Submitted towards partial fulfillment of the requirements for

Mechanical Engineering Design I

"Senior Capstone Design"

November 10, 2017

Department of Mechanical Engineering
Northern Arizona University
Flagstaff, AZ 86011

Dr. David Trevas

Final Proposals
Renewable Energy Toolkit
Team A5

Fahad Alsuwailem
Hamad Alsharhan
Mohammad Alsharidah
Mohammed Jarkhi
Talal Alenezi

DISCLAIMER

This report was prepared by students as part of a university course requirement. While considerable effort has been put into the project, it is not the work of licensed engineers and has not undergone the extensive verification that is common in the profession. The information, data, conclusions, and content of this report should not be relied on or utilized without thorough, independent testing and verification. University faculty members may have been associated with this project as advisors, sponsors, or course instructors, but as such they are not responsible for the accuracy of results or conclusions.

TABLE OF CONTENTS

1 Contents

1 BACKGROUND

1.1 Introduction

The project aims at development of a renewable energy toolkit to energy-enable off-grid clients through provision of power from sustainable sources. The idea is to devise a portable pack equipped with generator, storage devices and inverters. This is expected to greatly simplify the currently complicated process of harnessing energy from renewable resources in remote area applications.

Uninterrupted energy supply is essential to make use of almost whole of scientific advancements, for connectivity across the globe, for human comfort and for efficient use of other resources.

Simplification of renewable power harnessing is vital for making energy accessible to a broader coverage area. The project is directly focused on off-grid installations including schools, businesses, government institutions, remote populations and non-government organizations (NGOs). This is especially important for developing nations where grid network is thin and a considerable territory has no access to electricity supply.The renewable energy resource that are part of this study include sunlight, wind, biofuel and hydel reservoirs.

The project is essentially an educational project whereby the prototype developed is to be used in practical demonstration of the concept.

1.2 Project Description

The project description, given to us from our sponsor is:

The purpose of this capstone project is to leverage work of the NAU Solar Shack into a toolkit for Schools, NGOs, and businesses to improve their ability to advance STEM programs and evaluate renewable energy technologies. The toolkit must also include materials to train people how to build, own and operate appropriate small, off-grid renewable energy systems that produce electricity. The goal of this capstone project is to design, build and demonstrate a small, affordable, and useful renewable energy system, capable of providing electricity at an off-grid installation. The system must also include educational materials to support use of the toolkit. The outreach materials associated with the system is the most important part of the project.

We wish to enhance ability of people to evaluate and implement relevant projects along with understanding of science, engineering and financing involved. Examples include colleges and high schools in the Caribbean where labs such as the one at NAU can be emulated. This would be a teaching tool for students but also for electricians and existing businesses. Potential customer are NGO's, such as Partners in Health and Mercy Ships which are operating clinics and hospitals in the developing world, and rural Native American Nations. Also components, software, and data acquisition lessons can be used at wide range of Schools across social & economic spectrums.

1.3 Original System

- This project involved the design of a completely new renewable energy toolkit. There was no original system when this project began.

2 REQUIREMENTS

Requirements of the project can be identified as development of a portable, compact and low-cost package that can harness energy from renewable sources with little or no additional consumable raw materials.

2.1 Customer Requirements (CRs)

Juxtaposing the concept with conventional energy resources, **portability** can be identified as single most important requirement at the customer end. For that, compactness of design is an essential requirement.

As the application is specifically focused on off-grid applications that are typically hard to access areas not covered by fossil fuels supply, there is a need of system to be harnessing from an available **local source of energy**.

Reliability is another important facet of the need as there are little or no back-up options if the product is put in place.

The source of energy, therefore, needs to be available on-site and easily accessible so that the **no dependence on logistics** can be achieved.

A **cost-effective** solution is imperative as the product needs to compete in the market with existing systems in place.

Last but not the least, **safety** of both personnel and the installation is important.

