SOLAR (PHOTOVOLTAIC) BIOGAS HYBRID ENERGY CALCULATOR FOR HOME AND FARM SETUP

By

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A dissertation submitted in partial fulfillment of the requirements for the degree of Master of Engineering in Renewable Energy

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LUSAKA

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DECLARATION

I, **YESAYA WILTON MSISKA** do hereby declare that the contents in this dissertation are my original work and have not been previously submitted to any University for the award of a degree or any other qualification.

Signature…………………………………………Date………………………

APPROVAL

This dissertation submitted by **YESAYA WILTON MSISKA** is approved as fulfilling the requirements for the award of the degree of Master of Engineering in Renewable Energy at the University of Zambia.

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ABSTRACT

Zambia's electricity is largely from hydro power which has an installed capacity of 2,347 MW representing 96 % of national consumption while the remaining 4 % is from other sources such as fossil fuels. With low level of rainfall recorded in the past few years, Zambia was left grappling with electricity deficit which brought a rise in demand for renewable energy sources. This formed the basis for this study to design a solar (photovoltaic) biogas hybrid energy calculator for home and farm setup that could make it easier for retailers of renewable energy goods and services to design systems quicker and easier and give tentative costs of the systems. The calculator was designed using Visual Basic software on which three forms were created i.e. the Solar form to calculate solar system and backup system, the Biogas form for determining biogas digester for cooking and Solar-Biogas Hybrid form for calculating an energy mix. Literature were reviewed to help develop the calculator and validate the calculations which where imbedded in it and appropriate assumptions made to suit the design.

As an example, a load was selected consisting of fluorescent lamps, radio, laptop, 14" television, satellite decoder, deep freezer frost free, lights, and a 2 plate cooker, making a total wattage of 3.11kW and a Watt Hour usage of 17.826 kWh. The load parameters were imbedded in the software and a 32 % division between Solar and Biogas was selected. A system consisting of the following was designed: 2000W/24V inverter costing K 6000, 4* 250Ah Battery costing K20,800, 8 * 200 W solar panels costing K 9000, a 14 m^3 digester costing K8,405 and a 3 kVA biogas generator costing K8405. For the Biogas digester for cooking, a cooking period of 2 hrs was inserted and cow manure as substrate chosen. A 4 m^3 digester costing K 4,189 was designed and 1.3648 kg substrate quantity was determined.

Key words: Solar- biogas calculator, solar system, biogas digester, solar biogas system.

DEDICATION

This research is dedicated to my wife, my family and friends for the unwavering support during my period of study.

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ABRREVIATIONS

N_{sb}	Number of batteries in series
N_{pb}	N_{pb}= Number of batteries in parallel
I_{cc}	Charge Controller Current
I_{scM}	Module start circuit current
F_{safe}	Safe Factor
P_{inv}	Inverter power
P_{sum}	Power of all load running
P_{ind}	Power of all inactive load with Large Surge Current
Pv	Photo voltaic
KW	Kilo Watt
AH	Ampere Hours
RE	Renewable Energy
n_b	Battery efficiency
n_i	Inverter efficiency
n_c	charge controller efficiency
I_{dc}	DC Current
V_{dc}	DC Voltage
Peak avg	Average peak power
N_{sm}	Number of modules in series
V_{rm}	Module rated voltage
T_{sh}	Total sun hour
E_{safe}	Energy safe discharge
N_{tb}	Total number of batteries
D_{aut}	Number of autonomy days
C_b	Battery bank capacity
N_b	Number of batteries
V_b	Battery Voltage
D_{disch}	Discharge depth
E_{est}	Estimated energy storage
I_{rm}	Module rated current
N_{tm}	Total number of modules
E_{rd}	Daily average energy demand

CHAPTER ONE
INTRODUCTION

The hybrid solar biogas energy calculator is a study designed to come up with a standard calculation which will be embedded in a computer software having user interface and will be able to aid in a simplified but accurate way, the sizing and design calculation for biogas and solar installation.

The calculator is planned to work in such a manner as to be able to receive inputs such as the desired load wattage and in an intelligent manner be able to selectively calculate the system for the load appropriate for solar and that appropriate for biogas usage in economic sense.

Living in a world that is fast and dynamic, information is being easily accessed at the tip of the hand, this research is of importance as it will help many in quickly estimating what will be required in solar biogas installations.

1.1 Background

The Depleting oil and gas reserves, combined with the growing concerns of global warming, have made it inevitable to seek alternative/renewable energy sources. The integration of renewables such as solar and biogas energy is becoming increasingly attractive and is being used widely, for substitution of oil-produced energy, sole reliability on hydro power and minimizing atmospheric degradation (Wadud et al., 2013).

As economies grow, the demand for electrical energy (hereafter power) grows in line with rising populations, industrialization, and rising incomes. Typically, for the developing world, investments in electricity generation capacity fail to keep up with the rapid demand growth, and this triggers power shortages and rationing. Therefore, it is not surprising that some countries in the developing world continue to grapple with power deficits (Samboako et al., 2016).

Zambia is in the middle of a crippling electricity crisis as the country grapples with a 560 MW power deficit, a situation likely to only get worse as demand for electricity grows, at an estimated rate of at 200 MW annually (Siliya, 2015). ZESCO embarked on a countrywide power rationing mechanism in order to preserve the limited water available for power generation until the 2015/16 rainy season (Mulongoti et al., 2016). The shortage of electricity has been building for some time but has become more pronounced with reduced water levels at Kariba North Bank Power Station, Kafue Gorge Power Station and Victoria Falls Power Station.

As the countrywide power load-shedding continues, traders selling alternative sources of energy are cashing in on the rising demand. There is an increase in demand and enquiry for solar products, generators, charcoal and other sources of energy in Lusaka and other places. A check at Lusaka's town centre revealed that sales for solar panels and generator were rising sharply since 1st July 2015. This has been attributed to the power outages which have hit the country since 1st July 2015 due to power generation deficit.

With the demand for renewable energy rising, the desire for knowledge in the design and implementation of these energies has risen. Lack of information thereof has dissuaded many for venturing into the solar hybrid systems, obviously with a view that they are more complicated to undertake for a common man. The saddening part is that we see many grappling with energy issues when our beloved country is endowed with abundant renewable energy resources for us to harness and use.

The ability to easily design and implement a system not only helps people become energy sufficient but helps the spending power of a community and brings about development.

1.1.1 Renewable Energy

Renewable energy sources are those resources which can be used to produce energy over and over again, e.g. solar energy, wind energy, biomass energy, geothermal energy, etc. and are also often called alternative sources of energy. Renewable energy resources will play an important role in the world's future (Panwar et al.,2011). Due to slow and sure resource depletion of basic energy sources, such as, oil and gas, as well as limitation in hydro power, many countries carry out research in extension of alternative energy sources. (Konovalov et al., 2015). This awareness that fossil fuels are not infinite and the recognition that the use of fossil fuels constitutes one of the major sources of greenhouse gases that contributes towards global warming has indeed stimulated growing interest in renewable energy technologies (Mfune et al.,2008)

As indicated earlier Zambia is currently battling an electricity supply deficit and has low electrification rates, 45% in urban and 3% in rural areas, while aiming to reach 90% and 51% access by 2030 in urban and rural areas, respectively. The country has significant renewable energy resources, including hydro, biomass, solar, wind and geothermal energy that can be exploited for both on-grid and off-grid systems. This untapped potential in the sector, once known, can contribute to meeting future electricity demand, especially given that the costs of renewable energy are coming down (Singh et al., 2013)

1.1.1.1 Solar Energy

The radiant heat and light energy from the Sun is called Solar Energy. This is the most readily and abundantly available source of energy. Since ancient times this energy has been harnessed by humans using a range of innovations and ever-evolving technologies. In Zambia, since time in memorial, |Solar Energy has been used to preserve meat, drying crops drying animal skins and cloths etc. Today, solar energy is utilized at various levels. On a small scale, it is used at the household level for lighting, cooking, water heaters and solar architecture houses; medium scale appliances include water heating in hotels and irrigation. At the community level, solar energy is used for vaccine refrigeration, water pumping, purification and rural electrification. On the industrial scale, solar energy is used for pre-heating boiler water for industrial use and power generation, detoxification, municipal water heating, telecommunications, and, more recently, transportation (solar cars) (Karekezi and Ranja., 1997; Ecosystems, 2002). The earth receives more energy in just one hour from the Sun than what is consumed in the whole world for one year. Solar Energy comes from within the Sun itself through the process called nuclear fusion reaction. In this reaction four atoms of hydrogen combine to form one helium atom with loss of matter. This matter is emitted as radiant energy.

Solar photovoltaic technologies convert solar energy into useful energy forms by directly absorbing solar photons—particles of light that act as individual units of energy—and either converting part of the energy to electricity (as in a photovoltaic (PV) cell) or storing part of the energy in a chemical reaction (as in the conversion of water to hydrogen and oxygen.

Figure 1.1 shows a typical solar photovoltaic system having a solar panel charge controller, a battery and an inverter all connected together in order to supply to a load.

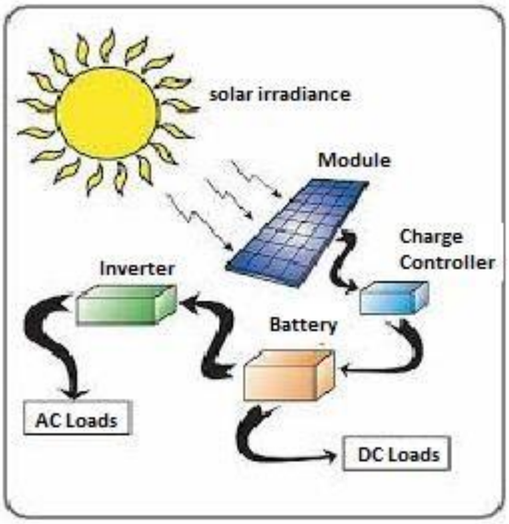


Figure 1.1 schematic diagram of a solar photovoltaic technology source: Assad, 2010

1.1.1.2 Biogas

Biogas systems make use of a relatively simple, well-known, and mature technology. The main part of a biogas system is a large tank, or digester. Inside this tank, bacteria convert organic waste into methane gas through the process of anaerobic digestion. Each day, the operator of a biogas system feeds the digester with household by-products such as market waste, kitchen waste, and manure from livestock. The methane gas produced inside biogas system may be used for cooking, lighting, and other energy needs. Waste that has been fully digested exits the biogas system in the form of organic fertilizer. Figure 1.2 shows an illustration of a simple biogas digester plant involving fecal matter as a substrate. The feacal matter from the digester is passed on to the digester where it is digested to produce biogas.

