

Renewable Energy Sources: Micro Hydro Power

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Abstract

The following research paper is an in-depth analysis of the implementation of Micro Hydro power systems in New Jersey. We present a look into a time tested, yet underused technology driven by water. Included within this document is an introduction to electricity and currents and how they apply specifically to Micro Hydro power. Residential homes and many commercial applications have the potential for Micro Hydro energy systems to be implemented in order to generate renewable and cost-effective energy. Micro Hydro site requirements and costs are discussed along with a variety of turbines and systems that can be installed.

Introduction

Water has been used as an energy source for thousands of years, with ancient civilizations using water to drive mills through the use of water wheels. Technology has grown over time, and the potential for water as a power source continues to be prominent. Large-scale examples such as the Hoover Dam and the Grand Coulee Dam are used to power large-scale projects.

Modern times are calling for a clean, efficient renewable energy source. A possible solution for a number of instances is the implementation of Micro Hydro power systems. Micro Hydro is the well-known principal of using water to drive a turbine and generate electricity; however Micro Hydro is implemented on a much smaller scale including private residences and businesses.

Not only is Micro Hydro a non-polluting energy source, but also it is much more efficient than the burning of fossil fuels for electricity. In respect to coal burning, the most common energy source, Micro Hydro power is greatly more efficient. Efficiency is the amount of electrical energy in respect to the amount of energy created and Micro Hydro units range from between 60% to 90%

efficient while modern coal burning techniques are 43% to 60% efficient.

Later in this paper, typical Micro Hydro sites will be discussed. This includes the various types of turbines that can be used, which to choose for certain sites and how to calculate the amount of electricity that a site will generate.

Electricity Background

Electricity is a property of matter that is characterized by the movement of an electric charge or the flow of electrons. It is also the cause of a number of physical phenomena including lightning, electric fields, and electric currents. Electric power is the rate at which electric energy can be converted to or from another energy form such as light, heat, or mechanical energy.

Micro Hydro power systems are able to generate electricity by using the movement of water from small streams to rotate a wheel or turbine in order to spin a shaft. The shaft's motion is used to power an alternator or generator that converts the rotational energy in order to produce electricity.

Alternating Current, also known as AC, is an electric current that has a magnitude and direction varying cyclically. This type of current reverses direction repeatedly. AC power can be represented by a sine wave. It is generally used in delivering electricity to businesses and residences. Audio and radio signals are also carried on electrical wires using alternating current.

Direct Current, also known as DC, is the constant flow of an electric charge from high to low potential. This type of current is only a one-direction flow. DC power changes from a small amount of output energy to a large amount of output energy continuously. It is used typically in conductors such as wires but can also be used in semiconductors, insulators, or even through a vacuum. In DC power, the electric charges flow in the same direction. This form of electricity was used originally by Thomas

Edison in the late nineteenth century when developing the light bulb.

Three phase current is a power source that uses three streams of electricity carrying voltages that are 1/3 of a full cycle different in time. When any one sine wave is at low power, the output of charge can still be maintained from the other two voltages. Utility companies generally only provide single phase power to private residences. A phase converter is needed to convert single to three phase current.

The most common type of current used in micro-hydro systems is a combination of AC and DC power. In the system, an alternator or generator can be used to convert the rotational energy from the turbine into electricity. Following this, an inverter is used to convert the low voltage DC power produced by the system into 120 or 240 volts of AC power for the home. A regulator can also be used to control the electricity being sent to the home for use.

A major electrical component of hydropower is the use of generators to induce electrical current. Generators are involved in the process of converting mechanical energy into electrical energy. Generators are essentially a mechanical source of power that is involved in electromagnetic induction, which is the process of creating electricity using change in the strength of the magnetic field per unit time, called flux. When turbines are moved either by impulse or reaction, they trigger the movement of generators. The generators, which usually have magnets attached to them, change the orientation of the magnets. Since magnets have a magnetic field based on a north and south pole, the direction of the magnetic fields change when the generators start to move. From there on, conducting wire or electrical wire that are placed in the magnetic fields of the generators, induce a current because they experience the change in flux. Therefore, the significant aspect is the created electrical energy from the motion of the magnets. This process allows for the powering of electrical devices.