2.2 Engineering Requirements (ERs)

The renewable energy kit proposed needs to be fulfilling following engineering requirements:

- Built-in energy-harnessing mechanism that should be easy to install
- A maximum dry weight of up to 50 kg

- Cost-effectiveness (proposed price < $1500)
- Energy output of at least 100W
- Digital control (preferably using mobile phone)
- Conversion of harnessed energy to DC voltage that shall charge the accumulator (battery)
- An inverter circuit that shall convert the DC to 50 Hz single-phase AC at 110V
- Modular jumper cables that transmit energy to a specific distance. For the project, the cable length is set to be 50m.
- The device should be capable of working along with varying loads i.e. inductive/capacitive loads.

2.3 Testing Procedures (TPs)

Testing of the design shall be carried out to ensure following:

- Weight of the design
- Energy efficiency of the overall system
- Storage capacity of the battery
- Waveform quality of AC output
- Load factor
- EP Class

3 EXISTING DESIGNS

Contemporary technologies that are in place to energize off-grid installations include solar panels and engine-based generators. Both of them are widely used by militaries and government/not government installations in off-grid far flung areas.

3.1 Design Research

Solar panels are photovoltaic plates that directly convert solar energy into DC electric potential. Charged batteries provide AC current through inverter circuit.

Other solar energy models that mainly focus on concentrated radiation harnessing are of low practical application.

Fuel-engine generators work on Otto or Diesel cycles and use supplied gasoline, diesel oil or natural gas as fuel. Some of them also work on high-sulfur fuel oil or furnace oil.

3.2 System Level

Below is a brief description of existing systems:

3.2.1 Photovoltaic Solar Panel

Photovoltaic solar panels are mon- or poly-crystalline sheet of photovoltaic material, that is energized by solar radiation. To store energy for the night and for foggy weather, batteries are used.

An inverter converts the DC battery output to AC that is used for AC applications.

3.2.2 Engine-based generators

These generators are reciprocating internal combustion engines working on Otto or Diesel thermodynamic cycles. Combustion of fuel energizes the shaft that rotates a dynamo (generator).

These generators have an added advantage for AC loads that inverter is omitted in this design. For DC, rectifiers are used.

3.3 Functional Decomposition

The renewable energy kit is essentially a multiple-input, single-output system having generators, storages and power-delivering cables. A box diagram is shown below:

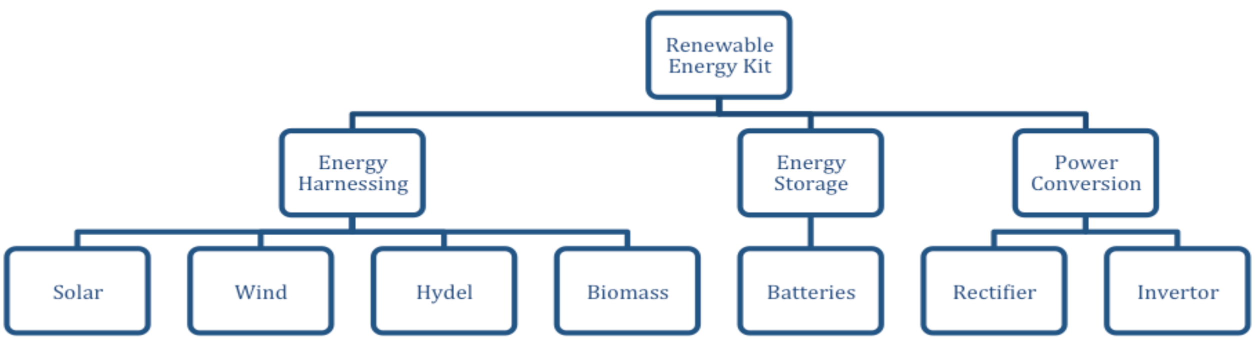


Figure 1: Process Diagram

3.3.1 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The four power generators operate to provide electricity to charge controller. They're independent in operation and each one can be taken offline for maintenance while others may keep on-stream.