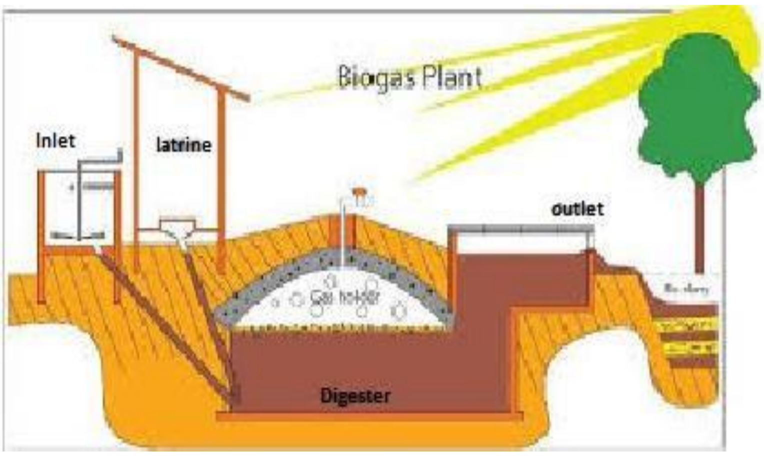


Figure 1.2 biogas system

1.1.1.3 Solar Hybrid System

The solar hybrid system are systems that incorporates solar energy technology and any other renewable energy technology i.e. hydro, wind, geothermal and bioenergy. Power generated by the P.V array during the day is utilized by certain loads and the excess is stored in the batteries. The energy produced from other renewable source of energy either stored in batteries or used to supply other high energy demanding loads. The ultimate goal of the system is to reliably deliver energy at a cost effective manner. Hybrid systems have the potential to significantly increase the reliability and security of power supply due to the use of two or more energy sources. The hybrid concept is therefore an attractive option for power supply in rural areas as it eliminates most of the disadvantages of these renewable energies

Solar-biogas technology is a combination of solar technology and biogas technology to form a hybrid system. Biogas gas is counted as an eco-friendly biofuel can be used to run biogas generators or modified diesel engines. Solar and biogas generate electricity simultaneously and the output is stored in a battery bank or supply Ac or Dc loads directly (Ashraf., 2015)

1.2 Statement of the Problem

Sizing up solar and biogas systems is quite complex and tedious, this has restricted systems flexibility and made system implementation expensive.

1.3 Significance of the Study

The absence of clean cooking facilities and electricity means billions of rural people are deprived of much needed socioeconomic development. Crop residues livestock residues (dung) and solar radiation are renewable energy resources that are abundantly available in rural areas of developing countries. Although it is not feasible for these resources separately to meet both thermal (cooking) and electricity demands, hybrid applications have not been given due attention (Rahman et al., 2014)

Solar biogas hybrid calculator makes it easy for retailers to easily give a tentative cost of the system in quickest possible time without going through rigorous calculations in giving estimated cost. This will make it easy to know which combination of technologies makes economic sense with regards to energy demand.

1.4 Objectives

1.4.1 General objective

The overall objective of this study was to develop a computer based system calculator as a one stop design solution for an optimized hybrid solar biogas system.

1.4.2 Specific Objectives

To determine the ability of the calculator of the calculator to calculate power back up systems and complete of grid systems.

To determine the ability of the biogas to size up a digester that would satisfy a desired cooking duration.

To determine the possibility of our calculator sizing up a system combining both solar and biogas and consequently give tentative cost.

1.5 ORGANISATION OF DISSERTATION

The dissertation has seven chapters. The chapters are:

Chapter one has the introduction where the background, statement of the problem, research objectives is presented. The chapter also presents the background of the study.

Chapter Two reviews the literature that has informed the study.

Chapter Three presents the methodology that the researcher used in the study.

Chapter Four presents the design of the calculator.

Chapter Five presents the results of the designed calculator.

Chapter Six presents the discussion section of the calculator results and finally Chapter Seven presents the conclusions and recommendations arising from the study.

1.6 closing Remarks

The chapter has presented the introduction to the thesis giving background, problem Statement, and purpose of the study. The next Chapter will discuss the literature that informed this study

CHAPTER TWO
REVIEW OF RESEARCH LITERATURE

2.1 Introduction

Over the years, the world energy demands has been increasing at rates that are alarming. The increased use of energy is threatening the depletion of the limited fossil fuel reserves and the destruction of the world's eco systems through the production of greenhouse gas emissions. Countries worldwide are now looking for alternative sources of energy that are cheaper cleaner and end environmentally friendly.
Solar energy and biogas are some examples of alternative energy resources that are being explored to come up with system that are efficient, reliable and robust to meet the energy challenges being faced today.

This study positions itself in the opportunity to add to the body of knowledge on the possibilities of using solar and biogas energy sources in the most efficient and cost effective way.

In this chapter, reviews are taken on what studies have been taken preceding to this one. We appreciate what other scholars have written in relation to solar and biogas technology.

2.2 Solar power System

Solar electricity is produced by changing sunlight to power using the photovoltaic (PV) effect. The PV effect causes an electrical current to flow through a solar cell when exposed to sunlight. Solar cells power everything from calculators and remote highway signs to homes, commercial buildings, and large power plants (Fitwi, 2014).

2. 2 Components of solar power system

2.2.1 Solar panel

A Solar Panel consists of number of Photovoltaic cells connected in series and parallel. These cells are made up of at least two layers of semiconductor material usually pure silicon infused with boron and phosphorous. One layer has a positive charge the other layer has a negative charge. When light from the sun strikes the panel, photons from the light are absorbed by the semiconductor atoms which then release electrons. The electrons from negative layer (n-type) semiconductor flow to positive layer (P –type), producing an electrical current since current flows in direction the electricity generated is direct Current (DC) (Shaika et al., 2010)

A Solar Panel contain no moving parts and produce no emissions while in operation. Extremely modular, photovoltaic devices can be used in small cells, panels, and arrays. Photovoltaic systems require little servicing or maintenance and have typical lifetimes of about 20 years (Bull, 2001).

2.2.2 Solar charge controller

A charge controller is an essential part of nearly all power systems that charge batteries i.e. solar photovoltaic, wind, hydro, fuel, or utility grid. Its purpose is to keep the battery properly fed and safe for long term (Nandar et al., 2011). A charge controller prevent overcharging, over discharging or overflow of current. Overflow and overcharging both can reduce the lifespan, durability and performance of the battery. Safety risk can also be occurred. Some controllers have display where battery condition and flow of power can be monitored (Abu et al., 2016).

If a battery is fully charged, it cannot store more energy coming from the PV panel. If the energy supply remains the same, then the battery voltage can be very high. This condition increase the chances to overheat the battery which may cause small explosion or load (such as lights, home appliances etc) can be damaged. Charge controller actually reduces the flow of energy to the battery when the battery reaches to a specific voltage. Some controllers regulate the flow of energy to the battery by switching the current fully on or fully off. This is called "on/off control." Others reduce the current gradually. This is called "pulse width modulation" (PWM). Quite a few charge controls have a "PWM" mode. PWM is often used as one method of float charging. Instead of a steady output from the controller, it sends out a series of short charging pulses to the battery a very rapid "on-off" switch. The controller constantly checks the state of the battery to determine how fast to send pulses, and how long (wide) the pulses will be. In a fully charged battery with no load, it may just "tick" every few seconds and send a short pulse to the battery. In a discharged battery, the pulses would be very long and almost continuous, or the controller may go into "full on" mode. The controller checks the state of charge on the battery between pulses and adjusts itself each time. It maintains a full charge but minimizes battery overheat and damages (Abu et al., 2016).

A circuit is overloaded when the current flow is higher than it can safely level. This can cause overheating and fire hazard can be happen. Overload can be caused by a short circuit in the wiring, or by a faulty appliance (like a frozen water pump). Most of the charge controllers have overload protection built in, usually with a push-button reset. (Abu et al., 2016).

2.2.3 Solar Battery

A group of electrochemical cells that convert stored chemical energy into electrical energy is called a battery. Batteries are classified into two types: (Sriram, 2011).

- Primary batteries or disposable batteries whose energy cannot be restored after it is depleted.
- Secondary batteries or rechargeable batteries whose energy can be restored after it is discharged by some electrical means.

Batteries are used to supply power to the load during periods of autonomy (no sunshine) whilst being charged by the PV array during periods of high solar radiation. The recommended batteries that should be used in stand - alone photovoltaic power system are deep-cycle lead acid batteries because of their high performance, long life time and cost effectiveness. (Assad, 2010, (Guda and Aliyu, 2015). A lead-acid battery is an electrical storage device that uses a reversible chemical reaction to store energy. It uses a combination of lead plates or grids and an electrolyte consisting of a diluted sulphuric acid to convert electrical energy into potential chemical energy and back again (Abu et al., 2016).

Every portable electrical/electronic device uses a battery to meet its energy requirements. For example, batteries are used in PCs, laptops, electric vehicles, power industries etc. Based on the application, different types of batteries are used. Commercially available electrochemical energy storage units are NiCd, Lead-acid, NiMH, NiZn and Lithium-ion battery cells or battery packs

The following factors should be considered when choosing a battery for a PV application (Zeman, 2014):

- Operating temperature range (e.g.: -15°C to 50°C)
- Self-discharge rate (% per month)
- Cycle life to 80% depth of discharge (DOD)

- Charge efficiency from 20% discharged
- Capacity (Ah) at 10 hr. & 100 hr. rates (C10 & C100)
- Required frequency for topping up the electrolyte
- Robustness for transport to site
- Resistance to overcharging
- Cost

2.2.4 Inverter

An inverter is an electrical device that converts direct current (DC) source such as batteries, solar panels, or fuel cells to alternating current(AC) (Mohamed et al,. 2012). The converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries (Gaurav et al., 2015)

2.3. Photovoltaic system sizing

PV system design is the process of determining the capacity (in terms of voltage and current) for each component of the stand-alone photovoltaic power system with the view to meeting the load profile of the residence for which the design is made. When sizing up system the following information has to be determined before the actual sizing of the PV array begins: (Guda and Aliyu, 2015)

- The daily average energy demand in watt hours (E_d)
- The dc voltage of the system (V_{dc})
- The average sun hours of the installation site per day (T_{sh})

2.3.1 Photovoltaic array sizing.

Sizing the array begins by first determining the required daily average energy demand (E_{rd}) as given in equation (1) (Assad, 2010).

$$E_{rd} = E_d /(\eta_b \eta_i \eta_c) \tag{1}$$

The average peak power ($P_{ave, peak}$) is then obtained by:.

$$P_{ave, peak,} = E_{rd} / T_{sh} \quad (2)$$

The total DC current of the system (I_{dc}) is then obtained by:

$$I_{dc} = P_{ave, peak,} / V_{dc} \quad (3)$$

The number of modules in series (N_{sm}) is then obtained by: (Ishaq et al, 2013).

$$N = V_{dc} / V_{rms} \quad (4)$$

Next, we obtain the number of parallel number of module strings (N_{pm}) by:

$$N_{pm} = I_{dc} / I_{rm} \quad (5)$$

The total number of modules (N_{tm}) that form the array is then finally determined by multiplying the number of modules in series by the number of parallel modules as in equation (6), thus giving the required array size.

$$N_{tm} = N_{sm} \times N_{pm} \quad (6)$$

2.3.2 Determining the size of the battery bank

The battery type recommended for use in solar PV power system is deep cycle battery, specifically designed such that even when it is discharged to low energy level it can still be rapidly recharged over and over again for years. The battery should be large enough to store sufficient energy to operate all loads at night, cloudy, rainy and dusty days.

