9

Energy from the Oceans

(OTEC, Tides, Waves, and Small Hydroelectric)

9.1. Introduction

Broadly the ocean sources of energy are Ocean Thermal Energy Conversion (OTEC) and the Tidal energy, Wave energy and fourth form of the energy that emanates from the sun-ocean system stems from the mechanism of surface water evaporation by solar heating *i.e.* hydrological cycle. These energy sources (except tidal) are the result of the absorption by the seas and oceans of solar radiation, which causes, like the wind, ocean currents and moderate temperature gradients from the water surface downward, especially in tropical waters. The oceans and seas constitute some 70 per cent of the earth's surface area, so they represent a rather large storage reservoir of the solar input.

The conversion of solar energy stored as heat in the ocean into electrical energy by making use of the temperature difference between the warm surface water and the colder deep water. The facilities proposed for achieving this conversion are commonly referred to as OTEC plants or sometimes as solar sea power plants (SSPP). Since the ocean waters are heated by the sun, they constitute a virtually inexhaustible source of energy. However, unlike direct solar energy, the ocean energy is available continuously rather than only in the daytime.

The operation of the OTEC plant is based on a well established physical (thermodynamic) principle. If a heat source, is available at a higher temperature and a heat sink at a lower temperature, it is possible in principle, to utilize the temperature difference in a machine or *prime mover* (*e.g.* a turbine) that can convert part of the heat taken up from the source into mechanical energy and hence into electrical energy. The residual heat is discharged to the sink at the lower temperature. In the OTEC system, the warm ocean surface water is the heat source and the deep colder water provides the sink.

The temperature gradient can be utilized in a heat engine to generate power. This is called *ocean thermal energy conversion* (OTEC).

is maximum, decreasing again below this temperature, the reason be floats). Thus there will be no thermal convection currents between the warmer, lighter water at the top and deep cooler, heavier water. Thermal conduction heat transfer between them across the large depths, is too low to after this picture, and thus mixing the retarded, so the warm water stays at the top and the cool water stays at the bottom. It is said, therefore, that in tropical waters there are two essentially infinite heat reservoirs, a heat source at the surface at about 27°C and a heat sink, some 1 km directly below, at about 4°C ; both reservoirs are maintained annually by solar incidence. The concept of ocean thermal energy conversion (OTEC) is based on the utilization of this temperature difference in a heat engine to generate power.

The surface temperatures (and temperature differences) vary both with latitude and season, both being maximum in tropical, sub-tropical, and equatorial waters *i.e.*, between the two tropics, making these waters the most suitable for OTEC systems.

Several such plants are built in France after World War II (the largest of which has a capacity of 7.5 MW). With a 22°K temperature difference between surface and depths, such as exists in warmer ocean areas than in north sea, the Carnot efficiency is around 7%. This is obviously very low, and comparable to that expected from a flat plate collector. In fact, by the time the overall efficiency has been reduced by using a practical engine (operating on a Rankine cycle say) together with heat exchangers, the propositions might seem hopeless. One major difference between these two heat sources is that solar energy arrives with a low power density, and requires a large acreage of flat-plate collector. Whereas on ocean thermal gradient source can operate with a small area collector by pumping sufficient water through the heat collector. Indeed the attraction of the solar sea power plant lies in its present day engineering feasibility and possible competitive cost with fossil fuel power stations. As stated the idea of ocean thermal energy conversion with a suitable working fluid was originated by *d' Arsonval*, but the technical feasibility of the open cycle system was demonstrated by Claude with an installation on the south coast of Cuba in 1929. It was a remarkable achievement at the time. The electric power generated was 22 kilowatts with an overall efficiency more than 1 per cent. The hot and cold water were conducted through the long pipes to the machinery ashore. With the limited technology and cheap fuel at that time, there was then little prospects for economic feasibility. A larger installation with two units totalling 7 megawatts was constructed on the Ivory coast by the French in 1956, but encountered troubles and was abandoned.

The process of OTEC, requires that the warm surface water and cold water from depth (about 1000-1500 m), be brought into proximity

so they act as the heat source and the heat sink, respectively for a heat engine. In other words, solar energy collected and stored as heat by the world's major oceans, can be converted into electricity through a generation process similar to that of conventional power plants, except that in the case of OTEC, no depletable fuel is required. Furthermore, although there is some seasonal variation in the ocean thermal resource at a given OTEC power plant location, there is little diurnal variation. Accordingly OTEC power plants are analogous to solar hydropower plants in that they smooth out the diurnal intermittance of the solar radiation, in contrast to other electric power options. Thus OTEC power plants provide a potentially substantial renewable source of base load electricity, albeit located mainly at sea.

Although it is possible to find good land sites where OTEC power plants can be located, by bringing the warm and cold water onto shore *via* aqueducts (artificial cannal/conduit), it is clear that such opportunities will be much limited on a global basis than the ample opportunities for generating substantial amounts of OTEC electricity abroad floating OTEC platforms. This is both because of the special technical requirements for on shore OTEC plants and because of the limited market potential (atleast in the near term) for OTEC electricity at such sites. On shore OTEC power plants will be viable mainly at locations where three requirements are all simultaneously satisfied with satisfactory economics :

(*i*) Coastal zone land must be available,

(*ii*) Sea floor must descend sufficiently rapidly from the shore based plant location ; and

(*iii*) The seasonal availability of warm and cold water without undue gradation by the warm and cold water effluents from the OTEC plant must meet certain criteria. In any event, it is probable that available and attractive on shore and near shore OTEC power plant location will be populated early in the development and implementation of the OTEC concept, both as convenient locations for pilot and demonstration plants and because they will constitute attractive intermediate markets for OTEC electricity and by products.

OTEC power generation system gives less efficiency, as stated above. However, because of the OTEC requirement for parasitic power (such as for pumping up the cold water supply) and other losses, the achievable net conversion efficiency is only about 2.5 percent (Carnot efficiency 7%). This compares a net efficiencies of 30 to 40% associated with conventional power plants.

Some engineers question whether such as an extremely low net efficiency will ever allow OTEC to become economically viable. However, it is important to consider the matter in more sophisticated terms than net efficiency ; since in the case of OTEC there is no fuel cost, only the requirement to pay for circulating much more warm and cold water, than is normally associated with power generation. This means that extensive areas heat exchangers will be required for "closed cycle" OTEC plants (which would employ a working fluid such as ammonia) or that degasifiers (to remove gases dissolved in the sea water) and tremendous turbines would be required for "open cycle" OTEC plants that would operate by the flash evaporation of sea water. Thus, although the net efficiency of the OTEC plant must certainly be positive and as high as is readily attainable, the key economics question is the resulting cost of OTEC electrical energy, not the actual value of the net efficiency.

9.2.2. Methods of ocean thermal electric power generation

There are two rather different methods for harnessing ocean thermal differences. One is the *open cycle*, also known as the *Claude cycle*, and other is the *closed cycle* system, also known as the *Anderson cycle*. These are covered in the next two sections.

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

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

The *Claude cycle* or *open cycle* which is older one, utilizes the vapour pressure of sea water itself as the working medium and has been demonstrated to be practicable. The other method, a *closed cycle* known as the Rankine cycle, uses a working fluid with higher vapour pressure

(such as ammonia, hydrocarbon or halocarbon) at the temperature available. This cycle is favoured for the future development in expectation of higher efficiency. The first published work on OTEC by d'. Arsonvol in 1881, suggests a closed cycle, and that article proposed sulfer di-oxide (SO_2) as the working fluid. However, the first OTEC experiments by Claude in the 1920s utilized on open cycle where sea water was evaporated under a partial vacuum.

9.2.3. Open cycle OTEC System (Claude cycle)

'Open cycle' refers to the utilization of sea water as the working fluid, wherein sea water is flash evaporated under a partial vacuum. The low pressure steam is passed through a turbine, which extracts energy from it, and then the spent vapour is cooled in a condenser. This cycle drives the name 'open' from the fact that the condensate need not be returned to the evaporator, as in the case of the 'closed cycle'. Instead, the condensate, can be utilized as desalinated water if a surface condenser is used, or if a spray (direct-contact) condenser is used, the condensate is mixed with the cooling water and the mixture is discharged back into the ocean. A schematic diagram of the open cycle system is shown in Fig. (9.2.3.1). Its corresponding T-S diagram is also

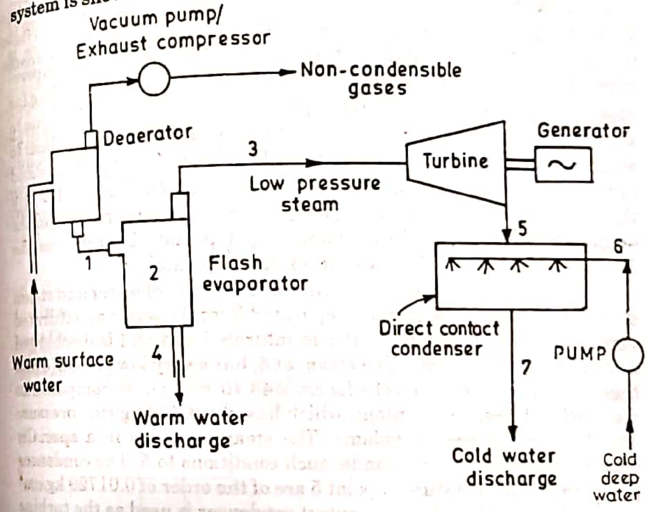


Fig. 9.2.3.1. Schematic of the OTEC open cycle.

shown in the Fig. (9.2.3.2). In the cycle shown warm surface water at say 27°C is admitted into an evaporator in which the pressure is maintained at a value slightly below the saturation pressure

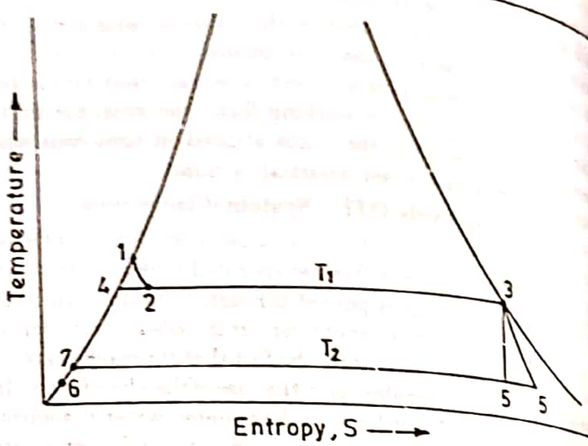


Fig. 9.2.3.2. T-S diagram corresponding to Fig. (9.2.3.1).

corresponding to that water temperature. At the new pressure, water which is entering the evaporator gets 'super heated'. As shown in Fig. (9.2.3.2) the warm water which is at 27°C, has a saturation pressure of 0.03619 kg/cm^2 (0.0356 bar) (point 1). The evaporator pressure is 0.03213 (0.0317 bar), which corresponds to 25°C saturation temperature. This temporarily superheated water undergoes *volume boiling* (as opposed to pool boiling which takes place in conventional boilers due to an immersed heating surface), causing that water to partially flash to steam to an equilibrium two phase condition at the new pressure and temperature of 0.03213 kg/km^2 and 25°C (point 2). Process 1-2 is a throttling and hence constant enthalpy process. The low pressure in the evaporator is maintained by a vacuum pump that also removes the dissolved non-condensable gases from the evaporator.

At point 2, the evaporator contains a mixture of water and steam of very low quality. The steam is separated from the water as saturated vapour at 3. The remaining water is saturated at 4 and is discharged as brine back to the ocean. The steam at 3, has a very low pressure and high specific volume (0.03213 kg/cm^2, 43.40 m^3/kg), as compared to conventional fossil power plant, which has about 160 kg/cm^2 pressure and 0.021 m^3/kg specific volume. The steam expands in a specially designed turbine that can handle such conditions to 5. The condenser pressure and temperature at point 5 are of the order of 0.01729 kg/cm^2 (0.017 bar) and 15°C. A direct contact condenser is used as the turbine exhaust steam will be discharged back to the ocean in the open cycle system. In the condenser, the exhaust steam is mixed with cold water from the deep cold water pipe at 6, which results in a near saturated water at 7. This water is allowed to discharged to the ocean. The cooling

water from the deep ocean which is at about 11°C, on reaching the condenser, its temperature rises to about 15°C, due to heat transfer between the progressively warmer outside water and cooling water inside the pipe, as it ascends towards the top.

It can be seen that very large ocean water mass and volume flow rates are used in open OTEC systems and that the turbine is a very low pressure until that receives steam with specific volumes more than 2000 times that in a modern fossil power plant. Thus the turbine resembles the few last exhaust stages of a conventional turbine and is thus physically large.

Because of the need in the open cycle to harness the energy in low pressure steam, extremely large turbines (compared to wind turbines) must be utilized. Further-more degasifiers (deaerators) must be used to remove the gases dissolved in the sea water unless one is willing to accept large losses in efficiency. On the other hand, since there are no heat transfer problems in the evaporator, the problem of bio-fouling control is minimized.

The cost of an open-cycle system for providing substantial number of megawatts is presently regarded by most OTEC workers as being significantly greater than for closed cycle system. The turbine cost constituted almost half the cost of the power system, but may be amenable to reductions that could result from design innovations.

9.2.4. The Closed or Anderson, OTEC Cycle

A schematic of a closed-cycle OTEC power plant is shown in Fig. 9.2.4.1. Heat exchanger known as evaporators and condensers are a key ingredient, since extensive areas of material are needed to transfer significant amounts of low quality heat of the low temperature differences being exploited. In other words, large volumes of water must

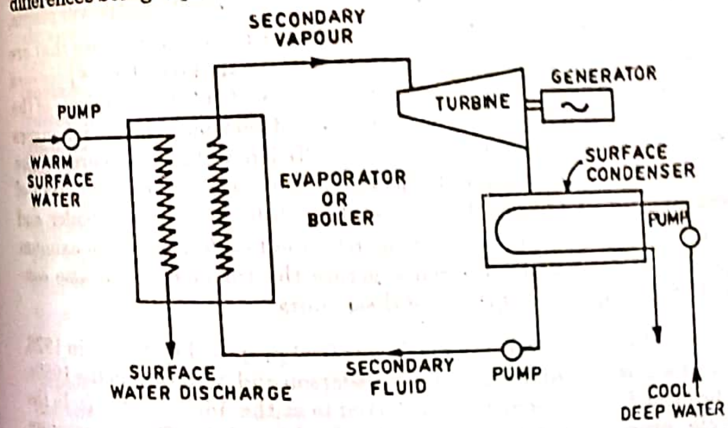
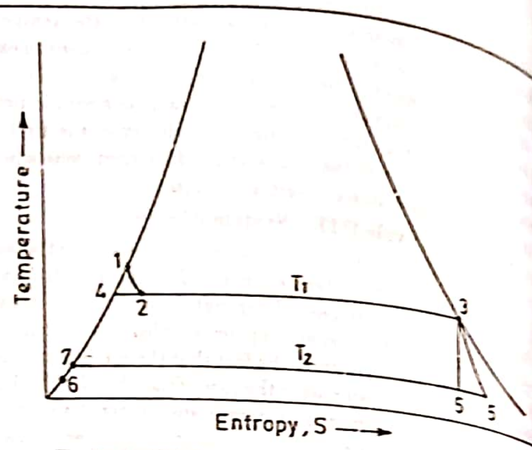


Fig. 9.2.4.1. Schematic of an OTEC closed cycle system.



