MICRO-HYDROPOWER SYSTEMS

Dušan Medveď, Marek Hvizdoš

ABSTRACT

This paper deals with the basics of how a micro-hydropower system works and introducing of the principal components of a micro-hydropower system.

1. INTRODUCTION

Flowing and falling water have potential energy. Hydropower comes from converting energy in flowing water by means of a water wheel or through a turbine into useful mechanical power. This power is converted into electricity using an electric generator.

Micro-hydropower systems are relatively small power sources that are appropriate in most cases for individual users or groups of users who are independent of the electricity supply grid. Hydropower systems are classified as large, medium, small, mini and micro according to their installed power generation capacity. Electrical power is measured in watts (W), kilowatts (kW) or megawatts (MW). A micro-hydropower system is generally classified as having a generating capacity of less than 100 kW. Systems that have an installation capacity of between 100 kW and 1000 kW (1.0 MW) are referred to as mini-hydro. Small hydro is defined as having a capacity of more than 1.0 MW and up to 10 MW.

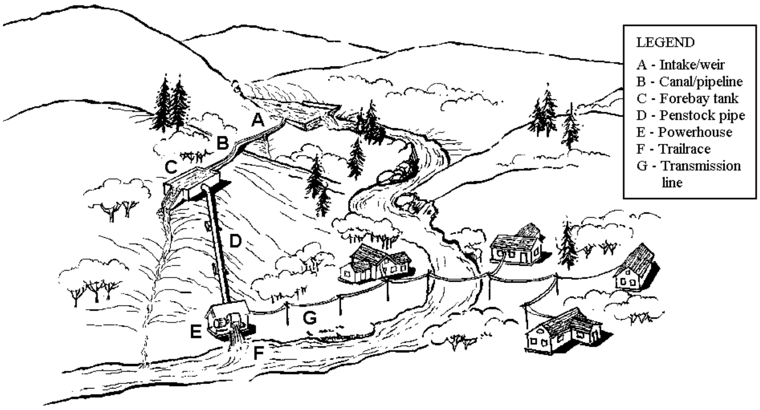

Fig. 1 Principal components of a micro-hydropower system

Micro-hydro systems have the following components:

- ***a water turbine*** that converts the energy of flowing or falling water into mechanical energy that drives a generator, which generates electrical power – this is the heart of a micro-hydropower system
- ***a control mechanism*** to provide stable electrical power
- ***electrical transmission lines*** to deliver the power to its destination

Depending on the site, the following may be needed to develop a micro-hydropower system (see Fig. 1):

- ***an intake*** or ***weir*** to divert stream flow from the water course
- ***a canal***/***pipeline*** to carry the water flow to the forebay from the intake
- ***a forebay tank*** and ***trash rack*** to filter debris and prevent it from being drawn into the turbine at the penstock pipe intake
- ***a penstock pipe*** to convey the water to the powerhouse
- ***a powerhouse***, in which the turbine and generator convert the power of the water into electricity
- ***a tailrace*** through which the water is released back to the river or stream

Many micro-hydropower systems operate “run of river,” which means that neither a large dam or water storage reservoir is built nor is land flooded. Only a fraction of the available stream flow at a given time is used to generate power, and this has little environmental impact. The amount of energy that can be captured depends on the amount of water flowing per second (***the flow rate***) and the height from which the water falls (***the head***).

2. PLANNING FOR A SYSTEM

If somebody is thinking seriously about installing a micro-hydropower system, he will want to plan a system that is sure to meet his energy and power needs. There are also various planning stages that are needed to consider. Many factors contribute to a successful micro-hydropower system.

2.1 Measuring of Potential Power and Energy

The first step is to determine the hydro potential of water flowing from the river or stream. It ineede to know the **flow rate** of the water and the **head** through which the water can fall, as defined in the following:

The **flow rate** is the quantity of water flowing past a point at a given time. Typical units used for flow rate are cubic metres per second (m^3/s) or litres per second (lps).

The **head** is the vertical height in metres (m) from the level where the water enters the intake pipe (penstock) to the level where the water leaves the turbine housing (see Fig 2).