Sizing the battery begins by first determining the estimated energy storage (E_{est}) required which is equal to the product of the daily average energy demand and the number of autonomy days (D_{aut}) as follows.

$$E_{est} = E_d \times D_{aut} \quad (7)$$

A safe energy storage (E_{safe}) is then computed by dividing the obtained estimated energy storage by maximum allowable depth of discharge (D_{disch}) as given by equation (8).

$$E_{safe} = E_{est} / D_{disch} \quad (8)$$

The total capacity of the battery bank in ampere-hours (C_{tb}) is then determined by dividing the safe energy storage by the rated dc voltage of one battery (V_b) as in equation (9).

$$C_{tb} = E_{safe} / V_b \quad (9)$$

At this point, the total number of batteries (N_b) can then be obtained by dividing the total capacity of the battery bank in ampere-hours by the capacity of one of the selected batteries in ampere-hours (C_b) as given by equation (10).

$$N_{tb} = C_{tb} / C_b \quad (10)$$

The number of batteries in series (N_{sb}) can now be determined by dividing the system dc voltage by the rated dc voltage of one battery as in equation (11).

$$N_{sb} = V_{dc} / V_b \quad (11)$$

At this point, we can then determine the number of parallel battery strings (N_{pb}) by:

$$N_{pb} = N_b / N_{sb} \quad (12)$$

Finally, since the number of batteries in series (N_{sb}) and the number of parallel battery strings (N_{pb}) are now known, then the size of the battery bank is fully determined and consists of $N_{sb}\ x\ N_{pb}$ batteries.

2.3.3 Determining the capacity of the charge controller

The solar charge controller is generally sized in a way that will enable it perform its function of current control. A good charge controller must be able to withstand the array current as well as the total load current and must be designed to match the voltage of the PV array as well as that of the battery bank. The standard practice of sizing the charge controller is to ensure that it is able to withstand the product of the total short circuit current of the array ($I_{sc}{}^{A} = I_{sc}{}^{M} \text{ x } N_{pm}$) and a certain safe factor (F_{safe}). The safe factor is necessary in order to allow for a reasonable system expansion. Thus, the desired charge controller current (I_{cc}) is as given by:

$$I_{cc} = I_{sc}{}^{m} * N_{pm} * F_{safe} \quad (13)$$

Where I_{sc}^{m} = the short circuit current of the selected module

2.3.4 Determining the capacity of the inverter

An inverter is used in the PV power system when AC power output is needed. The input rating of the inverter should never be lower than the total power of the different loads and must have the same nominal voltage as that of the battery bank. In practice, the capacity of the inverter is taken to be the sum of the total power of all loads running simultaneously and 3 times the total power of all inductive loads with large surge currents. Furthermore, the obtained value is then multiplied by a factor of 1.25 to make it 25% larger in capacity in order to allow for a reasonable system expansion. Thus, the inverter power is determined using equation (14) as follows: (Ishaq et al., 2013, Guda and Aliyu, 2015)

$$P_{inv} = 1.25(P_{sum} + 3P_{ind}) \quad (14)$$

Where P_{inv} = Power of the inverter

P_{sum}= Power of all loads running

P_{ind}= Power of all inductive loads with large surge currents

2.4 Types of solar power system

Photovoltaic systems usually comes in three common configurations: systems that feed power directly into the utility grid, stand-alone systems that charge batteries, perhaps with generator back-up, and applications in which the load is directly connected to the PVs as is the case for most water-pumping systems.(Franklin, 2017)

2.4.1 Dc load photovoltaic systems

DC load photovoltaic systems rely on PV power only. These systems comprise only PV modules and a load or can include batteries for energy storage (Eldhose and Joseph, 2016). When using batteries charge regulators are included, which switch off the PV modules when batteries are fully charged, and switch off the load in case batteries become discharged below a certain limit. The batteries must have enough capacity to store the energy produced during the day to be used at night and during periods of poor weather.

2.4. 2 Stand-alone photovoltaic system

A stand-alone photovoltaic power system is a complete set of interconnected components for converting solar irradiance directly into electricity and generally consists of the array, battery bank, charge controller, an inverter, protection devices and the system load (Guda and Aliyu, 2015). A stand-alone photovoltaic system includes a solar array usually flat plate and may include electrical components like charger controller, inverter, batteries and an optional onsite standalone generator for backup (Fara,, 2017). Figure 2.1 shows a schematic diagram of how the system is arranged.

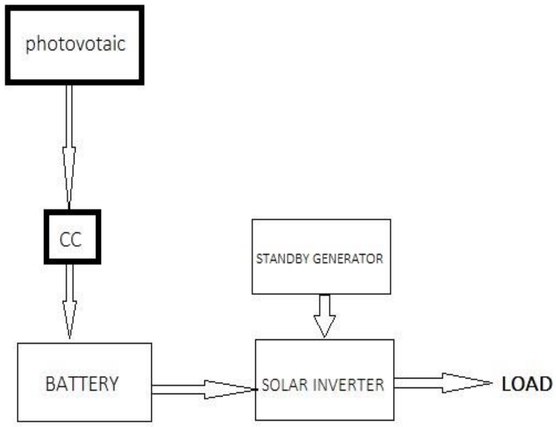


Figure 2.1 Schematic diagram of stand – alone system

2.4.3 Grid tied photo voltaic system

Grid tie Inverters are special kind of inverters that work by taking the DC power from the source, such as an array of photovoltaic modules and inverting it to AC power so that it can be fed into the grid (Narendiran, 2013) see Figure 2.1. The inverter synchronizes its frequency with that of the grid using a local oscillator and limit the voltage to no higher than the grid voltage. Typical modern GTI's have a fixed unity power factor, which means its output voltage and current are perfectly lined up, and its phase angle is within 1 degree of the AC power grid. The inverter senses the current of the AC grid waveform, and output voltage to correspond with the grid. Grid-tie inverters are also designed to quickly disconnect from the grid if the utility grid goes down. This is a requirement that ensures that in the event of a blackout, the grid tie inverter will shut down to prevent the energy it produces from harming any line workers who are sent to fix the power grid. (Gohul et al., 2011)

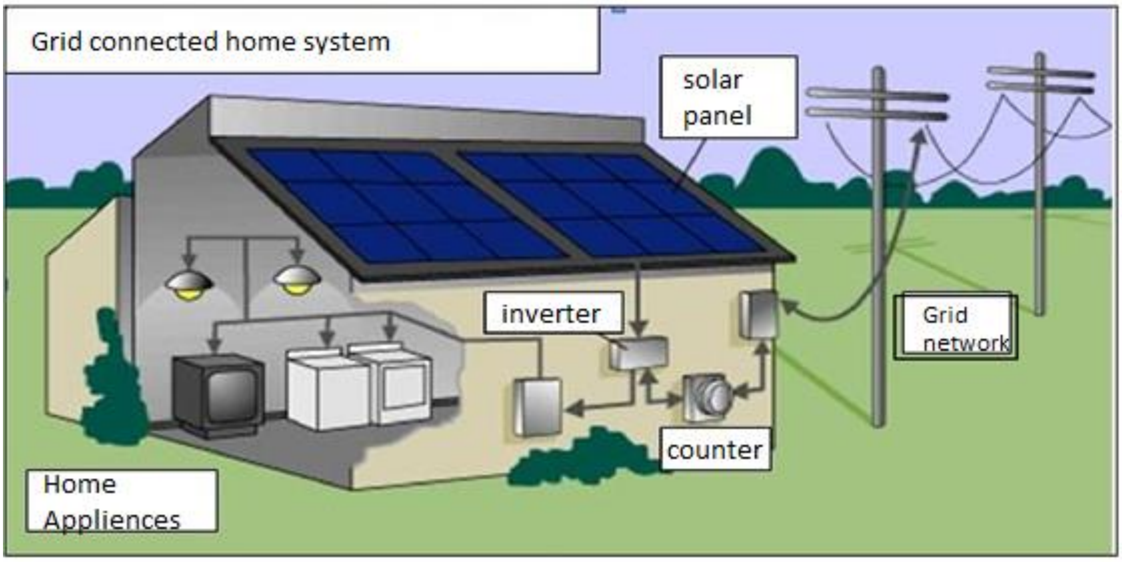


Figure 2.2 Grid connected system. Source: Rijeka (2012)

2.5. Biogas

Methane gas is produced by bacteria through the bio-degradation of organic material by anaerobes under anaerobic conditions. (Redman, 2008). It can be produced either from biodegradable waste materials or by the use of energy crops fed into anaerobic digesters to supplement gas yields. (Mann, 2013)

Anaerobic digestion is a biochemical process in which particular strains of bacteria digest biodegradable substance in an oxygen-free environment under suitable temperature and humidity environments. (Al-Rousan and Zyadi Biogas, 2015) the product of anaerobic digestion process is a clean and renewable form of energy which can be a substitute for conventional sources of energy which are causing ecological environmental problems and at the same time depleting at a faster rate (Sathianathan,1975). Biogas is mainly composed of 50 to 70 % methane, 30 to 40 % carbon dioxide (CO_2) and low amount of other gases as shown in Table 2.1 (Adnan, 2015). The solid by-product, digestate, can be used as a biofuel or a fertilizer. Biogas can be recovered from mechanical biological treatment waste processing systems.

Biogas is best used directly for cooking/heating, light or even absorption refrigeration rather than the complication and energy waste of trying to make electricity from biogas. Pumps and equipment can also run on a gas powered engine rather than using electricity (Fulford, 1996).

Table 2.1 Composition of biogas

Substance		SYMBOL	PERCENTAGE
Methane		CH4	0 – 70
Carbon dioxide		CO2	0 – 40
Hydrogen		H2	5 – 10
Nitrogen		N2	1 - 10
Water Vapor		H20	0.3

Source: (Mohd Ayub bin Adnan, 2010)

2.5.1 Combustion of biogas

Describing the reaction occurring in the combustion process is very difficult and depends on many factors such as temperature, pressure, type of burner, the composition of the mixture of fuel and combustion oxidizing hydrocarbons, etc. (Fulford.1996)

Understanding the combustion process provides a basis of performance criteria and emission standards used to regulate manufacturing and marketing of quality biogas stoves. Since the chemical reaction biogas burning is:

$CH_4 + 2O_2 = CO_2 + 2H_2$

and biogas contains 60% methane, while air contains 21% oxygen, the volume ratio for the stoichiometric mixture of air and biogas is 5.7:1 or a volume fraction of 17.5%. Biogas burns over a narrow range of mixtures from approximately 9% to 17% of biogas in air (30). If the flame has too much fuel, then it will burn incompletely, releasing carbon monoxide, which is poisonous, and soot particles. Therefore, the designs of appliances aim at maximizing the conversion of methane into carbon dioxide in order to minimize the release of unburned methane and products of incomplete combustion. Stoves usually run with a small excess of air to avoid the danger of the flame becoming rich. If too much air is supplied, the flame cools off, thus prolonging the working time and increasing the gas demand. (vienney et al., 2011)

2.5.1.1 Biogas Burner

The heart of most gas appliances is a biogas burner (Kossmann et al., 1999). Biogas will burn over a fairly narrow range of mixtures from 9% to 17% biogas in air. If the flame is “too rich”, has too much fuel, then it will burn badly and incompletely, giving

carbon monoxide (which is poisonous) and soot (carbon particles). Burners are usually run
"slightly lean", with a small excess of air, to avoid the danger of the flame becoming rich.

In most burners, air is mixed with the gas before it is burnt in a flame (pre-aeration). Post-aerated flames, where the gas is ignited at the end of the gas line, give very poor combustion. The amount of "primary air" added to the gas before the flame, varies depending on the design of burner, but is usually around 50% of the total air requirement. (Fulford, 1996).