Hydropower Background

Hydro power is the generation of electrical energy by harnessing water's kinetic energy created by gravity. Hydro power is centered on the efficiency of the water's kinetic energy converting to electrical energy. In hydro power, the kinetic energy of the water depends on two aspects, head and flow. The head refers to the vertical distance the water travels and the flow refers to the volume of the water that passes through the turbine in a given amount of time. The flowing water moves through the system and pushes the turbine to make it spin. The spinning of the turbine is turned into electricity by means of a

generator. The electrical energy created is usually stored in a battery which can then power electrical objects in house, such as appliances and lights. When looking at the full process of Micro Hydro power and the transference of energy from one form to another, one must also take into account that there are no toxic emissions because Micro Hydro is a very environmentally friendly source of power.

As with any other type of renewable energy source, there are many types of hydro power. This includes impoundment, diversion, and pumped storage.

Impoundment describes a certain hydro facility where a dam is used to store water. The water is used to run the turbine to create the electrical energy. These are the most widely recognized styles although they are actually not very common and are quite infeasible for most residential areas due to their costs and complexities. One widely known example is the Hoover Dam. Diversion is almost the same except it channels a portion of the river through a canal or penstock. Diversion is also called a "run-off-river," in some cases. Pumped storage, another type of Micro Hydro utility, needs its own facility. In pumped storage, water is pumped from a lower reservoir to an upper reservoir. When water is released from the top, energy is created. Of these methods, diversion is mostly used in real-world examples. In the potential sites that can be found in New Jersey, it is most likely that diversion would be the most effective method as well.

There are many sizes of hydro power that have been used in the past. Large hydropower, as defined by the United States Department of Energy, has capacities greater than 30 megawatts (MW). Small hydropower, the medium segment of hydro power usage, describes capacities between .1 and 30 MW. Micro Hydro power, which will be examined more closely in this study, has capacities under .1 MW. Micro Hydro power is more appropriate for the residential use. One Hundred Kilowatts of power is sufficient for a residential household. Anything greater would be simply wasteful.

Micro Hydro power is a site-specific type of renewable energy. Each different site requires a separate evaluation in order to determine the energy output. A Micro Hydro application is generally installed in home areas or any place where a small stream can be harnessed for power. This means that each individual site will most likely, but not necessarily, have a low head and a low flow. The head of a site is the vertical distance from the source, the surface, to the point of the water's outflow. The higher head a site has, the higher the final energy output will be. The flow of the site is a volume of fluid that passes through a given area per unit of time.

The flow of a site can be measured in many ways, some more precise than others. In some instances, the flow rate of a stream can be determined through the access of government records of stream flow. The Weir Method is one of the most precise methods, which involves a dam being used. A weir is a type of dam; one with a triangular or rectangular notch in the top. When using a triangular notch the width (L) of the notch must be measured from a certain distance (H) above the apex in feet. "H" is referred to as the head of the water above the apex, noted in feet. There is also a constant (C), which is based upon the head of the site, whose values are simply from a chart. The final equation is then:

$$\text{Flow of water in ft}^3/\text{sec} = (C) \times (4/15) \times (L) \times (H) \times (2gH)^{1/2}$$

When using a rectangular notch the length of the weir opening (L) must be measured in feet as well as the head of the weir (H) in feet. The final equation is then:

$$\text{Flow of water in ft}^3/\text{sec} = 3.33(L \cdot 2H) \times H^{1.5}$$

Simpler methods can also be used to measure the flow of a site. The bucket method is among one of the simplest and can be used for a rough measurement for people who are considering installing a Micro Hydro application in their stream. The stream must be dammed up and diverted so that water flows into a bucket. The rate that the bucket fills up is the flow rate of the river. For example, if after 1 minute five gallons have flowed into the bucket, then the flow rate of the river is 5 gallons per minute.

Once both the head and flow data is measured, the final equation to calculate the potential power of an application is:

$$P = .0846 \times Q \times H$$

Where "P" equals the potential power in kilowatts, "Q" is the flow in cfs and "H" is the head in feet. The number 0.0846 is a conversion factor. The answer to this equation gives the potential power of a site. However, this theoretical power is higher than the actual power that a site can produce. Energy is lost as it is converted from one form to another, so this lowers the actual power that one site can put out. After the Micro Hydro system is in place and has been in operation for a decent length of time, the actual output can be determined. The system must be able to output the amount of energy required to sustain the household or factory in order for the application to have worth. To make the use of a

Micro Hydro system feasible, reducing the energy used by a household is ideal. The potential power of the site must be determined in order to verify the feasibility of a Micro Hydro power installation.

