UNDERSTANDING MICRO-HYDROELECTRIC GENERATION

by
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Technical Reviewers:
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PREFACE

This paper is one of a series published by Volunteers in Technical Assistance to provide an introduction to specific state-of-the-art technologies of interest to people in developing countries. The papers are intended to be used as guidelines to help people choose technologies that are suitable to their situations. They are not intended to provide construction or implementation details. People are urged to contact VITA or a similar organization for further information and technical assistance if they find that a particular technology seems to meet their needs.

The papers in the series were written, reviewed, and illustrated almost entirely by VITA Volunteer technical experts on a purely voluntary basis. Some 500 volunteers were involved in the production of the first 100 titles issued, contributing approximately 5,000 hours of their time. VITA staff included Maria Giannuzzi and Leslie Gottschalk as editors, Julie Berman handling typesetting and layout, and Margaret Crouch as project manager.

The author of this paper, Christopher S. Weaver, P.E., is a senior engineer with Energy and Resource Consultants, an interdisciplinary consulting firm in Boulder, Colorado. He is a registered Professional Engineer, and has worked in the areas of electric-utility planning, solar energy, cogeneration, and air-pollution control as well as in small hydroelectric systems as a consultant. Weaver is the author of another VITA technical paper, Understanding Mini-Hydroelectric Generation. The reviewers of this paper are also technical experts in hydroelectricity. Theodore Alt, P.E., is a mechanical engineer who has been in the energy field since 1942. He has worked with the energy research and development group of the Arizona Public Service Company and the Government of Mexico's elrctric commission. Paul N. Garay, an associate engineer with F.M.C. Associates, has written many papers on various aspects of water transportation and energy uses of water.

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UNDERSTANDING MICRO-HYDROELECTRIC GENERATION

by VITA Volunteer Christopher Weaver

I. INTRODUCTION

GENERAL BACKGROUND

The power of flowing water can be used to generate electricity, or to do other kinds of useful work. Generating electricity in this way is called hydroelectric generation. It can be done anywhere that there is water and a hill or drop for it to run down, such as a drop in an irrigation canal, a place where a river runs through rapids or over a waterfall, or where a dam has backed up water above the level of the river, to name just a few examples. Hydroelectric generating plants come in all sizes--from huge plants that produce more electricity than most nations can use to very small plants that supply electricity for a single house. The smallest hydroelectric plants are often called micro-hydroelectric plants, or micro-hydro for short. Larger plants are usually called mini-hydro plants. Other names for this size of plant are "small-scale hydro" and "small hydro."

This report deals only with micro-hydroelectric plants. Micro-hydro is usually defined as having a generating capacity of up to about 15 kilowatts (KW). This is about enough power for 6 or 8 houses in a developed country, or it can provide basic lighting and other services to a village of 50 to 80 houses. Micro-hydro generation is best suited to providing small amounts of power to individual houses, farms, or small villages in isolated areas. Mini-hydro systems are larger. They can range from about 15 KW up to 15,000 KW, which is enough electric power for a medium-sized town, or for a whole rural region. However, the difference between mini-hydro and micro-hydro plants is not just size.

In general, micro-hydro plants use much simpler and lower cost technology than mini-hydro plants. For this reason, micro-hydro plants are usually well suited to village level development and local self-help projects. With their simpler technologies, they can usually be built by people without much special training, using mostly local materials and skills. They are usually lower in cost than mini-hydro and conventional hydro plants, but they are also less efficient, and the quality of the electricity is not as good. Mini-hydro plants, on the other hand, cost more, but they produce the same constant-frequency alternating current (AC) electricity as large electric power systems, so that they can even be interconnected with a larger system.

Micro-hydro plants generally produce low-voltage direct current (DC) electricity, or else low-voltage variable-frequency AC (these technical terms are defined in the section on electric power below). These kinds of electricity are suited to running lights, small motors, and electric cookers, but not to running large motors, many appliances, or most industrial machinery. Perhaps most importantly, micro-hydro plants cannot be interconnected with other generating plants in an electric system the way mini-hydro and large hydro plants can. Special machines called inverters can convert DC power to the AC power used in large electric systems, but these are expensive and have limited capacity. If you expect to need a fairly large amount of power, if you need to interconnect with a power line, or if you require high reliability, you should probably consider mini-hydro instead. Another VITA technical paper, Understanding Mini-Hydroelectric Generation talks about mini-hydro.

HISTORY OF HYDROELECTRIC GENERATION

Water wheels have been used since ancient times to supply power for grinding grain and other laborious tasks. The first modern hydraulic turbines were developed in the first part of the 19th century by Fourneyron in France. These were further developed by a number of researchers during the middle of the century, so that by 1890 most of the types of turbines now in use had been invented. Thomas Edison's invention of the electric light and of ways to distribute electricity occurred at about the same time, leading to a great boom in hydroelectric development in Europe and North America. Until about the 1920s, most hydroelectric developments were quite small--in the size range which is now called mini-hydro or even micro-hydro. This was for two reasons: people didn't know how to build really large dams and turbines, and the small electric transmission systems of the time made it difficult to sell large amounts of electricity. Generally, mini-hydro systems would be used to power a town and its surrounding area, while micro-hydro systems were used on isolated farms and ranches to provide power.

During the era of the 1950s and 1960s, advancing technology and cheap oil, combined with improved long-distance electric transmission, made it possible to sell electricity cheaper than the earlier small hydro plants could make it. Many hundreds of small hydroelectric facilities were abandoned or dismantled during this period. With the oil embargo of 1973, which has led to enormous increases in the cost of oil, small hydro once again appears competitive. Many of the early plants which were abandoned in the 1950s and 1960s are now being refurbished, and many new ones are being planned. Small hydro is also well suited for developing countries, and is being actively encouraged by many governments and development organizations in order to reduce oil imports and encourage development. Micro-hydro has a special role to play in developing countries, since it makes it possible to provide lighting, power, and communications (such as television and radio) even in areas far from the main electric power systems. Micro-hydro can thus play an important role in promoting rural development in remote areas.

II. HYDROPOWER FUNDAMENTALS

This section presents a few basic facts and principles about electric power and hydroelectric generation. Reading it will not make you into a hydroelectric engineer, but it will help you understand how hydroelectric systems work, and what makes a good or a bad hydroelectric site. It will also help you to understand the more detailed technical material that you will need to read if you decide to build a micro-hydro plant.