2.5.2 The Biogas Digester

Around the world, a countless number of designs of biogas plants have been developed under specific climatic and socio-economic conditions. Large scale industrial digesters and small domestic digesters are in operation in many places around the world. The purpose of all these digesters is to produce combustible biogas which can be burned to provide energy for a whole range of uses. (Knowles, 2017)

2.5.2.1 Selection of appropriate design

In developing countries, the design selection is determined largely by the prevailing design in the region, which, in turn takes the climatic, economic and substrate specific conditions into consideration. Large plants are designed on a case-to-case basis (Rajendran, 2012).

2.5.2.2 Typical Design Criteria

i. **Space**: this mainly determines the decision if the fermenter is above-ground or underground, if it is to be constructed as an upright cylinder or as a horizontal plant. Existing structures may be used like a liquid manure tank, an empty hall or a steel container. To reduce costs, the planner may need to adjust the design to these existing structures. Minimizing costs can be an important design parameter, especially when the monetary benefits are expected to be low. In this case a flexible cover of the digester is usually the cheapest solution. Minimizing costs is often opposed to maximizing gas yield.

ii. **Available substrate**: this determines not only the size and shape of mixing pit but the digester volume (retention time), the heating and agitation devices. (Kossmann et al., 1999).

2.5.2.3 Types of Digesters

There are number of different types of flows in simple digester that have been developed and they can be of the following kinds: (Samer, 2012)

1) batch flow,
2) continuous flow,
3) continuously expanding,
4) plug flow, and
5) Contact flow.

2.5.2.4 Biogas Digester Sizing

The digester size can be defined as the total size of the biogas unit, which includes the effective size of any volume occupied by the fermented material and the volume of gas storage. Size of the daily feed-in is the size of a mixture of dung with water added to the digester once daily or several times and the average concentration of total solids of 10%, where mixing the organic wastes with water depends on its water content The size of a biogas unit depends on several factors, which are:

1. The amount and type of organic waste to be disposed in the digester

2. The objective of treating the organic waste (the production of energy and/organic fertilizer)

3. Demand of natural gas and consumption pattern

4. On-site nature of the soil and the level of ground water

5. Air temperature in the region and wind direction throughout the different seasons

In order to determine the unit size of a biogas unit, the following mathematical equation must be achieved:

Digester size (m^3) = Daily feed-in (m^3 day-1) × Retention time (day) ……… (Samer, 2012)

2.3.2.5 Dimensions of the biogas digester

The size of the system depends on the desired volume of daily gas production. The volume the gas holder should equal one day's gas production (Anaswara, 2015)

Example

25 liters mini plant is filled with 20 liters of substrate (poultry waste, pig manure, water) in the ratio 1:3:6. 2 kg of poultry waste, 6 kg of pig manure and 12 litres of water are used.

From experiment the ratio 1:3:6 had,

Maximum biogas production =7890 ml / day =7.89 L/ day.

Maximum time taken for 7.89L biogas to burn off in the burner = 2 minutes 4 seconds.

Biogas needed for 1 minute burn off time =7.89/2.4 =3.2875L. ……….. 15

Expected cooking time/day from biogas =2 hrs =120minute.

Biogas needed to have a burn off time of 2 hrs = 3.2875×120=394.5L ≈ 400L…. 16

Capacity of plant to produce 7.89 L biogas from the result = 20 L.

Capacity of plant to produce 400L biogas ≈ 1000 L=1 cubic meters.

Therefore, the Capacity of the Biogas Digester on the whole = $1m^3$.

Digester Body

Digester body Volume = $0.6m^3$ (600 litres), since the gas holder volume is 400 L= 0.4 m3.

Rectanglar Shape of the Digester body.

Volume of the Digester body = Length of the digester body (L) × Breadth of the digester body (B) × Height of the digester body (H) = $0.6m^3$.

Let us choose the length of the digester body (L) = 2m.

Let us choose the breadth of the digester body (B) = 1m.

The height of the digester body (H) = Volume of the digester body ÷ (L×B) = 0.6 / (2 × 1) = 0.3 m.

Gas Holder

The volume of the gas holder should equal one day's gas production which is 400 L = $0.4m^3$.

Gas Holder Volume = 0.4 m^3.

Shape of the Gas Holder = Rectangle.

Volume of the Gas Holder = Length of the gas holder (l) × breadth of the gas holder (b) × height of the gas holder (h) = 0.4 m^3.

Since the length and breadth of the digester and gas holder are same, Length of the gas holder (l) = 2 m.

Breadth of the gas holder = 1 m.

Height of the gas holder (h) = Volume of the gas holder ÷ (l× b) = 0.4 / (2 × 1) = 0.2 m

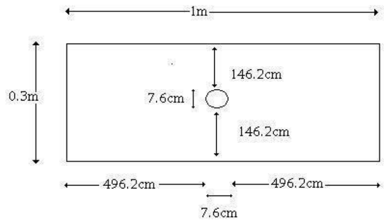


Figure 2.3a Side view of digester body

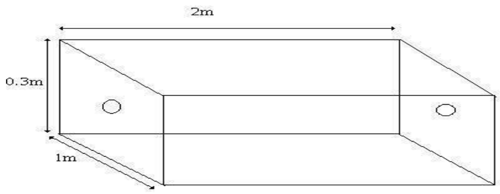


Figure 2.3b Three dimensional view of digester body

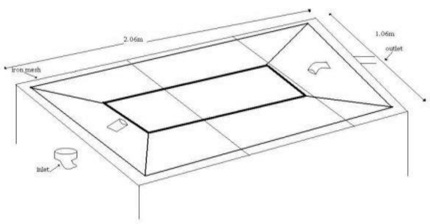


Figure 2.3c Top view of digester body

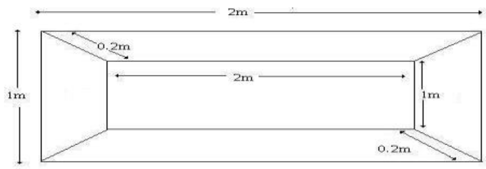


Figure 2.2d Top view gas holder

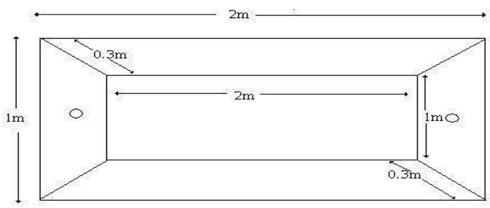


Figure 2.2f Three dimensional view of Body gas holder

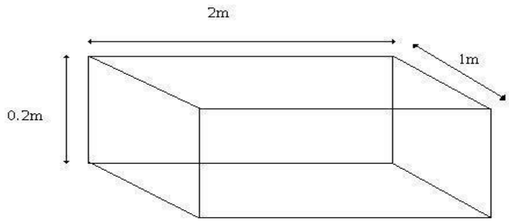


Fig-2.2e: Top View of the Digester

Figure 2.3 various views of Digester Body

2.6 Hybrid Systems

A hybrid power system can be defined as a combination of different, but complementary energy generation system based on renewable energy (Girma, 2013). A solar photovoltaic system can be combined with other energy sources, such as biogas generator, wind turbines, diesel generator, all to ensure a constant and sufficient supply of electricity. Since it is known that all renewable energy sources including photo voltaic systems are not constant in energy productions. It means that when there is no Sun the system does not produce electricity, although the need for energy is constant and, therefore must be met from other sources. Hybrid systems can be connected to a grid, stand – alone or as a support grid (Rijeka, 2012). Hybrid systems therefore has the potential to significantly increase the reliability and security of power supply due to the use of two or more energy sources (Tazvinga et al., 2011).

2.6.1 Solar - Biogas Hybrid System

Solar - biogas hybrid system is a technology employing solar photovoltaic systems and biogas internal combustion engine system both producing electricity to supply specified load.

The output of hybrid combination system with biogas generation and solar generation with maximum power tracking can be stored in a battery bank. This DC power is converted by the inverter into AC power in order to operate various electrical load. The inverter has in-built protection against short-circuit, overheating, low battery voltage and overload. The battery bank is designed to feed the loads up to a specified period with no sun or biogas, depending upon the system requirement. There are a number of biogas internal combustion engines on the market today but however if it is not available, existing diesel engines can be modified to run on dual fuel while still retaining the ability to use diesel fuel only, Petrol engines: These engines can run on 100% biogas (Tiwari et al., 2015).

2.6.2 Types of Solar Hybrid systems

2.6.2.1 Solar and biogas operated hybrid stove

Solar and Biogas operated hybrid stove is an attempt to utilize the non-conventional energy resources.

Hybrid solar stove is designed as shown in Figure 2.3 below. One part of the stove consists of biogas operated burner and digester, other part consists of solar operated coil, solar cell and battery assembly (Prassana et al., 2016)

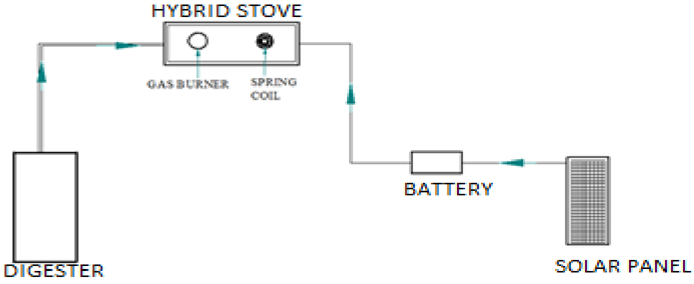


Figure 2.4 solar and biogas hybrid stove source: (Prassana et al., 2016)

2.6.2.2 PV/Diesel Hybrid standalone system

The PV/Diesel Hybrid standalone system is a system utilizing PV power and diesel generator power. The energy generated by the PV panels and stored in the battery bank has priority to supply the load. When the battery is discharged to its minimum allowable level, the diesel generator as a backup source is switched on. A decision can be made to charge the battery, when operating the generator operate the diesel generator. Figure 2.4 shows the how he hybrid system is configured to supply power. (Ishmail et al., 2015) Optimization of sizes of different components constructing the hybrid systems was one of the important issues that was considered while designing this system. It was concluded that a PV/diesel generator hybrid system is the more feasible system compared to a diesel generator system or standalone PV system. Maximizing utilization of the renewable source, minimizing the cost of generating energy and minimizing the pollutant emissions are objective functions of optimization (Khatib, 2011).