For example, in June 2002 at the Duhernal Dam in New Jersey, the Micro Hydro facility had a flow, in cubic feet per second, of 80. Its head was 13 feet. Using the overall equation, the power can be calculated as:

$$Q (\text{flow}) = 80 \text{ ft}^3/\text{s}$$

$$H (\text{head}) = 13 \text{ feet}$$

$$\text{Thus, } P (\text{power in kilowatts}):$$

$$= .0846 \times 80 \times 13$$

$$= 87.984 \text{ kilowatts}$$

Turbine Background

Turbines are the key to hydropower. They harness most potential energy from the flow of water to create power to sustain most types of technology nowadays. A turbine is essentially a rotating wheel that moves with the flow of water. The blades on a turbine use the pressure of the water to move. Earlier forms of turbines include waterwheels that formerly ran on the flow of water in a river. From this type of motion, the waterwheels would be able to power factories for as long as the water flowed. Windmills were also an earlier form of turbines. The most essential aspect of turbines is the fact that they convert one form of mechanical energy into another.

When deciding how to set up a Micro Hydro system, special attention must be given to the placement and types of turbines required based on environmental factors such as the head and flow of nearby water sources. Turbines take energy from the water by using the water's flow to create work upon the blades, changing linear motion to rotary motion and allowing mechanical motion to be converted into electrical energy with the help of a generator. The types of turbines available include the Francis turbine, Kaplan turbine, Pelton turbine, Turgo turbine, and the Crossflow turbine.

Each of these turbines falls under one of two categories: impulse and reaction. Impulse turbines include the Pelton, the Turgo, and the Crossflow turbines. Impulse turbines work by increasing the velocity of a water source through a nozzle and using the new speed to push the blades on the turbine. They are generally better for Micro Hydro applications because they can handle objects in the water without much difficulty, and they are easier to build and maintain. They also do not need pressure seals, which are normally required for reaction turbines. One major disadvantage, however, is that they do not work well in situations with a low head.

Reaction turbines include the Kaplan and the Francis turbines. Reaction turbines work by using the water's own pressure to push through the blades of the turbine, generating energy and leaving the water with everything except for a little less energy. At the same head and flow, reaction turbines generate more energy than impulse turbines and are more efficient at lower heads. Unfortunately, they are harder to build because of the extra pressure casing that they need to function and the extra maintenance costs required. They can, however, pay off the extra cost with time due to their ability to generate more electricity.

James B. Francis invented the self-named Francis turbine. This type of turbine is an inward flow reaction turbine, meaning that it depends on the impact of water directly on the blades of the turbine. The Francis turbine is the most widely used turbine currently for hydropower. While the water hits the turbine, the pressure of the water changes so that it gives up its energy to the turbine for its rotation. There are some engineering advantages of the Francis turbine. It was a major improvement on the waterwheel. The Francis turbine also has a ninety percent efficiency rating. One disadvantage of this system is the fact that it's mainly for high head-high flow situations; therefore it is usually inappropriate for Micro Hydro situations.

An evolution of the Francis turbine is the Kaplan turbine. The Kaplan turbine is propeller-type water turbine that has adjustable blades. Viktor Kaplan developed this type of turbine in 1913. It is also an inward flow reaction turbine. The major improvement on the Francis turbine by Kaplan was its new ability to work efficiently in low head-low flow situations; therefore, this type of turbine would apply to smaller flows of water to power homes, instead of major facilities. The engineering advantages of this turbine include its more efficient power and the mentioned ability to work in smaller areas.

Lester Allan Pelton from Vermillion, Ohio invented the Pelton turbine in the mid-1800s. He traveled to California during the Gold Rush and developed the turbine to harness the waterpower from the mountain streams in the area. In this way, the mills and machinery were powered during the time. The Pelton turbine is a type of impulse turbine, which is more efficient for a Micro Hydro application; however, it does have a few characteristics that would prevent it from being useful in a Micro Hydro application in New Jersey. The Pelton turbine is generally used in sites that are high head (at least 20 meters) and low-flow; however, the high head is an unlikely occurrence in New Jersey. There are many

advantages to the Pelton turbine, including that they can be adjusted to their site by changing the number of nozzles and buckets. In addition they can be adjusted by changing the diameter of the wheel. Another advantage is that the buckets are mounted in pairs in order to ensure balance and smoothness in the running operation.

The Turgo turbine is an impulse turbine that is essentially a modification of the Pelton turbine. The difference is that the exiting flow of water does not interfere with the incoming flow of water. Basically, the Turgo turbine's blades are shaped in such a way that the inflowing water bounces off the blade in one direction and exists in the other on the opposite side of the blade. The Turgo turbine is also smaller, but harder to build and easier to break. It is suitable for areas with medium head and low flow.