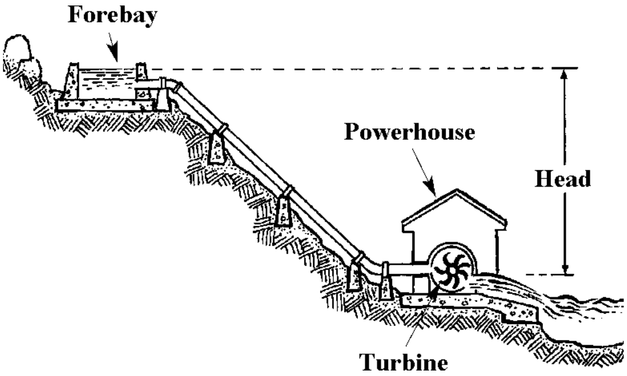

Fig. 2. Head of a micro-hydropower system

Power calculation

The amount of power available from a micro-hydropower system is directly related to the flow rate, head and the force of gravity. Now there must be determined the usable flow rate (the amount of flow that can be diverted for power generation) and the available head for the particular site, it can be calculated the amount of electrical power that can be expected to generate. This is calculated using the following equation:

$$P_{th} = Q \cdot H \cdot g \qquad (1)$$

Where:

Where:	P_{th}	theoretical power output; [kW]
	Q	usable flow rate; [m^3/s]
	H	gross head; [m]
	g	gravitational constant (9,8 m/s^2)

Example 1

A site has a head of 10 m with flow of 0,3 m^3/s; therefore, the potential power output is given by $Q \times H \times g$ (0,3 × 10 × 9,8), which is 29,4 kW.

This is only the theoretical available power, assuming that 100 percent of the power available in the water can be usefully converted. ***Efficiency of the system*** also needs to be taken into account. Energy is always lost when converted from one form to another, and all of the equipment used to convert the power available in the flowing water to electrical power is less than 100 percent efficient. To calculate the most realistic power output from the site, there must be taken into account the friction losses in the penstock pipes and the efficiency of the turbine and generator.

When determining the head, it is needed to consider gross head and net head. Gross head is the vertical distance between the top of the penstock that conveys the water under pressure and the point where the water discharges from the turbine. Net head is the available head after subtracting the head loss due to friction in the penstock from the total (gross) head (net head = gross head – losses in the penstock). Small water turbines rarely have efficiencies better than 80 percent. Potential power will also be lost in the penstock pipe that carries the water to the turbine because of frictional losses. Through careful design, however, this loss can be reduced to a small percentage; normally, the losses can be kept to 5 to 10 percent. Typically, overall efficiencies for electrical generation systems can vary from 50 to 70 percent, with higher overall efficiencies occurring in high-head systems. Generally, overall efficiencies are also lower for smaller systems. As a rule, the "**water to wire**" efficiency factor for small systems (for example, up to 10 kW) could be taken as approximately 50 percent; for larger systems (larger than 10 kW) the efficiency factor is generally from 60 to 70 percent. Therefore, to determine a realistic power output, the theoretical power must be multiplied by an efficiency factor of 0.5 to 0.7, depending on the capacity and type of system.

$$P = Q \cdot H \cdot g \cdot e \qquad (2)$$

Where: e efficiency factor (0,5 to 0,7)

Example 2

A turbine generator set to operate at a head of 10 m with flow of 0,3 m^3/s will deliver approximately 15 kW of electricity. This is given by $P = Q\ (0{,}3) \times H\ (10) \times g\ (9{,}8) \times e\ (0{,}5) = 14{,}7$ kW, assuming an overall system efficiency of 50 percent.

These calculations will give an idea of how much power there can be obtained from the water resource. Table 1 shows how much electrical power you can expect with various heads and water-flow rates.

