

# Product and Facility Design for Hydroelectric Generators in Malawi

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## Abstract

Currently, over 50% of the population of Malawi, Africa lives in poverty and many have little or no access to reliable power systems (Malawi, 2015). Due to this, a group from the University of Wisconsin-Stout travelled to Malawi to conduct research on how a developing country may manufacture electric generators.

The main question that needed to be answered was: how does one build an electric generator in a developing third world country? This overarching question can be broken up into 3 main parts:

- What tradeoffs, if any, need to be made when designing hydroelectric generators in Malawi?
- Is it possible to utilize available scrap to manufacture a consistent product? How can consistency be guaranteed?
- What changes need to be in place for a "safe" work environment to be created?

Methods utilized in answering these questions included visiting sites of manufacture and generator placement, observing current safety protocol, measuring current generator output, taking inventory of scrap material, and searching for what material sources are available.

The results of this research produced two new generator designs tailored to the region's manufacturing capabilities. It is believed that creating micro-hydro generators in this region of Malawi will be possible if certain metal casting processes and safety procedures are put in place.

*Keywords:* Malawi, generator, prototype, electricity, power

## Introduction

In Malawi, about 10% of the population has access to reliable electricity (Access, 2016). Most homes in this region utilize kerosene generators that are not only expensive, but are dangerous due to the gasses generated. This causes many younger people to suffer from respiratory issues,

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including coughing. Many homes and villages are in rugged and remote locations, far from the power grid. To solve this, Hastings Mkandawire, a Mandela Young African Leaders fellow, created hydroelectric generators from recycled materials. The generators are placed in small streams near individual villages. In 2014, Mkandawire visited the University of Wisconsin-Stout. Once there, he was awarded the Mandela Young African Leaders Fellowship, as well as a \$25,000 US-Aid grant to build a facility to produce his generators. At this ceremony, he was singled out by President Obama for his innovation.

There were problems in the initial design. Recycled components were becoming scarce, generator efficiency was low due to part variation, and the generators did not produce enough power for large appliances to function. To address these issues, a new design was created by UW-Stout students in 2014 which was further refined in the spring of 2015. The facility layout was also defined during the spring refinement. This design took into account that Malawi is a developing country.

This new design utilized scrap metal only for the frame, and incorporated plastic resin components that eliminated the need for purchased steel, expensive equipment, and skilled operators. Purchased parts were limited to copper wire, magnets, epoxy resin, and bearings. With the resulting improvements, estimated production time dropped from 40 hours to 3 hours. 'Lean methodologies' were applied in the facility design so that the production would run smoothly. The core idea of 'lean manufacturing' is to maximize customer value while minimizing waste. In this context, having a lean manufacturing process allows for creating higher-quality generators with fewer resources (What is Lean, 2016).

However, the estimations and designs done solely in the United States did not adequately solve the problems Hastings was having. To better understand the issues citizens of Malawi face in manufacturing, a trip to Malawi took place on January 1st, 2016. This paper details the questions that were asked as well as the observed findings.

## **Objectives**

The objective of this trip was to determine the viability of manufacturing micro-hydroelectric generators in Malawi. Micro-hydro generator systems are small hydroelectric power systems of less than 100 kilowatts (kW) used to produce mechanical energy or electricity for farms, ranches, homes, and villages (Microhydropower, 2013). To support this objective, the following eight questions were initially proposed (any modifications to the initial questions and reasons for exclusion are included in the list).

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1. Generally: how does American product design need to be modified to work in a developing country?
2. Generally: what tradeoffs, if any, need to be made in designing a safe and efficient facility in a developing country?
3. Is it possible to manage variable scrap material dimensions and quality and yet maintain a consistent product?
4. How does limited material availability affect product design for a developing country?
5. Can a developing country support the production of simple hydroelectric generators?
6. What quality inspection processes can be implemented in a developing country?  
     It was decided that epoxy would not be used  
     For the finished generators.
7. Much of the time was spent designing a new generator based off of newfound constraints and information. Also, there was no set process or design to base a troubleshooting procedure on
8. What industrial safety equipment and policies can be implemented in a developing country?

