhaustible and classified as a renewable energy source.

Although not yet widely used, tidal power has great potential for future electricity generation and is more predictable than wind energy and solar power. In Europe, tide mills have been used for nearly a thousand years, mainly for grinding grains.

Tidal power can be classified into two types,

- Tidal stream systems make use of the kinetic energy from the moving water currents to power turbines, in a similar way to underwater wind turbines. This method is gaining in popularity because of the lower ecological impact compared to the second type of system, the barrage.

- Barrages make use of the potential energy from the difference in height (or head) between high and low tides, and their use is better established. These suffer from the dual problems of very high civil infrastructure costs and environmental issues.

Modern advance in turbine technology may eventually see large amounts of power generated from the oceans using the tidal stream designs. Arrayed in high velocity areas where natural flows are concentrated such as the west coast of Canada, the Strait of Gibraltar, the Bosporus, and numerous sites in south east Asia and Australia. Such flows occur almost anywhere where there are entrances to bays and rivers, or between land masses where water currents are concentrated.

A factor in human settlement geography is water. Human settlements have often started around bays rivers and lakes. Future settlement may be concentrated around moving water, allowing communities to power themselves with non-polluting energy from moving water.

Tidal stream power

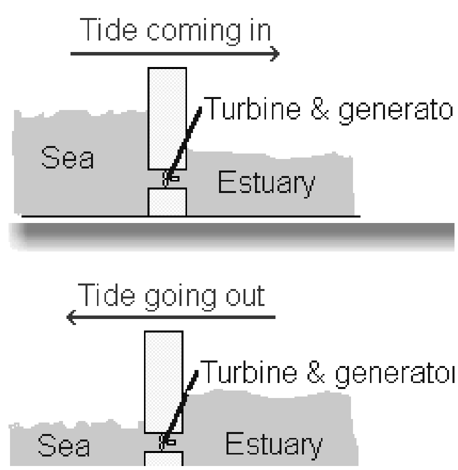
A relatively new technology tidal stream generators draw energy from currents in much the same way as wind turbines. The higher density of water, some 832 times the density of air, means that a single generator can provide significant power.

Even more so than with wind power, selection of location is critical for a tidal stream power generator. Tidal stream systems need to be located in areas with fast currents where natural flows are concentrated between obstructions, for example at the entrances to bays and rivers, around rocky points, headlands, or between islands or other land masses.

TIDAL BARRAGES

These work rather like a hydro-electric scheme, except that the dam is much bigger.

A huge dam (called a "barrage") is built across a river estuary. When the tide goes in and out, the water flows through tunnels in the dam.



The ebb and flow of the tides can be used to turn a turbine, or it can be used to push air through a pipe, which then turns a turbine. Large lock gates, like the ones used on canals, allow ships to pass.

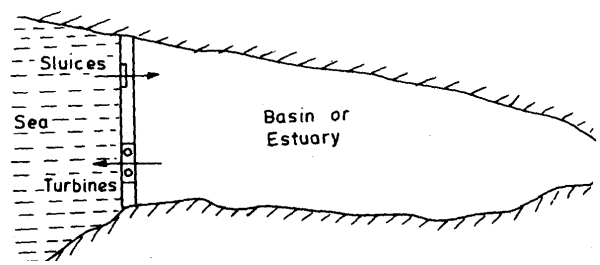
The basic elements of a barrage are caissons, embankments, sluices, turbines and ship locks. Sluices, turbines and ship locks are housed in caisson (very large concrete blocks). Embankments seal a basin where it is not sealed by caissons. The sluice gates applicable to tidal power are the flap gate, vertical rising gate, radial gate and rising sector.

Barrage systems are sometimes affected by problems of high civil infrastructure costs associated with what is in effect a dam being placed across two estuarine systems, and the environmental problems associated with changing a large ecosystem.

