# Hydropower

## From Appropedia

**Hydropower** can be used to do electrical or mechanical work. It is made by taking water and using it to do useful work. Some of the work that it has been known to do is saw lumber, and grind grain. The water is usually transferred through a variety of ways; shafts, pulleys, wheels,cables and gears. The hydropower dates back to the Greeks who used vertical axis water wheels as early as 85 BC and horizontal axis wheels from 15 BC. The hydropower was the only source besides wind power to do useful work until the steam engine came along in the early 19th century.

A lot more can be found in the book on pages 409-415.

## Contents

# Small hydropower plants

## parameters for the determination of a project

For centuries, power from hydroelectric resources has been captured by man: it is in 1688, that the MARLY machine, build from 14 wheels and pipes, allowed to pump back water from the Seine, located at an altitude of 162m, to supply in the needs of the ponds and fountains of Versailles. Today, to transform hydropower to electrical power, it is possible to construct very large but also small-sized plants. This article lists the parameters to determine small hydroelectric facilities. They have a place in the process of the development of small communities and in the process of sustainable development because of the economy in terms of $CO^2$-emissions. See http://www.kuleuven.ac.be-ei-public-publications-EIWP900-09_fr.pdf

## Vocabulary and definitions

Classes of powerplants: The technical literature considers small power plants, those plants that generate a power output less than 2000kW or 2 MW. The small power plants are divided into mini power (maximum power output 500kW), micro-power (maximum power output of 100 kW) and pico-power (0.2 kw to 5kW). These powers outputs are to be considered as orders of magnitude because, depending on the country or region, different figures have been cited. The pico-plants have been installed mostly in Asia, Vietnam (120,000) and the Philippines.

| Country | Micro (kW) | Mini (kW) | Small (MW) | Source |
|---|---|---|---|---|
| United States | <100 | 100-1000 | 1-30 | Dragu, 2002 |
| China | <500 | - | 0,5-25 | Dragu, 2002 |
| Italy | - | - | <3 | European Commission, 2000 |
| Portugal,Spain, Ireland, Greece, Belgium | - | - | <10 | European Commission, 2000 |
| France | 5-5000 | - | <8 | European Commission, 2000 |
| India | <100 | 101-1000 | 1-1,5 | Dragu,2002 |
| ESHA-European Small Hydropower Association | <100 | 101-500 | 0,5-10 | ESHA,1998 |

[1]

Category: plants can also be classified as “along the waterstream” or “other”. The first, "along the waterstream" receives water from the river or stream without accumulation infrastructure (dam, pool, pond ...). The volume of water available for the turbine depends on the instantaneous waterflow of the river.

The amount of instantaneous waterflow of a river system depends on the rains, which is dependant on the season. The instantaneous waterflow varies from day to day with a minimum therof, located usually at the end of the dry season if it is marked. The concept of average flow has no interest in powerplants "along the waterstream", however, it does allow to better estimate the potential energyoutput of an infrastructure if an accumulation is envisaged. Low water flow, ie the minimum flow of the river during 24h states the minimal poweroutput potential of an installation. If the hydrological observations (measures of the flow of the river) are done for several years, it is possible to know the average minimum waterflow attained annually, or it is possible to observe it every 5 years, or -even more rare-, every 10 years. Indeed, the severity of the drought is variable depending on the year. A flow measure during 365 days can not indicate whether the observed minimum is an exceptional speed (either low or high) or rather an average minimum. The hydrological data may be essential for the design of the proposed small hydroelectric plant. A lack of flow and thus availability of water will lead to disillusionment when the installation is working due to the large gap between the expected power output and true available power. There is of course no need to seek accurate hydrological data if the power output of the proposed installation is well below the maximum power of the site chosen for the project. Given that the turbine is to be placed near the river, it is highly desirable to know the variations of water level, to avoid seeing water invading the facilities during floods.