As mentioned above, this list of questions was modified from the original due to unforeseen project changes. These changes caused some of the questions to become impossible to answer, and caused others to become redundant. To make this paper more concise, the questions were rewritten as follows:

- What tradeoffs, if any, need to be made when designing hydroelectric generators in Malawi?
- Is it possible to utilize available scrap to manufacture a consistent product? How can consistency be guaranteed?
- What changes need to be in place for a "safe" work environment to be created?

### Methods Utilized

Methods utilized in answering these questions included visiting sites of manufacturing and generator placement, observing current safety protocol, measuring current generator output, taking inventory of scrap material through observation, and searching for what material sources are available.

To support the studies that are listed below, a prototype of a "new" design was created. Discussion on this prototype occurs in its own section, "The Prototype."

- To obtain an answer for how viable working with scrap materials was, measurements of all created parts were made using a dial caliper accurate to .001".
- To obtain time studies, a stopwatch was utilized and the steps to create each part of the prototype generator were recorded.
- The generator's voltage output was measured with a Metex Multimeter.

## **Results**

### **What Tradeoffs, if Any, Need to be Made When Designing Hydroelectric Generators in Malawi?**

After spending time in Malawi, it was found that a few non-typical factors must be considered when designing products for manufacture in developing countries. The factors are as follows:

- Machines such as lathes and mills are in short supply. Many operations must thus be done by hand. If a product design requires the use of multiple machines, it will not be successful.
- Large scale casting is difficult, if not impossible. There is a tradeoff between repeatability and size that must be considered. For example, generator bodies are cast as one part in most industrialized countries. That one part is too large for the miniscule casting industry that is present in Malawi, therefore the body has to be cast as multiple pieces to be assembled later.
- Manpower is a very plentiful resource that is considerably cheaper in developing countries. This allows for designs that require more handwork and assembly to be much more viable in developing countries than in developed countries.

Also, designs have to account for the fact that assemblies that require many different parts are almost impossible to make due to limited hardware components. Using similar components across an entire design (such as using the same size screw across assemblies) is generally good design practice, but is especially important in developing countries.

### **Is it Possible to Utilize Available Scrap to Manufacture a Consistent Product? How can Consistency be Guaranteed?**

The inconsistencies in the generators made from scrap materials caused the total voltage output to vary widely, a fact found through a discussion with Hastings. However, scrap pieces could easily be used in the generator frames without impacting electrical output. Scrap could also be melted down to create new parts.

Calipers appeared to be an available resource, thus lending to the

assumption that simple dimensional quality checks could be put in place to guarantee quality. It would also be possible to create go/no-go gauges for many of the parts. Anything that is more advanced (e.g. automated testing equipment) is out of the question due to cost and lack of training.

Electrical measuring tools (such as Multimeters), though rare, are still a viable option for quality checks and troubleshooting steps. Having this tool will allow the process to be refined further through the analysis of why some generators may have defects (such as low output) while others pass inspection.

High levels of accuracy and precision were obtained in the creation of the manufactured components due to the skill level of the technicians. The technicians cut 12 stator supports within 1mm precision on length and also built a circular stator within 1mm precision on concentricity. It can be concluded that for consistency to be "guaranteed," certification through a technical school is a must.

### **What Changes Need to be in Place For a "Safe" Work Environment to be Created?**

No tradeoffs need to occur to create a safe work environment. However, implementing safe practices at a facility can be heavily burdened by the current lack of training. It is very important to ensure that the individuals know what procedures are required and why these procedures are used. For example, even though the current facility had a welding helmet, it was rarely used. In fact, workers tended to look directly at the arc. In general, safe practices by Western standards are not part of the local culture, and must be taught and reinforced at the workplace. The worker with the technical school education was more likely to use the available safety equipment. Hastings Mkandawire was exposed to safety equipment when at Stout, and understands why it is needed, but must overcome his cultural practices to remember to use and encourage his workers to consistently use the safety equipment.