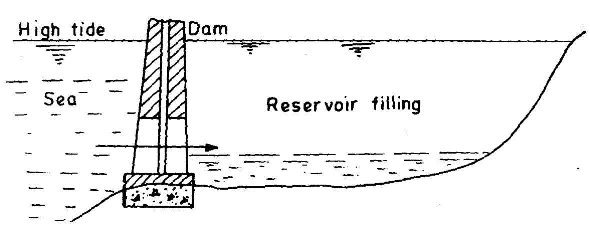
MODES OF OPERATION OF TIDE BARRAGES

Ebb Generation

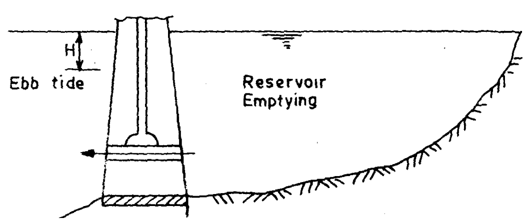
- **Single Basin Arrangement (Single Ebb cycle system)**. The basin is filled through the sluices until high tide. Then the sluice gates are closed. (At this stage there may be "Pumping" to raise the level further). The turbine gates are kept closed until the sea level falls to create sufficient head across the barrage, and then are opened so that the turbines generate until the head is again low. Then the sluices are opened, turbines disconnected and the basin is filled again. The cycle repeats itself. Ebb generation (also known as *outflow* generation) takes its name because generation occurs as the tide ebbs.



Plan



Sluice gate open (section)



Sluice gate closed (section)

Single Cycle Ebb generating system

The total theoretical work during a full emptying (or filling) period is obtained by integrating the expression

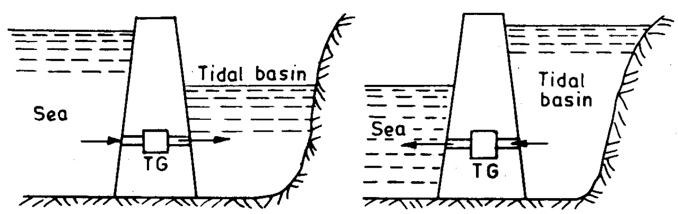
$$W = \int_R^0 dw = -g\rho A \int_R^0 h\,dh = \frac{1}{2} g\rho A R^2$$

where W is work done by water in kcal/kg or Joule; g is 9.81 m/s^2; m is mass flowing through turbine, kg; h is head in m; ρ is water density in kg/m^3 and A is basin surface area in m^2; R is tide range (diff. of height of high tide and low tide) in m.

Average theoretical power in watts is

$$P_{av} = \frac{W}{time}$$

- **Single Basin Arrangement (Double Ebb cycle system).** In this method, the generation of power is accomplished both during emptying and filling cycles. Both filling and emptying processes take place during short periods of time, the filling when the ocean is at high tide while the water in the basin is at low tide level, the emptying when the ocean is at low tide and the basin at high tide level.



High Tide **Low Tide**

Double Cycle Ebb generating system

Power generated at any instant

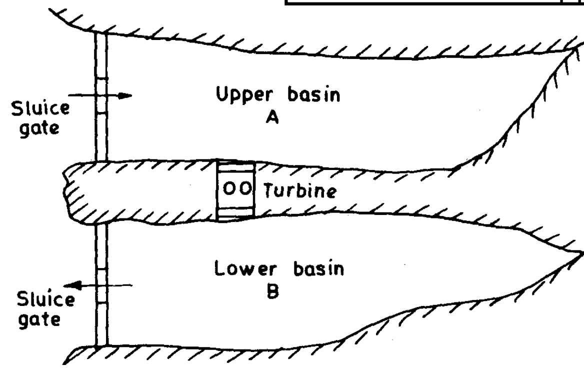
$$P = \frac{\rho Q h}{75} \, x \, \eta_0 \text{ H.P.} = \frac{\rho Q h}{75} \eta_0 \, x \, 0.736 \, kW$$

where ρ is average density of sea water = 1025 kg/m^3 and h is available head any time.

The total energy

$$= \int_0^t P dt = \int_0^t \frac{\rho Q h}{75} dt \, x \, \eta_0 \, x \, 0.736 \, kW \text{ per tidal cycle}$$

- **Double Basin Arrangement**. It requires two separate but adjacent basins. In one basin called "upper basin" (or high pool), the water level is maintained above that in the other, the low basin (or low pool). Because there is always a head between upper and lower basins, electricity can be generated continuously, although at a variable rate.



Tidal power plant double basin operation

Flood Generation

The basin is filled through the turbines, which generate at tide flood. This is generally much less efficient than ebb generation, because the volume contained in the upper half of the basin (which is where ebb generation operates) is greater than the volume of the lower half (and making the difference in levels between the basin side and the sea side of the barrage), (and therefore the available potential energy) less than it would otherwise be. This is not a problem with the "lagoon" model; the reason being that there is no current from a river to slow the flooding current from the sea.