Table 1. Typical Power Output (in Watts) With Various Head and Water-Flow Rates

	Flow Rate [lps]									
Head [m]	**5**	**10**	**15**	**20**	**40**	**60**	**80**	**100**	**150**	**200**
1	25	49	74	98	196	294	392	490	735	980
2	49	98	147	196	392	588	784	980	1470	1960
4	98	196	294	392	784	1176	1568	1960	2940	3920
8	196	392	588	784	1568	2352	3136	3920	5880	7840
10	245	490	735	980	1960	2940	3920	4900	7350	9800
15	368	735	1103	1470	2940	4410	5880	7350	13230	17640
20	490	980	1470	1960	3920	5880	7840	9800	17640	23520
30	735	1470	2205	2940	5880	8820	14112	17640	26460	35280
40	980	1960	2940	3920	7840	14112	18816	23520	35280	47040
60	1470	2940	4410	5880	14112	21168	28224	35280	52920	70560
80	1960	3920	5880	7840	18816	28224	37632	47040	70560	94080
90	2205	4410	6615	8820	21168	31752	42336	52920	79380	105840
100	2450	4900	7350	9800	23520	35280	47040	58800	88200	117600

3. BASIC COMPONENTS OF A MICRO-HYDROPOWER SYSTEM

Basic components of a typical micro-hydro system are as follows:

- ***civil works components*** (headwork, intake, gravel trap with spillway, headrace canal, forebay, penstock pipe, powerhouse and tailrace)
- ***powerhouse components*** (turbines, generators, drive systems and controllers)
- ***transmission/distribution network***

3.1 Civil Works Components

Civil works structures control the water that runs through a micro-hydropower system, and conveyances are a large part of the project work. It is important that civil structures are located in suitable sites and designed for optimum performance and stability. Other factors should be considered in order to reduce cost and ensure a reliable system, including the use of appropriate technology, the best use of local materials and local labour, selection of cost-effective and environmentally friendly structures, landslide-area treatment and drainage-area treatment.

3.2 Powerhouse Components

A turbine unit consists of a runner connected to a shaft that converts the potential energy in falling water into mechanical or shaft power. The turbine is connected either directly to the generator or is connected by means of gears or belts and pulleys, depending on the speed required for the generator. The choice of turbine depends mainly on the head and the design flow for the proposed micro-hydropower installation. The selection also depends on the desired running speed of the generator.

Other considerations such as whether the turbine is expected to produce power under part-flow conditions also play an important role in choosing a turbine. Part-flow is where the water flow is less than the design flow. All turbines tend to run most efficiently at a particular combination of speed, head and flow. In order to suit a variety of head and flow conditions, turbines are broadly divided into four groups (high, medium, low and ultra-low head) and into two categories (impulse and reaction).

Table 2. Group of Water Turbines

Turbine Runner	**High Head (more than 100 m)**	**Medium Head (20 to 100 m)**	**Low Head (5 to 20 m)**	**Ultra-Low Head (less than 5 m)**
Impulse	Pelton Turgo	Cross-flow Turgo Multi-jet Pelton	Cross-flow Multi-jet Turgo	Water wheel
Reaction	-	Francis Pump-as-turbine	Propeller Kaplan	Propeller Kaplan

Water Wheels

Water wheels are the traditional means of converting useful energy from flowing and falling water into mechanical power. Although not as efficient as turbines, they are still a viable option for producing electricity for domestic purposes. They are simple to control, lend themselves to do-it-yourself projects and are aesthetically pleasing. There are three basic types of water wheels: undershot, breastshot and overshot. Variations are Poncelet and pitchback types. The major disadvantage is that they run relatively slowly and require a high ratio gearbox or other means of increasing the speed if they are to drive a generator.

Turbine Efficiency

Typical efficiency ranges of turbines and water wheels are given in Table 3. Turbines are chosen or are sometimes tailor-made according to site conditions. Selecting the right turbine is one of the most important parts of designing a micro-hydropower system, and the skills of an engineer are needed in order to choose the most effective turbine for a site, taking into consideration cost, variations in head, variations in flow, the amount of sediment in the water and overall reliability of the turbine.