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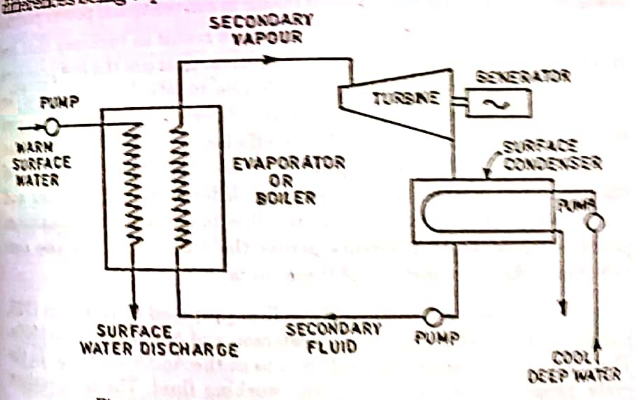


Fig. 9.2.4.1. Schematic of an OTEC closed cycle system.

be circulated through the OTEC power plant, requiring commensurately large heat exchangers. The actual components employed in an OTEC closed cycle system would appear more like the hardware illustrated in Fig. 9.2.4.2, another closed cycle schematic. This cycle requires a separate working fluid that receives and rejects heat to the source and

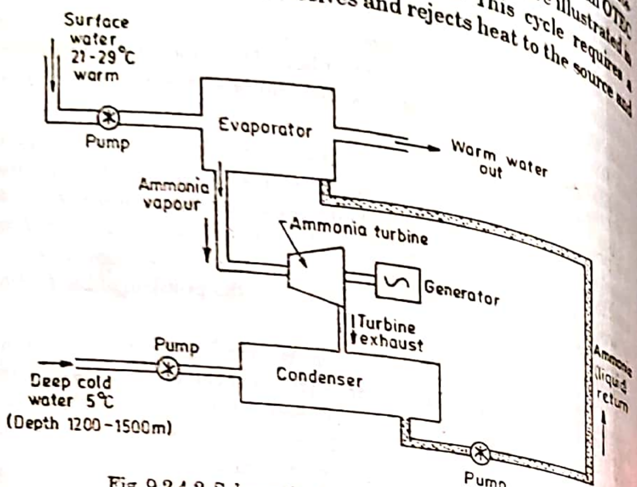


Fig. 9.2.4.2. Schematic of a closed OTEC ammonia cycle.

sink *via* heat exchangers (boiler or evaporator and surface condenser). The working fluid may be ammonia, propane, or a Freon. The operating (saturation) pressures of such fluids at the boiler and condenser temperatures are much higher than those of water, being roughly 10 kg/cm^2 ($\simeq$ 10 bar) at the boiler, and their specific volumes are much lower, being comparable to those of steam in conventional power plants.

Such pressures and specific volumes result in turbines that are much smaller and hence less costly than those that use the low pressure steam of the open cycle. The closed cycle also avoids the problems of the evaporator. It however, requires the use of very large heat exchangers (boiler and condenser) because, for an efficiency of about 2 percent, the amounts of heat added and rejected are about 50 times the output of the plant. In addition, the temperature differences in the boiler and condenser must be kept as low as possible to allow for the maximum possible temperature difference across the turbine, which also contributes to the large surfaces of these units.

The closed cycle approach was first proposed by Barjot in 1926, but the most recent design was by Anderson and Anderson in the 1960s. The closed cycle is sometimes referred to as the *Anderson Cycle*. In the cycle propane was chosen as the working fluid. The temperature

difference between warm surface and cool surface was 20°C. The cool surface was at about 600 m deep. Propane is vaporized in the boiler or evaporator at about 10 kg/cm^2 (10 bar) or more and exhausted in the condenser at about 5 bar.

Instead of usual heavier and more expensive shell and tube heat exchangers, the Anderson OTEC system employs thin plate type heat exchangers, which minimizes the mass and the amount of material and hence cost. The heat exchangers are placed at depths where the static pressure of the water in either heat exchanger roughly equals the pressure of the working fluid, this helps in reducing the thickness of the plates.

A fundamental requirement in closed cycle systems is to transfer heat efficiently across the heat exchanger surfaces constituting the evaporators and condensers, so as to achieve a high value of overall heat transfer coefficient (U) measured in watts per kelvin per square meter or W/°K/m^2. For the evaporation, this overall heat transfer coefficient is a measure of how effectively heat is transferred sequentially from sea water through the heat exchanger materially (a metallic alloy) and hence to the working fluid (*e.g.*, ammonia). For the condenser, an overall U characterized the reverse heat transfer process.

In an ocean environment, it is likely that a layer of slime known as "bio fouling" will *eventually* accumulate on the water side of the heat exchangers. Such slime is first comprised or micro-organisms, at which stage, the bio fouling is called "micro fouling". Subsequently, if the slime is not removed, additional bio-fouling in the form of micro-organisms will become attached, augmenting the slime layer. The occurrence of micro-fouling seems to be a pre-requisite for the attachment of macro organisms. A film of corrosion and possibly of calcareous (*e.g.* minerals) deposits can also accumulate on the water side (and conceivably through leakage—even on the working fluid side of the heat transfer surfaces). The total formulation of bio-fouling, corrosion, and so on, is referred to a "fouling" (or scaling) and will tend to inhibit heat transfer through it. The "fouling factor" is a measure of the thermal resistance 'R_f' of a fouling film. This thermal resistance is the reciprocal of the corresponding heat transfer coefficient 'h_f' of the fouling film. To maintain viable OTEC heat exchangers, provisions must be made to inhibit the formation of fouling layers and to remove any significant fouling that forms. Removal can be accomplished by periodically cleaning the heat exchanger surfaces through mechanical, chemical or other means.

Although both closed-and open cycle turbine systems are being explored, it appears that closed-cycle systems offer the most promise for the near future. Each of the possible working fluids (*i.e.* ammonia and propane) has advantages and disadvantages. Ammonia has better operating characteristics than propane and it is much less flammable. On the other hand ammonia forms a noxious vapour and probably could not be used with copper heat exchanger (see below). Propane is compatible with most heat-exchanger materials, but it is highly flammable and forms an explosive mixture with air. Ammonia has been used as the working fluid in successful tests of the OTEC concept with closed cycle systems.

9.2.5. Heat Exchangers (Evaporators)

The maximum (or ideal) efficiency for the conversion of heat into mechanical work (or electricity) in a turbine depends on the drop in temperature of the working fluid in its passage through the turbine and the turbine inlet temperature. In Fig. (9.2.4.2), the temperature drop in the turbine is 10°C (10 K) and the inlet temperature is 20°C (20 + 273 = 293 K), hence the maximum thermal efficiency is $\frac{10}{273} = 0.034$ or 3.4 percent. In an OTEC system, departure from ideal behaviour in the turbine and allowance for the energy required to pump the cold water from great depths would reduce the net efficiency for electric power generation to 2 to 2.5 percent. This may be compared with the almost 40 percent efficiency of a modern coal-fired power plant. In the OTEC system, the low conversion efficiency would be compensated by the enormous amounts of heat available in ocean surface waters. But in order to utilize this heat to generate electrical energy in economically useful amounts, water must be pumped through the heat exchangers in both evaporator and condenser at very high rates. In a facility designed to produce 100 megawatts of electrical power, for example, the total flow of water might be more than 500 million gallons (2.2 million cu. m.) per hour. The area of the heat exchange surfaces for both evaporator and condenser would be about 1 million sq. m. (Note that 100 megawatts is only about one-tenth of the electric power generated by a single modern coal-fired or nuclear plant.).

The effectiveness and cost of the heat exchangers are regarded as critical for the OTEC concept. The electric power that can be generated depends, in the first place, on the rate of heat transfer from the warm ocean water to the working fluid in the evaporator. Furthermore, conversion of this heat into electrical energy with maximum efficiency requires that the temperature of the working fluid entering the turbine should be as high as possible and that of the fluid leaving the turbine as low as possible. All these requirements can be met only if there is effective heat transfer in the heat exchangers.

Special efforts are being made to improve the engineering design of heat exchangers suitable for OTEC use. In addition, the constructional materials, must have good heat conductivity and be resistance to

corrosion and erosion by rapidly flowing ocean water. Among the materials being considered, the prime candidates are : (1) titanium (2), aluminium (or an alloy) (3) an alloy of copper (90 percent) and nickel, and (4) plastic.

(1) **Titanium** is resistant to corrosion and erosion by ocean water and it has good mechanical strength. At present, however, it is an expensive metal of limited availability. Nevertheless, since titanium is not a rare element in nature, the supply could probably be increased and the cost of the metal decreased if there were a sufficient demand.

(2) **Aluminium** is considerably cheaper than titanium, but the common form of the metal is more susceptible to corrosion by ocean water. However, some alloys have been found to be suitable for use with salt water. Even if the aluminium alloy heat exchangers had to be replaced more often than those of titanium, they might be more cost-effective in the long run.

(3) A 90/10 **copper-nickel** alloy has been used extensively in both land-based and shipboard power plant condensers with ocean water as coolant. It is less expensive than titanium although more than aluminium alloys. Although the copper-nickel alloy is resistant to corrosion by sea water, the copper is readily attacked if ammonia is present. Hence, copper heat exchangers could probably not be used with ammonia as the working fluid. In normal operation, the ocean water and ammonia would not be in contact, but small leaks in the heat exchanger surface, which are almost impossible to avoid, would result in severe deterioration of the copper.

(4) The possibility of fabricating heat exchangers from relatively inexpensive plastic material has attracted interest. The heat conductivity of plastics is normally too low for efficient heat exchange, but it could be increased by inclusion of graphite. But even the graphite filled plastic is inferior to most metals in this respect and correspondingly large heat-exchange areas would be necessary for a specified electrical output. Plastics are expected to be resistant to corrosion by ocean water and ammonia, but some may be affected by propane. Materials with sufficient mechanical strength and resistance to erosion by high-velocity sea water remain to be developed.

9.2.6. Bio-fouling

The deposition and growth of micro-organisms, called biological fouling (or bio-fouling), on the cooling-water side of the condenser heat exchanger, is a problem encountered in most power plants. It would also be expected to arise in both the evaporator and condenser heat exchangers of an OTEC plant. Bio-fouling is less with copper (or copper alloy) heat exchangers because traces of dissolved copper act as a biocide. Biofouling is important because it reduces the heat transfer efficiency and is usually dealt with by chemical (chlorination) or mechanical (brushes or rubber balls) means. Increasing the flow rate of the water is advantageous because the organisms are less likely to become attached to the heat-exchanger surfaces. However, the flow rate must not be high enough to cause erosion.

Bio-fouling effects and ways of dealing with them are being studied in connection with the design and location of OTEC plants. Such effects are expected to be especially significant for the evaporator heat exchanger where the warmer water would be conductive to the growth of marine organisms.

9.2.7. Site Selection

In selecting a site for an OTEC facility, the primary consideration is, of course, a significant temperature difference—at least about 20°C—between surface and deep ocean waters (for 700-900 m depth or more) that will permit year round operation. The greater the difference, the lower will be the cost of generating electricity. The best sites are in the tropical belt between about 20°N and 20°S latitude. There are, however, several locations outside this area, that might be suitable for OTEC plants. In choosing a site, consideration should be given to the potential for bio-fouling effects as noted earlier.

As a general rule, an OTEC plant would be located offshore in order to provide access to the deep colder water. However, an ideal situation might be one where the shoreline dropped steeply to a considerable depth. Most of the installation could then be more conveniently build on land.

9.2.8. Energy Utilization

If possible an OTEC plant should be less than about 30 km from shore. The electricity generated could then be transmitted inexpensively to land by submarine cable. At somewhat greater distances, the transmission costs would be increased but might be tolerable. If the plant is so far from shore that these costs become prohibitive, the electricity generated can be utilized at the plant site to produce energy-intensive materials.

One suggestion is to use direct electric current to decompose sea water by the process of electrolysis ; the main products would be hydrogen and oxygen. The hydrogen could be liquified and transported by tanker to a point where it could be used as fuel. Alternatively, the hydrogen could be combined with atmospheric nitrogen to form ammonia for use as fertilizer, thereby saving natural gas which is presently the main source of hydrogen for this purpose.

9.2.9. Hybrid Cycle

There are several variations on the standard OTEC open-cycle system. One variation is the "hybrid cycle" which is an attempt to combine the best features and avoid the worst features of the open and closed cycles. First, as shown in Fig. 9.2.5.1, sea water is flash

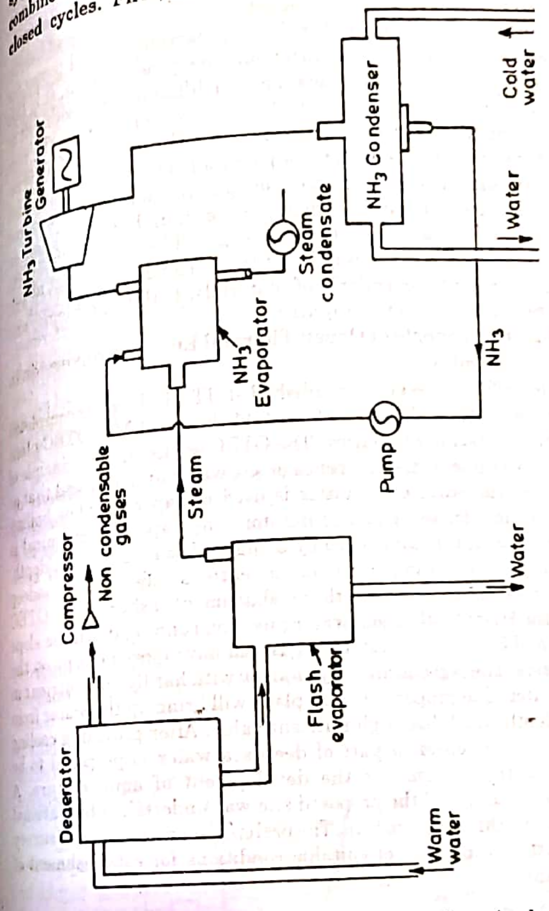


Fig. 9.2.5.1. Hybrid Cycle.

evaporated to steam, as in the open cycle. The heat in the resulting steam is then transferred to ammonia in an otherwise conventional closed Rankine cycle system.

9.2.10. Conclusions

A comparative study of the closed (ammonia), open (steam), and hybrid cycles showed the closed-cycle system to be most economical in cost and to require the least parasitic power.

Closed cycle is favoured for the future development in expectation of higher efficiency but does not yet have the advantage of having been put in practice. Compared with the prospects of wind power for large scale development to help meet out energy needs soon, it is this lack of experience that puts oceans thermal difference development at a disadvantage and leads to the emphasis on wind power. In the case of wind power the favoured method has been demonstrated as practicable in several countries over the past half century and has failed only the economic test in the era of cheap fuel whereas the favoured method of ocean thermal energy conversion has not been so demonstrated. It is to be hoped that it soon will be ; there are reports that Japan plans to lead the way in actual development. Research and actual development particularly of materials, fouling problems, and design are in progress in this country.

9.2.11. Prospects of Ocean Thermal Energy Conversion in India

The OTEC project cell established at IIT, Madras has completed the preliminary feasibility study for establishing *a*, 1 MW OTEC plant in Lakshadeep Island at Minicoy. The OTEC works on the principle of utilizing the temperature difference of sea water at depth and that at the surface. The surface sea water is used to vaporise a low boiling chemical which drives, a turbogenerator. The vaporised chemical is then compressed, it is condensed by using cold sea water from depth. Preliminary oceanographic studies on eastern side of Lakshadeep Island suggest the possibility of the establishment of shore based OTEC plant at the island with a cold water pipe line running down the slope to a depth of 800—1000 m. Both the island have large lagoons on the western side. The lagoons are very shallow with hardly any nutrient in the sea water. The proposed OTEC plant will bring up the water from 1000 m depth which has high nutrient value. After providing cooling effect in the condenser, a part of deep sea water is proposed to be diverted to the lagoons for the development of aqua culture. A hydrographic survey of the proposed site was undertaken by National Hydrographic Office, Dehra Dun. The preliminary assessment of survey indicates the availability of suitable conditions for establishment of OTEC plant.

9.3. Energy from Tides

9.3.1. Introduction

Tide is a periodic rise and fall of the water level of sea which are carried by the action of the sun and moon on the water of the earth.

Tide energy can furnish a significant portion of all such energies which are renewable in nature. It has been estimated that about a billion kW of tidal power is dissipated by friction and eddies alone. This is slightly less than the economically exploitable power potential of all the rivers of the World. It is only indication of the magnitude of tidal power available ; all of it is not economically feasible also. The first attempt to utilize energy of the ocean was in the form of tidal "mills" in the eleventh century in Great Britain and latter in France and Spain.