BASIC PRINCIPLES

Electric Power

Power is defined as an amount of energy divided by the time it takes to supply the energy, or in other words as the rate at which energy is delivered. Power is measured in units called **watts**, or (for large amounts of power) in units of **kilowatts**. One kilowatt is equal to 1,000 watts. Power is also measured in **horsepower**. One horsepower equals 746 watts.

Two other quantities that are important in talking about electric power are the **electric current** and the **voltage**. Electric current can be thought of as the amount of electricity flowing through a wire (like the amount of water flowing through a pipe), while voltage can be thought of as a measure of how much force is needed to push the current. Current is measured in **amperes**, or amps for short, while voltage is measured in **volts**. The electric power (in watts) is equal to the product of the current and the voltage, so that a current of 1 amp with a voltage of 100 volts would give a power of (1 x 100) = 100 watts.

Two types of electricity are commonly used. **Alternating current** (AC) electricity is generated in a way that makes it change directions (alternate) many times each second. The number of times it changes direction is called the **frequency**. **Direct current** (DC) electricity does not change directions; it always flows the same way.

Large electric power systems and many small ones use alternating current, in order to be able to use **transformers** to change voltages up and down. Transformers will not work with direct current. On the other hand, batteries can produce only DC, so small electric systems which use batteries generally use DC current. AC can be converted into DC using a device called a **rectifier**, while DC can be changed into AC using an **inverter**.

Mini-hydro systems, and large electric power systems such as those in cities use alternating current. In these systems, the voltage and frequency of the electricity produced are carefully controlled to keep them constant. Adding more load to an operating power system (such as by turning on more lights) tends to slow the generators down, which causes the voltage and (for AC systems) the frequency to drop. Conversely, shutting off lights will reduce the load, permitting the generator to run faster. These systems must have some kind of an automatic control which detects when the speed changes, and takes action (such as letting more water into a turbine) to bring the generators back up to the right speed. These controls are expensive, and most micro-hydro systems don't have them. As a result, the generator speed and voltage in micro-hydro systems will change as people turn lights on and off, so it is a good idea to keep this to a minimum. Batteries can help this situation by providing extra power when the system is heavily loaded, and absorbing extra power when it is lightly loaded.

Electrical equipment is rated in terms of the voltage and the type of current it is designed for, and the maximum amount of power it can produce (for a generator) or use (for things that consume electricity, such as motors and light bulbs). A generator with a rating of 5 KW at 100 volts is designed to produce 50 amperes at 100 volts at full load, which is 5,000 watts or 5 KW. The same generator could also produce smaller amounts of power. The amount of power put out by the generator must be equal to the amount of power being used by the electrical equipment connected to it (unless you are using batteries to store some power). The voltage ratings and type of electricity (DC or AC) used for the electrical equipment should always be the same as the voltage and type of electricity being supplied. If you connect a device rated for one voltage to a wire at another voltage, it almost certainly will not work, and the device is very likely to be damaged. The same is true of connecting AC devices to DC. However, many DC devices such as light bulbs and motors can also be used with AC, if the voltage ratings are the same.

The amount of **energy** produced in a generator or used by an electrical machine can be calculated by multiplying the amount of power used by the length of time that it is used. Energy is measured in units of joules--one joule is equal to one watt times one second. One joule is a very small amount of energy, so we commonly use units like megajoules (one megajoule is one million joules) or kilowatt-hours (abbreviated KWH). A kilowatt hour is equal to one kilowatt provided for one hour, which is 3.6 million joules. As an example, a 5-KW generator, if it ran at full load for one hour, would produce produce five KWH of electric energy. If it ran for two hours, it would produce 10 KWH.

Mechanical Power

Mechanical power is the force that causes machinery and other things to move. The engine of a car produces mechanical power, and so does an electric motor. Mechanical power can easily be converted into electrical power (this is what a generator does), and electrical power can be converted back to mechanical power (this is done by an electric motor). Mechanical and electrical power are measured in the same units--watts and kilowatts.

Head, Flow Rate, and Power Output

Water at the top of a hill or drop has energy, called **potential energy**, because of where it is. This potential energy is measured in terms of the "head," which is the vertical distance from the water level at the top of the drop to the water level at the bottom. Figure 1 shows how head is measured.

In natural streams, the potential energy or head of the water is dissipated by friction against the stream bed as the water flows downhill, or by turbulence at the bottom. However, if we put in a smooth pipe from the top to the bottom to reduce friction, and then put in a water turbine at the bottom, we can use the head in the water to turn the turbine and produce mechanical power. The amount of power we can theoretically get is given by:

$$P_{th} = F \times H \times 9.807 \qquad \text{(Equation 1)}$$

where P_{th} is the theoretical power output in watts,
F is the rate of flow of water through the pipe in liters per second,
H is the head in meters, and
9.807 is the conversion factor that accounts for the force of gravity on the water.

However, turbines and generators are not perfectly efficient, so the amount of electric power we can actually get from a micro-hydro plant with a given head and flow rate is less than P_{th}. This amount is given by:

$$P_{act} = P_{th} \times E_t \times E_g \times E_s \qquad \text{(Equation 2)}$$

where P_{act} is the actual useful power output from the plant,
E_t is the efficiency of the turbine,
E_g is the efficiency of the generator, and
E_s is the efficiency of the rest of the electrical system.

