Renewable Energy Systems

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Abstract

In this research paper, we examined renewable energy systems with the goal of maximizing efficiency. In particular, we studied wind energy, biogas, and hydropower.

Our design project presents a hypothetical problem with an idealized hydropower system where we must design a piping system that optimizes energy production and minimizes cost. We then designed a functional hydropower piping system for a case study in which a consumer wanted to switch to alternative energy. This design process showed the minimal requirements that a system needs to generate enough energy for a family.

Introduction

Recent changes in both international and domestic politics combined with renewed interest in the environment demand changes in the way people consume energy. The age of abundance that followed the US Victory in World War II greatly changed the way people lived, but the most significant change is in the way people consume. While this mass consumption has helped to fuel one of the richest economies in the world, these policies can no longer go on. In the International Energy Outlook 2007, it is projected that global electricity production will increase by 2.4 percent each year between 2004 and 2030 (7). The increasing demand for energy cannot be met with a decreasing supply of fossil fuels. If this trend continues, the world will only run out of energy sooner and possibly create a situation where scientist and engineers will run out of time to create a new way to power the world that will allow the inhabitants of earth to burn through resources as they currently do. This situation is setting up a new field that is about to become a major part of how people live.

Electricity generation from renewable energy sources is by no means a new concept. What are now considered renewable energy sources were once used exclusively as means of power for performing tasks that ancient civilizations needed in order to flourish. As the environmental movement grew, so did interest in alternative energy. Along with this interest from citizens, the government is also trying to foster change through financial incentives. The use of these clean sources is expected to increase at an average annual rate of 1.7 percent (7). If the right geographic conditions can be met, small-scale generation of electricity from wind, biogas, or hydropower can be an effective alternative to reduce or completely replace energy from conventional sources. In the near future, it is foreseen that these electricity generating techniques will become common due to the sheer demand and desire for new renewable energy technology (8).

Although wind and hydropower involve the mechanical (or kinetic) energy of wind and water, respectively, the true utilization of these technologies involves the production of electricity. Electricity is a high-quality form of energy. This means that we can use electricity to run a number of systems, even when the systems differ in nature. This characteristic of electricity makes it very useful and valuable in everyday life. In order to be more energy-efficient, it is necessary to match the quality of the energy with the task that needs to be done. This way, high-quality energy is not wasted on a job that does not require it. For instance, heating water is one task that does not require a particularly high quality of energy. Instead, energy-efficiency can be maximized using solar power or methane. Electricity use can be limited in this manner, and renewable energy can replace the need for excessive amounts of electricity (8).

Considering the importance of efficient and renewable energy sources, we designed a cost-efficient small-scale hydropower system to provide power for a home. To do this, we calculated the energy needed, as well as the flow and head of the stream. This is critical in making hydropower systems efficient and appealing to homeowners.

Wind Background

In a wind turbine system, the kinetic energy found in wind can be harnessed and turned into mechanical energy. This mechanical energy can be used to power machinery or to generate electricity. Wind turbines can help to capture this energy and convert it to a more useful form to be able to perform work in a home or business. The amount of energy that a turbine can produce depends on its size, as well as the area in which it is built. One should always strive to build a turbine in an area where the wind speeds are optimal for the specific turbine. Calculating the "capacity factor" of a turbine can be a key element in determining its productivity. The "capacity factor" is a percentage that compares the turbine's actual energy yield with the amount of energy that could be produced over the same period of time, provided the turbine was running at full capacity. Normal wind turbine systems often have a capacity factor between forty- and eighty-percent. The amount of energy that a wind turbine can produce depends on the height and size of the turbine (11).

Biogas Background

Biogas is a good form of renewable energy for people with excess manure or farm waste. Agricultural and animal waste is anaerobically digested, producing a mixture of carbon dioxide and methane gas. This gas is then used either to generate electricity from combustion engines or for direct combustion in cooking or lighting appliances. The waste needs to be stored in a special container while being digested, since the digestion must be anaerobic. Any small-scale farmer owning more than ten pigs that do not graze or more than three dairy cows could potentially reap the economic and environmental benefits of this type of energy system. However, the biogas unit must be planned, constructed, operated, and maintained properly; otherwise, the energy yield may not be as high. Biogas plants also need a large amount of water to be kept in good condition. When designing a biodigester, it is important to consider the size of the family, the daily lighting and cooking requirements, the amount of waste available for digestion, and the material available for construction of the digester. Using these factors, the correct digester type, the proper volume for the digester, and the retention time can be established (2).