Pumping

Turbines are able to be powered in reverse by excess energy in the grid to increase the water level in the basin at high tide (for ebb generation). This energy is more than returned during generation, because power output is strongly related to the head.

- **Two-basin schemes**. With two basins, one is filled at high tide and the other is emptied at low tide. Turbines are placed between the basins. Two-basin schemes offer advantages over normal schemes in that generation time can be adjusted with high flexibility and it is also possible to generate almost continuously. In normal estuarine situations, however, two-basin schemes are very expensive to construct due to the cost of the extra length of barrage. There are some favourable geographies, however, which are well suited to this type of scheme.

ADVANTAGES OF TIDAL POWER

- Once you've built it, tidal power is free.
- It produces no greenhouse gases or other waste.
- It needs no fuel.
- It produces electricity reliably.
- Not expensive to maintain.
- Tides are totally predictable.

- Offshore turbines and vertical-axis turbines are not ruinously expensive to build and do not have a large environmental impact.

DISADVANTAGES/LIMITATIONS OF TIDAL POWER

- A barrage across an estuary is very expensive to build, and affects a very wide area - the environment is changed for many miles upstream and downstream. Many birds rely on the tide uncovering the mud flats so that they can feed. There are few suitable sites for tidal barrages.
- Tidal power schemes do not produce energy all day. A conventional design, in any mode of operation, would produce power for 6 to 12 hours in every 24 and will not produce power at other times. As the tidal cycle is based on the rotation of the Earth with respect to the moon (24.8 hours), and the demand for electricity is based on the period of rotation of the earth (24 hours), the energy production cycle will not always be in phase with the demand cycle.
- Tidal ranges is highly variable and thus the turbine have to work on a wide range of head variation.
- The duration of power cycle may be reasonably constant but its time of occurrence keeps in changing. This causes load sharing problems. This can be minimized by using computerised programming.
- Sea water is corrosive and it is feared that the machines may get corroded. Hence stainless steel with high chromium content should be used.
- Construction in sea is a difficult task.
- Adverse environmental impact

Example

A tidal power plant of the simple single basin type, has a basin area of 30 x 10^6 m^2. The tide has a range of 12 m. The turbine, however, stops operating when the head on it falls below 3 m. Calculate the energy generated in one filling (or emptying) process, in kilowatt hours if the turbine generator efficiency is 0.73.

Solution

The total theoretical work W

$$= \int_R^r dw$$

R is the range = 12 m

r is the head below turbine stops operating = 3 m

$$W = \int_R^r -g\rho A h dh = -g\rho A \int_R^r h dh = \frac{1}{2} g\rho A (R^2 - r^2)$$

Thus the average power

$$P_{av.} = \frac{W}{time} = \frac{g\rho A(R^2 - r^2)}{44,700} = \frac{9.80 \, x \, 1025 \, x \, 30 \, x \, 10^6 (12^2 - 3^2)}{44700} \text{Watts}$$

$$= 911.25 \text{ x } 10^6 \text{ Watts}$$

$$= \frac{911.25}{1000} x \, 3600 \, x \, 10^6 \text{ kWh} = 3280.5 \, x \, 10^6 \text{ kWh}$$

Considering turbine generator efficiency, the energy generated

$$= 3280.5 \text{ x } 10^6 \text{ x } 0.73 = 2395 \text{ x } 10^6 \text{ kWh}$$

Example

The observed difference between the high and low water tide is 8.5 m for a proposed tidal site. The basin area is about 0.5 sq. km which can generate power for 3 hours in each cycle. The average available head is assumed to be 8 m, and the overall efficiency of the generation to be 70%. Calculate the power in H.P. at any instant and the yearly power output. Average specific weight of sea water is assumed to be 1025 kg/m^3.

