Micro Hydro Portable Inexpensive Power For Rural India

A Design Project Report
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Abstract

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Design Project Report

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The goal of this project is to design and build a micro-hydro electric power system for use in rural parts of India which do not currently have power, but do have access to streams and small waterfalls. There are many parts of this project which will be required before the end of the year. I will be spending the first semester designing the turbine and building it using various inexpensive or reused parts. The second semester will primarily consist of finding ways to bring this to market on a large enough scale to make an impact. In terms of deliverables, the first is building a micro hydro turbine which is inexpensive enough in terms of parts to be sold in rural and extremely poor areas of a developing country like India. The second would be to write a proposal/business plan for how one could viably take this product to market and have the desired impact of providing power to extremely poor regions of India. If the project is successful, then hopefully a complete blue-print would be in place for anyone to try to bring electricity to the most rural and remote regions of India which have been largely left behind as India has developed over the past ten years.

Report Approved by

Project Advisor: Date:

Executive Summary

The need for an inexpensive source of power in India is very significant. While it is one of the fastest growing economies in the world, much of the poor rural areas of the country have been left behind. This is for a variety of reasons of course, including both lack of capital, and a government with a reputation of both corruption and bureaucracy. To get around this unfortunate combination circumstances, the goal of this project has been to design a system inexpensive enough that an individual poor villager in India could afford to buy it on their own without needing much in the way of government support.

There were numerous elements that went into accomplishing this. It required extensive analysis of the region in question. I was fortunate enough to get to visit India in January and this provided a solid basis to plan around. It was clear that the people in Govindghat were not deeply impoverished; the problem was that between government corruption, and a simple lack of population, it was not worth it to provide stable power 24 hours a day. The power there gets turned off at 10PM every night and the people there either need to buy very expensive generators, or simply accept losing power at night.

With this information, it became clear that the best approach would be to design a generator specifically tailored in both power output and cost to be purchased and maintained by a single family. This provided clear direction for the rest of the project.

The next step was to actually build a prototype. This required finding an appropriate alternator, which turned out to be a fairly inexpensive part. The most difficult part of building the prototype was the impeller. After sifting through numerous possibilities, the impeller was settled finally with two different solutions. In small volume, it is fairly straightforward to acquire used impellers on auction sites like EBay. In significant volume, it is even less costly to have the impellers custom made at factories in India.

With the generator prototype built, we subsequently set about testing it to get an idea of the levels of power it could output. This took several tries in various parts of Ithaca before we were able to successfully get it to run. Once the generator was running we took voltage measurements but due to the conditions, were unable to get a power reading. However, we were able to make an estimate of the power generated and then extrapolate to determine how much power the generator could produce with the additional hydraulic head that would be found in India.

Finally, we computed the numbers to determine exactly what the cost of bringing the generator to Govindghat would be. The cost ended up being around $50.00 which was a little bit high, but still something that many of the residents of Govindghat could afford. As such, the project can be considered a success.

Contents

1 Introduction

2 Design and Implementation

3. Conclusion

A. Appendix A

Design Problem

To fully grasp the scope of the problem, it is simple enough to compute the number of villages currently with power. According to the most recent Indian census, there are 593,732 total villages in India, of which 488,173 have power. This means a whopping 17.8% of villages in India do not have power. When one further considers that more than two thirds of India's enormous population lives in these small villages, it becomes clear that this is a problem that effects millions of people.

Of course there are many components that go into determining the best approach for delivering power to poor people in rural areas. The first goal is to determine the appropriate source of power. The source of power should be first and foremost, inexpensive. The total cost needs to be computed including the cost of moving materials from wherever they can be obtained to the end destination.

Range of Solutions

Solar power sounds appealing at first glance, especially given India's reputation as a hot country. Unfortunately, many of the villages most in need of electrification are deep in the mountains, and have high transportation costs. With this in mind, designs with fewer parts that need to be brought in from far away have a significant advantage. This represents a significant drawback for using solar power, which will need solar cells brought in from at the very least the cities of India. The most important aspect of course is cost, and in the US, it typically costs roughly $8 per watt to install solar cells. This is unfortunately prohibitively expensive for families in rural India.