Renewable energy systems are constantly evolving and changing to meet the demand of the consumers involving both electricity and the environment. As people become increasingly willing to help the environment by making these types of investments, it is, in turn, becoming easier and more practical to implement these systems. Although there are many other forms of renewable energy technology, wind power, biogas, and hydropower are more carefully examined, due to their small-scale benefits. Specifically, it is important for people to understand the benefits of designing a renewable energy system. Motivated by a desire to better understand and make recommendations for specific hydropower systems, we studied a particular hydropower model, and made it cost-effective and energy-efficient to suit the homeowner's needs.

Hydropower background

Unlike wind power or biogas, hydropower requires some pressure difference on either side of the turbine, which will in turn move a mechanical component. The spinning turbine converts the potential energy of the water into kinetic energy. Due to its predictability and continuous availability, hydropower is a popular energy source for people with access to moving water. For our purposes, hydropower, specifically micro hydropower, may be defined as a system producing less than 500 kilowatts of energy. This definition varies among the international community; China, for example, defines "small" hydropower as being any system below 25 megawatts. Hydropower is very clean, and uses only the pressure of the water, not the water itself, to yield energy. Knowledge of both the flow in a river and the available head, or the vertical difference the water falls down, are essential when determining how much energy can ultimately be produced from this type of energy supplier. Other considerations involved when designing a hydropower turbine should include maintaining the wildlife of the animals in and around the area of the river. To avoid any major detrimental effects on the river and its surroundings, one can generally assume that one-third of the flow is the largest amount that can be put to use in a hydropower system. (9)

Micro hydro turbines can take many forms, but the most recognizable is the water wheel, which had formerly been used to grind up grain until this century. While water wheels can be used today for work that does not require a fast-spinning turbine, other types of turbines have since become more common. Turbines may be classified as either impulse turbines or reaction turbines. In impulse turbines, water is pushed at a high speed out of a nozzle. This action, consequently, turns the turbine wheel. Typically, impulse turbines can be found in situations where the head is relatively high. Reaction turbines, conversely, convert only part of the available head into kinetic energy; the rest remains as pressure head. These types of turbines work best where there is a low to medium head installation. Generally, the type of turbine that should be used is dependent on the flow and head, or the distance that the water drops. The Pelton wheel is the most common of the newer turbines, made up of a series of cups attached to a hub. When water enters the cups, it makes the turbine spin. A Pelton wheel generally has an efficiency of close to eighty percent, in some cases even reaching up to the low nineties. (6)

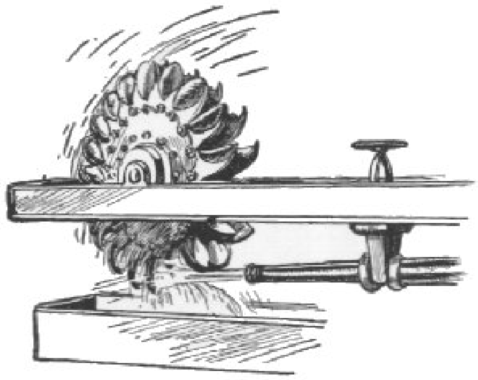

Figure 1: A Pelton Wheel (12)

Some people would like to use hydropower, but do not have access to a head high enough to generate substantial power. Daniel J. Schneider designed a hydropower plant for a low head to harness power from the United States' water flow without building dams that had the potential to flood and cause damage. His design involved a careful examination of fluid dynamics, similar to the flow dynamics that also applied to wind machines. Schneider's system is unique because the design of the entryway allows the water to strike the Schneider Hydroengine's cross section at a uniform velocity, a concept that is different from conventional turbines. The turbine can operate with a head of only three feet, and the design can suit various power needs, ranging from one kilowatt to one megawatt. (10)

When comparing hydro turbines to other kinds of renewable energy systems, such as photovoltaics or wind turbines, hydro turbines are advantageous because they provide energy twenty-four hours a day.