The large scale up and down movement of sea water represents an unlimited source of energy. If some part of this vast energy can be converted into electrical energy it would be an important source of hydro-power. The main feature of the tidal cycle is the difference in water surface elevations at the high tide and at the low tide. If this differential head could be utilized in operating a hydraulic turbine, the tidal energy could be converted into electrical energy by means of an attached generator. In principle, this is not very difficult as water, at the time of high tide, is at a high level and can be let into a basin to be stored at a high level there. The same water can be let back into the sea during the low tide through the turbines, thus producing power. Since the basin water level is high and sea water is low, there is a differential head comparable to the tidal range, that can be utilized for the running of the turbines. Basically it appears to be a simple proposition, the problems involved in it, are many. The Tides, as we see, although free, were inconvenient because they come at varying times from day to day, have varying ranges (heads) and, for large outputs required large capital expenditures. Their early use declined and eventually came to a half with the coming of the age of steam and cheap coal. With the beginning of the energy crisis in the 1970s, the tidal energy, like other renewable energy sources, received renewed attention.

The first tidal power plant was commissioned by General De-Gaulle at La Rance in 1966 which marked a break through. The average tidal range is 8.4 m (± 4.2 m), and the maximum is 13.5 m. Effective

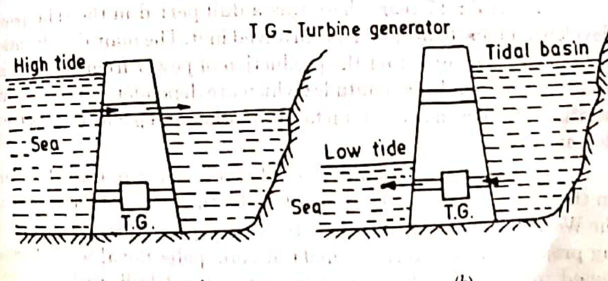


Fig. 9.3.1. Principle of Tidal power generation.

basin surface is 22 km^2 ; basin volume is 184,000,000 m^3. There are no special problems with this site, and it was a very sensible choice for the world's *first* tidal power station. It has used a single basin and submerged reversible propeller type turbine generators that could generate power with the water flowing in either direction through the turbine runner. Bulb turbines have been provided in this project, they are operating satisfactorily for the last 25 years.

The dam contains a small lock for commercial vessels, six movable sluice gates, and 24 turbo generators units of 10 MW each. The movable gates are used to accelerate filling and emptying of the storage basin at small differential water levels. Installed capacity of 240 MW, but of course the average power generating capacity is less, because power can be generated only intermittently. Maximum electric energy production capacity is 544,000 MW h/yr., which gives a plant capacity factor, without any allowance for maintenance or down time, of 0.26. Maximum utilization of the stored hydraulic potential energy is 18 per cent, which may be increased to 24% in future by additional of 80 MW more generating capacity.

There are presently two tidal power stations operating, one in France and one in the USSR. The one in France is a full commercial station. The one in the USSR is more in the nature of a pilot plant engineering experiment, and is rather small in size.

The French project at Rance near St. Malo in Brittany, uses a dam that goes straight across the estuary of the Rance river. The dam is not too long—750 m, shore to shore. The depth is never more than 12 m below mean sea level, there is an above surface rock part way across, the climate is moderate, Kisoloya Guba, on the Barents sea, 70 km north of Murmansk. It is small and was intended as a pilot project. It has one generator of 400 MW rating and delivers 700 to 800 MWh/yr, to the local electrical grid operation began in 1968.

Nearly for 17 years there was a dull period in the tidal power development due to the problems involved in it. The main disadvantage of tidal power plant is that the production of power from tidal station occurs at times and in magnitudes which are dependent on the relative positions of earth, moon and sun to one another and not on the electrical demand of consumers.

The success of La Rance stimulated interest in Canada where on the eastern coast, in the Bay of Fundy, the largest tidal ranges in the World occur—being as high as 16 m—on spring tides. The pioneering project in Nova Scotia, Canada at Annapolis Royal was commissioned in 1983. For the first time conventional bulb turbines were replaced by large rim generator units of straflo turbines with runner

Table 9.3.1. Comparative Statistics of some Recently Proposed Schemes

Country Site	*Installed capacity (MW)*	*Annual energy (GW h)*	*No. of 7.6 m diameter turbines*	*Mean tidal range (m)*
UK Seven Estuary	7200	13000	230	9.3
Mersy Estuary	525	1090	21	6.7
Strangford Lough	210	530	30	3.1
Eire Shannon Estuary	318	715	30	3.8
India Gulf of Kutch : Kandla	600	1600	43	5.2
Korea Garolim Bay	480	1200 approx.	32	4.6
Brazil Bacanga	30	55	2	4.1
U.S.A. Knoik Arm	2220	5500	80	7.8
Canada Cumber land basin	1147	3420	37	10.5
Cobequid Bay	4028	12600	106	12.4
Annapolis Royal	20	50	1	6.7
China Liangxia	3	11	6 (2.5 m)	~ 6
USSR Lumbousky	400	—	—	~ 6
Mezenskaya	10000	—	—	~ 9

diameter of 7.6 m and capacity of 10 MW. Though this type of turbine has been in use for many years in Europe, its runner diameter was limited to about 2 m by sealing problems at the runner periphery. If these prove successful, it will provide an attractive alternative to the bulb unit, since the straflo unit has much higher inertia, thus enhancing system stability, and access to the generator is easier, thus facilitating maintenance.

In India, there are possible tidal projects in the Gulf of Kutch and Cambay, and on a smaller scale, in the Sunderbans regions of the Bay of Bengal.

In Korea, there have been a series of studies by Canadian and French firms, the latest one being of Garolim Bay. A comparative statistics of some recently proposed tidal schemes are given in the table 9.3.1.

9.3.2. Basic Principal of Tidal Power

Tides are produced mainly by the gravitational attraction of the moon and the sun on the water of solid earth and the oceans. About 70 per cent of the tide producing force is due to the moon and 30 per cent to the sun. The moon is thus the major factor in the tide formation.

... away from the earth on the side facing the moon, and at the same time the solid earth is pulled away from the water on the opposite side. Thus high tides occur in these two areas with low tides at intermediate points. As the earth rotates, the position of a given area relative to the moon changes, and so also do the tides. There are thus a periodic succession of high and low tides.

Although there are exceptions, two tidal cycles (*i.e.* two high tides and two low tides) occur during a lunar day of 24 hours and 50 minutes (The lunar day is the apparent time of revolution of the moon about the earth). That is to say, the time between high tides and low tide at any given location is a little over 6 hours. A high tide will be experienced at a point which is directly under the moon. At the same time, a diametrically opposite point on the earth's surface also experiences a high tide due to dynamic balancing. Thus a full moon as well as a no moon produce a high tide. In a period of 24 hrs 50 minutes, there are therefore, two high tides and two low tides. Fig. (9.3.2.1). These are called semi-diurnal tides. The rise and fall of the water level follows a sinusoidal curve, shown with point A indicating the high tide point and point B indicating the low tide point. The average time for the water level to fall from A to B and then rise to C is approximately 6 hours 12.5 min.

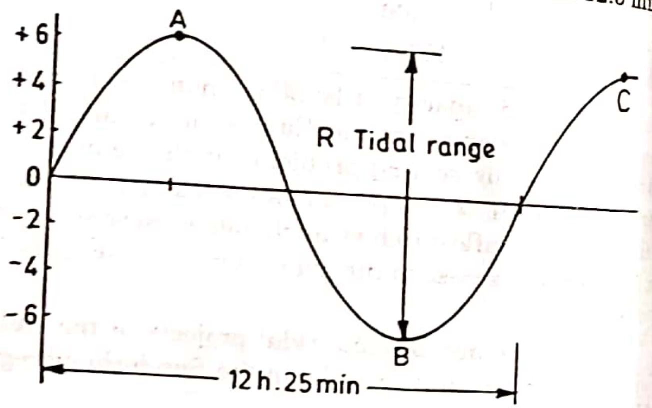


Fig. 9.3.2.1. The tides of sea.

The difference between high and low water levels is called the *range* of the tide. The *tidal range* R is defined as :

R = water elevation at high tide—water elevation at low tide.

Because of the changing positions of the moon and sun relative to the earth, the range varies continuously. There are however, some characteristic features of this variation.

At times near full or new moon, when sun, moon and earth are approximately in a line, the gravitational forces of sun and moon enhance each other. The tidal range is then exceptionally large, the high

tides are higher and low tides are lower than the average. These high tides are called *spring tides*, on the other hand, near the first and third quarters of the moon, when the sun and moon are at right angles with respect to the earth, *neap tides* occur. The tidal range is then exceptionally small ; the high tides are lower and the low tides higher than the average. Hence the range is not constant. It varies during the 29.5 day lunar month (Fig. 9.3.2.2) being maximum at the time of new and full moons, called the spring tides, and minimum at the time of the first and

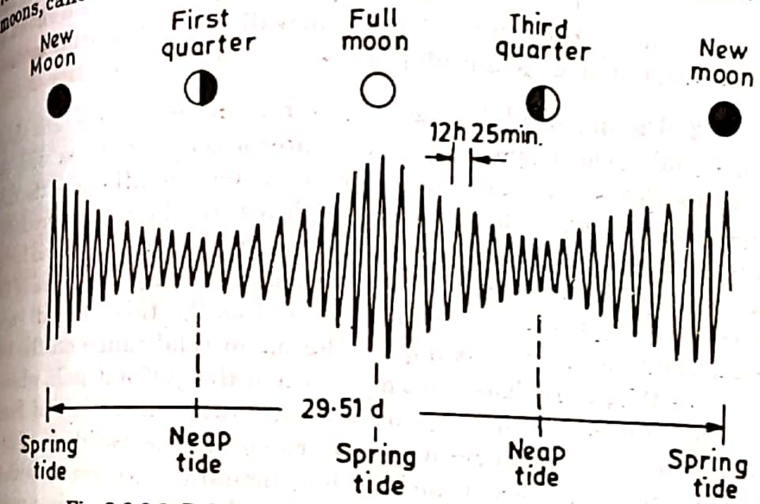


Fig. 9.3.2.2. Relative high and low tides showing variation in range during lunar month.

third quarter moons, called the neap tides. The spring-neap tidal cycle lasts one-half of a lunar month. A typical *mean range* is roughly one third of the spring range. The actual variations in range are some what complicated by seasonal variations caused by the ellipticity of the earth's orbit around the sun.

The variations in the periodicity and monthly and seasonal ranges must, of course, by taken into account in the design and operation of tidal power plants. The tides, however, are usually predictable, and fairly accurate tide tables are usually available.

Tidal ranges vary from one earth location to another. They are influenced by such conditions as the profile of the local shoreline and water depth. When these are favourable, a resonance like effect causes very large tidal ranges. Ranges have to be very large to justify the huge costs of building dams and associated hydroelectric power plants. Such tides occur only in a few locations in the world.

Following *points* have to be specially noted in connection with the tidal phenomenon.

(1) The tides are a periodical phenomenon but no two tides in any cycle are alike. Since the relative positions of sun and moon and

their distances from earth are continuously changing, the tides are al[so] influenced accordingly. Of the two high tides in a single day, one tide is higher than the other. In any month, the tides on the full moon and [new] moon days are particularly higher than the rest, as on these days sun's and moon's attraction acts in a directly additive manner. These are termed as the spring tides. In any year, the tides that occur at the time of versnal and autumnal equinoxes will we even higher due to the relative location of the sun and earth. Thus the tidal range R shown in the figure varies from time to time. Generally, a long time mean value of R is designated as mean tidal range at any particular place.

(2) The mean tidal range varies from place to place. The shape of the tidal cycle depends upon the interaction of the sea with the coast-line. Where the coast-line offers a resonating influence, the tidal range gets accentuated, at the other places, the land may produce a dampening effect on the tidal phenomenon. For instance, in land locked seas, the tidal phenomenon is always much subdued. Because of this interacting effect, the tidal range (as well as the tidal period) varies from place to place. For example ; the mean tidal range on the west coast of India is as high as 7 to 8 meters near the gulf of Kutch, whereas it is only one meter or so near Kerala, down south. Bay of Fundy (Canada) has one of the greatest tidal ranges in the world *i.e.* of 20 m, whereas the Adiatic sea at the Zara has virtually static water with the range being only of a few cm. Thus the tidal phenomenon is a unique feature of every coast line.

(3) In spite of their complexity, the tides are amenable to mathematical analysis. As a result the exact time and the water level for a high tide as low tide can be forecast with great accuracy.

9.3.3. Components of Tidal Power Plants

There are *three* main components of a tidal power plant *i.e.*

(*i*) The power house

(*ii*) The dam or barrage (low wall) to form pool or basin.

(*iii*) Sluice-ways from the basins to the sea and *vice versa*

The turbines, electric generators and other auxiliary equipments are the main equipments of a power house. The function of *dam* to form a barrier between the sea and the basin or between one basin and the other in case of multiple basins.

The sluice ways are used either to fill the basin during the high tide or empty the basin during the low tide, as per operational requirement. These are gate controlled devices.

It is generally convenient to have the power house as well as the sluice-ways in alignment with the dam.

The design cycle may also provide for pumping between the basin and the sea in either direction. If reversible pump turbines are provided, the pumping operation can be taken over at any time by the same machine. The modern tubular turbines are so versatile that they can be used either as turbines or as pumps in either direction of flow. In addition, the tubular passages can also be used as sluice-ways by locking the machine to a stand still. As compared to conventional plants, this, however, imposes a great number of operations in tidal power plants. For instance, the periodic opening and closing of the sluice-ways of a tidal plant are about 730 times in a year.

Dam (Barrage). Dam and barrage are synonymous terms. Barrage has been suggested as a more accurate term for tidal power schemes, because it has only to withstand heads a fraction of the structure's height, and stability problems are far more modest. However, the literature does not always make the distinction, even though heads are small with tidal power cut offs.

Tidal power barrages have to resist waves whose shock can be severe and where pressure changes sides continuously.

Since barrage length adds also to the price tag of the plant, short barrages are preferred even if basin size may have to be smaller as a result of site choice. Up to a height of 20 m, cost remains proportional to length as it is not changed by the need to build a dam wall to withstand high hydrostatic pressure. When, the elevation exceeds the 20 m limit, costs increase faster with length. Most tidal power plants do not have heads exceeding 20 m.

The barrage needs to provide channels for the turbines in prestressed or reinforced concrete. To build these channels a temporary cofferdam is necessary, but it is now possible to built them on land, float them to the site, and sink them into place.

Flatness is required for the sea bottom ; sandy bottom usually necessiates piling. There, where sand or rock can bear the weight of the structure to be implanted, the bottom can be prepared, the structure placed on it and then anchored. Prefabricated concrete blocks can be used as the core for large barrages and voids filled with rocks or concrete remaining holes with sand, and the entire construction then asphalted.

Construction of a barrage usually will influence the tidal amplitude. Indeed, such a construction modifies the effective length of the embayment or basin and its shape as well, particularly if the scheme involves supplementary spur dams, or brings about relocation or disappearance of natural obstruction as is foreseen for the severn plant and has occurred in the Rance estuary.

The construction influence the resonance of the bay, and most bays are less than the resonant length of the tidal wave. If resonance is reduced, the range will decrease ; if measures are taken to augment the resonance, tidal amplitude may be increased.

Tidal barrages require sites where there is a sufficiently high tidal range to give a good head of water—the minimum useful range is around three meters. The best sites are bays and estuaries, but water can also be impounded behind bunded reservoirs built between two points on the same shore line.

The precise design of barrage and its mode of operation depend critically on the requirements for power and on a careful analysis of the economics. The simplest and cheapest schemes would normally involve a single barrage designed to trap water in a basin at high tide and to generate on the ebb. More complex schemes could involve generation on both the ebb and flood tides, or the construction of a secondary basin which would permit water to be stored and discharged whenever desired. This would provide more firm power on a flexible basis. The expertise necessary to design and build such structures is available.

The location of the barrage is important, because the energy available is related to the size of the trapped basin and to the square of the tidal range. The nearer it is built to the mouth of an estuary or bay, the larger the basin, but the smaller the tidal range. A balance must also be struck between increased output and increased material requirements and construction costs.

Gates and Locks. Tidal power basins have to be filled and emptied. Gates are opened regularly and frequently but heads vary in height and on the side where they occur, which is not the case with conventional river projects. The gates must be opened and closed rapidly and this operation should use a minimum of power. Leakage is tolerable for gates and barrage. Since we are dealing with sea water, corrosion problems are actute, they have been very successfully solved by the cathodic protection and where not possible by paint. Gate structures can be floated as modular units into place.