Solution

Volume of the basin = Ah_0 = 0.5 x 10^6 x 8.5 = 4.25 x 10^6 m^3

Average discharge Q = volume/time period

$$= Ah_0/t$$

$$= \frac{4.25 \, x \, 10^6}{3 \, x \, 3600} = 0.03704 \, x \, 10^6 = 393.5 \, m^3/s$$

Power at any instant

$$P = \frac{Q\rho h}{75} \eta_0 \text{ H.P.}$$

$$= \frac{393.5 \, x \, 1025 \, x \, 8}{75} x \, 0.70 = 310.15 \, x \, 10^2 \text{ H.P.}$$

The total energy in kWh/tidal cycle

$$E = 301.15 \text{ x } 10^2 \text{ x } 0.736 \text{ x } 3 = 664.93 \text{ x } 10^2$$

Total number of tidal cycle in a year = 705

Therefore total output per annum

$$= 664.93 \text{ x } 10^2 \text{ x } 705$$

$$= 468.78 \text{ x } 10^5 \text{ kWh/year}$$

Problem

In an estuary, which is being developed for tidal power generation during the tide cycle the observed difference between the high and low water tides was 5.5 m. It is estimated that the estuary's area is 0.5 sq. km which can generate power for 3 hours in each cycle. Assuming the average available head to be 5 m, and the overall efficiency of generation to be 75%, calculate

(i) power in hp at any instant, and

(ii) total energy in the year

Sea water specific gravity can be taken as 1025 kg/m^3.

Answer: (i) 130.5 x 10^2 hp (ii) 203 x 10^5 kWh/yr.

ENVIRONMENTAL ASPECTS

The placement of a barrage into an estuary has a considerable effect on the water inside the basin and on the fish.

Turbidity

Turbidity (the amount of matter in suspension in the water) decreases as a result of smaller volume of water being exchanged between the basin and the sea. This lets light from the Sun to penetrate the water further, improving conditions for the phytoplankton. The changes propagate up the food chain, causing a general change in the ecosystem.

Salinity

Again as a result of less water exchange with the sea, the average salinity inside the basin decreases, also affecting the ecosystem. Again, lagoons do not suffer from this problem.

Sediment movements

Estuaries often have high volume of sediments moving through them, from the rivers to the sea. The introduction of a barrage into an estuary may result in sediment accumulation within the barrage, affecting the ecosystem and also the operation of the barrage.

Pollutants

Once again, as a result of reduced volume, the pollutants accumulating in the basin will be less efficiently dispersed. Their concentrations will increase. For biodegradable pollutants, such as sewage, an increase in concentration is likely to lead to increased bacteria growth in the basin, having impacts on the health of the human community and the ecosystem. The concentrations of conservative pollutants will also increase.

Fish

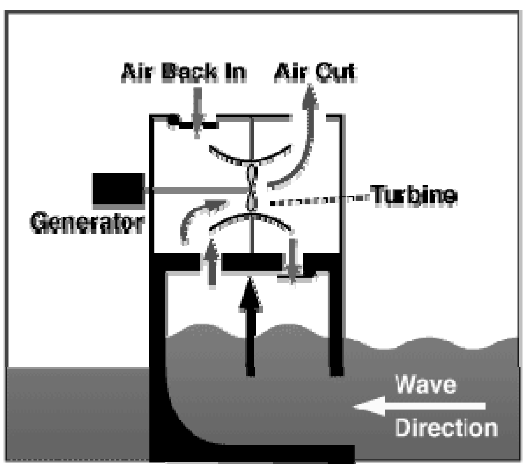
Fish may move through sluices safely, but when these are closed, fish will seek out turbines and attempt to swim through them. Also, some fish will be unable to escape the water speed near a turbine and will be sucked through. Even with the most fish-friendly turbine design, fish mortality per pass is approximately 15% (from pressure drop, contact with blades, cavitation, etc.). This can be acceptable for a spawning run, but is devastating for local fish who pass in and out of the basin on a daily basis. Alternative passage technologies (fish ladders, fish lifts, etc.) have so far failed to solve this problem for tidal barrages, either offering extremely expensive solutions, or ones which are used by a small fraction of fish only.

Global environmental impact

A tidal power scheme is a long-term source of electricity. A proposal for the Severn Barrage, if built, has been projected to save 18 million tons of coal per year of operation. This decreases the output of greenhouse gases into the atmosphere. More importantly, as the fossil fuel resource is likely to be eliminated by the end of the twenty-first century, tidal power is one of the alternative source of energy that will need to be developed to satisfy the human demand for Energy.

WAVE ENERGY

Kinetic energy (movement) exists in the moving waves of the ocean. That energy can be used to power a turbine. In this simple example, to the right, the wave rises into a chamber. The rising water forces the air out of the chamber. The moving air spins a turbine which can turn a generator.