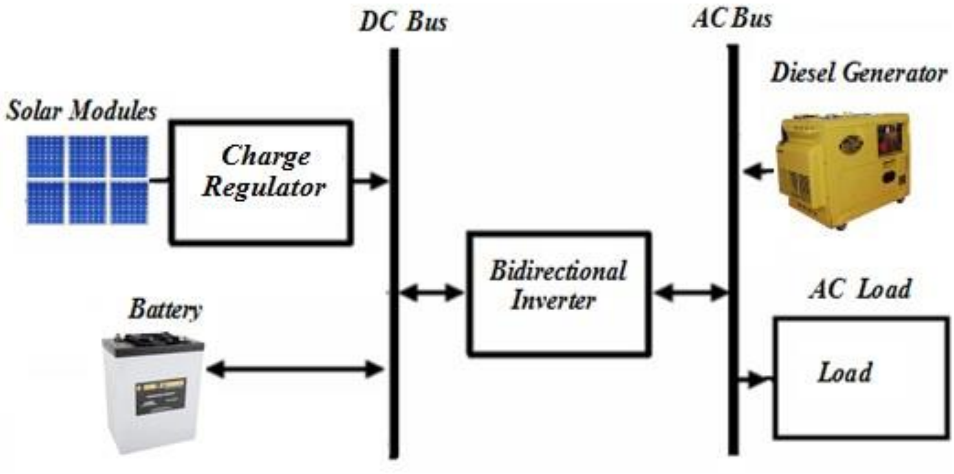


Figure 2.5 PV/Diesel Hybrid system

2.7 Relevance of the literature review

Solar and biogas systems have mainly been studied as separate technologies, and most companies deal with them as such (Ishaq et al., 2013, Kunatsa et al., 2013). Studies that have been done on solar hybrid systems have one common output that is electricity, whose production is shared by biogas generators and solar photovoltaic systems and sometimes feed into the batteries for backup (Mohammad et al., 2013). The literature reviewed has therefore given an overview of the two technologies and will therefore help us design a computer program that designs system useful to the user.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter brings to light the methods used to achieve the specific objectives of this research and ultimately shows how the objectives where achieved.

Relevant literature was reviewed to contextualize the problem at the global and national levels and also to clarify theoretical basis of biogas- solar photovoltaic systems. Information obtained from literature was used to establish performance and evaluation criteria: technical, economic and environmental.

Price survey of local solar and biogas accessories in retail outlets together with online (internet) information was used to acquire biogas- solar photovoltaic systems price data. Personal communication was also made with local experts in biogas- solar photovoltaic systems design and installation as part of the survey to acquire information on typical life of biogas- solar photovoltaic systems.

A visit was made to different solar installation sites and biogas installation organizations.

After obtaining relevant information and knowledge, standardized calculations for system design was generated and imbedded in the that was carrying out design for different applications. A specialized software called Visual Basic 2012 was used.

3.2 Substrate for Anaerobic Digestion program

A wide range of biomass types can be used as substrates (feedstock) for the production of biogas from anaerobic digestion in the biogas digester. Table 3.1 shows the substrate characteristics which were adopted to input in the calculator. The focus was the gas production per tonne of fresh material which saved as guideline on how much gas would be needed per particular cooking duration or running hours of the generator.

Table 3.1 Substrate Characteristics

All data approximately and can vary for exact data further samples are necessary	Dry solids (data can vary)	Organic dry solids (data can vary)	Specific gas production per oDS (data can vary)	Gas-production per tonne fresh material (data can vary)	Produced kilowatt-hours per t FM (35 %electrical efficiency CHP, Heating value 21 MJ/m3, 55 % Methane content, 3.6 MJ/kWh)	Kilowatt per tonne fresh material and day
Unit	% of Fresh material	% of DS	m3 /t oDS	m3/t FM	kWh/t FM	kW/t FM d
Animal carcasses (homogenised	30.0	90	900	243.0	496.1	20.7
Animal fat*	90.0	90	850	688.5	1405.7	58.6
Beet top	12.0	70	420	35.3	72.0	3.0
Blood*	8.0	90	600	43.2	88.2	3.7
Canteen waste/food waste	20.0	85	700	110.0	224.6	9.4
Cattle-dung	25.0	80	300	60.0	122.5	5.1
Cattle-slurry	8.0	80	320	20.5	41.8	1.7
Cereal slop (alcohol production)	6.0	90	480.0	25.9	52.9	2.2
Cereals/grains	85.0	95	650	524.9	1071.6	44.7
Chaff	85.0	90	350	267.8	546.7	22.8

Chicken litter/dung	40.0	75	420	126.0	257.3	10.7
Chip fat	95.0	87	1000	826.5	1687.4	70.3
Clover	15.0	88	520	68.6	140.1	5.8
Concentrated whey	15.0	90	800	108.0	220.5	9.2
Corn Cob maize (CCM)	60.0	95	600	342.0	698.3	29.1
Draff from beer production	20.0	80	500	80.0	163.3	6.8
Fat	95.0	87	1000	826.5	1687.4	70.3
Fermentation slops	1.8	98	750	13.2	27.0	1.1
Food waste (disinfected)	20.0	85	700	110.0	224.6	9.4
Fruit Pomace	20.0	90	520	93.6	191.1	8.0
Fruit residuals	20.0	80	350	56.0	114.3	4.8
Fruit slop	2.0	95	450.0	8.6	17.5	0.7
Fruit wastes	15.0	90	550	74.3	151.6	6.3
Glycerine*	100.0	95	750	712.5	1454.7	60.6
Grass fresh	18.0	90	450	72.9	148.8	6.2

Grass silage	25.0	85	550	116.9	238.6	9.9
Grease trap	13.0	95	800	98.8	201.7	8.4
Gut and Stomach/Intestines content	15.0	80	400	48.0	98.0	4.1
Hemp cake	88.0	93	105	85.9	175.4	7.3
Horse manure	28.0	80	250	56.0	114.3	4.8
Maize silage	32.0	95	660	200.6	409.6	17.1
Municipal solid waste, MSW (brown bin)	35.0	50	580	101.5	207.2	8.6
Old bread	65.0	95	700	432.3	882.5	36.8
Pig slurry	4.5	80	320	11.5	23.5	1.0
Potato top	12.8	87	420	46.8	95.5	4.0
Potato pulp	15.0	95	650	92.6	189.1	7.9
Potatoes	25.0	92	680	156.4	319.3	13.3
Pure fat (rendering plants)*	99.0	100	750	742.5	1515.9	63.2
Rape seed-silage	16.0	80	500	64.0	130.7	5.4
Rapeseed cake	85.0	93	680	537.5	1097.5	45.7
Residuals from	20.0	80	450	72.0	147.0	6.1

vegetables						
Sewage sludge	**12.0**	**80**	**490**	**47.0**	**96.0**	**4.0**
Silage effluent*	**1.4**	**95**	**800**	**10.6**	**21.7**	**0.9**
Source : FNR (Biogashandreichung), KTBL-website, LfL-website, Big East Biogas handbook						

3.3 Site Visits

In order to appreciate solar and biogas technology, visits were done to places with installed solar and biogas systems. Below are the sites which were visited and their details.

3.3.1 Nawaitwika Rural Health (NRC) Center Solar System

Nawaitwika rural health center is situated 25km from nakonde time offering medical care to the chiefdom of chief Nawaitwika. John Snow with the funding of united nations Aids provided a solar system for this facility for the purpose of providing power to an inventory system consisting of three Laptop and a printer. Figure 3.1 shows the installation at NRC.

Figure 3.1 Solar system at Nawaitwika RHC

System details

- Location: Nakonde

- Purpose: supplying power to drug inventory systems which is linked to Medical Stores in Lusaka as well to USAID servers.
- Inverter type: Hybrid inverter
- Size of inverter: 2 KVA/24V
- Solar panel: polycrystalline 230 W opti solar panel.
- Batteries: 100 Ah * 4
- Load size: 300 W

3.3.2 Inverter Backup System

A house hold in Olympia 16 Njoka road was visited where an inverter back up system is installed. The installed system is mainly used to provide power when mains power is an unavailable. Figure 3.2 shows the inverter and the battery installed at the site.

Figure 3.2 inverter and battery in olympia

System details

- Location : Olympia
- Owner: Monde Muwanei

Usage: power backup

Load: 95W

3.3.3 Kanyama Fsm Project Borda , Wasaza - Technical Experts

Lusaka Water and Sewerage Company (LWSC) and Water and Sanitation for the Urban Poor (WSUP) with funding from Stone Family Foundation engaged BORDA and WASAZA in 2011 to collaborate in the development of an innovative faecal sludge management approach, which aimed to provide the residents of Kanyama with an affordable and financially sustainable pit emptying service Solution.

58m3 biogas digester was developed, which also serves to capture and store biogas, which is used as a clean, renewable source of cooking energy at the KWT kitchen. During the first year of operations, the digester produced an estimated 12.4m³ of biogas per day with an average input of 1.2m3 FS per day. The availability of biogas has enabled the KWT kitchen, which caters for over 70 employees, to completely eliminate use of charcoal. Furthermore, the introduction of biogas as a cost effective and readily available energy prompted the KWT to invest in upgrading and expanding the kitchen into a commercial canteen. Using biogas instead of charcoal saves the KWT kitchen up to 11,000 kg of charcoal per year, a value of approximately $2,500 USD. Figure 3.3 shows the digester and the users of the digester while figure 3.4 shows the layout of the system.

Figure 3.3a

Figure 3.3b

Figure 3.3c

Figure 3.3 Kanyama Feacal sludge digester
(a) Dream team emptying feacle sludge (b) Biogas digester at Kanyama fsm
(c) Women using biogas for cooking

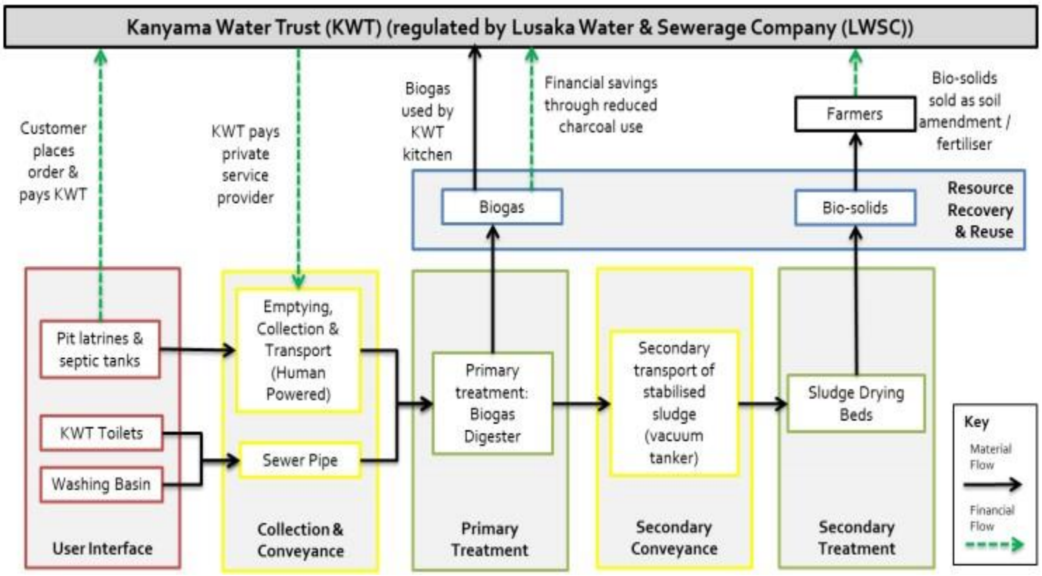


Figure 3.4 System layout

About The System

- Location : Kanyama, Lusaka, Zambia
- Purpose : Sustainable management (collection & treatment)of faecal sludge from low-income peri-urban community
- Beneficiaries: Lusaka Water and Sewerage Company (LWSC) & Kanyama Water Trust (KWT)
- size of the digester: 58m^3
- Substrate used: sewage sludge
- Quantity of substrate per day: 1.2m^3 /day
- Amount of yield per day: 12m^3 /day = Cost of the digester. $ 70 000

3.4 Market Cost Estimate

In designing the calculator, a cost estimate of the systems that is calculated was included. One of the important aspects of this calculator is to give an estimate of how much a particular system will cost for the person desiring to use it. For example, after parameters are inserted into the calculator, a system is designed which includes a particular size of an inverter, battery, panels and charge controller. The cost of each components is indicted giving a tentative cost estimate of the whole system. To archive this a market survey was done for the cost of the individual components of the systems.