Important Hydropower Equations

Discharge Coefficient Equation:
Used to calculate the discharge coefficient from data gathered from the weir.

$$C = 3.135 - 0.15 \times \left(\frac{H}{P}\right) + 0.54 \times \left(\frac{H}{P}\right) \times \left(\frac{L}{b}\right)$$

C= Discharge Coefficient
L = the length of the weir opening
H is the head about the weir in feet,
P is the height from the stream bed to the weir opening,
b is the width of the stream.

To find the flow, we used the equation:

$$Q = C \times L \times H^{(3/2)}$$

C=Discharge coefficient
L=length of weir opening in feet
H=head above the weird in feet

Total head loss was calculated using the following formula:

$$TotalLoss = Hloss \times \left(\frac{pipelength}{100}\right)$$

And the required flow for a given power and head was calculated using

$$Q = \frac{(Pkwh \times 11.8)}{(H \times h)}$$

Q= Flow in Gallons per Minute
Pkwh = Energy in Kilowatt Hours
H= Net head in feet
H= efficiency constant

Estimating Electrical Needs

When designing an electrical system it is of the utmost importance to know how much power the users will require. By designing a system that is too small, the user will be forced to rely on backup generators, which use some type of fossil fuel or suffer from power outages. On the other hand, a system that is too large will demand the expenditure of unnecessarily large amounts of money. Before considering the specifics of the system it is important to evaluate the electrical needs. (9)

There are many ways to go about this process; however, to get the best estimate, one should use previous electrical bills. When using this method it is necessary to have many years worth of records. This is extremely important because electricity usage is dependent on the time of the year. Generally, more electricity is used in the winter than during the summer unless the users have an air conditioner, since it is a major consumer of electricity. (8)

When evaluating the electrical usage it is also important to look for areas to conserve on electricity usage. Recently there have been many developments in energy efficient appliances. For example, compact fluorescent light bulbs, or CFLs, use 75% less energy than normal incandescent light bulbs. In addition they also produce less heat, so they will take away from the amount of energy required to cool the home. Home appliances can also be replaced with energy efficient models to help cutback total energy usage. These models are usually awarded an energy star by the government to signify that they are energy efficient. By reducing energy needs, the size and cost are reduced for the system that is to be built. (8)

Choosing Piping

When building a micro-hydro installation, the water is diverted from the stream and carried to the turbine in either a pipe or an open canal. The method of transporting the water varies according to the head, flow and turbine choice.

When a reaction turbine is used, low head and high flow, an open conduit is usually used. These turbines run off the kinetic energy of the stream. Since open channels provide less friction to the water they are more efficient for this setup.

However, when impulse turbines are used, a high head is required while only a small rate of flow is required. In this case it is necessary to run closed tubing from an area higher on the stream to where to the turbine is located. This builds up the necessary gravitational potential energy to produce power.

When designing the hydroelectric setup, it is crucial to minimize the both the length of pipe used and the amount of changes of direction. These factors both hinder the flow of the water and require a higher head or more flow to achieve the same level of power generation. For example a 90-degree elbow piece of 2 inch PVC pipe has the same amount of resistance as about five and one half feet of straight 2-inch pipe. The material of the pipe also affects the resistance. Steel pipe has about double the resistance of PVC pipe.

Using larger diameter pipe can minimize the resistance and head loss. However, as pipe diameter increases so does price. Therefore it is important to carefully balance the flow and head loss to yield enough power without using too large of a pipe. (8)

Types of Batteries

When designing a system to provide energy, it is tailored to meet the average needs. However, the system also needs to be able to provide for the peak demand. This can be accomplished in one of two ways.

If the site has access to the electrical grid, the system can be configured in a set up know as net metering.

In 1978, the Public Utility Regulatory Policies Act was passed by congress. This law forces power companies to purchase excess electricity from qualifying producers. This allows people with alternative energy systems to essentially use the power company's grid and plants as a giant battery. When the system produces more energy than is needed, electricity is sent into the grid, the power meter spins in reverse and the producer is credited on their bill for the energy they produce. However, when the system owner needs more electricity than they are capable of producing, the user draws power from the grid as a conventional power customer would. (8)

However, if the person does not have access to the grid or they choose not to buy electricity from the power company, they will need a system of batteries to store excess energy for peak demand.