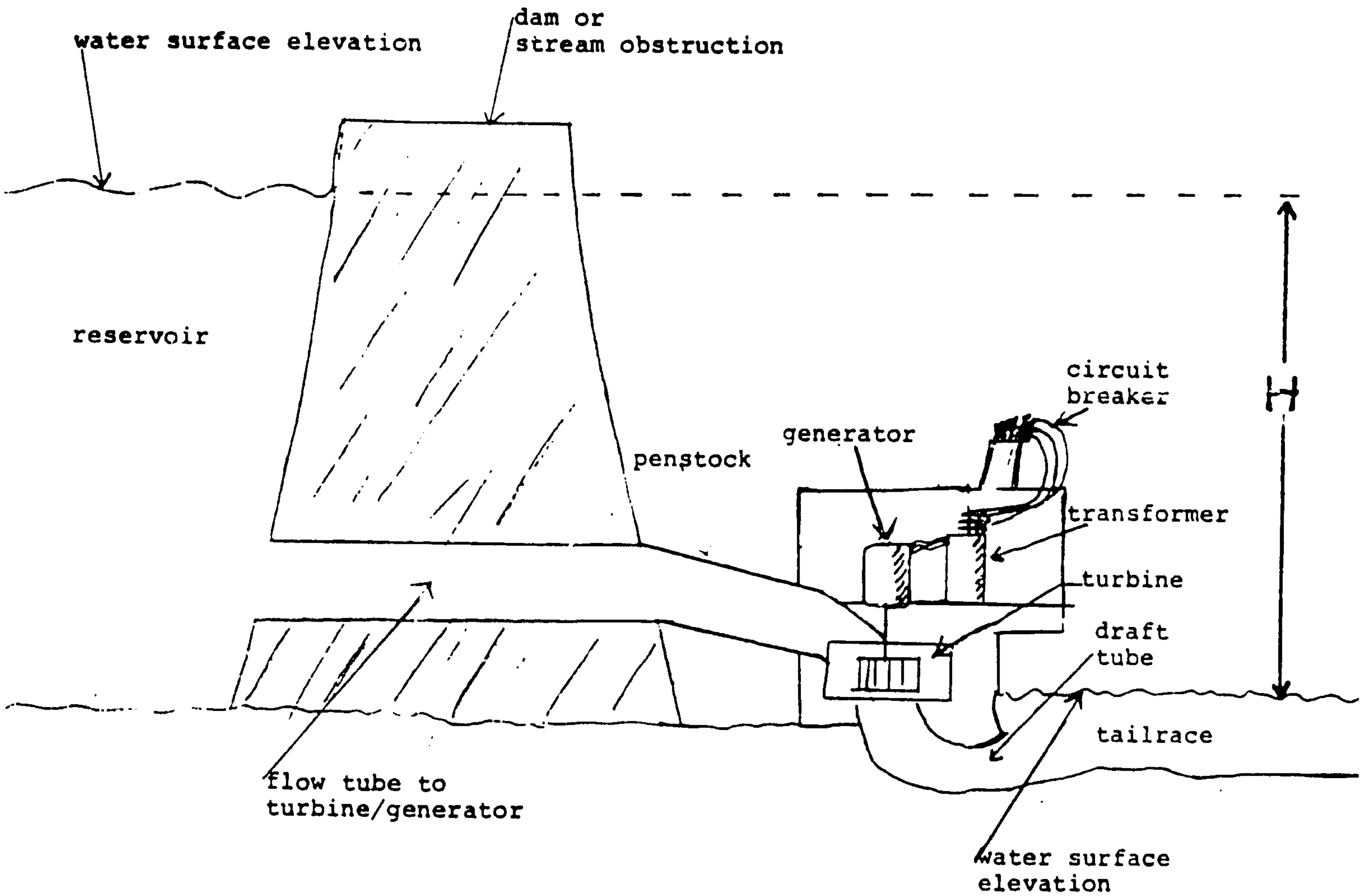

Figure 1. Typical Micro-Hydroelectric System Showing Major Components and Hydraulic Head

H = Head (in meters)

Efficiencies are always less than 1.0. Typically, E_t is about 0.85 for turbines from a specialized manufacturer, 0.6 to 0.8 for pumps used as turbines, and 0.5 to 0.7 for locally-built cross-flow turbines. E_g is usually 0.9 or more, for most kinds of generators. E_s will be about 0.9, unless you are transmitting power a great distance, or you are using an inverter, in which case it may be less.

Thus, a flow of 100 liters per second, with a head of 10 meters, could theoretically produce 100 x 10 x 9.807 = 9,807 watts, or 9.807 KW. With a turbine efficiency of 0.75, a generator efficiency of 0.9, and a system efficiency of 0.9, we would actually get 9,807 x 0.75 x 0.9 x 0.9 = 5,958 watts of useful power. The rest would be lost due to inefficiencies in the system.

III. MICRO-HYDROELECTRIC SYSTEMS AND COMPONENTS

There are many variations of micro-hydro systems. Some of the factors that will affect the kind of system you decide to build are: the amount of power you need; the amount of flowing water available; the available head; the source of the water (from an irrigation canal, a pipeline, behind a dam, or from a free-flowing river or stream); how much money you can afford to spend; and the manual skills and local materials available to you. This section describes the major components of a micro-hydro system, and explains some of the different choices.

BASIC SYSTEM LAYOUT

All micro-hydro systems, whatever their other differences, have a number of features in common. Each must have a source of water, and a place to put the water afterwards (the discharge). The source must be higher than the discharge; the greater the difference in height, the greater the available head will be. In addition, there must be some means of getting the water from the source to the power-plant, and then from the power plant to the discharge. Finally, there must be the power plant itself, which will contain one or more turbines driven by the flowing water, and one or more generators driven by the turbines. Alternatively, the turbines can supply mechanical power to drive some other machinery, such as a mill or saw, directly, without converting the mechanical power into electrical power and back. Sometimes, systems are arranged to supply mechanical power during the day, and then supply electricity for lighting at night.

Figure 2 is a sketch of a typical micro-hydroelectric system, showing the major components. Not all systems will have all of these components, however.