The charge controller regulates the current and protects the battery cells. The power cutout mechanism ensures breaking of circuit when battery is fully charged. Therefore, both of them act as protection devices.

A single charge controller is used for different power generators, apart from the PV cells. The solar charge controller is fitted with an additional component, maximum power point tracking (MPPT) to optimize the efficiency of the panels.

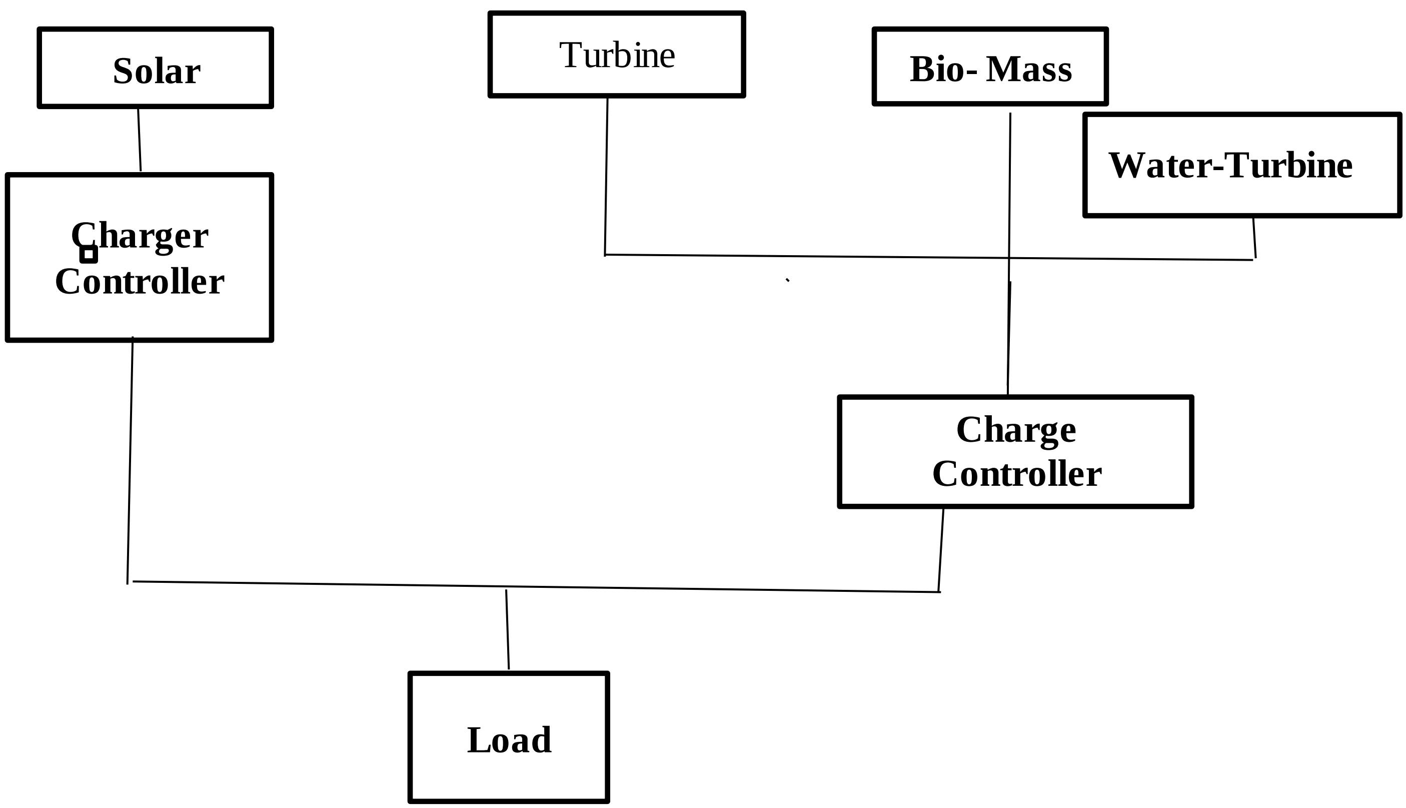


Figure 2: Function design

3.4 Subsystem Level

Below is a component-by-component description of the set-up.