Batteries are expensive, bulky, and require a lot of maintenance. The two most commonly used batteries today are lead-acid batteries and nickel-cadmium batteries. Lead-acid batteries are similar to car batteries, while nickel-cadmium batteries, or ni-cads, are similar to airplane batteries. Ni-cads are the more reliable battery because overcharging them does not cause damage. They are also smaller, lighter, more rugged, and not affected radically by cold weather. However, they are so expensive that most people prefer to use lead-acid batteries.

The most desirable battery is the deep cycle battery, designed for repeated charges. However, when these batteries are used they are only discharged a small amount, then recharged to preserve their usable lifetimes. These batteries will normally last for more than ten years under normal use and have been known to last longer when extra care is taken to make sure they are under the correct conditions.

Batteries are categorized by their voltage and storage capacity. Each cell of a lead-acid battery nominally produces close to 2 volts, and by arranging the cells into series, the voltages are added to obtain the required voltage. (8)

When dealing with electricity, the current measures the number of electrons passing a given circuit per unit time. The two types of currents are alternating current (AC) and direct current (DC). Alternating currents are currents in which the electrons head back and forth; this movement is measured by the current's frequency. In a direct current, on the other hand, the electrons are always moving in the same direction. (10)

Batteries only supply DC; this is problematic since DC needs to be changed into AC in order to be able to be used for some appliances. In order to change DC to AC, a power inverter is needed.

An inverter is necessary whether or not net metering is used, but when configured in a system that is connected to the grid it must have the ability to turn off the current during a power outage so as not to harm workers trying to restore power. Generally the inverter should be placed as close to the batteries or the turbine as possible to minimize voltage loss due to wiring. This is because there is more loss at lower voltages, and the inverter generally takes a small DC voltage such as 12V and converts it into standard 120V AC current to power household appliance. (8)

Design Constraints

The family living in this situation must generate 1.092 kilowatts of energy. They have a stream that is available year round, and they are interested in saving the environment. They have calculated that they would be able to utilize 495 gallons per minute, provided that they only take one-third of the flow for the turbine system.

Experimental Design

Ideally, the most efficient route for a turbine system would have the pipes going in a relatively direct route towards the turbine. Each bend or elbow increases the friction and, therefore, decreases the efficiency of the entire system.

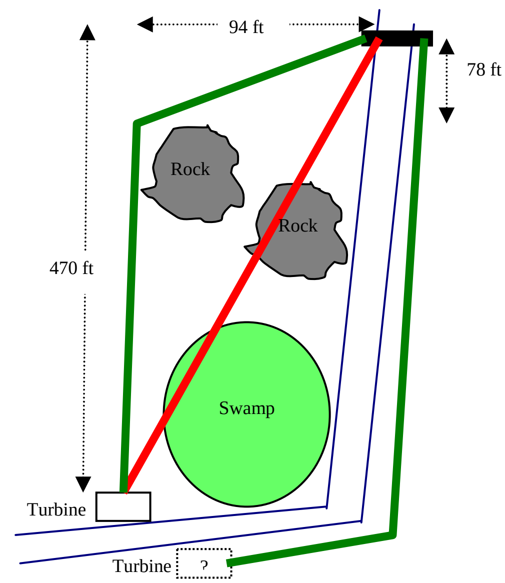

Figure 2: Hydropower Set-up

Design Considerations

The red line in Figure 2 represents an ideal system; however, this does not take into account the obstacles presented by the rock and the swamp. Therefore, one of the green routes would have to be taken, in order to create the most effective power-generating system while spending only what is necessary.

It is important to know not only the average flow rate of the river or stream, but also the minimum and maximum flow rates, in order to properly plan the turbine. Planning for times of minimum flow can help to ensure that enough energy will be provided; similarly, knowing the maximum flow can help prevent possible danger to the system during times of flooding. Therefore, we measured the flow in August, when it would be the slowest. Based on this data, we decided that we could use one-third of the available flow, so as not to disturb wildlife, the environment and people who live downstream. (8)

First, we found “C”, the discharge coefficient used to calculate the flow, by using the equation:

Where L is the length of the weir opening in feet, H is the head about the weir in feet, P is the height from the streambed to the weir opening, and b is the width of the stream.