Wind power is another intriguing potential solution, but has drawbacks of its own. Wind power is unfortunately quite expensive to install as the turbine needs to be very high up in the air. To build the tower required for a useful wind turbine would certainly require either government subsidies on the initial build, or a significant sum of money from the household wishing to build it. Typically, when all is said and done, wind power costs roughly $3 to $5 per watt, which is still quite high for a relatively poor Indian household. While there is nothing implicitly problematic with government cooperation, it is unattractive in this case for the very same reasons that have prevented the government from delivering power to these regions in the first place. Corruption and bureaucracy are both rampant and as such, government involvement in such an endeavor is best kept to a minimum.

In contrast to both wind and solar power, hydro power requires relatively simple parts, and can be viably implemented on a small scale. Of course, hydro power requires a steady flow of water which is not something all impoverished areas of the globe are blessed with having. However, the rural structure in India is such that the smallest and poorest villages are almost invariably near a steady flow of water. In the US, hydro power can be implemented for as little as $1-$2 per watt. This is much closer to something that would be affordable in the villages targeted by this project, but the aim is to actually improve upon these numbers.

Design and Implementation

With the choice of power types selected, it is important to determine exactly what type of hydraulic generator to employ. The factors that go into selecting an appropriate type of hydro generator are similar to factors that went into selected an appropriate energy source, cost of materials and suitability based on the environment.

The types of hydro generators which were considered were a Kaplan turbine, a Francis turbine, and a waterwheel turbine. They all have very different designs and as such, the cost of materials varies quite significantly. Furthermore, each of these turbine types is optimal for certain ranges of head. Between these two factors, it is relatively simple to select an appropriate type.

A Francis turbine has the basic design shown in Figure 1 below.

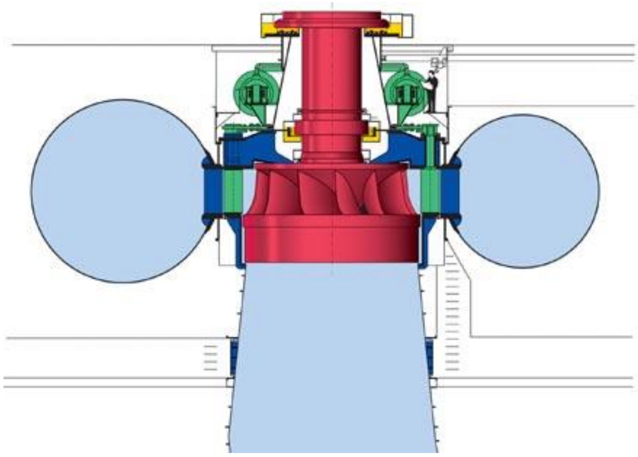

Figure 1

The Francis turbine requires a runner as can be seen in Figure 2 below.

Figure 2

This runner is the portion of the Francis turbine which actually spins from the flow of the water. The rotation of the runner is then connected to an alternator which converts the mechanical energy into electrical. Unfortunately the runner needs to be a specific shape and there are not many practical devices aside from a Francis turbine which require anything shaped quite like this. As such, these runners are both difficult to build out of scrap parts from other common items and expensive to buy new.

In contrast, another option is a Kaplan turbine which is a variation on a Francis turbine. The basic design of a Kaplan turbine can be seen in Figure 3 below.