When the wave goes down, air flows through the turbine and back into the chamber through doors that are normally closed.

This is only one type of wave-energy system. Others actually use the up and down motion of the wave to power a piston that moves up and down inside a cylinder. That piston can also turn a generator.

Most wave-energy systems are very small. But, they can be used to power a warning buoy or a small light house.

Wave power refers to the energy of ocean surface waves and the capture of that energy to do useful work - including electricity generation, desalination, and the pumping of water (into reservoirs). Wave power is a form of renewable energy. Though often co-mingled, wave power is *distinct* from the diurnal flux of tidal power and the steady gyre of ocean currents. Wave power generation is not a widely employed technology, and no commercial wave farm has yet been established.

In general, large waves are more powerful. Specifically, wave power is determined by wave height, wave speed, wavelength, and water density.

Wave size is determined by wind speed and fetch (the distance over which the wind excites the waves) and by the depth and topography of the seafloor (which can focus or disperse the energy of the waves). A given wind speed has a matching practical limit over which time or distance will not produce larger waves. This limit is called a "fully developed sea."

Wave motion is highest at the surface and diminishes exponentially with depth; however, wave energy is also present as pressure waves in deeper water.

The potential energy of a set of waves is proportional to wave height squared times wave period (the time between wave crests). Longer period waves have relatively longer wavelengths and move faster. The potential energy is equal to the kinetic energy (that can be expended). Wave power is expressed in kilowatts per meter (at a location such as a shoreline).

The formula below shows how wave power can be calculated. Excluding waves created by major storms, the largest waves are about 15 meters high and have a period of about 15 seconds. According to the formula, such waves carry about 1700 kilowatts of potential power across each meter of wavefront. A good wave power location will have an average flux much less than this: perhaps about 50 kW/m.

Formula: Power (in kW/m) = $k H^2 T \sim 0.5 H^2 T$,

where k = constant, H = wave height (crest to trough) in meters, and T = wave period (crest to crest) in seconds.

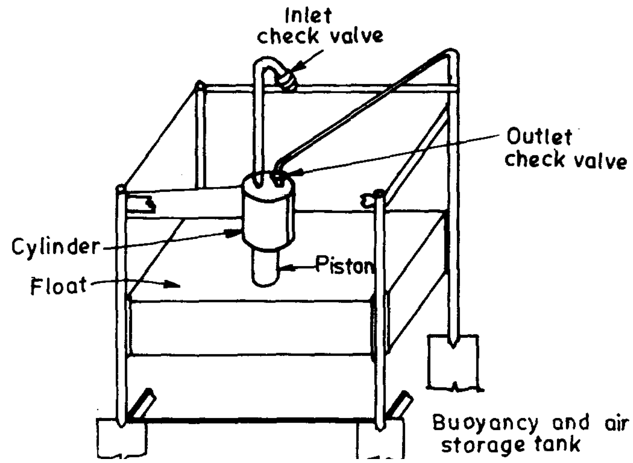
Modern Technology

Wave power devices are generally categorized by the method used to capture the energy of the waves. They can also be categorized by location and power take-off system. Method types are point absorber or buoy; surfacing following or attenuator; terminator, lining perpendicular to wave propagation; oscillating water column; and overtopping. Locations are shoreline, nearshore and offshore. Types of power take-off include: hydraulic ram, elastomeric hose pump, pump-to-shore, hydroelectric turbine, air turbine, and linear electrical generator. Some of these designs incorporate parabolic reflectors as a means of increasing the wave energy at the point of capture.

These are descriptions of some wave power systems:

- *PowerBuoy® technology (wave energy conversion by floats)* consists of modular, ocean-going buoys. The rising and falling of the waves moves the buoy-like structure creating mechanical energy which is converted into electricity and transmitted to shore over a submerged transmission line.