Though, in existing plants, vertical lift gates have been used, technology is about ready to substitute a series of flaps that operate by water pressure. Flap gates are gates that are positioned so as to allow water into the holding basin and require no mechanical means of operation. If used they, are positioned, in the case of modular construction, in the caissons. A caisson is then floated into place. They have to be built so that they will be adequate for the maximum tidal amplitude. Top hung on a gate-hoisting beam, a gate would transfer its hydraulic load to the concrete structure. If operation is to be rapid and efficient, gates must open under the maximum differential head ; this favours as flat as possible the tidal basin face of the sluice.

The flap gates allow only in the direction of the sea to basin. Hence, the basin level rises well above to sea level as ebb flow area is far less than flood flow area.

Power House. Because small heads only are available, large size turbines are needed ; hence, the power house is also a large structure. Both the French and Soviet operating plants use the bulb type of turbine. Of the propeller type, with reversible blades, bulbs have horizontal shafts coupled to a single generator. The cost per installed kilowatt drops with turbine size, and perhaps larger turbines might be installed in a future major tidal power plant.

The Bulb Group (Rance Example). A bulb type turbine is an axial flow turbine the bulb set, resembling in appearance a small submarine, is made up of an ogive shaped steel shell containing an alternator and a Kaplan turbine. It is placed in a horizontal hydraulic duct and entirely surrounded by water ; a shaft provides communication with the engine room of the power plant. The set function as a turbine and as a pump, and regulates the flow in both directions of flow, tide to reservoir (basin) and reservoir to tide.

The alternator is directly coupled to the turbine and turns it at some pressure. The turbine is a kaplan wheel with four mobile blades and guide vanes. The group, functioning as a turbine in the direct sense basin to sea, and furnishing power in reverse, sea to basin direction, functioning as a pump in direct sense. (Fig. 9.3.3.1).

Rim Type Turbines. Different types of turbines are under study ; usually mentioned are included shaft turbines, rim type turbines, or straight flow turbines, where the generator is attached peripherally on the turbine blades, an arrangement that couples two turbines of conventional type to one generator, and a hydraulic system in which upto six turbines are coupled to hydrostatic pumps and to drive a pelton-wheel, which, in turn, drives a high speed generator. The main problem in rim type turbine, in which the rotor surrounds the turbine runner as a rim carried by the runner blades, is the seals between the stationary parts and the rotating rim. Engineers who favour straight flow generators against the bulb turbine generators point out the lower inertia characteristic of the bulb type, claiming this could lead to problems during power system disturbances. The designers of a new type of straight flow units put forth savings in civil works and in generator and auxiliary electrical equipment because large unit capacities than with the bulb type unit, for the same head, would be possible.

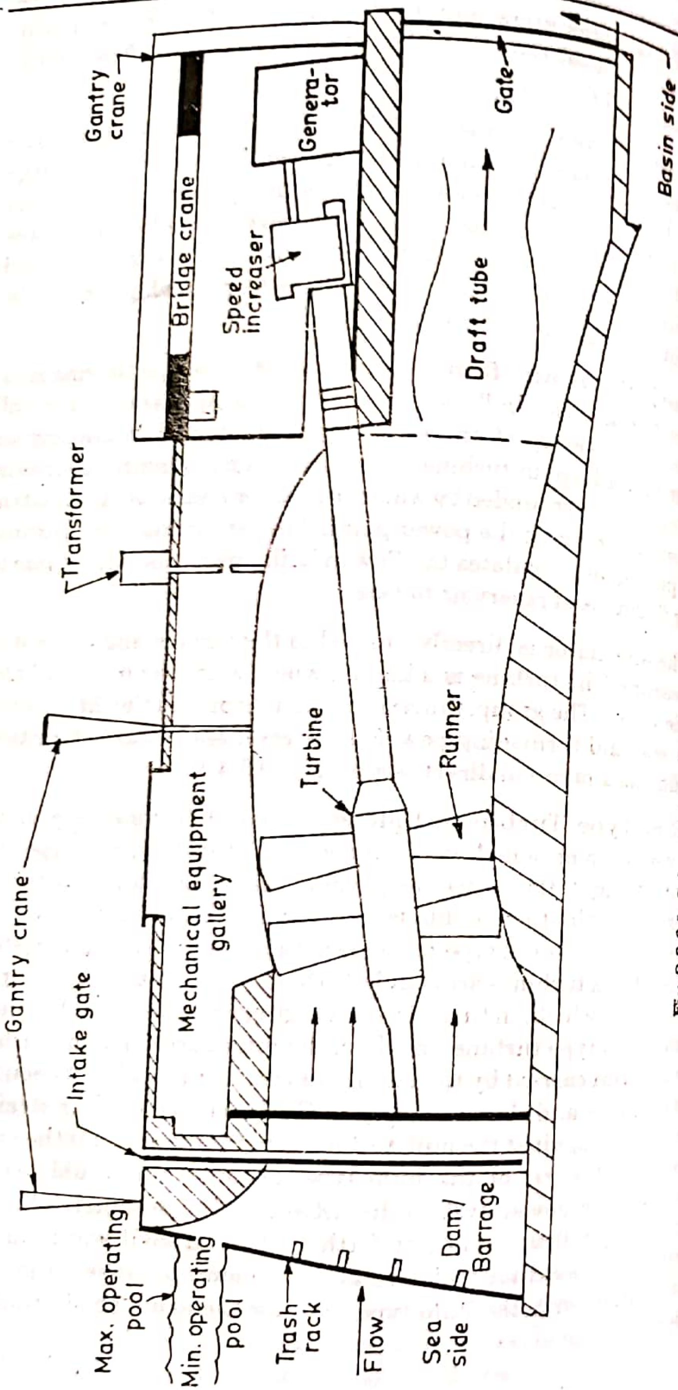


Fig. 9.3.3.1. Schematic layout of Tidal power house (Typical main unit way).

9.3.4. Operation Methods of Utilization of Tidal Energy

The generation of electricity from water power requires that there should be a difference in levels (or heads) between which water flows. A number of concepts have been proposed for generating electricity by utilizing the head that can be produced by the rise and fall of the tides to operate a hydraulic turbine. The power generation from tides involves flow between an artificially developed basin and the sea. However in order to have a more or less continuous generation, this basic scheme can be elaborated by having two or more basins. Accordingly we can distinguish the following types of arrangements :

(1) Single basin arrangement,

(2) Double basin arrangement.

Single-basin schemes can generate power only intermittently, but a double basin scheme can provide power continuously, or on demand, which is a tremendous advantage. The drawback is that the civil works become more extensive. In the simplest double-basin scheme there must be a dam between each basin and the sea, and also a dam between the basins, containing the power house. One basin is maintained always at a lower level than the other. The lower reservoir empties at low tide, and the upper reservoir is replenished at high tide. If the generating capacity is to be large, the reservoirs must be large, which usually means that the dams will be long.

(1) Single Basin Arrangement

The simplest way to generate tidal power is to use a single basin with a retaining dam in the following manner :

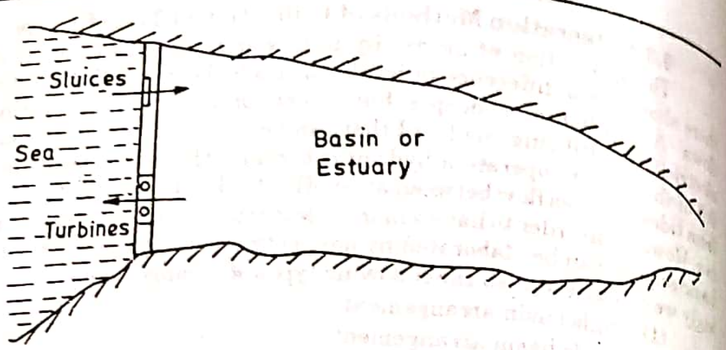
In a single basin arrangement there is only one basin interacting with the sea. The two are separated by a dam (or barrage) and the flow between them is through sluice ways located conveniently along the dam. Potential head is provided by rise and fall of tidal water levels, this is usually accomplished by blocking the mouth of a long narrow estuary with a dam across it, thereby creating a reservoir. The dam or barrage embodies a number of sluice gates and low head turbine sets. The generation of power can be achieved in a single basin arrangement either as a

(a) Single ebb-cycle system, or

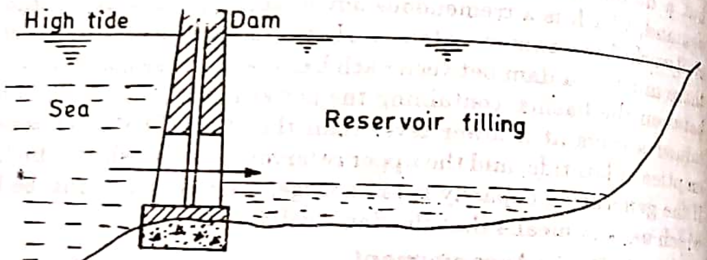
(b) Single tide-cycle system, or

(c) Double cycle system.

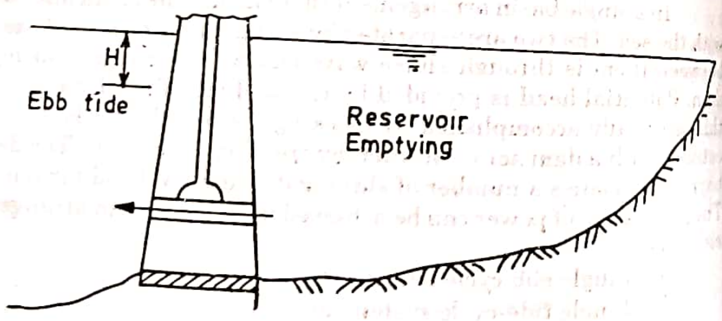
(a) *Single ebb cycle system.* When the flood tide (high tide) comes in, the sluice gates are opened to permit sea-water to enter the basin or reservoir, while the turbine sets are shut. The reservoir thus starts filling while its level rises, till the maximum tide level is reached. At the beginning of the ebb tide the sluice gates are closed. Then the generation of power takes place when the sea is ebbing (flowing back of tide) and the water from the basin flows over the turbines into the lower level sea water. After two or three hours when there is sufficient



(a) Tidal plant operation (plan).



(b) Sluice gates open, Turbine shut off (Section).



(c) Sluice gates shut, Turbine operation (Section)

Fig. 9.3.4.1. Tidal power plant (single basin operation).

difference between the full reservoir level and the falling tide level, to run the turbines, they are started and keep working until the rising level of the next flood tide and the falling reservoir level together reduce the effective head on the turbines to the extent where it can no longer work safely and efficiently. The turbines are then closed and the sluice gates opened again ; to repeat the cycle of operations. Since in an

estuary, the ebb tide has a long duration than the flood tide, the ebb operation provides an increased period of actual work.

(b) *Single tide cycle system*. In single tide cycle system, the generation is affected when the sea is at flood tide. The water of the sea is admitted into the basin over the turbines. As the flood tide period is over and the sea level starts falling again, the generation is stopped. The basin is drained into the sea through the sluice ways.

Flood operation scheme needs larger size plant, operating, for shorter period and hence less efficient as compared to ebb tide operation. The ebb operation plant will be of smaller size, but will operate over a large period. The aim and effort should be to obtain as long a period of operation as possible at the beginning and finishing the work at the minimum operating head. Adjustable blade bulb turbines area specially suited for such operations under low and variable heads. All these turbines may be reversible which can work as a pumps after the high tide, to increase the amount of water in the storage lake, until the generation can start. This way the turbine operation period may be prolonged to ten or more hours, out of the twelve hours-twenty five minutes of the tidal cycle.

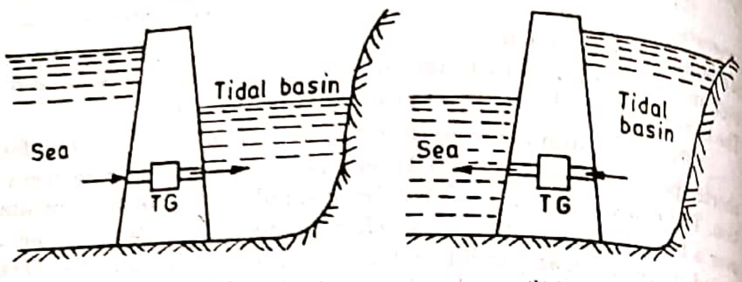
The tide-cycle requires a deeper reservoir so as to locate the sills of the sluice gates deeper and, thus, requires greater construction costs. It has been estimated that the energy produced by an ebb cycle system can be as much as 1.5 times that by a tide cycle system.

The *main disadvantage* in both the ebb-cycle as well as the tide cycle systems is the intermittent nature of their operation. However, since the intermissions occur at regular intervals, there is possibility of connecting another supplementary system, so as to balance the discontinuity. Such possibilities can regulate the output. The system can be so geared as to generate power, both during the ebb and flood tides with the help of single basin only. This system is known as the *double-cycle system*.

(c) *Double cycle system*. As stated above in double cycle system, the power generation is affected during the ebb as well as in flood tides. The direction of flow through the turbines during the ebb and flood tides alternates, but the machine acts as a turbine for either direction of flow. 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.

The flow of water in both directions is used to drive a number of reversible water turbines, each driving an electrical generator. Electric power would thus be generated during two short period during each tidal period of 12 h, 25 min. or once every 6h, 12.5 min.

TG. Turbine generator set (Reversible turbines)



(*a*) High tide (*b*) Low tide

Fig. 9.3.4.2. Double cycle system.

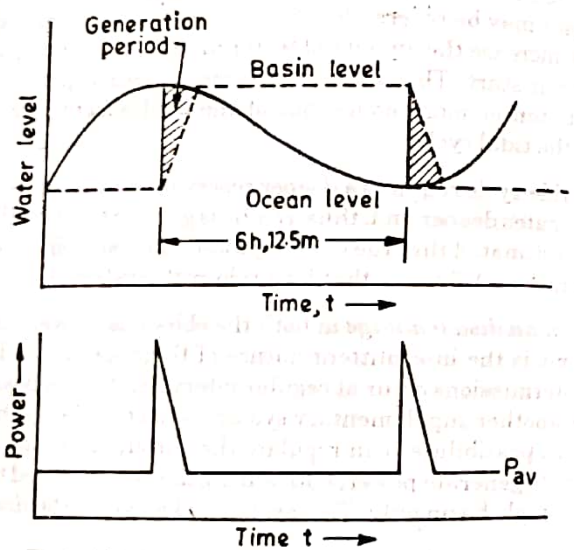


Fig. 9.3.4.3. Ocean and pool levels and power generated in a single-basin tidal system.

Though the double cycle system has only short duration interruptions in the turbine operation, yet a continuous generation of power is still not possible. Furthermore the periods of power generation coincide only occasionally with periods of peak demand. These problems are solved to some extent in the two-basin scheme described below. However, a fundamental drawback to all methods for generating tidal power is the variability in output caused by the variations in the tidal range.

(2) 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.

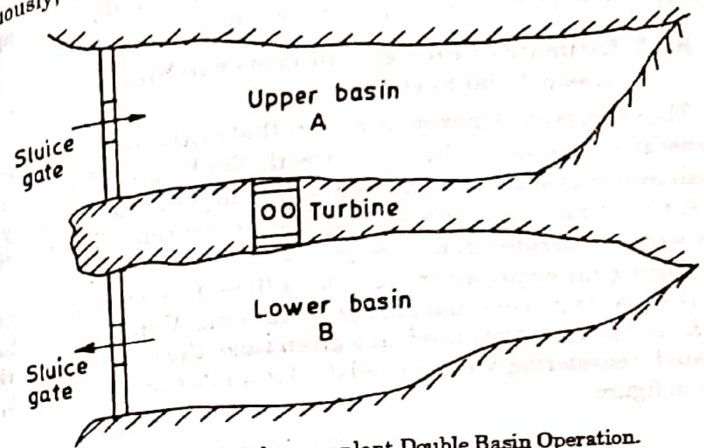


Fig. 9.3.4.4. Tidal power plant Double Basin Operation.

