Water power

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Power developed from movement of masses of water. Such movement is of two kinds: (1) the falling of streams through the force of gravity, and (2) the rising and falling of tides through lunar (and solar) gravitation.

While that part of solar energy expended to lift water vapor against Earth gravity is a minute fraction of the total, the absolute amount of energy that is theoretically recoverable from resulting streams is an enormous but unknown quantity. Of this, but a tiny portion is actually suitable for harnessing.

Water resources

The contribution of water-power installations to the nation's electric power supply at the beginning of World War II was about 30%. While the output from hydroelectric plants has grown, their contribution to the total electric power has dropped to about 13%, because steam-electric plants have grown at a much more rapid rate.

As of March 1980, the Energy Information Agency of the Department of Energy estimated that by the end of 1993 the total developed capacity of water-power installations could be 99,346 MW. However, that figure does not include a number of potential sites that could at some future time be considered. In theory, the Energy Information Agency estimates an eventual maximum potential of 187,000 MW, most of the undeveloped sites being in the Pacific Northwest and Alaska. Only a fraction of that will be developed for a variety of reasons. The most attractive sites have already been utilized. Hydro plants, with their initial high cost and generally long distances from major load centers, must compete with the large, efficient, fuel-fired stations, and the burgeoning, economical, large nuclear plants. Large dam sites usually must be justified not alone on the value of the power developed, but also on the benefits from flood control, irrigation, and recreation. Problems of migrating fish, conservation, and preservation of esthetic values are also factors. On the other hand, water-power developments add greatly to power-system flexibility in meeting peak and emergency loads. Modern excavation and tunneling techniques are lowering construction costs. The economies of lowhead sites are improved by the new, efficient, axial-flow turbines of the tubular type. *See also:* ENERGY SOURCES.

Silting. The capacity of hydro plants cannot be counted on for perpetuity because of gradual filling of reservoirs with sediment. This effect is serious for irrigation, flood control, and navigation. Even when a lake behind a power dam becomes filled completely with silt, electric power can be generated on the run-of-the-river flow, although output would vary with stream flow.

The rate of silting varies widely with drainage basins. Because the Columbia River carries comparatively little silt, the reservoirs at Grand Coulee and Bonneville dams should have lives of many hundreds of years. The Colorado River, on the other hand, is muddy. In the first 13.7 years after Hoover Dam went into operation in 1935, 1424×10^6 acre-feet (175,600 hectare-meters) of silt was dumped into Lake Mead. That is equivalent to a layer 1 ft deep over 2225 mi^2 (or 1 m deep over 1756 km^2). This inflow of silt has been diminished about 22% by the construction of other dams upstream, for example, the Glen Canyon Dam. It is expected that Lake Mead will have a useful life of more than 500 years.

Pumped storage. In pumped-storage hydroelectric systems, water is pumped from a stream or lake to a reservoir at a higher elevation. Pumping up to a storage reservoir is most commonly done by reversing the hydraulic turbine and generator. The generator becomes a motor driving the turbine as a pump. Power is drawn from the power system at night or on weekends when demand is low. It is not practical to shut down large, high-temperature steam stations or nuclear units for a few hours at night or even over a weekend. Because they must run anyway, the cost of pumping power is low, whereas the power generated from pumped storage at peak periods is valuable. Also, the pumped-storage system provides a means of supplying power quickly in an emergency situation, for example, during the failure of a large steam or nuclear unit. A pumped-storage system can be changed over from pumping to generation in 2 to 5 min. *See also:* PUMPED STORAGE.

Tidal power. A portion of the kinetic energy of the rotation of the Earth appears as ocean tides. The mean tide of all the oceans has been calculated as 2 ft (0.6 m), and the mean power as 5.4×10^{10} hp (40 TW) or, on a yearly basis, the equivalent of 3.6×10^3 kWh (4×10^{19} joules). Unfortunately, only a minute amount of this is likely to be harnessed for use. For tidal sites to be of sufficient engineering interest, the fall would have to be at least 15 ft (4.5 m). There are few such falls, and some of these are in remote areas. The only tide-power sites that have received serious attention are on the Severn River in England, the Rance River and Mont St. Michel in northern France, the San José and Deseado rivers of Argentina, the Petitocodiac and Memramcook estuaries in the Bay of Fundy, Canada, the Passamaquoddy River where Maine joins New Brunswick, Canada, and the Cambridge Gulf of Western Australia.

The Passamaquoddy site, which has a potential of 1800 MW (peak), is the only important tidal-power prospect in the United States. However, engineers do not consider its electrical output to be economically competitive with power that is produced by other means.

A second major handicap to tidal power is that, with a simple, single-basin installation, power is available only when there is a several-feet difference between levels in the sea and the basin. Thus, firm power is not available. Also, periods of generation occur in consonance with the tide—not necessarily when power is needed.

The only major tidal power plant in operation is the one near the mouth of the Rance River in Normandy, France. This plant operates on 40-ft (12m) tides. It began operation in 1967. It consists of twenty-four 10-MW bulb-type turbine-generator units of novel design. The system embodies a reservoir into which seawater is pumped during off-peak hours. Turbines are then run as pumps, power being drawn from the French electrical grid. The plant produces 5×10^8 kWh (1.8×10^{15} J) annually, including a significant amount of firm power.

Tidal power is an appealing and dramatic technique, and some other large plants may be constructed. However, the total contribution of the tides to the world's energy supply will be miniscule. *See also:* HYDROLOGY; TIDAL POWER.