Table 3. Typical Efficiency of Turbines and Water Wheels

Prime Mover	**Efficiency Range**
Impulse turbines:	
Pelton	80 - 90 %
Turgo	80 - 95 %
Cross-flow	65 - 85 %
Reaction turbines:	
Francis	80 – 90 %
Pump-as-turbine	60 – 90 %
Propeller	80 – 95 %
Kaplan	80 – 90 %
Water wheels:	
Undershot	25 – 45 %
Breastshot	35 – 65 %
Overshot	60 – 75 %

3.3 Drive Systems

In order to generate electrical power at a stable voltage and frequency, the drive system needs to transmit power from the turbine to the generator shaft in the required direction and at the required speed. Typical drive systems in micro-hydropower systems are as follows:

- ***Direct drive***: A direct drive system is one in which the turbine shaft is connected directly to the generator shaft. Direct drive systems are used only for cases where the shaft speed of the generator shaft and the speed of the turbine are compatible. The advantages of this type of system are low maintenance, high efficiency and low cost.
- ***"V"*** or ***wedge belts and pulleys***: This is the most common choice for micro-hydropower systems. Belts for this type of system are widely available because they are used extensively in all kinds of small industrial machinery.
- ***Timing belt*** and ***sprocket pulley***: These drives are common on vehicle camshaft drives and use toothed belts and pulleys. They are efficient and clean-running and are especially worth considering for use in very small system drives (less than 3 kW) where efficiency is critical.
- ***Gearbox***: Gearboxes are suitable for use with larger machines when belt drives would be too cumbersome and inefficient. Gearboxes have problems regarding specification, alignment, maintenance and cost, and this rules them out for micro-hydropower systems except where they are specified as part of a turbine-generator set.

3.4 Transmission/Distribution Network

The most common way of transporting electricity from the powerhouse to homes is via overhead lines. The size and type of electric conductor cables required depends on the amount of electrical power to be transmitted and the length of the power line to the home. For most micro-hydropower systems, power lines would be single-phase systems. For larger systems, the voltage may need to be stepped up using a transformer or a standard three-phase system in order to reduce transmission losses. Depending on the environment and geographical conditions, you may even need to consider an underground power line, which generally costs considerably more than overhead lines but may be safer.

4. CONCLUSION

Hydroelectric generation may offer an opportunity for farms off the utility power grid to supply their own electrical energy at a lower cost than running an engine/generator or than extending the grid to their property. However systems may only be possible when it is appropriate to pay a premium over utility electrical rates as electrical cost per kWh (especially for small systems) may be greater than the utility rate.

Unlike the seasonal fluctuations of solar and wind energy, micro-hydro power can provide constant year-round electricity for boats or remote locations lucky enough to have constant running water. Like most alternative energy sources, micro-hydro power is emission-free and very low-impact on the environment.

For commercial and industrial use, a micro-hydro generator could be used to power river signal buoys, or any riverside installations, as well as commercial marine applications.

5. REFERENCES

[1] Natural Resources Canada: Micro-Hydropower Systems: A Buyer’s Guide, 2004, Cat. No. M144-29/2004E, ISBN 0-662-35880-5. available on internet < http://www.aea.nt.ca/tips/documents/MICRO-HYDRO.pdf >

[2] Lance Brown: ON-FARM HYDROELECTRIC GENERATION. [online], Order No. 430.200-1, May 2006. [published: May 2006], [cited: June 2006], available on internet < http://www.agf.gov.bc.ca/resmgmt/publist/400series/430200-1.pdf >

[3] Celso Penche: Layman's guide on how to develop a small hydro site. Commission of the European Communities, Directorate-General for Energy by European Small Hydropower Association (ESHA). 1997. ISBN DG XVII - 97/010, available on internet < http://microhydropower.net/download/layman2.pdf >

This work was supported by Scientific Grant Agency of the Ministry of Education of Slovak Republic and the Slovak Academy of Sciences under the project VEGA No. 1/3141/06.

Author address:

Ing. Dušan Medveď
Katedra elektroenergetiky,
Fakulta elektrotechniky a informatiky, Technická Univerzita v Košiciach
Mäsiarska 74
042 01 Košice, Slovenská Republika
E-mail: Dusan.Medved@tuke.sk
Tel: +421 55 602 3560

Ing. Marek Hvizdoš, PhD.
Katedra elektroenergetiky,
Fakulta elektrotechniky a informatiky, Technická Univerzita v Košiciach
Mäsiarska 74
042 01 Košice, Slovenská Republika
E-mail: Marek.Hvizdos@tuke.sk
Tel: +421 55 602 3556