These numbers were all measured by constructing a weir, or small dam with a slot. The slot has sharply sloped top to make sure the measurements are accurate.

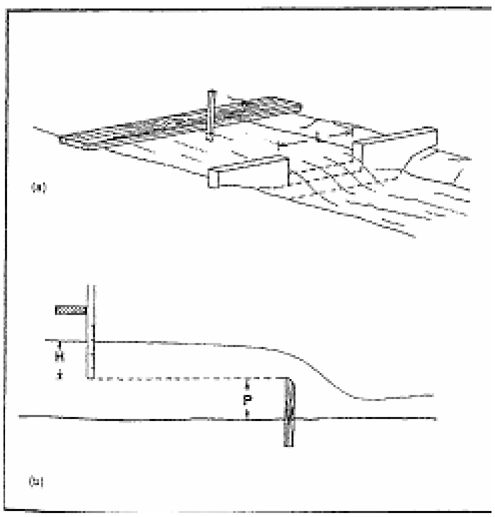

Figure 3: Weir Method

To find the flow in cubic feet per second, we used the equation:

$$Q = C \times L \times H^{3/2}$$

Next, we figured out the flow rate in gallons per minute, since 1 cfs is equal to 448.8 gpm. Once the flow is found, one-third can be used for hydropower purposes.

After the flow and the length of pipe required was calculated, the head loss for the proposed set up was determined based on estimates from head loss tables. These losses were calculated for different diameter pipes to lead towards our ultimate goal of picking the best for the situation.

Based on this information we chose our turbine by plotting the available head and flow onto the graph of the power output for the turbine. This is shown in the following figure.

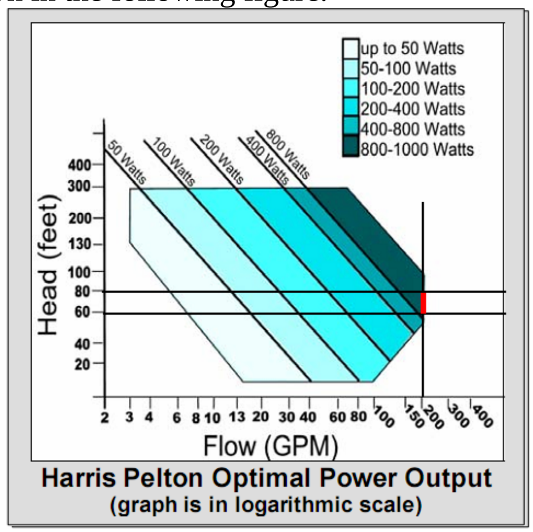

Figure 4: Energy Generated from Available Head and Flow

Next we plotted the curve relating flow to head that would produce 120% of the required average power to account for energy losses due to transmission and the efficiency of the generator.

The curve in Figure 5 was modeled by the following equation:

$$Q = \frac{Pkwh \times 11.8}{H \times h}$$

Where Pkwh is the average power needed, H is the height, h is the turbine efficiency, and Q is the flow (in cubic feet per second)

These curves were also plotted for each diameter of pipe taking into account the friction loss due to the pipes.

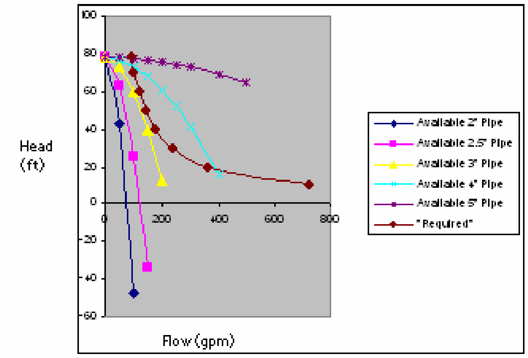

Figure 5: Graph of different pipe diameters

The 4-inch diameter pipe offers the power output closest to the required amount without producing less than the family needs.

Final Design

After performing all the necessary calculations and measurements, a final design was reached. It was determined to be more efficient to run the penstock on the right side of the stream so as to avoid the horizontal component of the pipe which would have been necessary to travel around the natural obstacles on the hill. After the proper piping configuration was determined, it was priced at $2951. This included the long sections of pipe and the necessary joints. The price quoted for the Harris Pelton Quad Nozzle turbine came to $2150. The plant cost $5101, but this does not include the cost of any of the electrical components. These will vary heavily based on the storage system that is chosen, the maximum current required and the distance that is necessary to transmit the power.