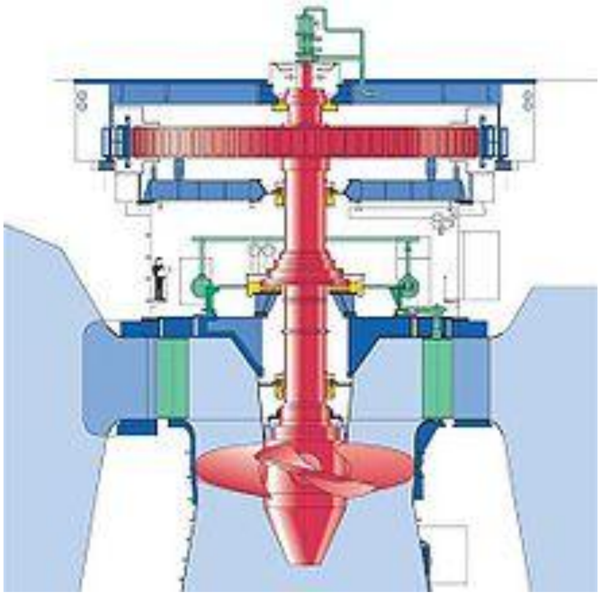

Figure 3

In many ways the Kaplan turbine is similar to the Francis turbine. The runner of a Kaplan turbine however represents a key difference. It is simply designed to spin as water moves past it. Unlike the runner on a Francis turbine, this is actually a common shape and can be found in numerous common products. This is obviously beneficial as it drives down the cost of acquiring the part.

The final option considered was a simple waterwheel. The benefits of a waterwheel from a cost perspective are quite obvious. It is a simple design as can be seen in Figure 4 below.

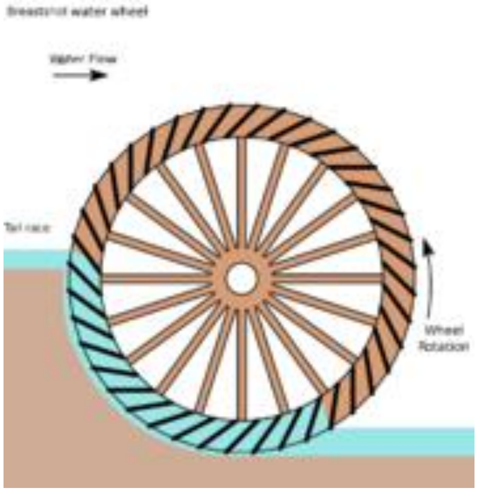

Figure 4

Perhaps the biggest advantage of a waterwheel is that its parts are so simple to design that no mechanical parts would need to be brought to the region, just the alternator. The mechanical components could easily be constructed on site from inexpensive materials. This obviously offers a potentially enormous advantage over any other design.

There is a second design consideration to keep in mind however, how appropriate each design is for the environment. Consider the small village of Govindghat in the Himalayas in the state of Uttarakhand, India. The town is big enough to have some power during the day, but power is usually shut off at around 10PM. As such, the people in the town have electronic devices such as lights, and water but do not get to use them once then power turns off. Furthermore, Govindghat, like many of these rural villages sits on the edge of a river, in this case, Lakshman Ganga. It passes through the center of the village and has a very swift current, as can be seen Figure 5.

Figure 5

Govindghat can be looked at as the typical town to be assisted in this project. The nearest city is Srinagar which is roughly 8 hours away by car, and itself only has a population of about 20,000.

With Govindghat and the Lakshman Ganga in mind, it is possible to compare the various turbines to see which is the most appropriate for the situation. A waterwheel, while most likely the cheapest solution has a limited range of acceptable head levels from the water. As can be seen in the Figure above, the water can flow quite quickly from the Lakshman Ganga and it will easily exceed the 4M maximum head for a waterwheel. A Francis Turbine is designed to operate between 10M and 350M. The low end of this scale may be achievable in some rivers, but by in large, the head in a river will be insufficient to really take advantage of the Francis turbine design. Since the damn necessary to achieve the head requirement would once again require government involvement, the Francis turbine is undesirable.

This leaves the Kaplan turbine. It has a head range of 2M to 40m, which should be roughly a good fit for the types of rivers found near villages in India. When combined with the simple necessary parts, the Kaplan turbine stands out as the best design.

With the Kaplan turbine selected, the question then becomes what is the best approach is to implement one without using any expensive parts. The runner, as one of the most critical parts needs to be shaped so that water flowing past it causes it to spin driving the actual generator. A typical runner for a Kaplan turbine looks like the image seen in Figure 6 below.

Figure 6

Just like with the Francis turbine, a runner for a Kaplan turbine is expensive to purchase directly. Fortunately, the concept of a shape which spins as water moves past it is common and can be found in many existing items. Both boats and jet skis push water with a propeller shaped roughly like the runner in Figure 6. An example boat propeller is shown in Figure 7 below.