3.4.1 The Hydropower Turbine

Hydropower turbines can be classified into three categories.

3.4.1.1 Pelton Wheel

Pelton wheel is an impulse turbine and is used on high-head, low-flow rate hydel channels.

3.4.1.2 Francis Turbine

Francis turbine is a medium head turbine. It is a highly optimized design.

3.4.1.3 Kaplan Turbine

Kaplan turbine is a low-head, high flow rate turbine.

3.4.2 Photovoltaic Cells

Commercial photovoltaic cells are of monocrystalline and polycrystalline forms.

3.4.2.1 Monocrystalline

Monocrystalline cells are lower in efficiency but they are cost-effective.

3.4.2.2 Polycrystalline

Polycrystalline cells provide higher efficiency but they're expensive.

3.4.3 Biofuel Engine

Biofuel engines are internal combustion engines that use alcohols or organic liquids instead of fossil fuels. With a very little modification in conventional engine, alcohols (methanol, ethanol) can be used to drive generator.

3.4.4 Wind Turbine

Wind turbines harness energy of wind through a large-span blade mounted on height. Through the gear terrain and generator, the energy can be converted into electricity.

3.4.5 Charge Controller

A charge controller circuit will be used to control the input energy stream for smooth charging of battery. Concept of a simple charge controller is:

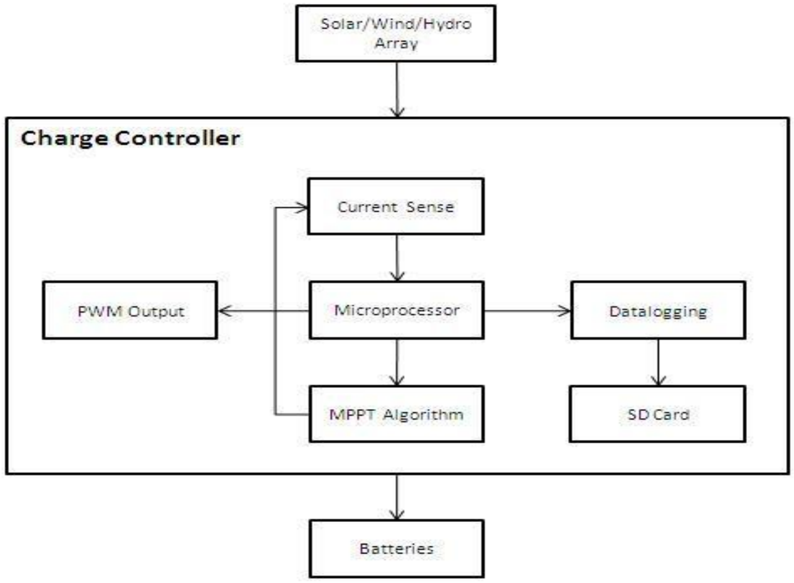


Figure 3: Concept Design

3.4.6 sign Battery

3.4.6.1 Traditional Lead-acid accumulator

Lead-sulfuric acid batteries are conventional source of medium-to-high level power storage. Energy is stored between cathode and anode lead plates due to electrolysis of sulfuric acid.

3.4.6.2 Maintenance free batteries

Maintenance-free batteries (e.g. calcium-based unit) are modern alternative to lead accumulators and are answer to high maintenance requirements of the same.

3.4.6.3 Li-ion battery

Lithium ion battery packs are becoming increasingly popular beyond their traditional installation in electronics. However, their cost is higher for large-capacity units.

3.4.7 Inverter

3.4.7.1 Modified sine wave inverter

Modified sine wave inverter outputs a pseudo sine wave. It is cost-effective but it cannot work with all appliances.