### **Discussion/Implications**

It is important to note that a casting industry needs to be in place to fully support medium to mass production of generators. Medium to mass production, in this context, was deemed to mean, "producing more than 20 reliable generators a week." With metal casting, the process required to produce a generator is simplified as metal would not have to be cut and welded into shape. Because of the simplified process, the time to produce generators is reduced, allowing for more generators to be produced in a

shorter time span. Quality can also be improved as there are fewer steps in the build process that could result in defects.

The other benefit of using a casting process is that specifically shaped scrap metal parts are not necessary as metal could simply be melted and cast into the correct shapes. This eliminates the time spent searching for parts in junk yards. Also, quality scrap metal parts in northern Malawi were becoming scarce as of January 2016, which made producing consistent generators difficult (Mkandawire, 2016).

## **The Facility**



The final facility was not ready by the time of arrival, so the Stout group worked with the team at a temporary location, which was a subleased room of an auto-repair shop.

## **Safety Standards**

The expectations for safety standards in Malawi were low after watching presentations on safety in other countries. It was a pleasant surprise when safety equipment was seen upon arrival at the facility. However, even though the group possessed a darkened welding helmet, gloves, long pants, jackets, and safety glasses, they were still rarely used.

Focusing on the welding violations, and using a resource from the American Welding Society, many violations were noted (Safety, 2005).

Violations include:

- 3.2.1.3 Designated Areas and Responsibilities – welding was done wherever it was convenient.
- 4.1.2 Signs – no signs were posted designating the fact that

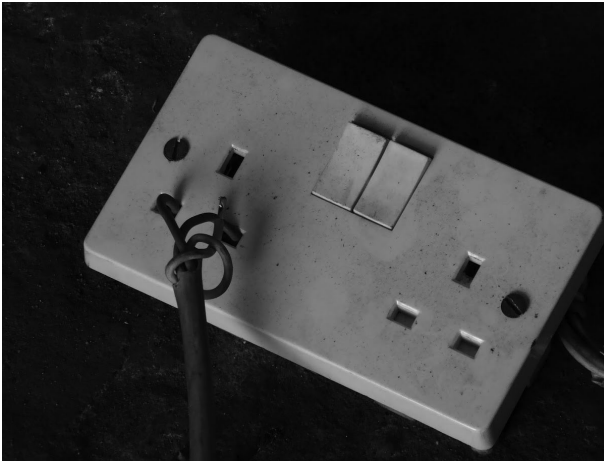
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welding would be done in the area.

- 4.2 Eye and Face Protection – welding operations were mainly carried out by holding the gun and closing one's eyes. Welding was often done out in the open, with onlookers staring directly at the work being done.
- 4.3 Protective clothing – gloves were only used if a piece of metal was to be moved immediately after the weld was finished. Tennis shoes and sandals were worn, as were short sleeved shirts.



The outside location ensures natural ventilation (Section 5) and there was no fear of confined spaces when working outside (Section 7). This will need to be reevaluated once the move to an indoor facility is complete.



Electrical safety was poor as can be seen in the image above.

United States Electrical Safety standards are standards created through years of labor, experience, and training. A study done by Kimberly-Clark Professional at the 2008 National Safety Council Congress may be applicable to this situation. In the study, 89% of the respondents reported witnessing safety violations in the work place. Of those, 63% stated training and education for safety was lacking (Why Do Workers, 2016). While many of the workers had some degree of technical training, it seemed apparent that the effects of not wearing personal protective equipment were not disclosed. If images of eye damage from welding were shown, wearing the mask might become more standard. Interestingly, safety equipment was used wherever danger was immediately apparent, such as wearing gloves with spinning cutting discs and extremely hot metals.

Besides lack of safety training, the environment and the economic situation of the region also had a hand in the lack of equipment use. For one thing, Malawi is in a tropical zone so it is often very hot, so hot that there are times when it is dangerous to be working outside. This makes it hard to wear longer shirts and pants. The scarcity of funds would also make it harder to buy safety equipment for all personnel.