In this system the turbines are located in between the two adjacent basins, while the sluice gates are as usual embodied in the dam across the mouths of the two estuaries. At the beginning of the flood tide, the turbines are shut down, the gates of upper basin A are opened and those of the lower basin B are closed. The basin A is thus filled up while the basin B remains empty. As soon as the rising water level in A provides sufficient difference of head between the two basins, the turbines are started. The water flows from A to B through the turbines, generating power. The power generation thus continues simultaneously with the filling up the basin A. At the end of the flood tide when A is full and the water level in it is the maximum, its sluice gates are closed. When the ebb tide level gets lower than the water level in B, its sluice gates are opened whereby the water level in B, which was arising and reducing the operating head, starts falling with the ebb. This continues until the head and water level in A is sufficient to run the turbines. With the next flood tide the cycle repeats itself. With this twin basin system, a longer and more continuous period of generation per day is possible. The small gaps in the operation of such stations can be filled up by thermal power.

The operation of the two basin scheme can be controlled so that there is a continuous water flow from upper to lower basin. However since the water head between the basins varies during each tidal cycle, as well as from day to day, so also does the power generated. As in the case with single basin scheme, the peak power generation does not often correspond in time with the peak demand. One way of improving the situation is to use off-peak power, from the tidal power generators or from an alternative system, to pump water from the low basin to the high basin. An increased head would then be available for tidal power generation at times of peak demand. This is very similar to pumped storage system in hydro-electric power stations.

9.3.5. Estimate of Energy and Power in Simple Single Basin Tidal System

The expression of maximum energy that can be generated during one generation period can be derived with the help of Fig. (9.3.5.1), which shows the case of the basin beginning at high-tide level, emptying through the turbine to the ocean, which is at low tide. (The identical energy will be generated in reverse process).

During the *emptying process*, the differential work done by the water is equal to its potential energy at the time. Considering a tidal range R, and intermediate head, at a given time, the amount of work is calculated, considering a small head dh, for a intermediate head h, as shown in figure.

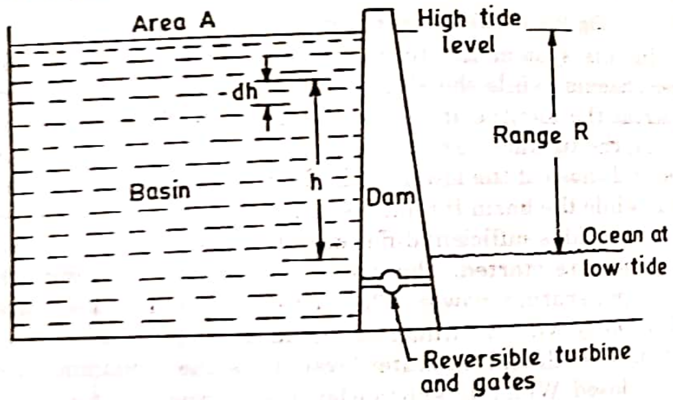


Fig. 9.3.5.1. Single Basin Tidal System.

We can write

$$dw = dm \cdot g \cdot h \qquad \text{...(9.3.5.1)}$$

but

$$dm = -\rho \cdot A \cdot dh \qquad \text{...(9.3.5.2)}$$

so that

$$dw = -\rho \cdot A \cdot dh\, g\, h \qquad \text{...(9.3.5.3)}$$

where W = workdone by water, kcal/kg or Joule.

g = gravitational constant

m = mass flowing through turbine, kg

h = head m

ρ = water density, kg/m^3

A = basin surface area, considered constant m^2

The total theoretical work during a full emptying (or filling) period is obtained by integrating the expression (9.3.5.3) *i.e.*

$$W = \int_R^0 dw = -g\rho A \int_R^0 h\, dh$$

$$= \frac{1}{2} g \rho A R^2 \qquad \text{...(9.3.5.4)}$$

The work is proportional to square of the tidal range.

The power is the rate of doing work.

The power is generated during emptying (or filling) and no power is generated during rest of the time. The *average theoretical power delivered* by the water is W divided by the total time it takes each period to repeat itself. Duration is 6 h, 12.5 minutes as shown in Fig. (9.3.4.1) (6h, 12.5 minutes = 22,350 seconds).

Thus average theoretical power in watts ;

$$\text{Pav.} = \frac{W}{\text{time}} = \frac{g\rho A R^2}{2 \times 22350}$$

$$= \frac{1}{44{,}700} g \rho A R^2 \qquad \text{...(9.3.5.5)}$$

Assuming an average sea water density = 1025 kg/m^3, the average power per unit basin area is given by

$$\frac{\text{Pav.}}{A} = \frac{1}{44{,}700} \times 9.80 \times 1025\, R^2$$

$$= 0.225\, R^2 \text{ watts/m}^2 \text{ (MW/km}^2\text{)} \qquad \text{...(9.3.5.6)}$$

The actual power generated by a real tidal system would be less than the average theoretical power obtained by the above expressions due to frictional losses and conversion efficiencies of turbine and electric generators. The actual power generated may be about 25 to 30 per cent of the theoretic power.

Example 9.3.5.1. A tidal power plant of the simple single basin type, has a basin area of 30×10^6 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 the head below turbine stops operating = 3 m.

$$W = \int_R^r -g\,\rho\,A\,h\,dh = -g\,\rho\,A \int_R^r h\,dh$$

$$= \tfrac{1}{2} g\,\rho\,A\,(R^2 - r^2) \qquad \text{...(1)}$$

Thus the average power

$$\text{Pav.} = \frac{W}{\text{time}}$$

$$= \frac{g\,\rho\,A\,(R^2 - r^2)}{44{,}700} \qquad \text{...(2)}$$

The average power generated

$$= \frac{1}{44{,}700} \times 9.80 \times 1025 \times 30 \times 10^6\,(12^2 - 3^2) \text{ Watts}$$

$$= \frac{1}{44{,}700} \times 9.80 \times 1025 \times 30 \times 10^6 \times 135 \text{ Watts}$$

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

$$= \frac{911.25}{1000} \times 3600 \times 10^6 \text{ kWh}$$

$$= 3280.5 \times 10^6 \text{ kWh}$$

Considering turbine generator efficiency, the energy generated

$$= 3280.5 \times 10^6 \times 0.73 = 2395 \times 10^6 \text{ kWh. } \textbf{Ans.}$$

9.3.6. Estimation of Energy and Power in a double cycle system

In a double cycle system, the estimate of energy and power can be made as per usual calculation of power in a hydropower plant, i.e. considering the average discharge and available head at any instant. Then total energy can be obtained by integrating the value of instantaneous power. The energy that is available for a tidal plant depends upon the range of the tide and volumetric capacity of the basin. The power from the plant is generally obtained in parts, in duration of 3 to $3\frac{1}{2}$ hrs in a flood tide cycle and for equal duration in an ebb cycle. There are approximately 705 full tidal cycle in a year. The power or total energy is first calculated per tidal cycle and then yearly total energy generated can be obtained as explained below :

Let V be the volume of the basin

$$V = Ah_0 \qquad \text{...(9.3.6.1)}$$

where A is the average cross sectional area of the basin in m^2, and h_0 is the difference between maximum and minimum water levels.

$$\therefore \text{ Average discharge } Q = \frac{Ah_0}{t} \qquad \text{...(9.3.6.2)}$$

t is the total duration of generation in one filling/emptying operation.

Now power generated at any instant

$$P = \frac{\rho Q h}{75} \times \eta_0, \text{ H.P.} \qquad \text{...(9.3.6.3 a)}$$

$$= \frac{\rho Q h}{75} \times \eta_0 \times 0.736, \text{ kW} \qquad \text{...(9.3.6.3 b)}$$

where ρ is the average density of sea water = 1025 kg/m^3,
h is the available heat at the instant,
Then total energy

$$= \int_0^t P\,dt = \int_0^t \frac{\rho Q h}{75}\,dt \times \eta_0 \times 0.736 \text{ kW per tidal cycle} \qquad \text{...(9.3.6.4)}$$

Then yearly power generation

$$= \int_0^t \frac{\rho Q h}{75}\,dt \times \eta_0 \times 0.736 \times 705 \text{ kWh/year.}$$

The available head, h, is a function of time and $\int_0^t h\,dt$ can be obtained graphically.

Example 9.3.6.1. 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

$$= 0.5 \times 10^6 \times 8.5 = 4.25 \times 10^6 \text{ m}^3$$

$$\text{Average discharge } Q = \frac{\text{volume}}{\text{time period}} = \frac{Ah_0}{t}$$

$$= \frac{4.25 \times 10^6}{3 \times 3600} = 0.03704 \times 10^6$$

$$= 393.5 \text{ m}^3/\text{s}$$

Power at any instant

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

$$= \frac{393.5 \times 1025 \times 8}{75} \times 0.70$$

$$= 310.15 \times 10^2 \text{ h.p. } \textbf{Ans.}$$

The total energy in kWh/tidal cycle

$$E = 301.15 \times 10^2 \times 0.736 \times 3 = 664.93 \times 10^2$$

Total number of tidal cycle in a year = 705

Therefore total output per annum

$$= 664.93 \times 10^2 \times 705$$
$$= 468.78 \times 10^6 \text{ kWh/year. Ans.}$$

9.3.7. Site Requirements

The utilization of tidal energy requires construction of a barrier (or barriers) across a narrow inlet to an estuary or bay, thus forming an enclosure (or basin) in which ocean water can be impounded. Electricity can be generated by allowing water to flow through a turbine from the basin filled at high tide to the open ocean during falling tides and also as the basin is being filled from the ocean during rising tides.

In each case, the maximum amount of electrical energy that can be generated depends on the product of the tidal range (R) and the mass (or volume) of water flowing through the turbine. The volume is equal to the range multiplied by the area of the impounded water. Hence, the electrical energy is proportional to the square of the range and the area of the enclosed basin. A favourable site for a tidal power plant should then have a large tidal range, and the geographic features should permit enclosure of large areas with reasonably short dams or other barrages. Sluice gates in the dams permit water to pass to or from the enclosed basin (or basins).

9.3.8. Storage

Storage is necessary when alternative electricity production schemes are not, or can not be, connected with the electrical grid. Tidal power plants are not an exception to this rule ; there is a strong case for associating them with storage to provide for the varying needs of the consumer, also taking into account the eventual presence close-by of other plants. The tidal power plant has, by its very nature, many of the components required of a pumped storage scheme. It has also the advantage that, with such a scheme, added tidal power becomes a firm day time source of power.

This is important because the principal saving provided by tidal energy is that of fuel, and probably also of pollution abatement costs. The fuel saved depends on the type of plant whose load factor is reduced and how such plants perform with the addition of tidal power or without it. Evidently, this argument applies only to highly developed countries where there are numerous other plants, and for less to developing countries.

The alternate to storage, when energy is available (but power is not needed because of timing), is not to generate, but the potential thus left untapped is not recoverable at a later time. It is pretty much a case of "store it or you will never have it when needed and no potential is available". Hence the extra capital investment may well be justified.

For tidal power being produced in 'mechanical form' only *batteries, compressed air,* and *hydraulic storage* can be considered. *Flywhere* could be used, but its technology is not yet ready.

Flywheel Storage. By connecting a flyhweel to a motor/generator, it is spinned upto high speed and absorbs energy. This energy can be returned to the motor—generator by decreasing the flywheel's speed. However only small quantities can be stored, and they are limited to short periods of time.

Batteries Storage. Perhaps most flexible and practical are electro-chemical batteries. These batteries are the most common, but research is being conducted with less expensive and lighter types. Also presently available are aqueous solution nickel and nickel cadmium types, but they are much more costly. Again, this type of storage is suited to small plants, particularly self contained ones.

Hydraulic Storage. Hydraulic (or pumped—water) storage is most frequently mentioned in connection with tidal power plants. Two reservoirs, at different elevations, are linked by pumps and turbines and their motors and generators. They constitute the accumulator (a reversible pump-turbine, connected to motor-generator achieves the same result). Off-peak energy, which could be used, is put to work to pump water from the lower into the upper reservoir, which can be run through the turbine and generator and provide energy when needed at a later time.

Power can be provided immediately on demand ; storage stabilizes an otherwise intermittent source and constitutes an efficiency improvement, Reservoirs must be found or built, of course, and a certain amount of energy is lost, to activate and work the pump.

Compressed Air Storage. Air is compressed during off-peak periods and thus stored underground. It can then be called upon to work gas turbines and provide electricity. Tidal energy can be used directly to drive air turbo compressors.

9.3.9. Advantages and Limitations of Tidal Power Generation

Advantages. (1) The biggest advantage of the tidal power is besides being inexhaustible, it is completely independent of the precipitation (rain) and its uncertainty. Even a continuous dry spell of any number of years can have no effect whatsoever on the tidal power generation.

(2) Tidal power generation is free from pollution, as it does not use any fuel and also does not produce any unhealthy waste like gases, ash, atomic refuse.

(3) These power plants do not demand large area of valuable land because they are on the bays (sea shore).

(4) Peak power demand can be effectively met when it works in combination with thermal or hydroelectric system.

Limitations. There are a number of reasons, why the tidal power generation is still a novelty, rather than a normal source of energy. The reasons can be enumerated as below :

(1) The fundamental drawback to all methods of generating tidal power is the variability in output caused by the variations in the tidal range.

(2) The tidal ranges is highly variable and thus the turbines have to work on a wide range of head variation. This affects the efficiency of the plant.

(3) Since the tidal power generation depends upon the level difference in the sea and an inland basin, it has to be a intermittent operation, feasible only at a certain stage of the tidal cycle. This intermittent pattern could be improved to some extent by using multiple basins and a double cycle system.

(4) The tidal range is limited to a few meters. Thus the bulb turbine technology was not well developed, use of conventional kaplan runners was the only alternative. This was found to be unsuitable. Now with the development of reversible flow bulb turbines, this difficulty is overcome.

(5) The duration of power cycle may be reasonably constant but its time of occurance keeps in changing, introducing difficulties in the planning of the load sharing every day in a grid. This handicap can be removed now with the help of computerised programming.

(6) Sea water is corrosive and it was feared that the machinery may get corroded.

Stainless steel with a high chromium content and a small amount of molybednum and the aluminium bronzes proved to be good corrosion resistant at La Rance project. The vinyl paint exhibited good results.

(7) Construction in sea or in estuaries is found difficult.

(8) Cost is not favourable compared to the other sources of energy.

(9) It is feared that the tidal power plant would hamper the other natural uses of estuaries such as fishing, or navigation.

9.3.10. Prospects of Tidal Energy in India

The possible sites for tidal power generation in India are obviously those where high tidal ranges occur *e.g.* Gulf of Cambay (Bhavnagar Sonrai), Gulf of Kutch (Kandla, Navalakhi) and of Houghly river. The maximum tidal range in the Gulf of Cambay (10.8 m) and is attractive for a tidal plant. There are two possible sites on the western bank

namely, Sonrai creek and Bhavnagar creek which have the essential requirements for locating probable plants. However, the silt change of the Gulf of Cambay is about 5000 ppm which is thought to be high and needs a closer study for future development. Gulf of Kutch has a maximum spring tide range of 7.5 m. The silt change here (near Navalakhi in the Gulf of Kutch) is much lower (nearly 1000 ppm).

The tidal ranges and power potential of these sites are indicated in the table 9.3.10.1.

Table 9.3.10.1. Tidal Power Potential in India

Sites	Spring Tidal range in metres	Assumed area in Sq. kms.	Total maximum potential energy 10^6 kWh/yr.	Single Basin Cycle		Two basins			
						Alternatively operating		Cooperating	
				MW	10^6 kW/yr.	MW	10^6 kWh/yr.	MW	10^6 kWh/yr.
Gulf of Kutch Navalakhi	7.5	10	1110	43	376	48	419	16.4	143
Gulf of Cambay	10.8	10	2300	89.4	784	100	880	34.2	300
Sagar	4.85	10	464	18	157	20.1	176	6.9	60
Diamond Harbour	3.9	10	686	26.6	233	29.7	262	10.15	89

There is at present no indication regarding the cost of generation from tidal power. Preliminary studies already carried out by the CPWD and for tidal station in the Gulf of Cambay indicated higher cost of generation from conventional sources. However, the cost of coal and other allied materials is increasing which may open up the possibility of exploitation of this source of power. Adequate data will have to be collected for any realistic assessment of tidal power potential and possible impact on the environment, current patterns, tidal reflections, sedimentation, erosion etc. Detailed feasibility reports based on full technology assessment are called for before venturing into this field.