3.4.1 Price of Solar Systems

The prices for the various solar systems ware obtained from Necor Zambia limited, Radian stores, and Davies and Shirtliff. These companies order items from various manufacturers outside Zambia and resells them at a market competitive price.

'<u>Inverter cost</u>

The prices of inverters were obtained from various solar supplying companies see Table 3.2 below that shows the inverter charger prices.

Table 3.2 Inverter chargers prices**.**

BRAND	SIZE	SYSTEM VOLTAGE	PRICE	SUPPLIER
Opti Solar Power Junior Pure Solar Inverter	600 VA	12 V	K 2,500	Necor Z limited
Fortuner standard home ups	850VA	12 V	K1,445	Radian Stores
Effecto sp 1000	1000VA	12 V	K 5,000	Necor Z limited
Effecto sp 2000	2000VA	24 V	K 5,025	Davies and Shirtliff
Effecto sp 3000	3000VA	24 V	K 6225	Necor Zambia limited
Effecto sp 5000	5000VA	48 V	K 11,775	Davies and Shirtliff

<u>Battery cost</u>

The prices of batteries were obtained from from Necor, Radian stores and ID solar. See Table 3.3 below that shows battery prices.

Table 3.3 Battery prices

BRAND	SIZE	SYSTEM VOLTAGE	PRICE	SUPPLIER
Rolls battery AGM	200 AH	12 V	K 3,500	ID Solar
Leoch AGM	150 AH	12 V	K 3,000	Radian Stores
Necor AGM	100 AH	12 V	K 1,700	Necor Z Limited
Leoch	70AH	12 V	K 950	Radian
Leoch	50 AH	12 V	K 600	Radian
Leoch	250 AH	12 V	K 4,500	Radian

Solar Photo voltaic Panels price list

The prices of Solar Photovoltaic Panels were obtained from Leyo solar and Necor Zambia Limited. See Table 3.4 below that shows solar panel prices.

Table 3.4 Solar Photo voltaic Panels

BRAND	SIZE	PRICE	SUPPLIER
QXPV	80 W	K 540	Necor Z limited
QXPV	100 W	K 630	Necor Z limited
QXPV	120 W	K 750	Necor Z limited
QXPV	150 W	K 877,5	Necor Z limited
QXPV	200 W	K1,170	Necor Z limited
Leyo Solar	250 W polycrystalline panel	K 1237,5	Necor Z limited
Leyo Solar	315 W poly solar	K1,559.25	Leyo
Leyo Solar	310w Multi crystalline	K1534.45	Necor Zambia limited

3.4.2 Price of Biogas System

The price of the biogas system was obtained from SNV and Agri Pro Focus in their market analysis study and Shenzhen Puxin Technology Co. Ltd who supply Puxin Assembly Biogas Plant which is a do it yourself (diy) kit biogas system for convenient transport and easy assembly.

3.4.2.1 Price of Biogas Digesters

Prices for solar biogas digester system where considered, these being:

I. Zam digester

The Zam digester has been designed to adapt to the Zambian conditions hence the name and cost structure. The rationale of designing was to ensure that the cost of the digester is affordable to the majority of the targeted customers. It is believed that the product can be developed further to relate with the targeted market through branding. The Zam digester is a product used and meant for the Zambian people and is intended for the rural setting. It was generally observed that the people referred to biogas as, "Magesi" or "Malaiti" meaning energy or power in the local language hence the model name. Table 3.5 shows the pricing of the zam digester

Table 3.5 Biogas digester brand and price in ZMK

#	Product Name	Model	Specifications/Use	Price (ZMW)
1	Zamdigester	Magesi 1	4 Cubic Metre	K 4,189.00
			Bio-slurry	
			20-40 kg Manure/Day	
			0.8-1.6 Cubic Metres of Biogas/day	
2	Zamdigester	Magesi 2	6 Cubic Metre	K 5,266.00
			Bio-slurry	
			40-60 kg Manure/Day	
			1.6-2.4 Cubic Metres of Biogas/day	
3	Zamdigester	Magesi 3	9 Cubic Metre	K 6,848.00
			Bio-slurry	
			60-90 kg Manure/Day	

			2.4 -3.6 Cubic Metres of Biogas/day	
4	Zamdigester	Magesi 4	14 Cubic Metre	K 8,405.00
			Bio-slurry	
			100-140 kg Manure/Day	
			4.0-5.6 Cubic Metres of Biogas/day	
5	Zamdigester	Magesi 5	21 Cubic Metre	K 11,377.00
			Bio-slurry	
			150-210 kg Manure/Day	
			6.0-8.4 Cubic Metres of Biogas/day	

II. Puxin biogas digester

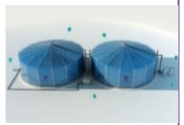
Puxin assembly biogas plant is a do it yourself (diy) kit biogas system for convenient transport and easy assembly. The prices of the puxin biogas digester is shown in Table 3.6

It is surface-mounted; there is no need for earthwork and heavy construction. It can be assembled by client himself/herself according to the manual provided without any training. It is a high efficient biogas system with hollow sunlight sheet green house and pad for insulation and heating.

It is applied to treating organic waste to get biogas for generating electricity, cooking etc. and nutritious liquid or solid organic fertilizer for gardening, agriculture etc. It is the ultimate solution for families, restaurants, hotels, resorts, livestock farms, slaughter houses, food processing plant, municipalities to treat their organic wastes (food waste, sewage sludge and animal manure etc). See Table 3.7

The product is composed of a greenhouse made with hollow sunlight sheet and metal supporting frame, a membrane digester with a gas storage bag combined in one, a stainless steel sink, a stainless steel outlet, a biogas filter and a biogas booster pump.

Table 3.6 Puxin digesters prices

Different Size of PUXIN Portable Assembly Biogas Plant							
Model No.	PX-ABS-1.2M3	PX-ABS-3.4M3	PX-ABS-15M3（3 ）	3A	PX-ABS-66M3	PX-ABS-260M3	PX-ABS-1380M3
Image							
Greenhouse volume(m³)	1.18m³	3.4m³	15m³	15m³	66m³	260m³	1380m³
Water level (m)	0.5	1.1	2	1.25	2	4	4
Fermentation capacity（m³）	0.5	1.7	13.28	8.3	54.38	200	800
Gas storage（m³）	0.5	1.3	1.22	6.2	3.21	50	400
Height(m)	1.23	1.95	2.5	2.5	3	5.72	7.46
Dia. digester (m)	1.2L*0.8W	1.56L*1.20W	2.908	2.908	5.88	8	16
Dimensions(m)	1.2L*0.8W*1.23H	1.56L*1.20W*1.95H	2.908D*2.5H	2.908D*2.5H	5.88D*3.0H	8D*5.72H	16D*7.46H
Biogas Production(m³/d)	0.5	2	15	8	50	200	800
Eletricity (kwh/d)	0.75	3	22.5	12	75	300	1200
Land space（㎡）	0.96	1.87	6.63	6.63	27.14	48.9	200.96
Concrete base Need（m³）	——	——	——	——	4.07	9.79	50.24
Warranty	1 Year						
Product Material Specification							
Inlet and outlet of digester	S stainless steel						

Mental supporting frame	A aluminum alloy						
Hollow sunlight sheet of green house	PE						
Temperature for Biogas Fermentation	(1)Normal temperature: 10 -30 C celsius; (2)Middle te mperature: 30 -35 Celsius; (3)Higher temperature: 50- 55 Celsius.						
Shipping volume（m³）	0.3	0.5	2.5-3	2.5-3	4.5	8	30
EXW PRICE（USD)	450	850	2596	2596	8612	21980	81755
Source: Puxin biodigester							

Table 3.7 Waste treatment by the digester

Green House Raw Material	1.2 m³	3.4 m³	15 m³	15 m³(A)	66 m³	260 m³	1380 m³
Food waste (kg)	6.25	25	187.5	100	625	2500	10000
Pig manure (kg)	11.25	45	338	180	1125	4500	18000
Cow manure (kg)	15	60	450	240	1500	6000	24000
Chicken manure (kg)	6.5	26	195	104	650	2600	10400
Human manure (kg)	8	32	240	128	800	3200	12800
Vegetable (kg)	16.25	65	488	260	1625	6500	26000
Biogas Production (m³/d)	0.5	2	15	8	50	200	800
Eletricity (kwh/d)	0.75	3	22.5	12	75	300	1200

Biogas generator

The prices of generators were obtained from Puxin a biogas digester company. See Table 3.8 that shows generator prices.

Table 3.8 Biogas generator prices

Size of generator	Technical specification	price	brand
0.7kW	Frequency (Hz) 50/60 Running Power (KW) 0.6 Peak power (KW) 0.7 DC Output 12V/ 8.3A Alternator Type: Single Phase AC Synchronization with Brush Engine Type Single Cylinder, 4-Stroke, OHV, Forced Air-cooled Bore × Stroke (mm) 54×38 Starting Method Recoil start only Engine Oil Capacity (L) 0.35 Min. Fuel Consumption 0.84m³/hour	K 3000	puxin
1.2 kW	Suitable gas: Biogas Gas consumption: 0.55~0.65m3/kWh 230V 50 Hz Running Power: 1200W Peak Power:1300W General Temperature Requirement: - 5°C~40°C General altitude:(2000m(It may cause problem if the altitude level is higher than 2000 meters) 620×460×470mm/set 55kg/set	K3500	puxin

1.5W	Rated Power 1500 W Max .Power 1800W Frequency 50HZ DC Output 12V 8.3A Generator Type Bruss,coppergenerator,SingleCylinder,4stroke,Air-cooled	K 4650	puxin
	Engine Type 168FG 188FG Starting method Electric starting Ignition System T.C.I. Engine oil capacity(L) Add0.6Loil before using g Gas consumption (m^3/h) 1.05		
3kW genset	Suitable gas: Biogas Gas consumption: 2.1m3/h, (220V 50 Hz) Running Power: 3000W Peak Power: 3500W General Temperature Requirement: -5°C~40°C Continue working time: cooling after continuous operation 4 hours Dimension: 700×525×560mm/set Weight: 75kg/set Gas pressure: 2Kpa-6Kpa	K 7650	puxin

Biogas requirement for generator.

1- Biogas no less than 65% Methane (CH 4)

2- Gas pressure: 2KPA ~ 6KPA

3- Biogas should be processed by desulfuring and dehydration before entering into the generator sets. (Otherwise, it will damage the engine cylinder, spark plug and other parts.) The warranty will not cover damaged cause wrong operation.

CHAPTER FOUR
SYSTEM DESIGN

4.1 Solar Biogas Hybrid Calculator Design

The calculator was designed to calculate four possible systems i.e. the solar systems, the biogas system for cooking only, the solar - biogas system for cooking and essential loads and the solar - biogas system utilizing a biogas generator. This was arrived at in order to cater for different needs of people. The calculator was designed with three different forms for calculating the four different systems using Visual Basic C. See Appendix 2 for the calculator code.