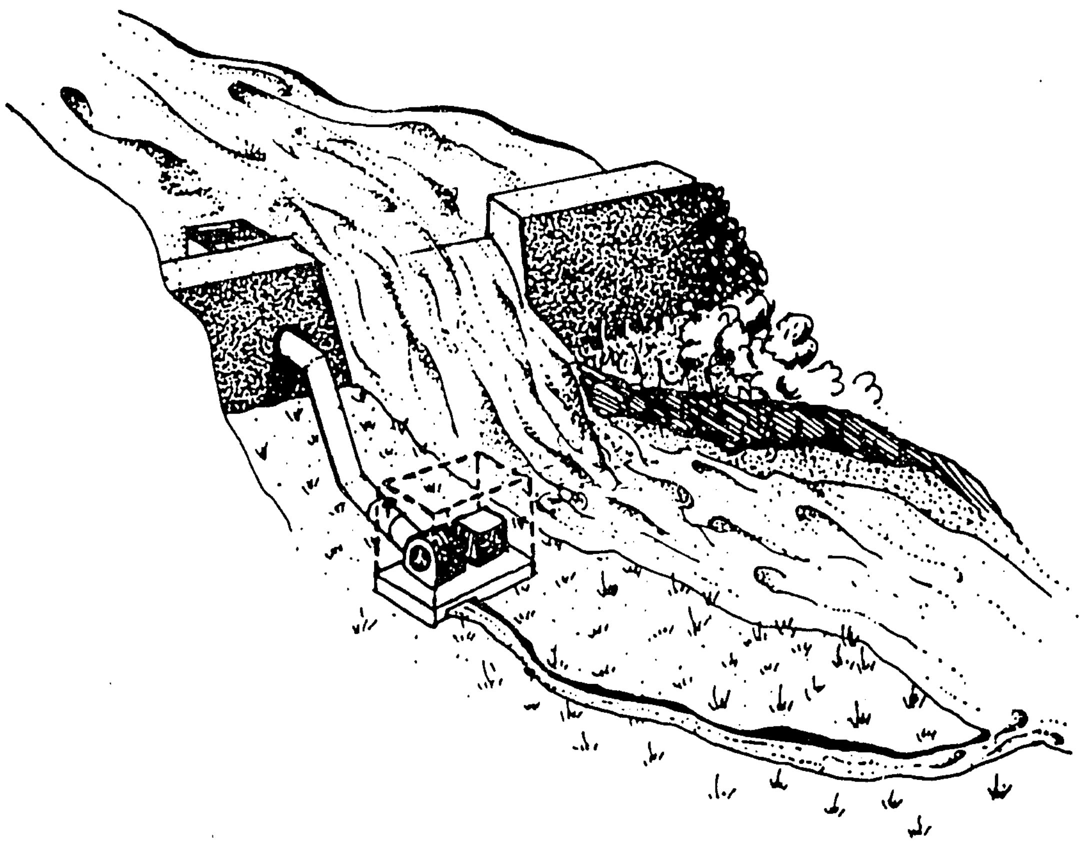

Figure 2. A Micro-Hydro Power System

Beginning at the source of the water, the water must first be collected and channelled to the turbine. Water may be backed up behind a **dam** (as shown in Figure 2), or diverted out of a flowing stream by some kind of **diversion structure**. After it is diverted, it flows into a canal, called the **headrace** until it is directly uphill from the power plant. Once there, the water enters the **penstock**, which is the pipe leading to the turbine. Alternatively, the penstock may go all the way to the source, eliminating the need for the headrace. In some systems with low head, there may not be a penstock--water from behind a dam may simply flow straight into the turbine. After leaving the turbine, the water passes out through the **draft tube** into the **tailrace**, which is a canal leading to the discharge point. The powerhouse is usually built near the discharge, so the tailrace can be very short, and may be absent completely.

The water flows through the turbine, forcing it to turn. Usually, the flow through the turbine is controlled by one or more **valves or gates**, which allow the flow to be reduced or shut off completely. The turbine is either connected directly to a generator, or it may be connected by means of gears or belts and pulleys to the generator or other machinery to be driven. The generator, the electric wires, and the other devices associated with them are referred to as the **electrical gear**. The different kinds of turbines and electrical gear are discussed in more detail below. The structural parts of the hydro plant--the dam, headrace, penstock, draft tube, tailrace, and power house are called the **civil works**, although this term is more common in larger plants than in micro-hydro plants. These are also discussed in more detail below.

Civil Works

The extent and the cost of the civil works needed for a micro-hydro plant vary a great deal, depending on the nature of the site where the plant is located. Generally, the more water hydropower plants must handle, and the further they must carry it, the more expensive the civil works will be. For this reason, micro-hydro plants with a lot of head are usually cheaper than low-head plants, since the lower head means a greater amount of water is required. However, many low-head plants can be built to take advantage of existing irrigation and water-supply works, such as dams and canals. Combining micro-hydro with a water supply or irrigation project can also help to make that project more practical, since the power from the hydro plant can help to pay for some of the cost of the total project.

The civil works can usually be built from local materials, using local construction techniques and labor, along with a few imported materials such as cement. The exception to this may be the penstock, which must be able to withstand the pressure of the water. If the head is more than 5 meters, this will require metal pipe. This can be expensive, since a fairly large diameter pipe is required in order to reduce the amount of head lost from friction.

In building the civil works, it is important to have advice from someone who is knowledgeable about dams and canals and other hydraulic structures, since building something to carry flowing water is not the same as building a house or a wall. This is especially true of dams. You should never build a dam across any stream without checking to make sure what is legal in your area, and you should never build a dam more an about 1.5 meters high in flat country, or, in hilly country, any dam that will back up a significant amount of water without advice and supervision from a competent engineer. If a dam should break, it can release water with great violence, and even a seemingly small amount of water can cause enormous destruction and loss of life.

Hydraulic Turbines

A hydraulic turbine is a machine which converts the head or potential energy in water flowing through it into mechanical energy (also called work) which is used to turn a shaft. There are a number of different kinds of hydraulic turbines. The two kinds of turbines that are most useful for micro-hydro plants are the Michell or Banki turbine (also called the crossflow turbine) and the Pelton turbine (also called the Pelton wheel). Crossflow turbines are used for low and moderate heads, up to about 40 meters, while Pelton turbines can be used at any head above 20 meters.

Some other types of turbines that are commonly used are propeller or Kaplan turbines for low heads, and Francis turbines for moderate heads. Except for the crossflow turbine, all hydraulic turbines are high-technology items which must be built by a specialized manufacturer. A list of manufacturers of small turbines is given in the appendix.

Crossflow turbines can be built by a local machine shop, but a specialized manufacturer may be able to make a more efficient unit. Low-Cost Development of Small Water Power Sites (listed in the appendix) gives instructions for building a crossflow turbine.

In response to the increasing interest in small hydro, a number of manufacturers have recently begun to come out with standardized turbines for small hydroelectric plants. Since each turbine does not need to be individually designed and built, this reduces the turbine's cost significantly. These turbines are normally sold as part of a package, which includes a generator and control system. These packages usually produce high-quality AC power, the same as is available from electric utilities, but they are fairly expensive, especially in micro-hydro sizes.

It is also possible to use ordinary rotating water pumps as hydraulic turbines. Typically, a pump uses mechanical power to increase the head of the water being pumped. By reversing this process, a pump can convert head into mechanical power. Since pumps are mass-produced in great quantities, their cost can be less than a third of a specially-made turbine. However, this lower cost must be balanced against a generally lower efficiency, which reduces the amount of power you can get from a given amount of water. Nevertheless, if you have plenty of water a pump can be a very low-cost choice, especially if you can get one second hand. Most pumps work best as turbines when the head of the water going through them is about 30 to 60 percent greater than the head they were designed to produce as pumps. A local pump dealer or serviceman can provide more information.