3.4.7.2 Pure sine wave inverter

Pure sine wave inverter outputs sine wave and is safe to work with all appliances. It is higher in cost.

4 DESIGNS CONSIDERED

4.1 Design #1: Wind Energy

Pros	Cons
• No emissions • Affordable • Little disruption of ecosystems • Relatively high output	• Output is proportional to wind speed • Not feasible for all geographic locations • High initial investment/ongoing maintenance costs • Extensive land use

4.2 Design #2: Solar Energy

Pros	Cons
• Non-polluting • Most abundant energy source available • System last 15-30 years	• High initial investment • Dependent on sunny weather • Requires large physical space for PV cell panels • Limited availability of polysilicon for panels

4.3 Design #3: Hydro Power

Pros	Cons
• No emissions • Reliable • Capable of generating large amounts of power	• Environmental impacts by changing the environment in the dam area • Hydroelectric dams are expensive to build • Dams may be affected by drought

4.4 Design #4: Biofuel

Pros	Cons
• Abundant supply • Fewer emissions than fossil fuel sources	• Source must be near usage to cut transportation costs

• Can be used in diesel engines • Auto engines easily convert to run on biomass fuel	• Emits some pollution as gas/liquid waste • Increases emissions of nitrogen oxides, an air pollutant • Uses some fossil fuels in conversion

5 DESIGN SELECTED – First Semester

The project aims to develop a renewable energy toolkit that can make use of renewable energy from multiple sources and output an uninterrupted supply through the cumulative energy harnesses.

5.1 Rationale for Design Selection

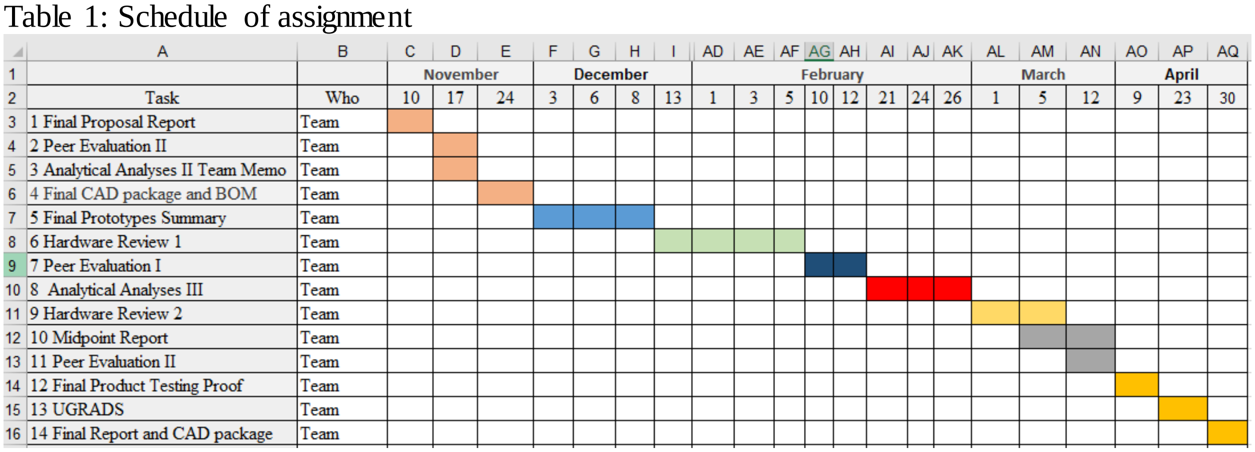
An off-grid installation has advantage in exploitation of locally available energy sources. This is due to high logistic cost and unreliable supply; and high cost of transmission setup from urban areas. Therefore, one or more sources of renewable energy can be utilized.

The concept of using more than sources is to increase reliability and reducing dependence on favorable season/weather. For example, solar and hydel are considered summer energies, biofuel winter energy and wind energy are also highly dependent on local climate patterns. So, two smaller plants of different technologies are more reliable than a larger plant of single technology.