9.4. Ocean Waves

9.4.1. Introduction

Ocean and sea waves are caused indirectly by solar energy like the wind and OTEC. Wave energy derives from wind energy, which drives in turn from solar energy. As stated earlier, the wind energy is caused by the uneven solar heating and subsequent cooling of the earth's crust and the rotation of the earth. Wave energy at its most active, however, can be much more concentrated than the solar energy. Devices that convert energy from waves can therefore produce much higher power densities that solar devices.

The power in the ocean waves has been part of the human experience for thousands of years. However, the history of attempts to exploit this power for human purposes has been extensive. It was the recent energy crisis that prompted serious attempts at harnessing the waves for the production of electricity. During the decade of the 1970s dozens of patents were filed to do this, though most are complicated and rather fragile in the face of the gigantic power of the ocean storms. Patents have been issued on a variety of devices and many schemes have been described conceptually. Some small-scale prototype devices have been tested. Upto now no major development programme has been carried out through in any country. Small devices are available, however, and are in limited use as power supplies for buoys and navigational aids. From the engineering development point of view, waves energy development is not nearly as far along as wind and tidal energy.

World sites that may be suitable for 'harvesting' of energy from waves include the Molakai and Alenuihaha channels in the Hawalian islands, where 2 to 3 m-high (crest to trough) waves are typical during normal trade wind periods, the Pacific coast of North America, the Arabian sea of India and Pakistan, the North Atlantic coast of Scotland, the coast of New England etc.

9.4.2. Advantages and Disadvantages of Wave Energy

Advantages are : (1) The wave energy has the advantage over wind or solar that the energy has been naturally concentrated by accumulation overtime and space and transported from the point at which it was originally present in the winds.

(2) The degree of power concentration effected by waves is quite substantial whereas the power density in wind may, at a good site, average some hundreds of watts per square meter, wave from being transported across a plane perpendicular to the wave propagation direction at a good site is from 10 to 100 times at large.

(3) It is a free and renewable energy source.

(4) Wave power devices do not use up large land masses unlike solar or wind.

(5) These devices are relatively pollution free and, because they remove energy from the waves, leave the water in a relatively placid (calm) state in their wakes.

Disadvantages are : (1) The major disadvantage of wave energy, as compared to wind, is that the energy is available on the ocean. The extraction equipment must operated in a marine environment with all that implies in terms of maintenance, construction cost, life time, and reliability. The energy may have to be transported a greater distance to shore.

(2) Wave, energy converters must be capable of withstanding very severe peak stresses in storms.

(3) There is relatively scarcity of accessible sites of large wave activity.

(4) Wave energy conversion devices that have been proposed are relatively complicated.

(5) Economic factors such as the capital investment, costs of the maintenance, repair and replacement, as well as problems of biological growth of marine organisms, are all relatively unknown and seem to be on the large side.

9.4.3. Energy and Power from the Waves

A two-dimensional progressive wave as shown in Fig. (9.4.3.1), is represented by the sinusoidal simple harmonic wave shown at time

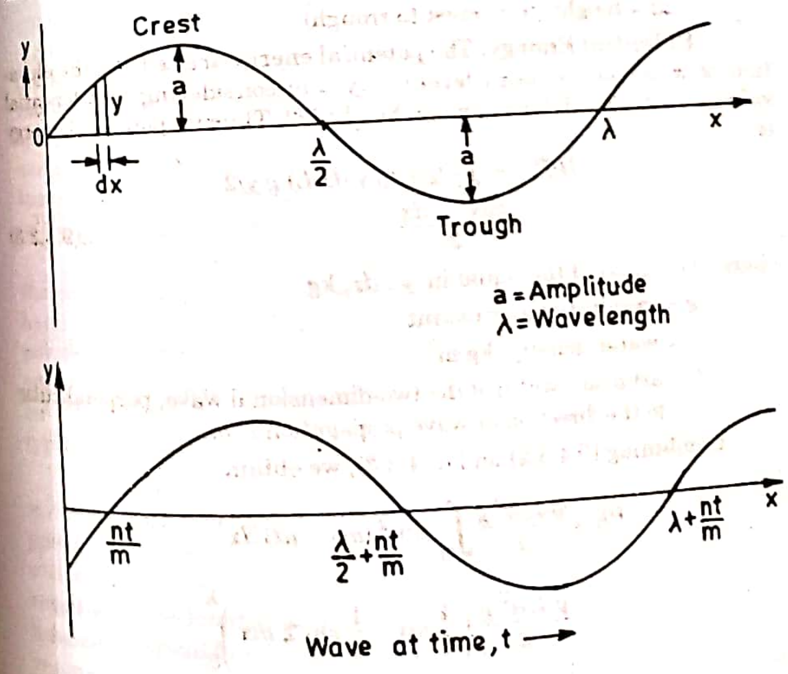


Fig. 9.4.3.1. A typical progressive wave.

$t = 0$, and at time t. The wave may be expressed by the following relation involving some parameters :

$$y = a \sin\left(\frac{2\pi}{\lambda} x - \frac{2\pi}{\tau} t\right) \quad ...(9.4.3.1)$$

where y = height above its mean level in m.
a = amplitude in m.
λ = wave length in m.
t = time in seconds
τ = period in seconds

$$2\pi = \left(\frac{x}{\lambda} - \frac{t}{\tau}\right) = \text{phase angle (dimensionless)}$$

The relationship between wavelength and period is approximately

$$\lambda = 1.56\, \tau^2 \quad ...(9.4.3.1\ a)$$

The expression (9.4.3.1) can be expressed as

$$y = a \sin (m\,x - n\,t) \quad ...(9.4.3.2)$$

where $m = \frac{2\pi}{\lambda}$ and $n = \frac{2\pi}{\tau}$ = phase rate

$2a$ = height (from crest to trough).

Potential Energy. The potential energy arises from the elevation of water above mean level (*i.e.* $y = o$) considering a differential volume $y \,.\, dx$, it will have a mean height $\lambda/2$. Thus its potential energy is

$$dPE = m\,g\,y/2 = (\rho\, y\, dx\, L)\, g\, y/2$$
$$= \frac{g\rho y^2 L\, dx}{2} \quad ...(9.4.3.3)$$

where m = mass of the liquid in $y \,.\, dx$, kg
g = gravitational constant
ρ = water density, kg/m^3,
L = arbitrary width of the two-dimensional wave, perpendicular to the direction or wave propagation x, m.

Combining (9.4.3.2) and (9.4.3.3), we obtain :

$$PE = \frac{\rho L a^2 g}{2} \int_0^{\lambda} \sin^2 (mx - nt)\, dx$$
$$= \frac{\rho L a^2 g}{2} \left(\frac{1}{2} mx - \frac{1}{4} \sin 2\, mx\right)_0^{\lambda}$$
$$= \frac{1}{4} g\, \rho\, a^2\, \lambda\, L \quad ...(9.4.3.4)$$

The potential energy density per unit area is PE/A,

where $A = \lambda L$, in J/m^2.

$$\therefore \quad \frac{PE}{A} = \frac{1}{4} g\, \rho\, a^2 \quad ...(9.4.3.5)$$

Kinetic Energy. The derivation of the K.E. is rather complex and beyond the scope of the book. From hydrodynamic theory this can be expressed as

$$\text{K.E.} = \frac{1}{4} g\, \rho\, a^2\, \lambda\, L \quad ...(9.4.3.6)$$

and the K.E. density is

$$\frac{\text{K.E.}}{\text{A}} = \frac{1}{4} g\, \rho\, a^2 \quad ...(9.4.3.7)$$

Total energy and power density can be written as

$$\frac{E}{A} = \frac{1}{2} g\, \rho\, a^2, \quad ...(9.4.3.8)$$

$$\frac{P}{A} = \frac{1}{2} g\, \rho\, a^2 \,.\, f \quad ...(9.4.3.9)$$

where f is the frequency. (The Power P = energy × frequency).

9.4.4. Wave-Energy Conversion Devices

The mechanical energy in waves takes different forms. There is the energy of forward motion of the wave—the highly noticeable energy that slams into ships and cliffs. Some of the proposed schemes are oriented toward this forward motion kinetic energy. Any geometric arrangement that absorbs energy by converting the forward momentum of the wave into motions of its internal parts, without re-emitting as much energy as it absorbs, can extract this forward motion energy.

Also very promising from the energy extraction point of view is the potential energy of the raised water at the wave crest. The gravity head between crest and trough is not large enough to permit practical power generation by driving a hydro-turbine directly, but the potential energy in the wave is very considerable. The rate at which work is done on a large ship by the ocean as the ship is lifted up by the swell is typically several times the power being delivered by the ship's engine.

It is not difficult to invent a variety of ratchet, valve, or intermittent-pump mechanisms that can convert wave energy to hydraulic, pneumatic, or electrical form. The engineering challenge is to find a cost-effective way to do it on a large scale. Since waves come in a wide range of wave lengths and amplitudes, any effective device will either have to be broad band-that is, non resonant—or it will have to have its resonance frequency continuously adjusted. Many mechanisms have been proposed, and a number are being investigated. For example, waves can be made to compress air in the top of *floating tank*, using one way air valves. Electricity is generated as the air is bled out through a pneumatic or air turbine.

In a different devices, waves passing a pipe standing vertically in the water and equipped with an internal flop valve that allows water to move upward in the pipe but not downward, cause a water column to rise in the pipe, to a height many times the wave height. The water can be released from an elevated part in a controlled manner, to drive a conventional hydro turbine. Another class of mechanism employs the floats with different dynamic response characteristics. The differential motion is used to operate a pump or mechanical engine. For example, a long vertical cylinder extending far below the surface will remain nearly stationary as the waves pass by. A toroidal float surrounding it will rise and fall with the valves, and can be made to push and pull on pump plungers attached to the cylinder.

Some of the main concepts for converting wave energy into mechanical or electrical are described briefly as follows :

Wave-Energy Conversion by Floats

Wave motion is primarily horizontal, but the motion of the water is primarily vertical. Mechanical power is obtained by floats making use of the motion of water. The concept visualizes a large float that is driven up and down by the water within relatively stationary guides. This reciprocating motion is converted to mechanical and then electrical power is generated.

A system based on this principle is shown in Fig. (9.4.4.1), in which a square float moves up and down with the water. It is guided by

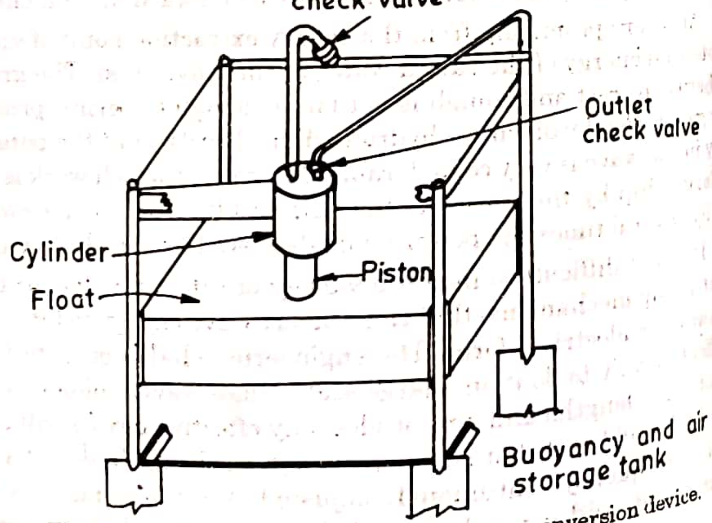


Fig. 9.4.4.1. Schematic of a float wave-power conversion device.

four vertical manifolds that are part of a platform. There are four large under water floatation tanks which stabilizes the platform. Platform is supported by buoyancy forces and no vertical or horizontal displacement occurs due to wave action. Thus the platform is made 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 therefore relatively stationary. The piston and cylinder arrangement is used as a reciprocating compressor. The downward 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, through an outlet check valve *via* the four manifolds. In this way, the four floatation tanks serve the dual purpose of buoyancy and air storage, and also the four vertical manifolds and float guides. 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.

High-Level Reservoir Wave Machine

The concept of this device is illustrated with reference to Fig. (9.4.4.2), in which a magnification piston is used. The pressurized

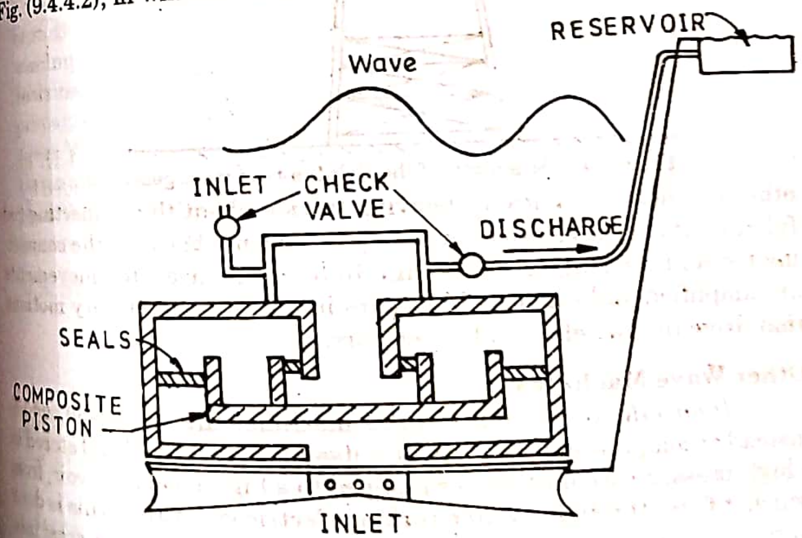


Fig. 9.4.4.2. Schematic of a high-level reservoir wave machine.

water is elevated to a natural reservoir above the wave generator, which would have to be near a shore line, or to an artificial water reservoir. The water in the reservoir is made to flow through a turbine coupled to an electric generator, and then back to sea level. Calculations made shown that a 20 m diameter generator can produce 1 MW power.

The Dolphin-Type Wave-Power Machine

This type of wave-generator, which is designed by Tsu Research laboratories in Japan is shown in Fig. (9.4.4.3). The system consists of following major components :

(i) a dolphin, (ii) a float, (iii) a connecting rod, and (iv) two electrical generators.

This device uses the float which has two motions. The first is a rolling motion about its own fulcrum with the connecting rod. Revolving movements are caused between the float and the connecting rod. The

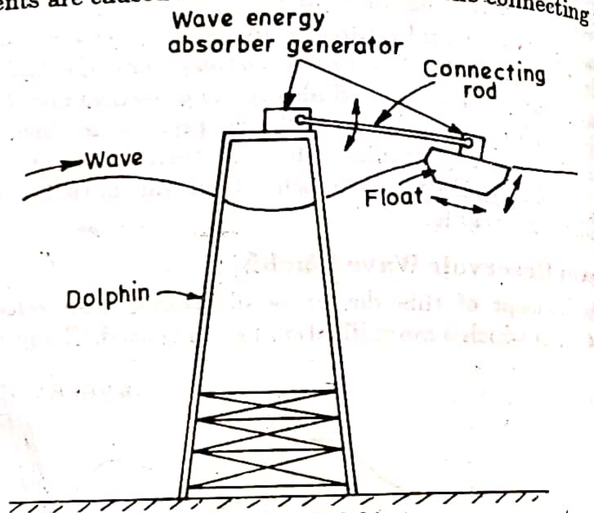


Fig. 9.4.4.3. Schematic of the Dolphin-type wave generator.

other is a nearly vertical or heaving motion about the connecting rod fulcrum. It causes relative revolving movements between the connecting rod and the stationary dolphin. In both the cases, the movements are amplified and converted by gears into continuous rotary motions that drive the two electrical generators.