Pictured above is one of the best examples of safety seen at the facility. He is wearing full protective clothing and safety goggles. However, personal protective equipment was not available to everyone.

### **Training/Education**

Some of the workers had formal training with machines commonly found in manufacturing (such as lathes, mills, and arc welders). However, many did not or had just learned by watching. Most likely, this resulted in some of the safety violations witnessed in the Safety Standards section.

A discussion with one employee regarding his schooling resulted in some interesting comments, which are paraphrased below:

- The schools teach maintenance, not design.
- How does one learn how to create new designs?
- How do you go about designing something new?

These questions were asked after the prototype was designed as the employee thought he did not have the skillset to design *anything* because he was not creative. This thought was immediately corrected. The mindset was that he was not creative was most likely stimulated by economics. Since the citizens in the area could not afford new items, it was very important to have workers that were great at maintenance. Oftentimes, this maintenance required a great deal of creativity. After hearing the explanation on how maintenance requires creativity, the employee began to realize that he was fairly creative and different ideas were discussed for improvement projects that he came up with almost on a daily basis.

### **Why Build Locally?**

Building locally is important for a few reasons:

- It could spur local manufacturing
- It is much more economical, as labor and most raw materials are plentiful and cheap
- Local building could jump start learning opportunities. Increased education in a country has many large benefits (including financial stability)
- Money would stay almost entirely within the country, increasing opportunities through an improved economy

### **The Prototype**



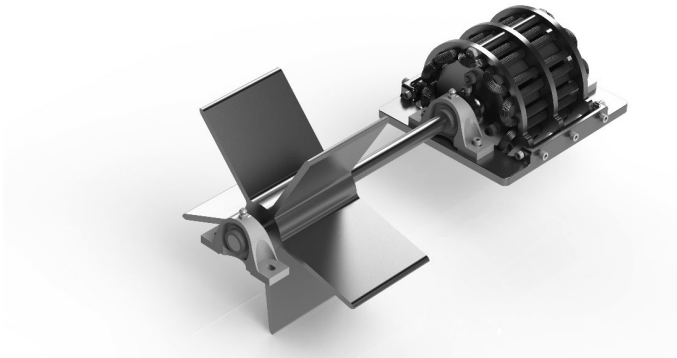
Up until this point, the team in Malawi had been repurposing old generators and motors. After understanding the capabilities of the personnel and equipment, a new design was created for the purpose of testing whether or not it was feasible to create a generator from pure scrap. One of the constraints placed upon the design was to use a minimal amount of material (this design is further discussed in the Cage Style section below). The team began creating the new prototype once a few rough sketches were completed. The picture above is the final result. While the output of this prototype was inconsistent, it was deemed that creating a generator from pure scrap is possible.

### **The New Designs**

If the reader is interested, he or she may navigate to [generatormodels.joshuamiller.io](http://generatormodels.joshuamiller.io). All of the solid models created for these designs are there for public use. If the models are used, please give credit to the initial creator(s).

- Two items are the same across both designs.
- The parts are cast from metal.
- Magnets, or electro-magnets, of sufficient magnetic strength are used. "Sufficient magnetic strength" can be calculated using the final voltage output of the generator, the average rotations per minute the rotor will spin, the number of magnets used, and radius of the magnets around the shaft.

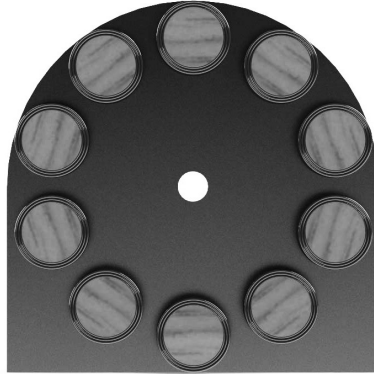
### **Cage Style**



This style borrows the base design from the popular generator designs of today, and modifies it so that it is more feasible for a third world country to develop. Material is saved by slicing the body of the generator into multiple parts and using spacers to achieve the desired size. This is also easier to manufacture because the molds used to cast the parts can be smaller. The

main tradeoffs with this design are that the internal pieces are now lacking protection and there are more components to make and assemble.