## Listing of the main elements of an installation

An installation, no matter how small, always includes the following elements (following the flow of water):

1. a main water intake which ensures that as long as there is water in the river, it is directed towards the power plant. This intake is fitted with a valve that can cut the water supply in case of failure of the turbine or in case of repairs of the infrastructure.
2. an intake channel more or less long will lead water from the main water intake to the head intake or startup room. This channel can also create a greater drop height when choosing a suitable route.
3. the intake of the startup room ensures filling the pipeline linking the intake to the turbine. The correct creation of the startup room allows to keep the penstock submerged. The intake is foreseen of a emergency release to allow the evacuation of excess water by reducing the water needs of the turbine.
4. the penstock (pipe between the intake of startup room and turbine) creates the water column which allows the startup of the turbine. This pipeline usually of steel for conventional plants, but can be carried out in polyethylene for pico-power. Its diameter is calculated to avoid loss of charges in the flow of water. A large pipe is expensive in purchase and placement but reduces the loss. When the height of the water column is low, there is no penstock but a concrete construction in which water flows to supports the water column.

5. the turbine room of the facility, is a kind of wheel that is rotated by the flow of water flowing through it. The type of wheel is to be chosen depending of the given instantaneous waterflow, but also depending of the water pressure. Some of these turbines resemble the old bucketwheels are particularly suitable for plants that need to operate with significant waterflow variations. The turbines may be vertical or horizontal axis.
6. The speed regulator controls the speed of the turbine. In times of normal operation, speed is a balance between the hydraulic load that turns the turbine and the resistive load of the electricity production. In case of a ruptured electrical circuit, the resistive electrical is canceled and the speed of the turbine will accelerate because the hydraulic load remains unchanged. Too much speed can be fatal to the equipment and the presence of the regulator corrects the beginning of the acceleration also called the runaway.
7. The electricity generator, is another essential part as it will convert the mechanical energy of the turbine into electrical energy. This conversion into electricity facilitates the provision on places that can be removed from the turbine. Today, the generator is an alternator that provides alternating current, a type of electricity that is more widespread than direct current. To provide an alternating current conforming to the needs of network users, the alternator must turn in a speed range set by the manufacturer. Between the generator and the turbine, which rotates much more slowly, a gearbox is installed to make the operation of the two machines compatible. The generator is set synchronous or asynchronous, as determined or set on the frequency of the cycles of current of the network, being 50 cycles per second except on the American continent where it is 60 cycles. If the plant is the only or main power source of the network, install a synchronous alternator.

8. Electrical cabinet for control and distribution. For the safety of the facilities and also the people, one should distribute the current on the network via a switchboard where the devices (fuses, disconnectors) allow the controlling of the distribution. At the other end of the network similar equipment should be installed to control the distribution with the client.
9. The electrical distribution network includes wiring that allows the transport of the power to the users. This network is either low voltage, ie operating voltage of client devices, or high voltage. This is necessairy when the transport distance is over 500m. Indeed, to carry 20 kW at a voltage of 220V, one requires a 90 amp electrical cable of at least 10mm2 section. If the voltage is 5000V, a section of 1mm2 is sufficient. The cost of this cable will probably be cheaper than the other one.
10. The leakage channel is the route of escape of the water that has gone trough the turbine. This channel is connected to the stream that resupplies the watervolume that is diverted to the water intake. It is important that this channel is not flooded in case of riverflood. Indeed, the rise of water level can cause flooding of the engine room (generator and turbine) with a risk of damage.

Other equipment to provide is an sand trap on the feeder canal. The grains of sand that accompany the water on the turbine have an abrasive effect that reduces the life of the machine. The biggest materials (stones, bricks) have an even more destructive effect and gratings should be installed at the entrance to the intake line but also at the penstock to prevent such incidents.