Figure 7

The problem with the boat propeller is that it presents large gaps where water can pass it unimpeded and as such without actually contributing any energy. This is not a problem for a boat, which uses the blade to push water, but is a significant problem for a generator attempting to capture as much energy as possible from a fixed amount of water.

A Jet Ski on the other hand uses an impeller, as opposed to a water propeller. An impeller is typically used to drive fluid through a tube. In a jet ski, the water is pulled through the tube and shot out the back producing forward motion. This is actually is similar mechanically to the requirement for the runner on a Kaplan turbine.

Given the use of a propeller, the encasing of the turbine becomes significantly easier. As can be seen in Figure 3, the ideal design for the turbine is to have water flow roughly horizontally into the center, before being directed downward past the runner and out the bottom. The casing of the runner has to be large enough to accommodate the runner and shaped to implement a similar flow of water.

PVC is a common material and could most likely be used to encase the runner, but it only comes in a limited selection of diameters. The maximum common size for PVC is 6 inches in diameter. This means that the runner selected must be less than 6 inches in diameter. This also lends further reason to selecting an impeller over a boat propeller as they are usually a bit smaller.

With an encasing to channel the water and a runner to capture the mechanical energy, the next task is to convert the kinetic energy of the spinning runner into electrical energy. This can easily be done with any number of designs, and is a subject which has been covered extensively. Both AC and DC motors can be used as generators. Making a generator out of the requisite parts is also a possibility as the design is simple, and the necessary parts are inexpensive.

Upon inspection, however, it turns out that a permanent magnet DC motor is simple enough, and common enough, that buying a suitable fully assembled motor is actually inexpensive. Keeping in mind the amount of labor required to build an entire generator, it seemed much easier to simply buy appropriate models which are preassembled.

There are numerous sources of adequately sized DC motors, but the simplest seemed to just be used treadmill motors as they are inexpensive and designed to run at fairly high power levels.

Thus, the three main components of this Kaplan turbine were the PVC casing, the impeller as the runner, and a DC motor as an alternator. Images of each can be seen in Figure 8 below.

Figure 8 A

Figure 8 B

Figure 8 C

The PVC selected was a T joint allowing the alternator to easily sit on top of the joint with a shaft connected to the impeller inside. This ended up being much easier than using an elbow joint which is curved and as such, needs the alternator to be supported in a manner that keeps it flat. The tradeoff of using the T-joint was that it was open from both sides. For testing purposes, a PVC cap was used to block one side of the T-joint, forcing the water to flow in the other end, make a 90 degree turn past the impeller and out the side of the joint.

Figure 9: Impeller Connected to Alternator

Figure 10 Generator Side View

Figure 11 Inside Generator

Figure 12 Alternator Sits on top of PVC

The final product was subsequently tested in the gorges in Ithaca and the results were promising. As mentioned above, a Kaplan turbine typically requires 2M of head for reliable operation. In Ithaca though, the rivers and gorges struggle to provide much more than .5M of head without having pipes laid out over prohibitively long distances. However, the water was moving through the T-joint smoothly and clearly providing force to the impeller. When the impeller was out of the water, it took a reasonable amount of force to make it spin and drive the alternator. With the water moving past it on the other hand, it took almost no extra force to make it move. As such, it seems clear that just a little bit more head from the water would have been sufficient to drive the alternator.

In light of these encouraging results, we attempted to increase the head of the water passing the impeller. As such, we moved to a different area of the gorge with a bit of extra head and tested there. Testing in this location was a bit more challenging. The location can be seen in Figure 13 below.

Figure 13 Water flowing through Pipe at Gorge

As can be seen in the figure, using this location required adding a 4 foot section of straight pipe off the fall. This pipe was then connected to the generator from Figure 10 with the impeller pointed straight down. The head at this location was easily measurable as it is just the height of the falls. In this case, we had approximately 1M of hydraulic head.

The results were exciting as the impeller was clearly rotating inside the generator. In order to get a better idea of how much power was being produced, we attached a multimeter to the output ports of the alternator and measured the voltage. we were actually getting roughly 10V at the output although it fluctuated quite a bit, sometimes dipping as low as 2V.