### Disc Style



A previous group of students tried creating a disc style generator, but it had been deemed a failure. This was caused by two issues. One was that the discs were comprised solely of epoxy, which is expensive. Another was that the magnets used were too weak, which caused the voltage that was produced to be very low.

The design would have sufficed if stronger magnets were used. If one merely searches the internet for "1000 Watt turbine" he or she will find examples of disc generators that were built at home (sspence, 2016).

This design makes up for its bulky nature by having very few parts and is generally simple to produce. Instead of having multiple rings that fit together to create a rotor and stator, it only has two plates. Because of the simple nature of the design, the molds used to create the disc shape would also be much less complex. The process used to ensure quality would also be less extensive than with the cage style.

The main difficulty with this design is creating the rotating electrical connection required to maintain power to the electromagnets.

### Limitations of the Study

Even the most thought out and planned projects have unforeseen issues. In the weeks leading up to the departure, the group received new details via email about the current state of the manufacturing facility as well as new details about the work Hastings wanted the group to do. It was found that there was no consistent production process in place. It was also found

that the facility was still being finished. However, enough objectives were completed that this project can still be evaluated with some accuracy.

### **Future Work**

More work has to be done before this project becomes a reality. This includes, in order:

1. Studying the benefits of AC vs DC generators
2. Creating the electrical component part list if AC to DC conversion is needed
3. Setting up an aluminum casting process in Malawi
4. Finalization of the generator design by an engineer with more experience in the field
5. Finding suppliers of wire and scrap metals so that components could be created
6. Creating molds so that the components could be cast
7. Finalizing a quality inspection plan

### **Conclusion/Evaluation**

In the original proposal, the project was to be evaluated on three criteria:

1. The voltage output of the generator.
2. The cost to build and maintain the final product/process.
3. The repeatability of the proposed manufacturing process.

### **Voltage Output**

The completed prototype generated 44 volts. When one looks at the prototype that was created, and the way that it was manufactured, an output of 44 volts is acceptable. It is anticipated that once proper manufacturing processes are in place, this number will be much higher. More testing will be needed.

### **Cost of Production and Maintenance**

The cost of the final process will come mainly from material purchase, since labor is exceedingly cheap in Malawi. In 2009, the average annual wage was \$286 USD in urban settings (Durevall & Mussa, 2010). The prototype generator took 2 workers about 3 days to build. The cage generator design should take the two workers only one day to build, and the disc style generator should only take 6 hours to build. Although the labor cost savings are low, this permits a significant increase in output.

The costs of importing aluminum and setting up an aluminum

foundry, as well as the costs of importing wire and magnets, are still being analyzed. One possible method that would reduce costs would be to utilize scrap aluminum. Use of the electromagnet design significantly reduces costs, as the magnets are by far the most expensive components of the generator. Other sources of financial aid are now being researched by Hastings.

### **Repeatability**

The designs that were conceived after the trip simplify the necessary components to the point where quality (when defined as the ability to produce consistent voltages) can easily be obtained by switching from hand cutting and welding to casting critical parts. The only issue is that for either of the designs to work, a casting facility must be introduced in northern Malawi. Through contacts that were made over the course of the trip, it was found that metal casting as a process will almost certainly come to the region as it exists successfully in the southern part of the country. It benefits many different industries and thus has many different vested interests.

### **Final Evaluation**

This project and trip is considered a success for multiple reasons. One is due to the fact that multiple new class projects were brought back to the University of Wisconsin – Stout. As a polytechnic university, this is highly beneficial. Also, because of this trip new designs were created so that generators could be manufactured in Malawi. These designs would have been much more difficult to conceive if limitations of existing materials and the issues faced by manufacturing processes were not witnessed firsthand. Lastly, because of these new designs an industry new to the region (metal casting) may finally come into existence. This could kick start a small industrial revolution in a struggling country and give many rural homes access to reliable electricity.

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