Electrical Gear

The electrical gear or electrical system for a micro-hydro system consists of the electric generator, other electrical devices in the powerhouse, and electric wires that take the electricity from the powerhouse to the place where it is to be used. There are a number of different possible arrangements for this. One of the most common arrangements for micro-hydro systems is a low-voltage DC system, similar to an automobile's electrical system. This arrangement can also be used to produce moderate-voltage AC power (like that which is available from an electric utility) by means of an inverter. Another arrangement, which is commonly used in mini-hydro, is to generate moderate-voltage or high-voltage AC directly, using a synchronous generator.

A sketch of a low-voltage DC system is presented in Figure 3. This system uses a generator called an alternator, which produces low-voltage AC. This power goes through a rectifier and voltage regulator which convert it to DC, which is then either used directly, or used to charge batteries if more power is being produced than is needed. In many modern alternators, the rectifier and voltage regulator are built in. The batteries then return this power later, when more power is being used than produced. The final link in the system consists of one or more wires going from the batteries to the lights and other items that are to be powered. Alternatively, the system may be connected to an inverter, which converts the low-voltage DC power from the batteries to AC, for use with appliances requiring AC power. In either case, the wires usually go through a fuse or a circuit breaker in order to protect the system from being damaged by a short circuit or overloaded by too much demand.

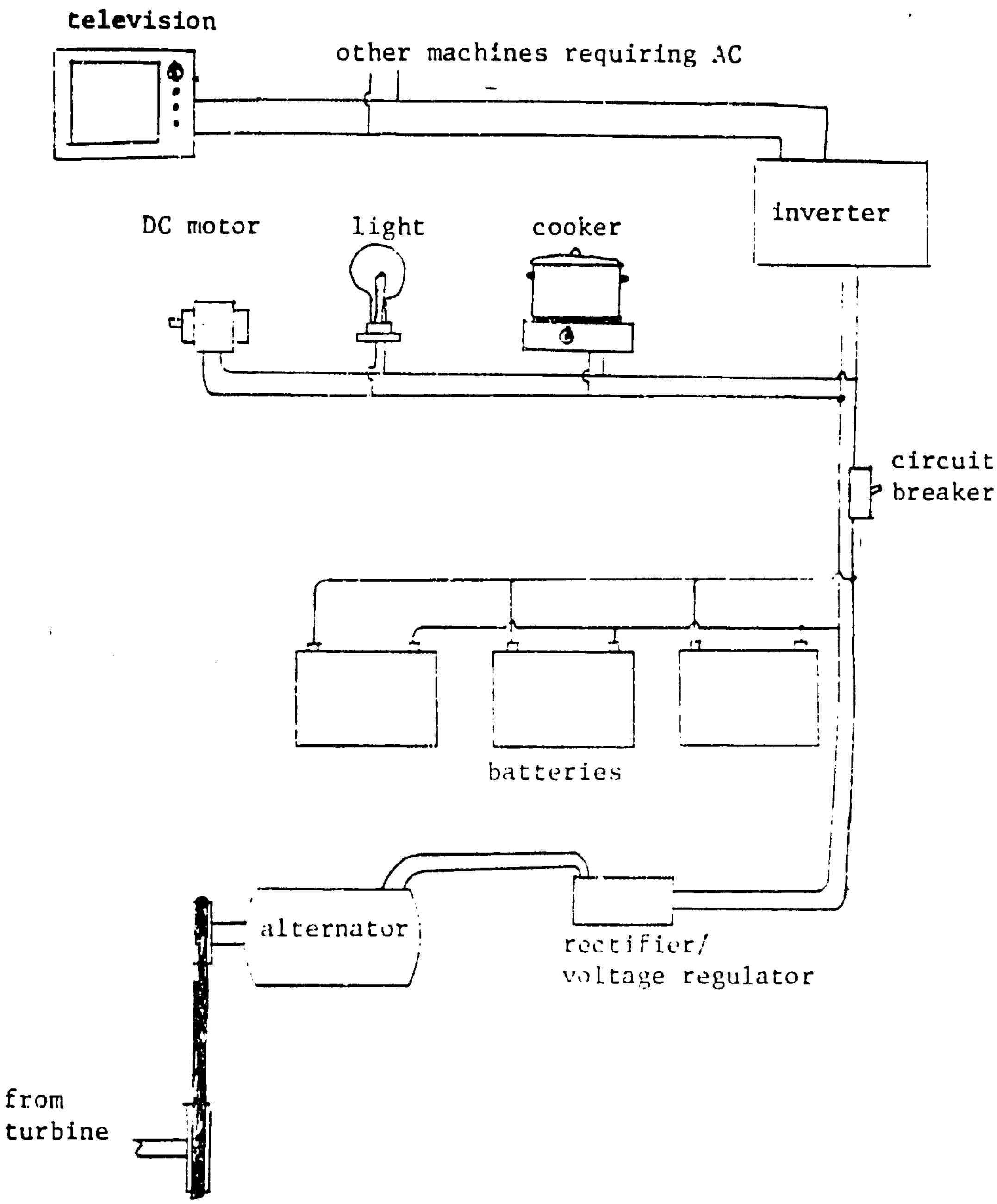

Figure 3. A Low-Voltage DC Electric Power System

The low-voltage DC system has many advantages--it is simple and cheap, and can even be made of parts salvaged from an automobile electrical system. However, it requires special low-voltage light bulbs, and motors which are capable of being run with DC. This problem can be eliminated by using an inverter, but this adds to the cost. Low voltage systems also require heavy wire, and it is difficult to transmit low-voltage power for more than a short distance, since the lower the voltage, the higher the losses in the wire will be. If the hydro site is not within about 50 to 100 meters of the place you will use the electricity, you should either use an inverter to produce AC, or generate it directly with a synchronous generator.

Synchronous generators can produce moderate-voltage AC directly, or can produce high-voltage AC which is then converted to moderate voltages with a transformer. The latter is best if you need to transmit power any distance. However, unlike DC systems, AC systems have no place to store electricity, so they must always adjust the amount of power they produce to match the amount being used. This requires a control system, which can add a great deal to the cost of a micro-hydro plant, and which also requires specialized maintenance. It is usually best to buy synchronous generators as part of a "package," which includes the generator, turbine, and control system. These packages are available from some of the hydro turbine manufacturers listed in the appendix.

Any electrical system requires special knowledge and understanding. This is especially true of high and moderate voltage systems, since these can be very dangerous--causing shocks and electrical fires if they are set up wrong. Low-voltage DC systems are much safer, since it is nearly impossible to be electrocuted by them, but they can still cause fires. You should not work on even a low-voltage system unless you are sure you know what you are doing, and you should not work on a moderate or high-voltage system at all without help from a professional electrician or other knowledgeable person. You should also be very careful to arrange the powerhouse, electric wires, and other parts of the system so that children and animals cannot come into contact with them and be injured.