Design Analysis

Given the situation, this design proved to be effective in achieving our goal of providing 1.092 kilowatts of power. We could possibly improve our design by investigating running the pipes over the rocks and through the swamp. Perhaps if the situation on the hill was configured differently we could have had an even more efficient design. However it would be necessary to do a analysis of the cost to see if this would be possible.

Conclusion

This project has shown the importance of various factors in determining how a particular renewable energy system should be built. Optimal results could be achieved using the proper turbine; with the given scenario, this ended up being the Harris Pelton Quad Nozzle Impulse Turbine in twenty-four volt configuration.

Pipe diameter also plays a large role in both the cost and efficiency of a hydropower turbine system. Smaller pipes are cheaper, yet the larger pipes provide less resistance and less head loss in the flow. Finding a balance between these two factors is essential to the construction of a hydropower turbine.

Calculating each measurement for a realistic turbine system helped us to understand the steps an actual engineer takes in order to create a means of obtaining energy for a home or small business.

By doing this research paper, we were able to reflect our new knowledge on renewable energy systems and their efficiency on a small scale. We then applied this knowledge to maximize the effectiveness of a variety of renewable energy systems such as wind energy, biogas, and hydropower. In this paper, we designed an effective hydropower system for an area where a swamp and rocks prevented the implementation of a direct piping route.

Future work

It is evident that there is a strong need for renewable energy technology and sources. Therefore, research in this field is continually expanding, and exploration is undoubtedly necessary. It is predicted that by the year 2025, residential energy use in the United States will increase by twenty-five percent. It is also predicted that new technologies in alternative energy will provide a steadily increasing amount of energy to supply this rising demand. Scientists and industry experts may disagree over how long the world's supply of oil and natural gas will last, but there is concrete evidence that if we continue the way we are now, its disappearance is inevitable. However, with current technological discoveries and advancements, we can be assured that alternative energy in the future will be cheaper and more efficient than today. (5)

Technological improvements have made solar-electric modules more cost-effective. In the 1980s, the average price of energy captured with photovoltaics was ninety-five U.S. cents per kilowatt-hour. Today that price has dropped to around 20 cents per kilowatt-hour, according to Collins, a member of the American Solar Energy Society. It is predicted that future advances will include "thin film" photovoltaic technology, a high-tech coating that converts any surface covered with the film into a solar-electric power source. (5)

National Renewable Energy Laboratory researchers, meanwhile, are working to devise more efficient and cheaper solar-electric systems. Most traditional photovoltaic solar units on the market today convert between eleven and thirteen percent of the sun's light into energy. Engineers believe that this statistic can be improved, in order to make for more efficient solar converters.

Compared to other renewable energy sources, wind power competes with conventional energy at a price less than four cents per kilowatt-hour. Wind energy projects around the world now generate enough energy to power nine million typical U.S. homes. One of the newest trends in wind power is the construction of offshore wind farms, or clusters of electricity-generating turbines erected in open-water areas with strong winds. Europe now has seventeen wind farms spinning offshore. The Arklow Bank Offshore Wind Park, eight miles off the eastern coast of Ireland, is one such project. Its seven turbines generate enough electricity to power sixteen thousand homes. While few homes generate their own wind power in the United States, many power companies allow consumers to opt for power generated at a wind plant or other renewable source. Currently this is being implemented in new jersey through the NJ Clean Power program.(4)

Tapping into the ground offers another option to regulate household heating and cooling. In most areas of the United States, the ground below the frost line maintains an average temperature between 50 and 54 degrees Fahrenheit. Ground-source heat pumps, also called geo-exchange systems, use this relatively constant temperature to keep homes at comfortable temperatures. The devices employ a series of underground, liquid-filled tubes or wells. Liquid flows through the pipes into the home, where a heat exchanger either adds or subtracts heat from indoor air, depending on the season. In winter, that means added warmth can be captured from the ground.

Since renewable energy is such a growing field, we feel that more research needs to be done in order to maximize efficiency of certain parts. People also need to be aware of the benefits of using similar systems to the one we have created, since they can provide energy and pay themselves back within a reasonable amount of time.

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