To optimize this set-up, it is imperative to develop a 'renewable energy toolkit' to add up energy from multiple sources and remove a major hurdle in rolling out renewable energy in off-grid areas.

6 Proposed Design

Table 1: Schedule of assignment



	A	B	C	D	E	F	G	H	I	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ
1			November			December				February								March			April		
2	Task	Who	10	17	24	3	6	8	13	1	3	5	10	12	21	24	26	1	5	12	9	23	30
3	1 Final Proposal Report	Team																					
4	2 Peer Evaluation II	Team																					
5	3 Analytical Analyses II Team Memo	Team																					
6	4 Final CAD package and BOM	Team																					
7	5 Final Prototypes Summary	Team																					
8	6 Hardware Review 1	Team																					
9	7 Peer Evaluation I	Team																					
10	8 Analytical Analyses III	Team																					
11	9 Hardware Review 2	Team																					
12	10 Midpoint Report	Team																					
13	11 Peer Evaluation II	Team																					
14	12 Final Product Testing Proof	Team																					
15	13 UGRADS	Team																					
16	14 Final Report and CAD package	Team																					

Table 2: Budget

Source	Cost
PV Solar panel	$60.17
Biomass	$25.13
Water wheel turbine	$50.52
Wind turbine	$31.49
Load	$6.48 for 4 light bulbs
Total:	$173.79

7 Appendix:

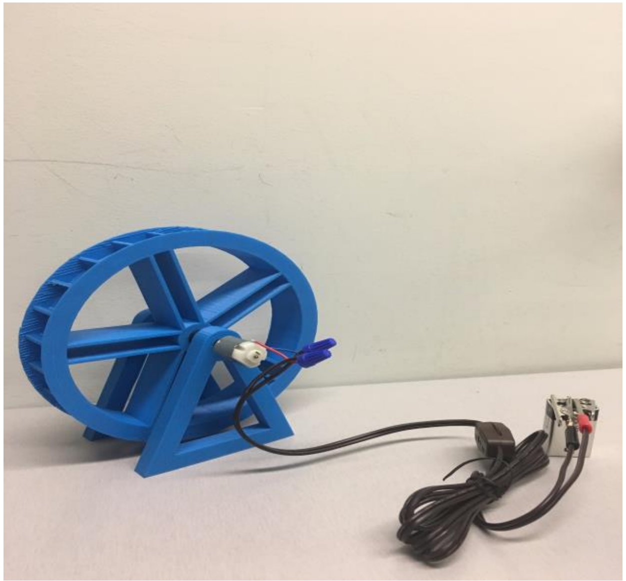


Figure 4: wheel turbine

Figure 5: wind turbine

8 References

1. R Sen, SC Bhattacharyya, *Off-grid electricity generation with renewable energy technologies in India: An application of HOMER*, - Renewable Energy, 2014 - Elsevier
2. P Palensky, D Dietrich, *Demand side management: Demand response, intelligent energy systems, and smart loads*, - IEEE transactions on industrial …, 2011 - ieeexplore.ieee.org
3. SM Shaahid, I El-Amin, *Techno-economic evaluation of off-grid hybrid photovoltaic–diesel–battery power systems for rural electrification in Saudi Arabia*, - Renewable and Sustainable Energy Reviews, 2009 – Elsevier
4. Stephen Sangwine (2 March 2007). *Electronic Components and Technology, (Third Edition)*. CRC Press. p. 73. ISBN 978-1-4200-0768-8
5. https://medium.com/power-africa/rethinking-the-cost-of-off-grid-power-lets-do-the-math-1e31bddb1240
6. https://energy.gov/energysaver/grid-or-stand-alone-renewable-energy-systems\ Retrieved 2017-11-03
7. http://www.aadnc-aandc.gc.ca/eng/1314295992771/1314296121126 *Aboriginal Affairs and Northern Development Canada*. 2012-05-01. Retrieved 2017-11-05