We attempted a second measurement in order to get the exact power coming out of the generator. We set up the circuit shown in Figure 14 below.

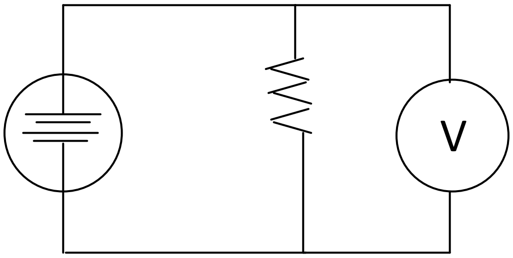

Figure 14

We used a power resistor with an R value of 1 ohm. The volt meter across the resistor measures the voltage drop, and the power from the generator is then just computed from Equation 1 below.

$$P = \frac{V^2}{I}$$

Equation 1

Unfortunately, as can be seen in Figure 13 above, we were dealing with fast moving currents. We were also trying to increase the capacity of the resistor to handle addition power by letting it sit in the water. As we were making the measurement, the resistor came loose from the main generator and was lost in the water. In future experiments, it would be interesting to see how much power was actually coming out of the generator.

Without this data, we were forced to make a best guess estimate of how much power actually was coming out of the device. Running through the calculations shown in Appendix A, our best estimate was that the generator was producing 70 watts. This is likely well below the peak power output it is capable of as it is designed for more than the 1M of head applied.

With this power resulting from the generator at just 1M, we have reason to be optimistic about the overall capabilities of the generator. The 1 M of head in the experiments is clearly less than the head supplied by the water in Figure 5 at the actual site.

With that in mind, the river should supply plenty of extra hydraulic head, implying that the generator should be a viable option for producing power in rural areas of India with significant rivers such as the Lakshman Ganga.

So now with the turbine itself designed, the question becomes what exactly does it cost, and what is the cheapest way to get it to a town like Govindghat. Govindghat is a two day drive from New Delhi, the capital of India, and eight hours from SriNagar. Very few of the necessary supplies can be found in Govindghat itself; however one needs to go varying distances in order to get each one.

Prices in India can fluctuate quickly as the economy there expands and emerges. As such, it is important to establish a baseline on prices in the US. The alternator was bought online new for $24.00 from the site www.allelectronics.com . It is an alternator for electric scooters which are common in India. While the budget will be a conservative estimate, it is actually possible for the price to come down, as finding used alternators from those scooters is not a difficult proposition in India and will dramatically decrease the costs.

The T-Joint for the PVC cost $31.00 from Lowes. This is certainly a high number, however it was deemed acceptable because PVC costs much less in India than it does in the US. Specifically, PVC T-joints with a 6 inch diameter cost Rs. 200 in India, which translates to roughly $4.00 depending on the exchange rate between the Indian Rupee and the US dollar at the time. Since the PVC is fairly heavy and so widely available, it will be advantageous to get it from the nearest location to the site as possible in order to reduce shipping costs.

Finally, the impeller is the most challenging part to locate. There are several options for procuring one, but each has its drawbacks. The impeller used on this prototype was a used Seadoo impeller purchased on EBay for $25.50. While the US version of Ebay has numerous impellers for sale from all over the country, Ebay in India does not. This means that a suitable impeller either needs to be shipped to India, or acquired some other way there.

Fortunately, India remains a major manufacturing center, and getting custom made impellers of this general design is less challenging there. After finding a factory in New Delhi which makes similar parts, the quote given was roughly $20.00 per unit assuming an order of 1000 units or more. If there are fewer than 1000 units produced, the impeller will cost much more. The most important factor however is the total cost to the end user per impeller. Since it will cost roughly $40.00 per impeller to ship 20 impellers at a time from the US to India, the total cost to the end user of an impeller bought in the US becomes $65.50. At this rate, it will become cheaper to buy 1000 impellers in India at $20 each, once there is demand for just 300 impellers total. Before then, it will still make more fiscal sense to buy used impellers in the US and ship them to India.