SYSTEM COSTS, OPERATION, MAINTENANCE, AND OTHER CONCERNS

The cost of a micro-hydro plant will vary, depending on what kind of equipment you use, how much material and equipment you need to buy, how much it costs for the civil works, and other factors. For instance, if you were able to use salvaged pipe to carry water down a steep hill, building the diversion structure, headrace, and tailrace yourself from local stones, and using a second-hand irrigation pump connected to an alternator and battery salvaged from an automobile, your system would cost very little.

On the other hand, if you had to hire a contractor to build a dam, a long headrace canal, powerhouse, and tailrace, then purchased a new hydro-turbine and generator from overseas, you might wind up spending more than $30,000 for a 5-KW generating plant. Of course, any figure between these two extremes would also be possible.

The best sources of price information for hydro turbines and generators are manufacturers. You will need to estimate the cost of the civil works yourself, or talk to a qualified contractor if the job is too complex for you. For the costs of other materials, such as pipe, electric wires, and so forth, it is best to consult local suppliers. Equipment such as alternators, batteries, and rectifiers can be gotten from auto or marine supply stores and places that sell wind generators. The costs for alternators are about $80 for a 500- to 1,000-watt car alternator (including the rectifier and voltage limiter); costs for larger sizes will be more. Batteries cost about $50.00 for a size that holds about 1/2-KWH. Inverters cost about $500 for one with 1-KW capacity.

Maintenance and operation of micro-hydro plants generally takes very little time. It is necessary to check the plant daily to make sure the intake is not getting clogged, and that the system is in good working order. Depending on the design of the plant, you may also need to adjust the intake valve occasionally to match the water flow into the turbine with the amount of power you are using. More extensive maintenance, such as oiling the machinery, tightening any belts, and checking the water level in the batteries should be done every month. It may also be necessary to clean out silt, weeds, and so forth in the civil works, and to repair any leaks or deterioration. This is usually done about once a year or more often if needed.

APPLICATIONS OF MICRO-HYDROELECTRIC GENERATION

Micro-hydropower can be used anywhere that there is flowing water and a difference in elevation for it to run down. However, it is usually not worthwhile building a micro-hydro plant if there is another source of electricity nearby. Thus, micro-hydro is most useful in providing electricity for basic services such as lighting, electric cooking, running small motors like those of sewing machines and electric fans, and running televisions and radios (with special adapters) in isolated rural areas. A hydro turbine can also be used directly to provide mechanical power to drive a machine such as a saw, a mill, a grain huller, or any other low-power machine. In one reported project in Colombia, a village uses a small Pelton turbine to run a sawmill during the day. At night, the same turbine is connected to a generator, providing power for lighting and other uses.

In another set of projects in Pakistan, the government has assisted villages in setting up micro-hydro units, which provide electricity for three or four light bulbs per house. This electricity is also used for small industrial equipment such as arc welders, electric maize shellers, and electric wheat threshers. A number of industries have also been established to use mechanical power from the turbine directly to run equipment such as flour mills, rice hullers, band saws, wood lathes, cotton gins, corn shellers, and grinders.

IV. COMPARISON WITH ALTERNATIVE TECHNOLOGIES

The major use for micro-hydro generation is to provide small amounts of electric power in isolated areas, where other sources of electricity, such as an electric utility, are not available. If an electric utility or some other large electricity source is available, it is almost always cheaper and easier to buy electricity from that source. Where a large source is not available, however, there are still a number of other possibilities. The most important of these are: diesel and gasoline-engine generators, wind-electric generation, photovoltaic cells, and human- or animal-powered generators. These are each discussed below.

DIESEL AND GASOLINE-ENGINE GENERATORS

Diesel and gasoline generators are convenient and cost less to buy than most other means of producing electricity, but they require fuel, which is becoming increasingly expensive. The cost of a diesel generating system is typically $1,000 to $3,000 per kilowatt, depending on the size (small systems cost more per kilowatt), and gasoline generators are even cheaper. However, the cost of supplying diesel fuel for the generator will be at least $0.20 per KWH (for diesel fuel at $0.50 per liter), which amounts to $1,750 for a 1-KW unit running continuously for a year. Gasoline engines are lighter in weight and cheaper than diesels, but also less efficient. The cost would be even greater for them.

WIND-ELECTRIC GENERATION

Wind-electric generation can be a very advantageous form of power production where the wind is strong and reliable. In some cases, wind-electric generators have even been able to compete with conventional large utilities in cost. Generally, a small wind-electric system consists of a wind turbine, which usually looks like an airplane propeller mounted on a pole. These must be purchased. Some other designs of wind turbines use sails and operate at lower speeds; VITA can provide information about building these. In either type of system, the turbine is used to turn a generator (usually an alternator) that charges batteries and provides electric power directly. These systems are very similar to the kinds of micro-hydro systems using batteries that were described earlier. Wind-electric systems can be expected to cost about $2,000 to $4,000 per kilowatt of generating capacity. The cost per kilowatt-hour will vary, depending on the amount of wind. Usually, only about 20 to 30 percent of the total possible KWH per year are actually generated, even in fairly windy locations. Thus a 1-KW unit could conceivably produce 8,760 KWH per year, but would actually produce only about 1,800 to 2,600 KWH.

PHOTOVOLTAIC CELLS

Photovoltaic cells, or solar cells, can change sunlight directly into electricity. This electricity can then be used to charge batteries for nighttime lighting, or it can be used directly to run motors and other small devices during the day. Solar cells are presently an area of great interest in both developed and less-developed countries, and it seems likely that they will eventually make a significant contribution to rural development. However, solar cells are still three to four times too expensive to be practical for most uses. A solar-cell system now costs about $12,000 to $17,000 per peak kilowatt of generating capacity. Since sunlight is not available at night or on cloudy days, however, the actual number of kilowatt-hours generated per year is only about 20 to 30 percent of the maximum--about the same as for wind generators.

Solar cells are most advantageous where very small amounts of power are needed, since their cost per watt does not increase even in very small sizes. A 100-watt hydro plant might not cost much less than a 1,000-watt plant, but a set of solar cells to produce 100 watts costs about one tenth as much as a set to produce 1,000 watts. Thus, if you only need a little power (to charge batteries for a television, for example) solar cells may be the best choice.