  Following diagram explains the basic principle of its working:

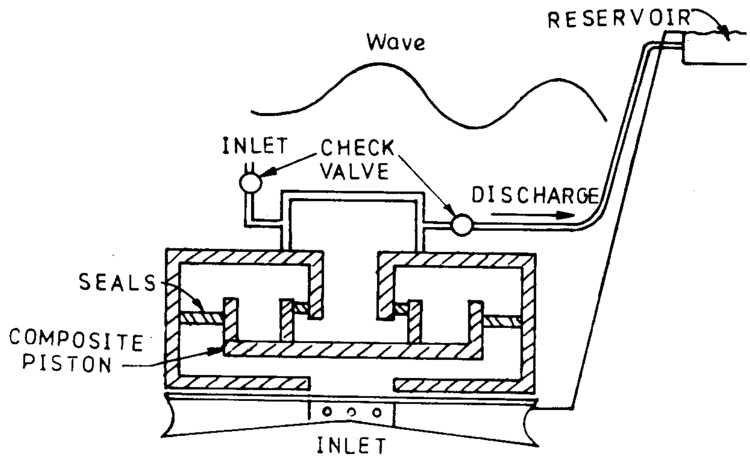


  Here a square float moves up and down with the water. It is giuded by four vertical manifolds that are part of platform. There are four large under water floatation tanks which stablise the platform. Platform is supported by buoyancy forces. The platform remains stationary in space. A piston which is attached to float as shown in figure moves up and down inside a cylinder. The cylinder is attached to platform and is used as a reciprocating compressor. The doenward motion of the piston draws air into the cylinder via an inlet check valve. This air is compressed by upward motion of the piston and is supplied to the four under water floatation tanks. An air turbine is run by the compressed air which is stored in the buoyancy storage tanks, which in turn drives an electrical generator producing electricity which is then transmitted to the shore via an under water cable.

- An example of a surface following device is the *Pelamis Wave Energy Converter*. The sections of the device articulate with the movement of the waves, each resisting motion between it and the next section, creating pressurized oil to drive a hydraulic ram which drives a hydraulic motor.

- With the Wave Dragon wave energy converter *(high level reservoir wave machine)* large "arms" focus waves up a ramp into an offshore reservoir. The water returns to the ocean by the force of gravity via hydroelectric generators.

  Following figure explains this technique.



- The AquaBuOY wave energy device: Energy transfer takes place by converting the vertical component of wave kinetic energy into pressurized seawater by means of two-stroke hose pumps. Pressurized seawater is directed into a conversion system consisting of a turbine driving an electrical generator. The power is transmitted to shore by means of a secure, undersea transmission line.
- A device called CETO, currently being tested off Fremantle, Western Australia, has a seafloor pressure transducer coupled to a high-pressure hydraulic pump, which pumps water to shore for driving hydraulic generators or running reverse osmosis desalination.
- A device installed near Wollongong, New South Wales, uses a parabolic reflector to concentrate wave energy into an oscillating water column which drives air through a Denniss-Auld turbine, designed to rotate in a constant direction in the oscillating airflow.

The *challenges* of wave power are:

- efficiently converting wave motion into electricity... generally speaking, wave power is available in low-speed, high forces and motion is not in a single direction. Most readily-available electric generators like to operate at higher speeds, with lower input forces, and they prefer to rotate in a single direction.
- constructing devices that can survive storm damage and saltwater corrosion. Likely sources of failure include seized bearings, broken welds, and snapped mooring lines. Knowing this, designers may create prototypes that are so overbuilt that materials costs prohibit affordable production.
- low total cost of electricity... wave power will only be competitive when total cost of generation is reduced. The winning team will be the one that develops the lowest-cost *system* (which includes the primary converter, power takeoff system, mooring system, installation & maintenance procedures)

ASSIGNMENT

WIND ENERGY

Q.1. (AMIE W06, 8 marks): Define different types of mechanical control used in wind energy conversion system (WECS). How are pitch control and yaw control associated with the types of generator used in WECS?

Q.2. (AMIE S06, 5 marks): Explain about yaw, pitch and teething control in a horizontal wind generator with neat sketches.

Q.3. (AMIE W06, S07, 6 marks): Compare vertical axis turbine with horizontal axis turbine.

Q.4. (AMIE S06, 5 marks): Explain the working of Savonius type wind mill.

Q.5. (AMIE S12, 6 marks): Explain the functioning of Darrieus type wind energy system.

Q.6. (AMIE S07, 7 marks): Describe the construction and working of a three blade horizontal shaft wind turbine generator unit.

Q.7. (AMIE S07, 7 marks): List the different wind turbine plants situated in India. Describe in detail the main considerations in selecting a site for wind energy forms.