## Key criteria for evaluating the hydropower potential

### amount of waterflow and drop height; remoteness of the consumers

When a need of power emerges, we should seek one site or several sites that could host a hydroelectric powerplant. We understand that the research begins by identifying all sources of energy such as wind, solar, biomass and so on. Our preposition considers the conclusion of this inventory as a preceeding to the decision to install a hydroelectric plant, perhaps in addition to wind turbines or solar energy collectors.

A power plant demands a drop height and a waterflow. Terrain reconnaissance on the field or on topographic map pinpoints the locations of both waterflow and a slope of the terrain. These spots are easily identified on the ground where the river flows torrentially but other locations may also be appropriate. The extent of the drop is easily to determine for a surveyor by means of a theodolite. However, the estimation of the available waterflow is much more difficult because of its variation depending on the season (see instantaneous flow and low waterflow above). It is wise to underestimate the rate available because the powerplant should also not take off all water from the network. For example, in complete removal, the aquatic biotope will be severely disrupted by lack of water and make the spawning of fish impossible. Therefore, a reserve of waterflow should be left in the river to avoid biological depletion. It is possible that other -already authorized- waterusages impose a higher reserve waterflow.

When several sites are identified, the remoteness of the consumer is another criteria for inclusion in the feasibility analysis. Remoteness means a longer power line and makes monitoring of the plant more difficult. An electrical power line represents a important expense and is a source of powerloss.

## Determining the powerpotential of a site

The following mathematical formula allow to estimate the hydropower potential:

$P = 10xQxHxr$

Knowing that: P expresses the electrical power in kilowatt-hour of the current generator; Q expresses the waterflow in the penstock in m³/sec; H expresses the difference in water level between the entrance to the penstock and the leakage channel of the turbine, expressed in meters; R is the overall efficiency of the facility, including the loss of load in the penstock, the turbine efficiency and alternator efficiency. A total efficiency of 60% is acceptable for the estimated hydroelectric potential.

As an example, with Q being 0,1 m³/sec and H being 10m we get a potential of 6kWh.

The efficiency of the turbine is a charisteristic of the machine given by the manufacturer. This efficiency depends on the waterflow. Indeed, if the inflow is, for example, only half of the expected speed (or nominal waterflow), it is easy to understand that the piece of the waterflow that will run between the rotating parts and the fixed parts without reacting on the blades of the machine does little or nothing. So the effective waterflow drops sharply and leads to an efficiency drop.

The potential of a site can be improved if the hydroelectric equipment is not a hydroelectric facility along the waterstream but equipped with an accumulation pond. In these circumstances it is possible to, for a few hours of the day, provide sufficient waterflow for periods of greater consumption of electricity. When the population of the village sleeps, they generally consume much less electricity. This decrease in electricityrequirements accompanies, trough the speedregulator discussed above, a decrease in waterconsumption. The saved amount can be used at times of greater need. This accumulation pond should be considered in the context of a daily regulation. If deals around overcoming the insufficiencies of low water flows, the accumulation intake reaches a size that is outside the context of small power plants.

## Assessment of electricity needs

It is difficult at first to estimate the effective electricity output since it depends on the project which is associated with the construction of the hydroelectric powerplant. It is known that the provision of electricity promotes its use. Without any regulation system of the consumption (limiting the amount available to the consumer via electrical switchboard, billing of the consumption). The lighting of offices is an important element for the development of the electricity grid, as well as the sponsoring of communication facilities such as the telephone network, operation of television channels, computers. The electrical energy is also useful to activate the cooling chain (storage of medicines, vaccines ...). Foremost, we must exclude, in the context of a micro-powerplant, thel use of electricity as a means of heating because consumers will become prohibitive for the small network. To give a general idea however, an installed capacity of 2kW per family is a correct value to identify the electricity needs in a village community. However, Vietnamese experience transposed to the Philippines cites lower values. Once the provision of electricity for a workshop is also considered, it is sufficient to determine the installed capacity to the whole of the envisaged equipment. In the case of a carpentry, engines consuming more than 1500W are common. It is also possible to set, among the regular customers of a small network, priority clients such as those that manage a cooling chain for vaccines and drugs, or a surgical hospital. These customers will be supplied as long as possible. These provisions should be exposed to all users as a way to maintain cohesion and avoid conflicts. This regulating system allows to supply electricity to more customers but for a more limited period.