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Application

The basic relation for power *P* in kilowatt from a hydrosite is $P = QH/11.1$, where *Q* is water flow in ft^3/s, and *H* is head in feet. Actual power will be less as occasioned by inefficiencies such as (1) hydraulic losses in conduit and turbines; (2) mechanical losses in bearings; and (3) electrical losses in generators, station use, and transmission. Overall efficiency is always high, usually in excess of 80% to the station bus bars.

Choice of site. The competitive position of a hydro project must be judged by the cost and reliability of the output at the point of use or market. In most hydro developments, the bulk of the investment is in structures for the collection, control, regulation, and disposal of the water. Electrical transmission frequently adds a substantial financial burden because of remoteness of the hydrosite from the market. The incremental cost for waterwheels, generators, switches, yard, transformers, and water conduit is often a smaller fraction of the total investment than is the cost for the basic structures, real estate, and transmission facilities. Long life is characteristic of hydroelectric installations, and the annual carrying charges of 6–12% on the investment are a minimum for the power field. Operating and maintenance costs are lower than for other types of generating stations.

The fundamental elements of potential power, as given in the equation above, are runoff *Q* and head *H.* Despite the apparent basic simplicities of the relation, the technical and economic development of a hydrosite is a complex problem. No two sites are alike, so that the opportunity for standardization of structures and equipment is nearly nonexistent. The head would appear to be a simple surveying problem based largely on topography. However, geologic conditions, as revealed by core drillings, can eliminate an otherwise economically desirable site. Runoff is complicated, especially when records of flow are inadequate. Hydrology is basic to an understanding of water flow and its variations. Runoff must be related to precipitation and to the disposal of precipitation. It is vitally influenced by climatic conditions, seasonal changes, temperature and humidity of the atmosphere, meteorological phenomena, character of the watershed, infiltration, seepage, evaporation, percolation, and transpiration. Hydrographic data are essential in order to show the variations of runoff over a period of many years. Reservoirs, by providing storage, reduce the extremes of flow variation, which are often as high as 100 to 1 or occasionally 1000 to 1.

Economic factors. The economic factors affecting the capacity to be installed, which must be evaluated on any project, include load requirements, runoff, head, development cost, operating cost, value of output, alternative methods of generation, flood control, navigation, rights of other industries on the stream (such as fishing and lumbering), and national defense. Some of these factors are components of multipurpose developments with their attendant problems in the proper allocation of costs to the several purposes. The prevalence of government construction, ownership, and operation, with its subsidized financial formulas which are so different from those for investor-owned projects, further complicates economic evaluation. Many people and groups are parties of interest in the harnessing of hydrosites, and stringent government regulations prevail, including those of the U.S. Corps of Engineers, the Federal Power Commission, the Bureau of Reclamation, the Geological Survey, and the Securities and Exchange Commission.

Capacity. Prime capacity is that which is continuously available. Firm capacity is much larger and is dependent upon interconnection with other power plants and the extent to which load curves permit variable-capacity operation. The incremental cost for additional turbine-generator capacity is small, so that many alternatives for economic development of a site must be considered. The alternatives include a wide variety of base load, peak load, run-of-river, and pumped-storage plants. All are concerned with fitting installed capacity, runoff, and storage to the load curve of the power system and to give minimum cost over the life of the installation. In this evaluation it is essential clearly to distinguish capacity (kW) from energy (kWh) as they are not interchangeable. In any practical evaluation of water-power in this electrical era, it should be recognized that the most favorable economics will be found with an interconnected electric system where the different methods of generating power are complementary as well as competitive.

As noted above, there is an increasing tendency in many areas to allocate hydro capacity to peaking service and to foster pumped-water storage for the same objective. Pumped storage, to be practical, requires the use of two reservoirs for the storage of water—one reservoir at considerably higher elevation, say, 500 to 1000 ft (150 to 300 m). A reversible pump-turbine operates alternatively (1) to raise water from the lower to the upper reservoir during off-peak periods, and (2) to generate power during peak-load periods by letting the water flow in the opposite direction through the turbine. Proximity of favorable sites on an interconnected electrical transmission system reduces the investment burden. Under such circumstances the return of 2 kWh on-peak for 3 kWh pumping off-peak has proven to be an attractive method of economically utilizing interconnected fossil-fuel, nuclear-fuel, and hydro power plants. *See also:* ELECTRIC POWER GENERATION; HYDRAULIC TURBINE; POWER PLANT; NUCLEAR REACTOR.

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Bibliography

E. A. Avallone, T. Baumeister III, and A. Sadegh (eds.), *Marks' Standard Handbook for Mechanical Engineers*, 11th ed., McGraw-Hill Education, 2007

H. W. Beaty and D. G. Fink (eds.), *Standard Handbook for Electrical Engineers*, 16th ed., McGraw-Hill Education, 2013

Edison Electric Institute, *Statistical Yearbook of the Electric Power Industry*, annually

Additional Readings

M. Z. Jacobson and M. A. Delucchi, Providing all global energy with wind, water, and solar power, Part I: Technologies, energy resources, quantities and areas of infrastructure, and materials, *Energ. Policy*, 39(3):1154–1169, 2011 DOI: http://doi.org/10.1016/j.enpol.2010.11.040

M. Z. Jacobson and M. A. Delucchi, Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies, *Energ. Policy*, 39(3):1170–1190, 2011 DOI: http://doi.org/10.1016/j.enpol.2010.11.045

E. Smalley, Water power to the people, *Nat. Energy*, 1:16092, 2016 DOI: http://doi.org/10.1038/nenergy.2016.92

S. Waters and G. Aggidas, Tidal range technologies and state of the art in review, *Renew. Sustainable Energy Rev.*, 59:514–529, 2016 DOI: http://doi.org/10.1016/j.rser.2015.12.347

International Water Power and Dam Construction (magazine)

U.S. Geological Survey: Hydroelectric power water use