The Crossflow, also known as Banki, turbine is very special in that it uses techniques from both the reaction and impulse turbine designs. The crossflow turbine is especially well suited for a micro hydro installation in that it operates well in low-head and low-flow sites, which are the most typical sites for Micro Hydro applications. The Crossflow turbine can work efficiently in heads as low as three feet and as high as forty feet. Another advantage to the crossflow turbine is that it is typically low cost and can even be manufactured at home. In addition, the Banki turbine requires virtually no maintenance, which is true of most turbines, leaving Micro Hydro power as a very efficient and easy source of energy. Water hits the runner of the wheel and pushes it, which gives off most of the energy used by the wheel; however, water also hits the blades of the wheel upon exiting giving off even more energy. The Banki turbine is very similar to the Pelton wheel; however, it is more efficient for Micro Hydro sites.

Case Studies

Micro Hydro is a popular resource across the globe. Since it is renewable and does not harm the environment, many homes and companies are beginning to look into installing turbines into their own local streams.

Micro Hydro is a very site-specific resource. Without the proper head or flow, the system does not function properly. Sites need at least a 1m head, and the water must be moving to activate the turbine. Areas that are flat or have stagnant water must install costly canals to move the water.

Micro Hydro is already very popular in the United Kingdom and Europe. The system is beginning to spread to Australia and rural parts of North America. Soon Micro Hydro could show in areas closer to the east coast of the USA.

Micro Hydro is beginning to develop in Asia and Africa and around the rest of the world also. For rural areas, which cannot be included in normal power grids, this provides a small amount of electricity that can make a large impact on those it reaches. Less than 1 kW of power is more than sufficient to power an entire house in most situations. People who have never experienced the benefits of modern technology can be reached through this power and begin to improve their lives.

In this project, two different case studies are compared. One is Morehead Valley in British Columbia, Canada. The second is Muang Samphanh, Laos.

Morehead Valley used a Kaplan turbine for its 8.2m of head. The site can produce 32 kW of power for the entire 66 square kilometer area. The system is built to last many decades and withstand harsh weather.

The total project at Morehead Valley cost \$92,000 (American) to build, including cost of the turbine, other materials and labor for installation. Although it was a very expensive project, the power will pay itself off in a few years.

The turbines in Laos, however, are temporary set ups. This site only has an occasional 1m of head and can only produce 50W of power. Instead of cement and metal, the locals of Muang Samphanh used wood to construct propeller turbines and canals. This system was also less expensive, costing only around \$100 (American) for each site. These however will have to be replaced much sooner than the Morehead Valley site.

The system in Morehead Valley is obviously more feasible for any American site. The sites in Laos cannot last in American weather. It would be unreasonable to replace the system year after year, and the site would start losing money. Also the power needs in America are much higher. The site needs a large power output to make it worth the expenses.

Future Work

The research shows that Micro Hydro is underused in New Jersey and other larger populated areas. If this power is used on a large scale, energy conservation efforts can be increased to make an impact on the amount of limited resources wasted each year. This resource has the most potential for completely renewable power, but it is the most underused. New Jersey for example has 150+ rivers or streams, but information on Micro Hydro in New Jersey is limited.

Research should also be conducted on the combinations of renewable resources. Solar power and wind power in combination with Micro Hydro

power will provide higher efficiency power output and a more dependable resource configuration.

Future consideration for this type of power will come from education on the implementation and benefits of this power. Many people have never heard of or considered this power. A large effort must be made to bring this technology into a more prominent position in the public eye. With understanding will come the development of better resources.

Conclusion

As Micro Hydro power continues to grow around the world, it is important to show the public how feasible Micro Hydro systems actually are in a suitable site. Micro Hydro power can be used from New Jersey to California, from North America to South America, and from the Americas to across the world. The only requirements for Micro Hydro power are a water source, the proper equipment—a turbine and a generator—and a proper installation, which not only helps each individual person but also helps the world and the environment as a whole. Micro Hydro power is generally a more cost-effective source of energy, which after a while, pays for itself, and it is also environmentally-friendly. Rather than burn fossil fuels, the United States and the rest of the world can begin to look towards new sources of energy which are better for everyone.

Through researching the scientific, historical, and sociological background of Micro Hydro power, our group has realized the potential that hydroelectric power carries and the importance of water in the world. As non-renewable resources are being used up daily by the transportation industry, powering homes, and the industrial world, it is obvious that newer, more efficient, renewable sources of energy must be found, and hydropower, specifically Micro Hydro power, is a great alternative.

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