4.2 Design calculation Theory

The objective of our study was to develop a computer based system calculator as a one stop design solution for an optimized hybrid solar biogas system. The first step that was considered in trying to achieve this object was to adopted calculations that would be used to develop a coding for the calculator to calculate the systems.
The various literature reviewed played a vital role in enabling us settle for calculations appropriate for system design.

4.2.1 Biogas system calculations

In imbedding calculations for determining biogas digester size and gas holder in the system, the following procedure was followed in calculating the biogas digester (Anaswara, 2015)

1. selecting the substrate
2. maximum biogas produced by the substrate per known quantity
3. quantity of biogas burned per min
4. desired cooking hours

4.2.1.1 Calculation

1. Substrate:
    - Cow manure
2. Biogas produced by the substrate per known quantity:
    - 0.35m^3 per 20kg of cow
3. Quantity of biogas burned per min:
    - 3.2875l/min

4. Desired cooking hours :

- 2hrs
- Liters of biogas needed. 2*60min---- 120min

Biogas needed in 120 min = 120 * 3.2875

= 394.5l

5. Digester size

20 kg produces 350 l then 394 l will be produced by X amount of kg there fore

20 kg ------- 350

X kg ------- 394.5l

$$X = \frac{20\ X\ 394}{350} =$$

X = 22.52Kg

Digester size (m^3) = Daily feed-in (m^3 day-1) × Retention time (day)

= 22 Kg * 30 * 2

= 1320 l

= $1.3m^3$

4.2.2 Solar system calculations

When trying to size up a solar system, the load demand is taken into consideration. Load demand is the amount of power a particular appliance need for it to run. So it is of outmost importance to look at what load needs the power and how long the power will be demanded. These parameters are key in creating a calculator that will be able to size up a system by first determining the load, secondly determining the size of the inverter, thirdly size of the battery and then the size of the photovoltaic and charge controller. Typical loads found in a house hold were considered when sizing up the various components of a solar system. (See Table 4.1)

Table 4.1 Load Appliances

APPLIANCE NAME	POWER (WATTS)
Air conditioner	1350
Ceiling fan	75
Desktop computer	360
Food mixer or blender	110
Heater	1500
Iron	1100
Lights [energy sever]	11
Lights indecent	60
Flood Lights	250
Microwave	1450
Radio-stereo	110
Oven	5000
Refrigerator (frost-free)	445
Toaster	1100
Vacuum cleaner	700
Water heater (electric)	3200
Television	200
Deep freezer	500
Laptop	75
Printer	100
Satellite dish	30
VCR	40
Kettle	2500
Mobile phone charger	15
Fluorescent lamp	40

Source: Ishaq, (2013)

4.2.2.1 Inverter sizing

The inverter’s main functios n are: Converting DC electricity into,AC electricity and regulation of effective value of the output voltage. With reference to Section 2.1.2.3, to determine the size of the inverter, the following ware considered

- Total load required to use for use in a selected period of time
- An expansion factor of 1.30

At a time of listing the load, it was assumed that the high surge load actual value would be considered.

The power consumption of appliances is generally given in Watts as seen in Table 4.2 (To calculate the total power you sum up the power of all selected items is taken)

Table 4.2 Selected appliances

APPLIANCE	LOAD
Television	200 W
Radio	100 W
Heater	1500 W
Energy Light	60W
Fluorescent lamp	40 W
TOTAL	**1900W**

Therefore

P_{INV} = total load / expansion factor P_{INV} (15)

= 1900 *1.30 = 2470 W

From the list of inverters available, an inverter with power rating approximately 30% higher to the total load found is selected (Ishaq et al, 2013).

4.2.2.2 Determining the size of the battery

The performance and life of an inverter system largely depend on battery quality. When determining the size of the battery, a question is asked of how long the load will demand for power in the absence of sun power or grid electricity. How many hours will the load run on battery? This is called the battery capacity and it is expressed in ampere hours (Ah).

The formula for battery capacity is given as;

$$B_c = P * B_t / B_v \tag{16}$$

E,g 90 W * 3hrs/12 V = 22.5Ah

The above method of battery sizing is not the best as it makes a more expensive battery bank. If, however it is established that all the load will be on for a specified period of time then it is favorable to use. The method below which considers the time duration in which the load will be on is a more favorable one. Table 4.3 shows the typical loads selected to be used in the calculation.

Table 4.3 Typical house hold loads

Load	wattage	Hour of use	Energy [Wh]
T.V	200	6	1200
Printer	100	0.5	50
Total	300	6.5	1250

Assumptions

- System voltage is 12 V
- Days of autonomy =1
- Allowable depth of discharge 70%

Calculations

Energy storage [Es] = total energy / system voltage

= 1250/12

= **104.16 Ah**

Total Energy storage [Es] = 104.6 / 0.7

= **149.428 Ah**

With regards to the value found the available battery equal or greater to the total energy storage found would be chosen.

4.2.2.3 Determining the Size of the Photovoltaic Panel

The heart of a photovoltaic system is the solar module. Manufacturers wire many photovoltaic cells together to produce a solar module. When installed at a site, solar modules are wired together in series to form strings. Strings of modules are connected in parallel to form an array.

- Taking Daily sun hours as 5hr
- Solar panel specification - SUNTECH STP200-18-UB-1, Vrm = Vmp = 18.2V, Irm = Imp = 7.63 A,

Total dc current = energy demand [Es]/sunlight hours

= 104.16/5

= 20.832Ah

Number of parallel module = total dc / I_{rm}

= 20.832/7.63

= 2.73

≈ 3

Number of series module = system voltage / V_{rm}

=12/18.2

= 0.666

There the series is 1

Total number of module = number of parallel modules * number of series modules = 3 (Guda and Aliyu, 2015)

4.2.2.4 Charge Controller Sizing

Cc = Pv module short circuit current *number of parallel modules * safety factor

=8.75*3 *1.25

=32.8125

Number of charge controllers = required charge controller current/ charge controller current [Icc] = 32.1825/40

= .0.804

Therefore the number of charge controller required is 1. (Guda and Aliyu, 2015)

4.3 Solar biogas calculator

4.3.1 Main user interface

The main user has three sections namely the biogas, solar and the hybrid.

The biogas section has three buttons, i.e. the calculations button, the substrate gas production button and digester button. See Figure 4.1 which shows the main user interface When the calculations button is pressed, the biogas for cooking calculator interface is opened where a digester size and substrate quantity will be determined see Figure 4.2. When the substrate gas production button is selected, an interface is opened where characteristics of the biogas substrate will be entered to be stored for use during calculation. When the digester button is pressed, the digester interface is opened, where digester characteristics can be entered.

The solar section has three parts the i.e. calculations button, the charge controller button and the solar panel, inverter, battery button. When the calculations button is pressed, the solar calculations interface is opened where the solar and power back up systems can be entered. When the charge controller buttons is pressed, the charge controller attributes interface is opened where charge controller specifications can be entered. When the button with inverter, battery, solar panel, and inscription is pressed, the attributes section opens, where spec of the inverters and solar panels can be entered.

Figure 4.1 Main user interface

4.3.2 The Biogas for Cooking Section

4.3.2.1 Biogas Calculator Part

This form was designed to determine a biogas digester, the quantity of substrates required and the amount of gas required for a desired cooking duration. The users enters the desired cooking hours and chooses the substrate which is available to them. From this information, the number of liters of biogas, the required substrate quantity in kgs, the digester size and the cost of digester is determined see Figure 4.2. The flow chart shown in Figure 4.3 shows the steps taken in getting the results.

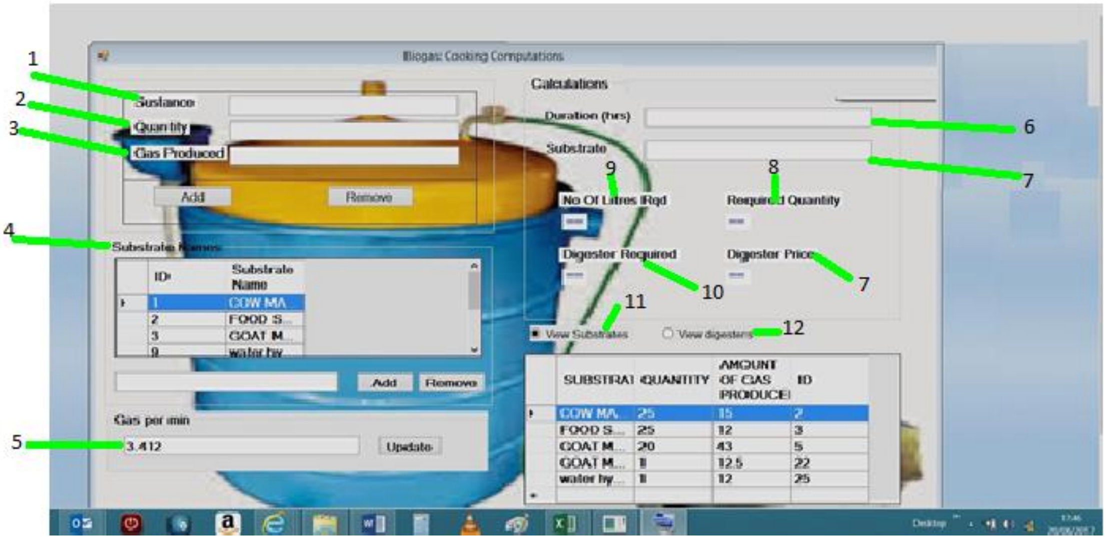


Figure 4.2 Biogas calculation interface

On the Biogas calculator interface

1. Substrate……………… Shows the substrate
2. Quantity ………………. Shows the quantity of substrates in KG that is required to produce a certain quantity of gas
3. Gas produced ………….. Shows the gas produced by a substrates liters
4. Substrates names ……….. That's where the substrates characteristics are added.
5. Gas per min……………. Shows the amount of gas that can consumed per min with reference to a particular gas burner.
6. Duration ……………….. That is where the desired cooking duration is entered
7. Substrates………………. The desired substrates appears with which the calculator is computing its value
8. Required quantity ……… Shows the required substrate in kgs that is required to produce the desired cooking duration
9. No of required liters. …… This shows the calculated amount of gas in liters required for the cooking duration
10. Digester required ……… Shows the digester size suggested by the calculator for the cooking duration per day

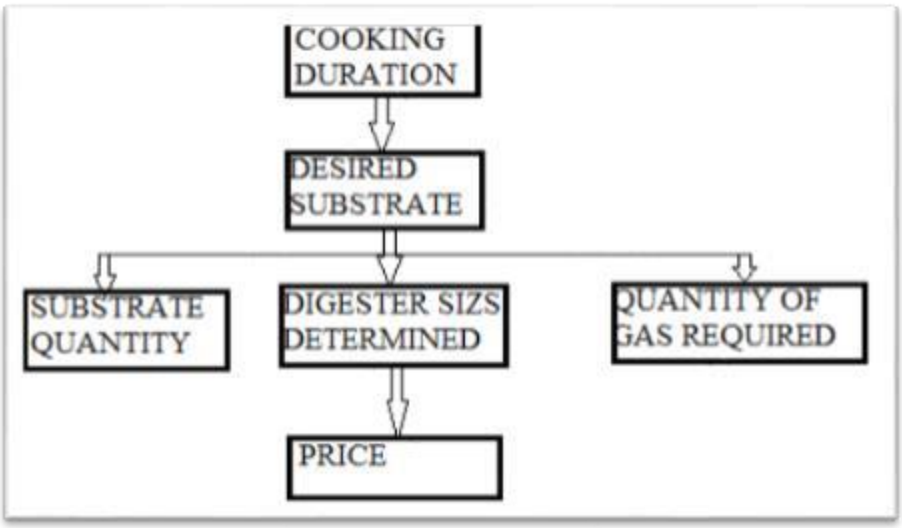


Figure 4.3 Biogas calculation Flow chart

Calculation flow

Substrate (A):