Other Wave Machines

Hydraulic accumulator wave machines are also used, which instead of compressing air, the water itself is pressurized and stored in a high-pressure accumulator or pumped to a high-level reservoir, from which it flows through a water-turbine electric generator. This is done by transforming large volumes of low-pressure water at wave crest into small volumes of high-pressure water by the use of a composite piston. The piston is composed of a large-diameter main piston and a small-diameter piston at its centre. The main piston moves up and down with the entering of the wave water through the opening. A closed water loop exists above the small piston. The pressure on the main piston is magnified on the small piston during the upstroke. The high-pressure

water is conducted through a one-way valve to a hydraulic accumulator at the top of the generator. Two air (or other gas) volumes counter balance and act as cushions in a chamber above the main piston and in a sealed compartment in the hydraulic accumulator. The latter also maintains the high water pressure. Part of the high-pressure water flows through a Pelton wheel or Francis hydraulic turbine that drives an electrical generator and is then discharged to a storage chamber below the turbine.

In another differential motion concept, called the *"nodding duck"* employs large cam-shaped "ducks" mounted on a very long, floating frame. The 'ducks' oscillate or 'nod' relative to the frame, driving hydraulic pumps. This 'nodding duck' scheme though only in the model testing stage, has been investigated more than most of the other concepts, and is currently one of the leading contenders in the British wave energy programme. It is a rather serious criticism it was claimed by a wind-power proponent that the energy pay back time for wave power systems in general and the nodding duck scheme in particular may be excessively long, owing to the large amount of steel and concrete required. This claim was disputed by the inventor of the nodding duct concept.

It is interesting to recall that S.J. Savonius used a rotor of the type generally known as a Savonius rotor and generally used as a windmill to extract energy from the waves of ocean. The rotor was fixed with its axis horizontal and perpendicular to the direction of wave propagation (near the shore, to which it was anchored rigidly, in this case). Water passing the rotor flowed both forward and back at different times and depths ; the asymmetric Savonius rotor can take power from both the forward and back flows. Power outputs of a few kilowatts per square meter were obtained with equipment that was far from perfect.

9.5. Small Scale Hydroelectric

9.5.1. Introduction

Small scale hydroelectric facilities can supply in principle significant amounts of electricity for irrigation or potable water pumping, lighting, or health or educational purposes. The total potential amount of such a resource is very poorly documented but is apt to be large.

Upto 1972, hydro engineers concentrated on developing the larger sites, where the economy of scale enabled the production of energy at a cost low enough to compete thermal power, fueled with low cost oil. However with the prospect of rapidly depleting fossil fuels coupled with steady rise in oil prices, attention has returned to the smaller sites previously regarded as uneconomic. Moreover, the remarkable advancement in the technology of development of turbines suitable for utilising small falls and small discharges efficiently has increased the chances of development of *small* (*mini* and *micro* included) hydel installations to a large extent. Manufacturers have been quick enough to develop packages designs for small units. For very small hydroplants of less than 500 kW capacity, *electronic load controllers* have been developed to replace the governor. These controllers maintain a constant load on the turbine and hence constant flow, surplus power is diverted to a resistor and either wasted or used to heat water.

Many countries now have active small hydro development and rural electrification programmes, due to the several advantages offered by these plants.

The advantage of their operation in hilly and remote areas and the elimination of long transmission system, and lesser gestation periods have lent added attraction. It has little or no adverse environmental impact, effects on stream ecology are minor.

China has concentrated on small hydro, has over 1 lakh sites developed and is now exporting low cost units. These mini hydro schemes which are spreaded all over the country, are supplying about 10% of China's total installed capacity which is in the vicinity of 7,000 MW. Other countries such as Malaysia, Indonesia and Phillipins are actively pursuing small and micro-hydro, developing sites using a minimum of elaborate equipment.

In India, the potential of small hydropower is estimated to be 5,000 MW at present, while further investigations and surveys are expected to indicate a higher potential. *Small hydropower is covered in the renewable energy programme*. The alternate hydro-energy centre at Roorkee works on the development of solar hydro-power systems as well as *Hybrid* hydro systems. If small hydro-power stations are set up all over the country, decentralized availability of power will be become possible.

Sites for low-head installations can be found everywhere in the mountain region, plains or even at the sea level. They may range from micro sets (less than a megawatt) to the largest axial flow turbines (upto 50 MW). Also, low head hydro-power sites can be close to power consumption areas, which is an advantage. In water logged areas like the Sundarbans in Bengal or remote hilly areas such as Ladakh, low head installations are often the only source of energy.

It is in this context that the Bulb-Turbine, the youngest member in the family of hydro-turbines came into picture. Bulb turbine including its generator is enclosed in a shell known as bulb which can be conveniently installed horizontally in a low head stream. It has more or less a straight flow-path. It can work under a head from as low as half a metre to a head of 95 meters. It can generate power from as-low-as 5 kW to as-high-as 50 MW. Bulb turbines can easily be standardised in the step of 100 kW in the micro-range, in the step of 1 MW in the mini range and in the step of 5 MW in the range of small turbines.

The small hydro power potential which remains largely untapped so far because of an impression that :

1. Small hydro electric projects entail higher capital costs on per kW installation basis.
2. Higher managerial and administrative costs.
3. Relatively low utilization.
4. Unstable operation of isolated systems due to low inertia.
5. Certain problems caused by the disbursed nature of projects in site identification, preparation of reports, proper construction planning and management and operation etc.

Yet one can not deny a place for small hydel in the larger energy frame work primarily because :

1. Small or mini hydro power (SHP) is a non-consumptive generator of electrical energy utilizing a renewable resource which is made continually available through the hydrologic cycle of environment.

2. Small hydro power (SHP) is essentially non-polluting and release no heat. Adverse environmental impacts are negligible and for small installation may be totally eliminated.

3. With the development of compact efficient machines the investment per kW installed is not very high. SHP projects do not require large capital investment.

4. Compared to other conventional energy generation schemes, these projects have low gestation period ranging from 8 to 24 months.

5. Operating costs are low and the equipment does not need trained and skilled personnel. With the introduction of microprocessor the SHP station may run virtually unattented. Further freedom from fuel dependence together with long life of SHP plant make installation resistant to inflation.

6. SHP is ideal decentralized energy generation source. It can supply energy to rural feeders thereby cutting distribution losses to a large extent.

7. SHP can be synchronised with grid and has been demonstrated in national demonstration projects in H.P., Haryana and Tamilnadu. SHP synchronisation with utility grid improves voltage profile.

8. With the interconnection and synchronisation with grid, plant utilization factor becomes very high. Thus SHP becomes economically attractive.

9. Due to their small size and local availability of utility grid, SHP stations generally use induction generators. Thus induction generators are not only inexpensive but also the problem of synchronization and interconnection is also vastly simplified.

10. SHP can be a catalyst in remote areas using relative simple technology in mobilizing productive resources and cutting enhanced economic opportunities for local residents.

11. Most of these schemes, in India, can be constructed on existing canals and irrigation system thereby necessitating minor modification and result in minimal disturbances to surrounding environment.

12. SHP can be developed to augment hydro power capacity at existing irrigation dams and power houses. The possibility of retrofits and additional turbines and generators makes the upgrading of present installations attractive. The determinants in the economic feasibility of alternative proposals of power generation may not necessarily depend upon the variables of the highest gain, from any individual scheme, but variables on the basis of the impact on economy of the system as a whole. From the considerations of higher efficiency and lower cost per kW capacity, a larger set may be individually more economical but this individual economic gain might be out weighted by the adverse economy as a consequence of :

(a) Low operation efficiency due to partial loading.

(b) Sudden loss of unit.

(c) Longer gestation period due to sizeable difference between the generation capacity of the unit and the increment rate of load developed in the region served by the plant.

(d) Transport difficulties in hilly areas.

(e) Transmission losses.

(f) Transmission Costs.

(g) High cost of fossil fuels when compared to thermal power.

In coming years the small hydel (mini, micro and small) shall be more feasible and economical than other sources like thermal power because cost of fossil fuels.

9.5.2. What is Small Hydel Development ?

There is no formal definition of a small hydro plant but this may generally be taken as power station/plant having output upto 5000 kW. Some associate the concept of small hydro with low head say upto 15 m. This may not generally be true as there is no restriction on head for small hydro development. Stations upto output of 1000 kW are called micro and upto 5000 kW as mini hydroplant. Concepts of small hydro

are naturally relative and vary from country to country depending on the size of its existing development. In U.S.A. even 15000 kW is considered small hydro development while in France and some other countries it is upto 3000 kW. The hydro-electric installations having plants of higher unit rating can generally be made by utilising conventional technology of hydro equipment and tailor made designs both for equipment and civil works for power stations. It may be mentioned that source of energy from sea waves, coastal tides and ocean water itself, attempts in development of which also are gaining momentum, are not included in small hydro development. These are distinct types of development requiring all together different type of technology. Conceptually small hydro development can be categorised in two types—*one utilizing small discharges but having high head* and the second utilising *large discharges under comparatively very small head*. These are also distinguished by the nature of the generating plant required in these two types. For high head discharges being small, the physical size of the plant required is small. For the second type, as the discharges handled are high, the physical size of the generating unit and the power station consequently is quite big compared to the general notions of the rating. Also for the latter type proper arrangement for entry of water and its discharge is required to be made.

9.5.3. Nature of Small Hydro Development

Equipment technology is available to utilise discharge as small as 200 litres/sec. (0.2 cumec), head ranging from even 1 metre and producing an output of 1 kW with reasonable cost. Development of potential, relatively small is of course dependent on the pressing need and the resources.

The small hydro development of the first type which is confined mainly to hilly areas is characterised by relatively very simple features of works. The civil work involved comprise a small structure to divert the flow of the hill stream/river, small water conductor system such as a channel, flume or buried conduits, power house building and a small length of transmission line.

There is no need for substantial storage and generally run of river is utilised. The power generally consumed in the local area eliminating requirement of long transmission lines. The grid line would normally be far away and hence the need of local development.

Features of development of the second type which normally belongs to the plains are somewhat different. The head available is rather low and discharges have to be comparatively large to be economically viable. The development thus can take place on small river, irrigation outlet, canal falls etc. The difference usually comes in because of regulating arrangement for inlet and discharge of water and the type of the generating equipment that may be bulb or tube type requiring larger size of power house. The grid transmission line would generally be available nearby and the power station also be connected to it.

9.5.4. Classifications of Small hydro Power Stations

As per central Electricity Authority and Bureau of Indian standards, the SHP stations are classified as follows :

1. Depending on Capacity.

Size	unit size	Installation
Micro	upto 100 kW	100 kW
Mini	101 to 1000 kW	2,000 kW
Small	1001 to 6000 kW	15,000 kW

2. Depending on Head.

Ultra low head	Below 3 metres
Low head	less than 30 metres
Medium head	Between 30 to 75 metres
High head	Above 75 metres.

The above mentioned definitions vary from country to country.

On the basis of heads available small hydel schemes (mini, micro and small) may be further categories as

(i) Independent scheme.

(ii) Sub ordinate scheme.

Independent Scheme. Independent schemes are those schemes where a stream flow is captured, regulated and developed for the principle objective of power generation only, in these schemes high head scheme and medium head schemes are considered but medium head schemes are successful. The low head schemes are not found economical for using as independent generation. These schemes are successful in Himalayan territories states like, Himachal Pradesh, Jammu and Kashmir, Nagaland and Manipur etc.

Sub ordinate Schemes. The subordinate schemes are those where the principle objective is other than power generation. The region in which there is extensive network of irrigation canals and water is stored in the form of reservoir are used for subordinate scheme where primary aim is irrigation or drinking water and secondary aim is power generation. The feasible sites for subordinates schemes is indogagetic plains (canals) and Peninsular India (reservoirs).

9.5.5. Components of a Hydroelectric Scheme

The basic and common components of a hydroelectric schemes are given below : (refer Fig. 9.5.5.1)

(a) Diversion and intake

(b) Desilting chamber

(c) Water conductor system

(d) Forebay/balancing reservoir

(e) Surge tank (if necessary)

(f) Penstock

(g) Power house—Turbine, Generator, Protection and control equipment, Dewatering, Drainage system, Auxiliary, Power system, Grounding, Emergency and stand by Power system, Lighting and Ventilation.

(h) Tail race channel.

Dam, Barrages, solid boulder structure and trench type weir are usually employed to divert, the required flow from the river bed/streams to the intake structure (Fig. 9.5.5.1).

For small hydro stations usually solid boulder structure and trench type weirs are employed. Trench type is suitable where rock is not available in the river bed. Boulder type could be preferred if boulders are available in the river and rock is encountered in the river bed within one meter depth. If solid boulder structure type weir is provided in non-rocky foundations, maintenance and repair of damages due to scour may create problems. The diversion weir should be capable of diverting all the lean season flows and the structure should be reasonably safe during monsoon floods. In hill streams, diversion structures face a recurring problems due to choking of intake. Further underground structures are vulnerable to damage from heavy boulders and bed loads. Trench type weirs are preferred from this consideration.

Densilting Chamber is necessary where the water contains large quantities of course silt to minimise erosion damage to the turbine runner etc. The extent of desilting requirements would depend on the quantum and type of silt carried by the stream and the runner material. Abrasion effect becomes more pronounced with increasing head. The desilting chamber may be designed to exclude the particles coarser than the sizes mentioned in table for various heads of water to achieve a power draft free of abrasion effects.

Head	Size of the Silt particles to be removed
Medium head	0.2 to 0.5 mm
High head	0.1 to 0.2 mm.

Water Conductor system should be designed to ensure least loss of head and loss of water due to seepage. Further flow velocity should be adequate enough to prevent reduction of discharging capacity due to settling of silt. The canal can be lined with tiles. For small power stations, it may be economical to adopt lining with low density poly ethylene (LDPE), film with single tile cover especially where it traverse porous strata.

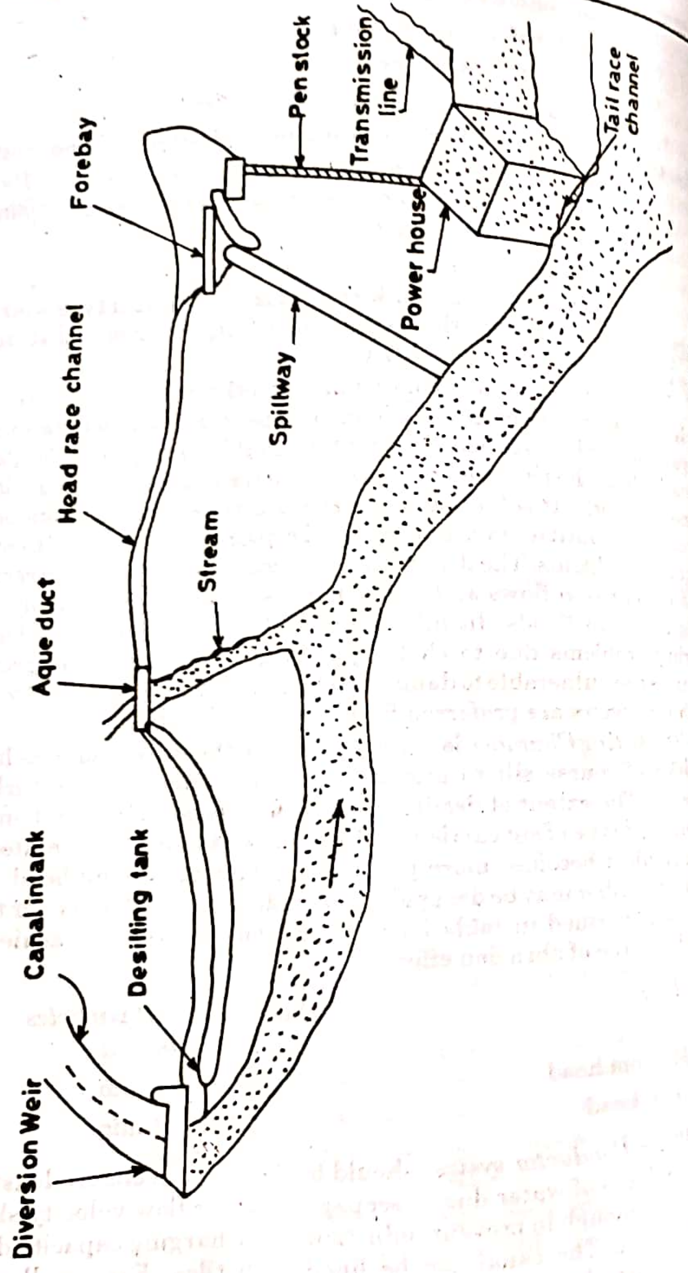


Fig. 9.5.5.1. Typical arrangement of small Hydro Power Station.