HUMAN AND ANIMAL POWER

Humans can generate power by pedaling a bicycle-like apparatus connected to a generator. Animals such as horses and bullocks can also be used to produce power, by having them turn a crank connected to the generator through speed-increasing gears or pulleys. The original English unit of power, in fact, was the horsepower, which was defined to be roughly the power that a draft horse could supply. One English horsepower is about 750 watts, but this is actually more work than can be expected from most horses. After allowing for the inefficiency of the generator and the gears, it seems likely that only 200 to 300 watts of electricity could be generated per animal. For humans, the amount that can be produced comfortably is even less--probably around 50 watts. This would be enough to charge batteries for a radio or television, or to provide a few hours of light, but not for much else. The cost of such a system would be fairly small--from nothing at all (using salvaged parts) to U.S. $100 or $200 for a new alternator and batteries. However, don't forget that both humans and animals require fuel in the form of food.

V. BUILDING A MICRO-HYDRO PLANT

Building a micro-hydro plant is a complex process that requires a great deal of planning and preparation. The major steps in this process are described below.

PREPARATORY STEPS

Not all of the steps listed below will be necessary in every case. You should use your own judgment, but generally, the larger and more complex your plant will be, the more time you should spend in the preparatory stage.

- Decide how much electric power you will need, and whether you need AC power or low-voltage DC power.

- Find a promising site for your hydro plant. The best sites have a reliable water supply year-round and a large vertical drop in a short distance (the more drop, the less water is required).

- Calculate the amount of power available at the site, using Equations 1 and 2 (page 5). Decide whether that will be adequate for your needs. Be sure to consider the efficiency of the equipment in making this decision.

- Make sure that you can install electric wires from the site to the place you want to use the electricity.

- Check for legal and institutional problems with the site you have chosen. Find out what laws you must obey and what licenses you will need to build and run the plant.

- Check for environmental effects of the plant. Some of the concerns here are the effect of the dam on fish, possible flooding of cropland or other valuable land, and the possibility of creating a breeding ground for disease-causing organisms such as water snails if bilharzia or schistomiasis is a problem in your area. Also check for the effects of the environment (e.g., flooding) on the plant.

- Check for bad social effects--people whose use of the stream will be disrupted, women unable to wash clothes on the bank, and so forth. These must be balanced against the positive social effects of electric light, machines, and so forth.

- Estimate the cost of building a hydro plant at the site, and the total amount of energy (in KWH) that the plant will produce per year. Calculate the annual cost of the plant (including loan payments, annual maintenance, and all other costs) and divide by the number of KWH per year to get the cost per KWH.

- Estimate the cost per KWH of other sources of electricty, such as wind or a diesel generator. Also try to estimate the social and environmental effects, and any legal or institutional problems they might have.

- Consider all of the costs, the social and environmental effects, and the different characteristics of the possible alternatives, and decide whether to go ahead with a micro-hydro plant, to investigate some other kind of generator, or to do nothing at all.

DESIGNING THE PLANT AND PLANNING ITS CONSTRUCTION

Assuming you have decided to go ahead with a micro-hydro plant, the next step is to design it. This does not need to be a lengthy project--just make sure you know everything that will be needed, how much it will cost, where you will get it, and when you will need to order it in order for it to arrive on time. Unless you are very confident of your knowledge, you will probably want to get additional help at this point. Some of the books listed in the appendix (especially Low-Cost Development of Small Water Power Sites, may be useful to you. If your system will be at all elaborate, and especially if it will involve constructing any dams or canals, it is a good idea to show your plans to a qualified engineer before proceeding.

BUILDING THE PLANT

This phase includes all the things involved in going from the design to the operating plant.

- Prepare a budget and facilities schedule.

- Arrange financing, if you are planning to borrow the money to build the plant.

- Order the turbine, generator, batteries, pipe for the penstock, the inverter, and any other items that you plan to purchase. Allow enough time for delivery--it can take several months to get a hydro turbine. It may be well to use a reverse-operated commercial pump. Commercial pumps, which can also be used as turbines, have much shorter delivery times.

- Take delivery on important components such as the turbine and generator, and make sure that all planning for the civil works is complete.

- Build the dam, powerhouse, headrace, tailrace, and other civil works, and install the penstock and valves.

- Install the turbine, the generator, and the other electrical gear. Test everything thoroughly, first component by component, then the system as a whole.

OPERATING THE PLANT

Make arrangements for regular inspection and maintenance of the plant and the rest of the system, cleaning out the water intakes, oiling the machinery, tightening the belts, etc. Depending on the system, you may also need to check on the water supply, and adjust the intake valves if too much or too little water is being used. This usually takes very little time--a few minutes a day are enough.

You can carry out most of the preparatory steps of this process using this paper. Once you begin designing and building the plant, however, you will need much more help. Some of the books listed in the bibliography may be useful to you. You may also want to talk to local experts, consultants, or VITA for further assistance.

VI. FOR MORE INFORMATION

The bibliography at the back of this paper lists a number of useful books and magazines which can provide general information, as well as some which give specific directions for evaluating a potential hydro site. This reference list is followed by a list of manufacturers of small hydroelectric equipment, who may be able to provide further information and references.

Hydroelectric equipment in the 0- to 5-KW range tends to be rather expensive if bought from a manufacturer, but is likely to last longer and work better than homemade systems. Manufacturers can also be very helpful in telling you how to go about evaluating a site, setting up and installing their systems, and making sure they work properly. If you are contacting manufacturers about a specific site, you should first find out (at least approximately) the head and either the minimum and maximum flow rates or the amount of power you want to generate. For information on using pumps as turbines, you should contact a local pump supplier, who will be able to get information from the manufacturers.

The best source of information about things like building dams, canals, and other civil works is probably a local builder. Try to find someone who has experience in building irrigation systems or other water systems. The best source of information on generators and electrical equipment is probably a local electric-motor seller or repairman. This person will know how to contact the manufacturers for your specific requirements, and will also be a great help in setting up the electrical system. You can also try to contact electric motor and generator manufacturers yourself. Boating supply stores and auto supply stores are some of the best sources for lights and appliances used with low-voltage DC systems.