## Constraints for exploitation

1. A small hydroelectric powerplant is very expensive to install, around 1500 € to 3000 € per installed kW; operating costs are however quite low. The material is generally robust and lasts a lifetime if regular maintenance is exerciced for several decades. If we sign up for the perspective of a sustainable development, we should consider that in terms of the economic life-expectancy of the facility, the replacement of the facility will be incorporated by the users of the network agreeing to pay for the supplied power. The billing of the consumption allows to build up the needed capital for the maintenance and future replacement; it avoids abusive consumptions. About the pricing, it must be designed in function of the objectives of the powerplant project. About the pricing, we suggest progressive pricing (the more one consumes, the more the price per kW is increased, obviously within certain limits) which reduces the risk of waste, and sectorial pricing (collective or community consumptions are are charged at more favorable rates). See http://www.ciele.org/filieres/hydraulique.htm
2. Operating costs are low if the facility is regularly maintained: the damaged parts are replaced quickly (stock of spare parts), abnormal wear is investigated to identify the causes. Losses on the network are eliminated without delay.
3. Who says maintenance, says manager and personnel trained for the task at hand.

4. Control of consumption and illegal connections are punished. A too great consumption (overloading the network) will lead to a voltage drop that can cause damage to connected equipment, especially engines. The client is asked to sign a service contract which stipulates his rights and obligations.
5. Public information campaign on things to avoid and prevention: The area of the water intake in the river is to be avoided by the other users of the river (risk of getting caught up in the waterflow and risk of drowning); intake channel may be used for other purposes (laundry, irrigation), the manager informs the public to incidents such as blocked grates, overflow, etc ... The practice of bathing is regulated or prohibited in the absence of a basin with restraints to prevent the risk of drowning or sudden spills of large volumes of water. Information on the dangers of electrocution will be presented at both the facility and at the home.
6. In the spirit of sustainable development, the facility must take into account other water uses , both existing or planned, at the time of the drafting of the powerplant project. The sharing of the water must be done fairly; ie on the basis of criteria that all stakeholders comply to.
7. Estimates of budget, deadline for implementation: From an average unit cost of 2000 €/kW installed, it is easy to estimate the investment budget for 10, 100 or 1000kW, as being € 20,000 to € 2,000,000. On the other hand, pico-powerplants of 300W are sold in Vietnam for U.S.D. $20 and are very popular. It is likely that the complexity of a facility of more than 100kW extends the delay of realisation because of forgoing feasibility studies, which probably increases the quality and reliability of the project. Compact installation kits are sold in commerce, requiring only a minimum of know-how for the installation. This equipment series offers the advantage of being available quickly and to be well calibrated for operating conditions. Unless you have control of

all parameters (location, project funding, expertise for the construction of infrastructure), an installation project requires several years between the first sketches on paper and the effective operation of the distribution network.

8. Small powerplants and local development: Many places on earth are not yet equipped with electric network due to lack of interest (economic or political) to install utilities. The low population density is one of the main reasons for this lack. A micro-powerplant offers a solution for decentralised development where the local undertaker or local authorities can act autonomously. A well designed and well maintained installation offers a very low return price, within the reach of small and medium enterprises. The social impact of these small facilities is considerable in the fight against poverty. See http://www.tve.org/ho/doc.cfm?aid=1636&lang=English

The Chinese authorities have helped a great amount of areas removed or isolated from major electricity distribution networks in acquiring small powerplants. Similar projects have been developed, especially in Kenya. These measures allow the local population to develop activities that meet their expectations and to avoid, for example, migration to the already congested suburbs of major cities. These populations can emerge from the isolation, communicate with the rest of the world and participate in the evolution.

# References

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