The final issue is of course how much does it cost to actually get these materials to Govindghat. The impellers will need to be manufactured in New Delhi as any purchased closer to Govindghat will just be made in New Delhi and then shipped to the location they are purchased from. The alternators unfortunately will also need to be purchased in New Delhi for the same reasons. The cost of shipping these impellers and Alternators to Govindghat is roughly $8.00.

Finally, there is the question of the T-joints. They can be acquired in New Delhi for $4.00 as mentioned above. They can also be acquired for $6.00 in SriNagar, which is much closer to Govindghat. Shipping the T-joints to Govindghat from New Delhi will cost $2.00 and from SriNagar will cost $1.00. This brings the total cost to $6.00 if they are acquired and shipped from New Delhi, and $7.00 if they are acquired and shipped form SriNagar.

The other benefit of acquiring the T-joint in New Delhi is that it means all the parts will be in New Delhi and as such, it can actually be fully assembled there before being shipped to the destination. While labor in India is inexpensive, it will be less expensive to put together in New Delhi as part of a small assembly operation that ships finished generators all over the country rather than shipping the individual parts to the site and assembling there.

This brings the total cost of delivering the generator to Govindghat up to

Alternator:	$24.00
Impeller	$25.50
PVC Casing	$ 4.00
Transportation Costs	$10.00
	$63.50

With economies of scale, the price of materials could be reduced to

Alternator:	$24.00
Impeller	$20.00
PVC Casing	$ 4.00
Transportation Costs	$10.00
	$58.00

This yields a total cost per watt of $0.83, based on the conservative 70 watt output estimate found above. There is also potential for this cost to come down further as power increases with more hydraulic head applied.

Conclusion

The initial goal of this project was to devise a solution which could be used in rural areas of India in order to give power to people who do not have it. The requirements were to design a generator which had the lowest cost possible and took advantage of the natural surroundings along with readily available materials near the target locations. We decided ultimately that it was better to aim for a generator for an individual rather than for whole villages at a time in order to reduce the level of government involvement necessary.

Ultimately, we were successful in building a device which was both affordable to many people in rural areas of India and which all indications are would supply a reasonable amount of power to a rural house.

Of course, there are other elements necessary to really take advantage of such a system. For one, it would be necessary to use an inverter which is commonly available all over India. The inverter would smooth out the power delivered by the generator and convert it into usable power for consumer electronics.

All in all however, it seems clear that the design we came up with and implemented is a viable short term solution for the power problems plaguing rural areas of India. Ultimately $58.00 is something that would be affordable to many of the inhabitants of Govindghat. As such, this project seems to have successful met the goals laid out in the project plan.

Appendix A

Estimating power from the generator:

The reading at the experiments was for roughly 10V coming out of the generator. In order to get an idea of how much power was produced, I later took the generator apart and simply spun the shaft connected to the alternator at a controlled speed of 1 revolution per second. This yielded approximate 1V at the output terminals on the multimeter. Assuming linear scaling, this implies that the alternator was spinning at 10 revolutions per second when 1 M of hydraulic head was applied. Since each blade of the impeller goes around 120 degrees, and has a pitch of 2 CM, it is clear that 2cm * 3 blades per rotation = 6CM of water must move past the impeller per rotation. As the entire tube was filled, this means the total volume of water which needs to pass the impeller per rotation can be calculated as seen below in Equation 2, given a pipe with a 6 inch diameter

$$V = \pi\left(\frac{6 inches}{2}\right)^2 \times \frac{6\ cm}{2.54\ {}^{cm}/_{inch}} = 65.88\ inches^3 = \frac{.0011\ m^3}{revoltion}$$

Equation 2

Since there were 10 revolutions per second, we can assume that the water was moving past the impeller at a rate of approximately .011m^3/second. We know that water has a density of 1000KG per m^3 which means that approximately 10KG of water were passing the impeller each second. Since it was dropping 1 meter, the simple formula of power = m*g*h yields a total input power of 10*9.8*1 = 98 watts. If there was an input power of 98 watts, and we assume that the generator had an efficiency of roughly 70%, the power out of the generator would then be 68.7 watts ~ 70 watts.