If the forebay is to be used as a balancing reservoirs storage for about 4—6 hours could be provided if justifiable on economic reasons. If the forebay is just used as a transit point, a storage of about 2 minutes may be adequate creation of pondage is preferred in cutting from economic reasons.

When the length of the water conductor conduit is more than 5 times the head on the machines, surge tank is necessary. In case of mini/micro hydel schemes, where impulse turbines are used, the pressure surges can be avoided with deflection of jet. This would eliminate the need of surge tank though this would involve some wastage of water, in reaction-type turbine, water wasting relief valves or air vessel can be provided to avoid governor instability and hunting due to oscillations in the water column.

Penstocks can be made of steel pipes (ERW or Spiral Welded MS pipe), Hume pipes and PVC pipes depending on the design pressure, Commonly a bell mouth entry is provided to reduce the head losses and to ensure a smooth entry of water from the forebay tank into the penstock. Intakes are provided with trash racks to prevent entry of trash, debries and ice (in clod climate). Flow velocity through trash rack is kept at 0.6 to 0.9 metres per sec., so that head losses are not significant. Clogging to an extent of 30 percent of the trash rack area may be considered in the design without materially decreasing the head on the turbine. Trash rack for small intakes should be slopped to fascilitate cleaning of the debris. The bar spacing should be close enough to restrict the passage of any object that should not pass through the turbine.

Tailrace is a simple water channel or a cut and cover conduit with a maximum water velocity of 1 meter/second transporting the water from the turbine outlet (draft tube) to the river.

9.5.6. Civil works design considerations for Mini and Micro Hydel Projects

Introduction. A large potential of energy remains untapped in India in hilly streams and canal falls in the range of mini and micro hydro. The rough estimates show that the total potential in small hydro is of the order of 5000—6000 MW. At present only about 3 to 4% of this potential has been utilised. The construction for generation of about 200. MW is in progress in different parts of the country. This clearly shows that the country has embarked upon the programme of development of small hydro on a very large scale. But the main deterrents in taking up small hydro is their larger per kW costs as compared to the conventional large hydro which is also available in abundance. The immediate step required to be taken for making mini/micro hydro economically viable is to make efforts to reduce the cost of equipment and civil works.

Tail Race Channel

Water after flow through machine is fed to the stream downstream of power house. It may be trapezoidal or rectangular channel constructed in stone masonry or brick masonry depending upon the material available locally.

Materials for Construction

Efforts should be made to use the locally available material. The material generally used are Reinforced concrete, structural steel, stone masonry Brick masonry etc. Research is going on for the development of new materials *e.g.* Ferrocement and steel Fibre Reinforced concrete. These are discussed briefly as follows :

Ferro Cement. Ferrocement a composite material, usually brittle, is reinforced with fibres dispersed throughout the composite. In ferro cement structures, the reinforcement consists of small diameter wiremesh in which the proportion and distribution of the reinforcement are made uniform by spreading out the wire meshes throughout the thickness of element. This dispersion of the fibres in the brittle matrix offer not only convenience and practical means of achieving improvement in many of the engineering properties of the materials such as fracture, tensile and flexural strength, toughness, fatigue resistance and impact resistance but also provides advantages in terms of fabrication of products and components.

The use of ferrocement may be made in gates, penstocks slabs etc.

Steel Fibre Reinforced Concrete

Steel fibre reinforced concrete (SFRC) is a new concrete for which gradients are hydraulic cement, fine and coarse aggregate and discontinuous discrete steel fibres. In recent years, it has been recognised that the additions of small closely spaced and uniformly dispersed discrete steel fibres in concrete would substantially improve its static and dynamic properties. The SFRC has better characteristics as compared to ordinary concrete as regards compressive strength, tensile strength, flexural strength, shear strength, fatigue strength and impact resistance.

SFRC may be used for Forebay, gates and penstocks.

9.5.7. Turbines and Generators for Small Scale Hydro Electric

(1) *Bulb or Tubular Turbine*. This is rather a recent development in which complete turbine and the generator is enclosed inside the conduit which carries water from headrace to tail race. This enclosure is a water tight housing (or bulb), which is supported centrally within a horizontal water channels. The turbine is essentially of Kaplan type or a propeller type. The generator may be directly coupled to the turbine shaft or driven through a set of gears for increasing the speed to reduce

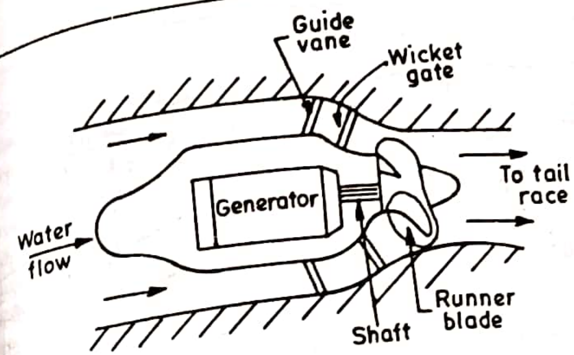


Fig. 9.5.7.1. Bulb Turbine.

the generator size. The generator is usually on the upstream side of the turbine now a days. The turbine, located at the downstream end, is connected to the generator, by way of a sealed shaft. Water flows in the axial direction around the bulb and through guide vanes and wicket gates to the turbine runner with propeller type blades. (Fig. 9.5.7.1).

This development is most suitable for utilisation of comparatively low heads, the range being from 3 to 18 m. The output rating of the bulb type design are available right from 200 MW to 40 MW, though the bigger one may not come under small hydroelectric development.

Arrangement of the bulb unit (See figure) indicates that this is rather complicated. But the design has been almost perfected and there are a large number of units of various sizes in operation all over the world. The efficiencies of the generating set of this type are very high compared to the size and are comparable with those of conventional units as hydraulic losses are kept minimum. The units are available as package units which facilitates erection and dismentling.

(2) *Tube Turbine*. Modification of the Kaplan—type turbine have been developed for water-heads below some 15 m (50 ft). In one such type, called the *tube turbine*, the turbine was a horizontal (or almost horizontal) shaft is located in a tubular channel ; the water flows in an axial direction through the channel with the runner. The water is directed between the propeller blades by fixed guide varies, and the flow is controlled by wicket (or similar) gates.

If the shaft is horizontal the channel slopes downward beyond the turbine so that the attached generator is above the water level in the tail race. (Fig. 9.5.7.2). Alternatively, the turbine shaft may be sloped upward to achieve the same objective. An advantage claimed for the tube turbine is that the water does not change direction and hence lose energy before it enters the turbine.

This type of turbine is a varient of bulb turbine. In this type of management, only the turbine is housed inside the conduit and the

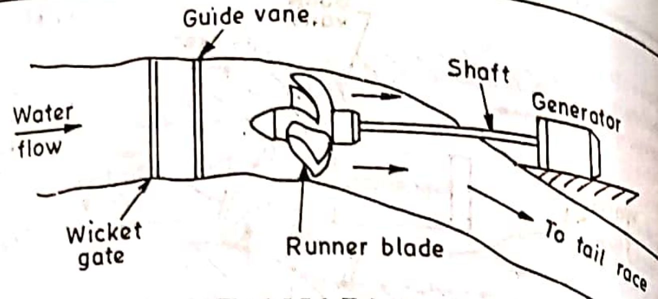


Fig. 9.5.7.2. Tube Turbine.

generator is mounted outside in a pit by bringing the turbine shaft out of the turbine casing. This type is also known as "pit type". The arrangement can be either with horizontal shaft or inclined shaft as explained above. The arrangement is having the advantage of easy accessibility of the generator.

(3) *Straflo Turbine*. This is another design rather marvellous, the turbine of which is similar to that in bulb type. In this arrangement there is no separate rotor provided for the generator as the poles are mounted on the periphery of the turbine runner. There is an elaborate specialised arrangement of seals for preventing water getting into poles. As the name suggests the shaft is horizontal in this design and the water flows is always axial. Such a design requires smaller size of the power house. Another advantage in this type is a large range of output and head that can be utilized.

Generators :

Conventionally hydro electric A.C. Synchronous generators are used. The generator (rotor) should withstand turbine runaway speed *i.e.* speed attained on sudden load through off. Brushless excitation system generators are used in small hydro power stations which reduces maintenance costs and time. Induction generators need excitation source and as such can only operate when connected to an existing electrical system.

Speed Regulation :

The speed regulation of turbine is an important and complicated problem. The magnitude of the problem varies with size, type of machines, type of electrical load and whether or not the plant is tied into an electrical grid. It should also be kept in mind that runaway or no load speed can be higher than the design speed by factors as high as 2.5. This is an important design consideration for ally rotating parts, including the generator. The cost of standard speed governor is disproportionately high in the smaller sizes. Regulation of speed is normally accomplished through flow control. Adequate control requires sufficient rotational inertia of the rotating parts.

The precision of governing necessary will depend on whether the electrical generator is synchronous or induction type. There are advantages to the induction type of generator. It is less complex and therefore, less expensive. Its frequency is controlled by the frequency of the grid it is feeding into, thereby eliminating the need of an expensive conventional governor. It can not operate independently but can only feed into a network and does so with lagging power factor which may or may not be disadvantage, depending on the nature of the load. Long transmission lines, for example, have a high capacitance and in this case the lagging power factor may be an advantage.

9.5.8. Protection, Control and Management of Equipments :

Small hydro power plant controls are required for unit start, unit shut down, unit synchronising and unit loading and control (speed and voltage), unit electrical and mechanical protection and emergency shut-down, hydraulic control.

A major cost in small hydros is operation and management man power. These costs can be prohibitive in microhydel. Low cost automation is therefore, of importance if mini and micro hydel is to survive unit starting and synchronising can be manual. But emergency shut down must be fool proof to avoid damage. It is considered that even if man power is provided for management, the level of expertise will be of low level. Accordingly, dependable and sample control/remote control of unit is required. Microprocessors are being used.

Control of induction generator grid connected units is easy synchronisation, speed and voltage control are automatically taken care of. Generator are less in cost. Automation costs are very low. Large scale installation of these units on our existing irrigation works like canals etc., can be highly economical.

In isolated areas local grids can be formed and smaller units can be induction generator type and can be controlled from a manned control mini hydro station where synchronous generator are installed.

9.5.9. Advantages and Limitations of Small Scale Hydroelectric

Advantages. (*i*) Smaller hydro projects takes the shortest time for developing a unit, and

(*ii*) Once it is built the running expenditure is almost negligible.

(*iii*) The operation and maintenance of such power station is the simplest.

(*iv*) These energy sources are free from hazards of pollution.

(*v*) Unlike the big hydrodevelopments, these have no environmental problems, no submergence of land, no loss of agricultural land, no dislocation of habitation, no inter-state problems and ecology of the region remains unaffected.

(*vi*) The construction of the various elements of the works, which are always simple, can generate employment for local people. The small hydro projects can will be operated and maintained by the local people. This factor alone can be the greatest incentive for the development which has been exploited most beneficially by China. In China, small communes have been encouraged to construct, own, operate and maintain such power stations.

Limitations. There are numerous reasons for comparatively smaller rate of development of small hydro-electric projects. Most of the factors responsible for this state of affairs have been quite formidable. These are not intended to be elaborated here. The main reasons are :

(*i*) Prohibitive economics compared to that of conventional hydro power which is still abundantly available in the country.

(*ii*) Non-availability of indigeneous equipment for generating plant (except for a particular type in a restricted range) and the import procedures are time consuming.

(*iii*) Remoteness of sites especially, in the hilly areas and adverse geological conditions in Himalayan region.

(*iv*) General lack of a awareness of benefits from small development.

With concentrated efforts it would be possible to improve the conditions and create proper climate for development. The present sources of small energy development which is mainly diesel, would become too scarce a commodity to be used for power generation in very near future.

9.5.10. Hybrid Systems

Small hydro can be extensively developed to exploit the available resources to meet rural energy requirements. Further electrical energy being the highest form of energy can be used to upgrade other systems. These hybrid systems may be used to harness/exploit and upgrade other available renewable resources which are presently unutilised/underutilised in rural areas. In addition to developing various hybrid systems, biomass gasification based cogeneration systems are proposed for peak load demands when microhydel systems are operated in decentralised manner. The required biomass will be obtained from high yielding and high density plantation.

In decentralised system, the power from micro-hydel system is preferably fed to the cluster of villages for meeting their requirements of power for domestic and street lighting, irrigation and rural industries. Depending upon the availability of power, hybrid systems in consultation with District Industries Officer could also be put by private enterpreneurs. The peak demand exceeding the micro-hydel capacity will be met by biomass gasification based cogeneration system.

A major cause of low benefit—cost ratio (reported to be 1.68) of isolated small hydroplants is due to poor utilisation of power (low head factor). This can be overcome by using surplus off-peak high grade energy in hybrid systems.

The peak load carries a special significance in utility generation industry. Higher the peak load, greater will be capacity of power generation. If the total load of the system is taken by a single power plant. This induces higher initial investment, low efficiency of generation and higher generating costs. To overcome above problems, the micro-hydel system is proposed to operate as base load plant and biomass gasifcaction based electrical generation system as peak load plant. The first combined system (300 kW micro-hydel and 200 kW biomass gasification based co-generation) is coming up at *Kakroi* (Haryana). The production cost per unit of electricity in micro- hydel system having annual plant factor of 0.40 comes to Rs. 1.25 and integration with biomass gasification system this reduces to Rs. 0.66. The integrated system also meets the entire energy requirement. However this requires prior information regarding the load curve before selecting the capacities of micro-hydel and gasifier systems.

9.5.11. Conclusion

It has been concluded a compaign should be made to give proper publicity for finding out the maximum mini, micro and small hydro electric generation sites on the following grounds :

(*i*) that mini, micro and small hydro electric power is a new source of renewable energy.

(*ii*) that mini, micro and small hydro electric is an alternative way of developing hydro electric resources of a country *i.e.*, it can develop the same potential as would be available for normal schemes.

(*iii*) that mini, micro and small hydro potential is more economical,

(*iv*) that it saves fossil fuels,

(*v*) that it reduces the transmission losses,

(*vi*) that it is suitable for isolated loads,

(*vii*) that it is easy to operate,

(*viii*) that it has low gastation period,

(*ix*) that its equipments can be standardized easily.

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QUESTIONS

9.1. What is the basic principle of ocean thermal energy conversion (OTEC) ? (3)

9.2. What are the main types of OTEC power plants ? Describe their working in brief.

9.3. Describe the 'closed cycle' OTEC system, with its advantages over 'open cycle' system.

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9.4. Explain with sketches the various methods of tidal power generation. What are the limitations of each method ? (10)

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9.5. What are the difficulties in tidal power developments ?

9.6. The basin area of a tidal power plant is 20×10^6 m^2. The tidal range is 8 m, calculate the energy generated in kwh. (5) [Ans. 10.358×10^6 kwh]

9.7. In Gulf of Cambay, which is being considered for possible tidal power generation, during the tide cycle, the observed difference between the high and low water of the tide was 10.8 m. It has been estimated that this estuary having an area of 10 sq. km can generate power for 3 hours in each cycle. Assuming the average available head to be 10 m, and the overall efficiency of the generation system to be 75%. Calculate :

(i) The power (in h-p) at any instant and

(ii) The total energy generated in the year. Take specific weight of sea water = 1025 kg/m^3. [Ans. (i) 102.5×10^4 h-p, (ii) $E = 15955.56 \times 10^5$ kWh/yr.]

9.8. In an estuary, which is being developed for tidal power generation during the tide cycle the observed difference between the high and low water of the tide 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) The power in hp at any instant and

(ii) The total energy in the year.

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

[Ans. (i) 130.5×10^2 hp ;
(ii) 203×10^5 kwh/yr.]

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9.9. What are the advantages and limitations of wave energy conversion?

9.10. Write a short note on wave energy conversion machines.

9.11. Write a short note on small head hydro power development.

9.12. What type of turbine is best suited for micro hydel plant ? Describe it.

9.13. Describe the different types of turbines are in use for small scale hydroelectric plants.

9.14. What are the advantages and limitations of small scale hydroelectric power generation ?