Q.8. (AMIE W12, 6 marks): Explain the functions and use of windmills. How do vertical shaft windmills compare with windmills having horizontal shaft?

Q.9. (AMIE W12, 8 marks): What is the total power of a wind stream? What do you mean by coefficient of performance and tip speed ratio of a windmill. On what factors does the performance of wind mills depend? How is the power output of wind turbine controlled and utilized?

Q.10. (AMIE S13, 4 marks): Derive an expression for energy available in wind.

Q.11. (AMIE S13, 6 marks): Differentiate between global (planetary) and local winds. Discuss factors affecting the distribution of wind energy on the surface of the earth.

Q.12. (AMIE S13, 10 marks): Sketch the Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT) and explain the function of main components.

Q.13. (AMIE W13, 8 marks): Explain the characteristics of various types of rotors used in windmills.

Q.14. (AMIE W14, 8 marks): What is wind energy? How is it harnessed through various types of windmills? Write applications of wind energy.

Q.15. (AMIE W14, 4 marks): Justify the statement that, wind energy is an indirect form of solar energy Differentiate between local and global winds.

Q.16. (AMIE W06, 6 marks): A propeller wind turbine runs at 40 rpm. Calculate (i) total power density in wind stream (ii) maximum obtainable power density and actual power density (take efficiency as 35%) and (iii) total power produced and torque at maximum efficiency. Turbine diameter is 120 m, wind velocity is 15 m/s and air density is 1.226 kg/m^3.

Q.17. (AMIE S06, 5 marks): A propeller type wind turbine having blade diameter of 60 m is in operation at a speed of 175 rpm with a wind velocity of 25 m/s the atmospheric air temperature being 30^{0}C. Calculate the total power density in the wind, maximum obtainable power density and average total power at normal conditions with an efficiency of 30%.

TIDAL/WAVE ENERGY

Q.18. (AMIE S06, 5 marks): What are various methods of tidal energy generation? Explain in detail.

Q.19. (AMIE W06, S12, 8 marks): What are the limitations of single pool tidal system? How are these overcome in modulated single-pool tidal system and two pool tidal system?

Q.20. (AMIE S07, 7 marks): With a simple layout and tidal cycle curves, explain single effect single basin tidal scheme.

Q.21. (AMIE S07, 7 marks): With a schematic diagram, explain the working of an oscillating hydraulic piston wave energy pumped storage plants.

Q.22. (AMIE W12, 4 marks): Discuss the scope of utilizing ocean wave energy to generate electricity.

Q.23. (AMIE W12, 10 marks): How is tidal energy converted to electrical energy? What do you mean by schedule and range of a tidal wave? Discuss different tidal power schemes and configurations with neat sketches.

Q.24. (AMIE S13, 6 marks): What is the source of tidal energy? What is the minimum tidal range required for a practical tidal plant ? I low much is the potential in tides ?

Q.25. (AMIE S13, 6 marks): Explain the functioning of modulated single pool tidal system.

Q.26. (AMIE W13, 12 marks): The basin area of a single basis type tidal park plant is 25 x 10^6 m^2. The tidal range is 10 m. The turbine, however, stops operating when the head on it fails below 4 m. Calculate the energy generated in one filling process, if the turbine generator efficiency is 0.7.

Q.27. (AMIE W14, 8 marks): Explain the concept of power generation through tides. Describe the monthly variation of the availability of tidal energy with the help of a suitable diagram. Discuss the working of a linked basin tidal energy conversion scheme.

Q.28. (AMIE S12, 6 marks): For a tidal mill, having a blade length of 3 m, compute the power captured by the blades when the tidal current is 18.52 km/h and the power coefficient of the tidal mill is 0.45. If a wind mill has the same diameter as the tidal mill and the wind speed is equivalent to the tidal speed and the power coefficient is also 0.45, compute the power captured by the blades. Prove that the two powers have the same ratio as the ratio of water density to air density.

Q.29. (AMIE S06, 5 marks): Calculate the average power available for one tidal period for the data given below:

Surface area = 10,000 m^2

Range of tide = 9 m

Q.30. (AMIE W06, 6 marks): A single pool tidal power plant has a basin area 30 x 10^6 m^2. The tide has a range 12 m. The turbine can work with head of 3 m. Estimate the total power generated in one filling emptying cycle. Efficiency of turbine generator is 73%.