Many organizations may be able to provide information or assistance to you in developing a small hydroelectric site. The first place you ask should be a local authority or other organization which is concerned with dams and canals. These organizations will probably employ engineers knowledgeable in the area, and may be able to refer you to consultants, government agencies, or others who may be able to help. If there is a government agency concerned with rivers, dams, navigation, or similar areas, it will probably be a good source of information. You will need to contact such an agency anyway to find out whether there are any laws or regulations that may prevent you from developing a hydroplant. Another good source may be the departments of civil engineering, mechanical engineering, or agricultural engineering at a nearby university or technical institute. Finally, VITA and other international organizations may be able to provide information, technical assistance, or both, in some cases.

SUGGESTED READING LIST

MAGAZINES

International Water Power and Dam Construction, Business Press International, Ltd. Oakfield House, Perrymount Road, Haywards Heath, Sussex RH16 3DH, Great Britain.

This magazine is an excellent source of information on all forms of hydropower. It frequently carries articles on aspects of mini-hydro, and has devoted several special issues to the topic. It also advertises engineers, manufacturers, and consultants in the hydropower field.

Alternative Sources of Energy, Alternative Sources of Energy Inc., 107 S. Central Ave., Milaca, Minnesota 56353 USA.

Issue No. 68, July/August 1984, is a special issue on hydropower.

BOOKS AND REPORTS

Low-Cost Development of Small Water Power Sites by Hans Hamm. Available from VITA, c/o VITA Publications Sales, 80 S. Early St., Alexandria, Virginia 22304 USA.

This book was written in 1967, so it is somewhat out of date. Nonetheless, it is an excellent, understandable guide to assessing a hydro site, determining head and flow, and so on, and includes a good discussion of low-technology hydro schemes. It is a good book for beginners. It also contains a good set of instructions for building a Banki turbine, which is the only kind of turbine that can be built with village-level technologies.

Micro-Hydro: A Bibliography, Beth Moore and John S. Gladwell, Idaho Water Resources Research Institute, University of Idaho, Moscow, Idaho, USA, 1979.

This bibliography is somewhat old, but contains a very complete set of references to the literature on micro-hydro, from introductory material to how-to-do-it manuals and engineering textbooks.

Simplified Methodology for Economic Screening of Potential Small Capacity Hydroelectric Sites, Electric Power Research Institute, EPRI EM 3213, Project 1745-8, P.O. Box 50490, Palo Alto, California, 1983.

Small Michell (Banki) Turbine: A Construction Manual. VITA. Available from VITA, c/o VITA Publications Sales, 80 S. Early St., Alexandria, Virginia 22304 USA.

This book describes a low-cost water turbine that can provide AC/DC electricity for your home. It includes complete step-by-step instructions for making parts and assembly, and is illustrated.

MANUFACTURERS AND DISTRIBUTORS

UNITED STATES

Allis-Chalmers Fluid Products Co.
Hydro Turbine Division
Box 712
York, Pennsylvania 17405

Arbanas Industries
24 Hill St.
Xenia, Ohio 45385

Axel Johnson Engineering
666 Howard Street
San Francisco, California 94105

Bouvier Hydropower Inc.
12 Bayard Lane
Suffern New York 10901

BBC Brown Boveri Corp.
1460 Livingston Ave.
North Brunswick, New Jersey 08902

Canyon Industries
5346 Moquito Lake Rd.
Deming, Washington 98224

C-E/Neyrpic Hydro Power, Inc.
969 High Ridget Rd.
Box 3834
Stamford, Connecticut 06905

Elektra Power Corp.
744 San Antonio Rd.
Palo Alto, California 94303

Essex Development Associates
110 Tremont St.
Boston, Massachusetts 02108

Fairbanks Mill Contracting
North Danville Village
RFD 2
St. Johnsbury, Vermont 05819

Flygt Corporation
129 Glover Ave.
Norwalk, Connecticut 06856

General Electric Co.
Small Hydroelectric Operation
One River Rd.
Bldg. 4, Rm. 305
Schenectady, New York 12345

Generation Unlimited
701 Placentia Ave.
Costa Mesa, California 92627

Hayward Tyler Pump Co.
P.O. Box 492
80 Industrial Pkwy
Burlington, Vermont 05402

Hydro-Tech Systems, Inc.
P.O. Box 82
Chattaroy, Washington 99003

Hydro Watt Systems, Inc.
146 Siglun Rd.
Coos Bay, Oregon 97420

International Power Machinery Co.
833-835 Terminal Tower
Cleveland, Ohio 44113

The James Leffel Company
426 East Street
Springfield, Ohio 45501

Layne & Bowler, Inc.
P.O. Box 8097
Memphis, Tennessee 38108

Mini Hydro Co.
110 East 9th St.
Los Angeles, California 90079

Micro Hydro, Inc.
P.O. Box 1016
Idaho Falls, Idaho 83401

New Found Power Co., Inc.
P.O. Box 576
Hope Valley, Rhode Island 02832

Northwest Energy Systems
P.O. Box 925
Malone, Washington 98559

Oriental Engineering and Supply Co.
251 High St.
Palo Alto, California 94301

Philip C. Ellis
RD 7, Box 125
Reading, Pennsylvania 19606

Real Goods Trading Company, Inc.
308 East Perkins Street
Ukiah, California 95482
(This organization also sells wind generators and photovoltaic systems, and many low-voltage DC appliances. Their catalog is an excellent introduction to low-voltage power generation.)

Scantech
162 Battery St.
Burlington, Vermont 05401

Small Hydro East
Star Route 240
Bethel, ME 04217

Sunny Brook Hydro
P.O. Box 424
Lost Nation Rd.
Lancaster, New Hampshire 03584

Ted Miller Associates
2140 S. Ivanhoe
Denver, Colorado 80222

Worthington Group, McGraw-Edison Company
Box 91
Tarrytown, Maryland 21787
(Worthington is a pump company that has done a lot of work on using its pumps as turbines.)

FOREIGN

Atlas Polar Company, Ltd.
Hercules Hydrorake Division
P.O. Box 160, Station O
Toronto, Ontario
Canada

Barber Hydraulic Turbine Division of Marsh Engineering Limited
P.O. Box 340
Port Colborne, Ontario L3K 5W1 Canada

Canbar Products Ltd.
P.O. Box 280
Waterloo, Ontario
Canada

China National Machinery Company
Beijing
People's Republic of China
(Contact the Chinese embassy in your country for information.)

Dependable Turbines Inc.
#7, 3005 Murray St.
Port Moody
British Columbia
Canada

Neyrpic
Rue General Mangin, BP 75
38041, Grenoble Cedex
France

Ossberger-Turbinenfabrik
P.O. Box 425
D-8832 Weissenberg/Bavaria
West Germany

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