Cow manure ………………. $300m^3$ /tonne

Biogas burner (B) …………………... 3.2875L/min

Desired cooking period (C)………… 2hrs

Retention time (y) …………………….30

1.0 Biogas gas needed for a 2hr cooking period

D = C * 60 * B
2 * 60 * 3.2875
= 394.5 L = 0.394

2.0 Amount of Substrate required (E)
E ----- 0.394
1Kg ------- 0.3
E = 1.3 kg

3.0 Digester sizes

F = E * Y * 2
1.3 * 3 * 2
2.6 kg

4.3.2.2 Digesters Sizes

The digester interface allows the user to input the characteristics of the digester and display them. The interface is linked to a data base where they are stored and called upon during calculation. (Figure 4.4)

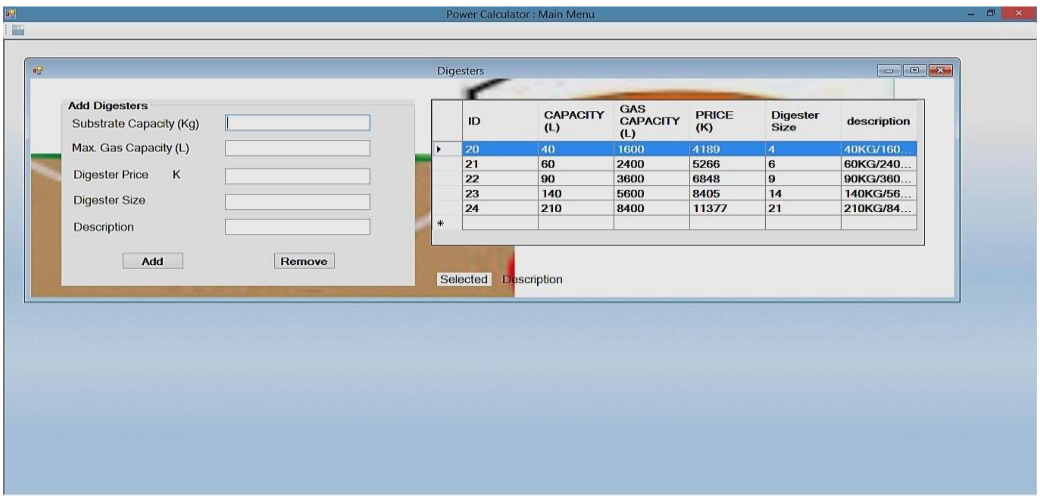


Figure 4.4 Digester characteristics interface

4.3.3 Solar System Section

The solar system section was designed adopting the solar system calculations. The solar section has two main parts i.e. the attributes part and the calculations part.

4.3.3.1 Solar attributes part

The attributes part allows the user to input the attributes of the batteries, inverters, solar panels and the charge controller. These attributes are linked to a data base and are used during system design by the calculator (Figures 4.5 and 4.6).

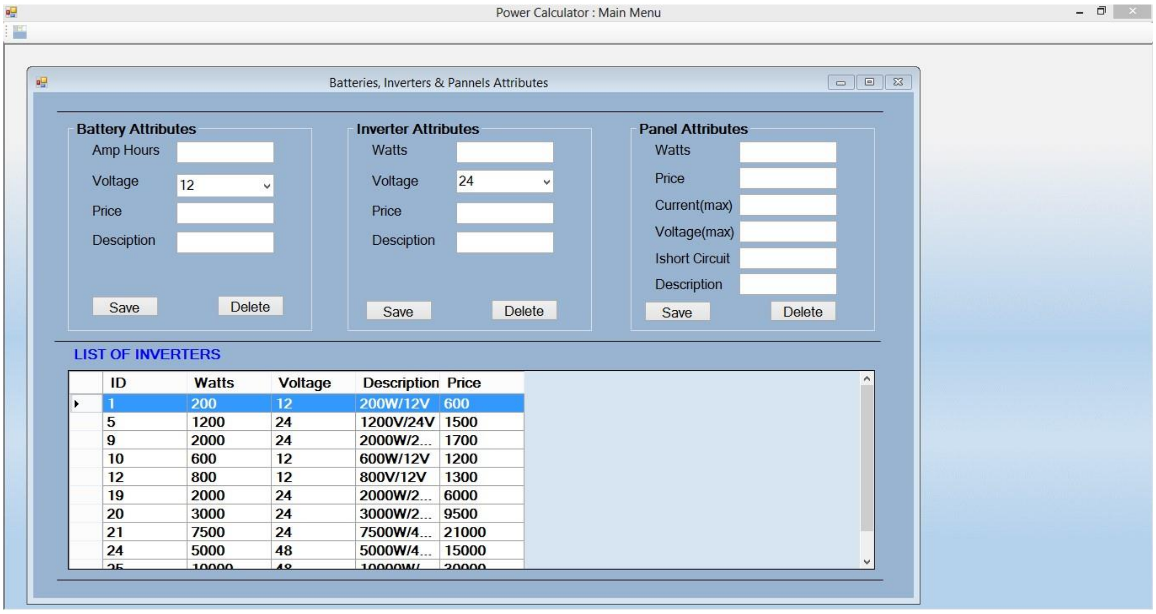


Figure 4.5 Solar systems Attributes window

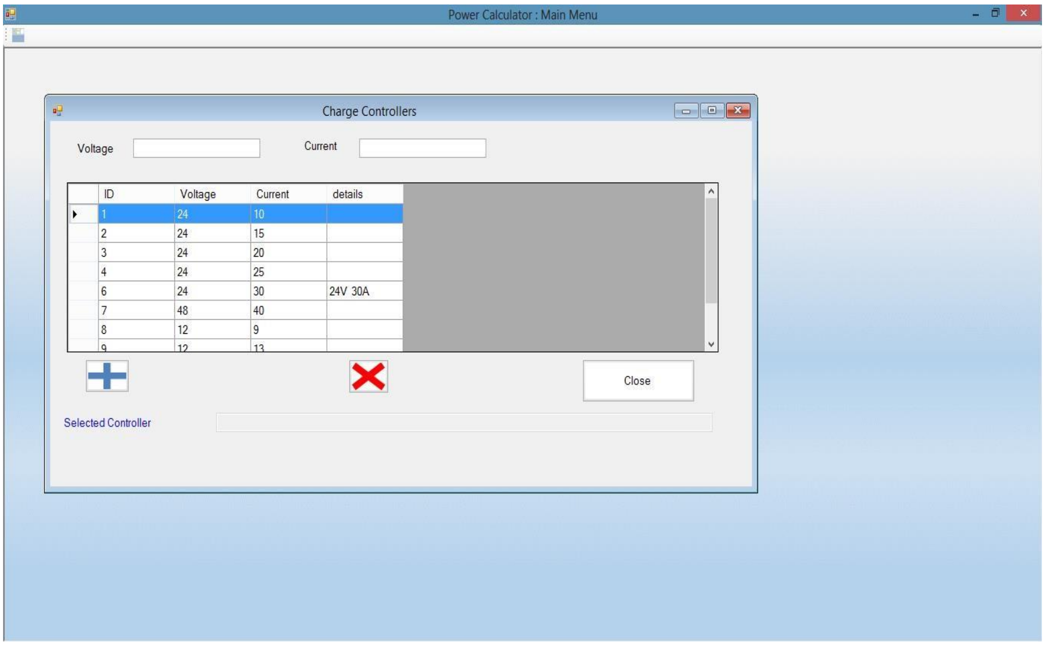


Figure 4.6 Charge controller attributes interface

4.3.3.2 The Solar Calculator Part

The calculator part allows the user to input the load that they wish to be on solar or power back up system. From the load inputs the system determines the appropriate size of the battery, inverter and the panel. Also gives a cost of each of the items. Figure 4.7 shoes the layout of the solar calculator interface.

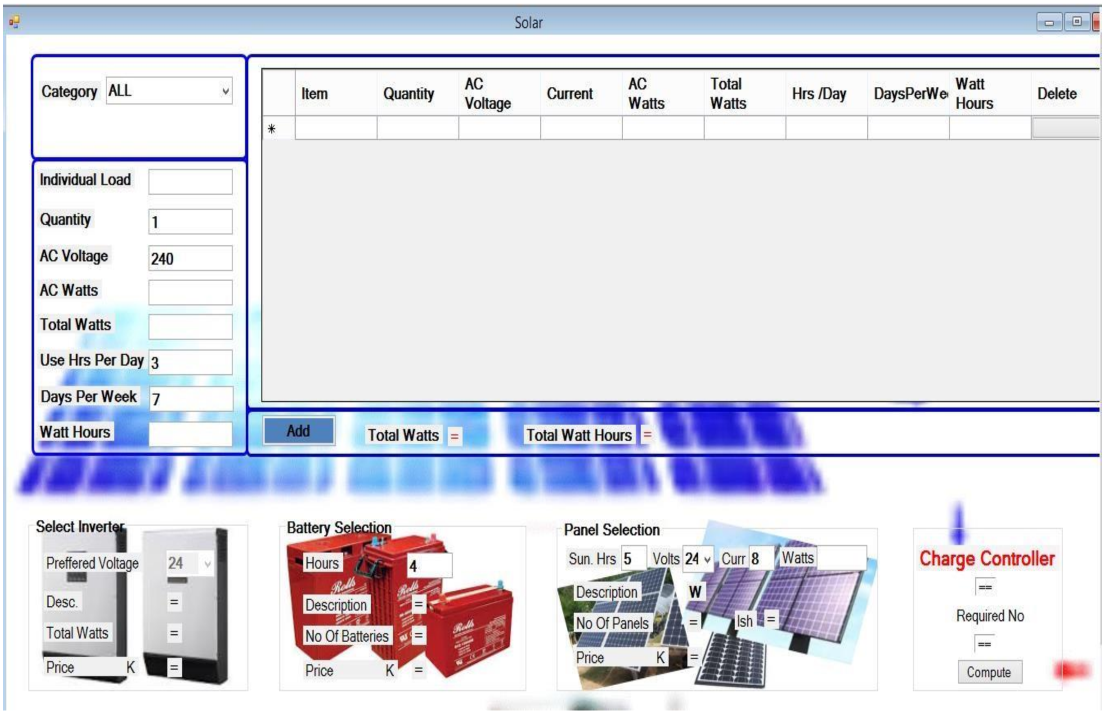


Figure 4.7 Solar calculator interface

4.3.4 The solar - biogas form

The form was designed to be able to compute solar system and biogas generator systems inclusive of the digester meant to feed the generator and substrates quantity required (Figure 4.8).

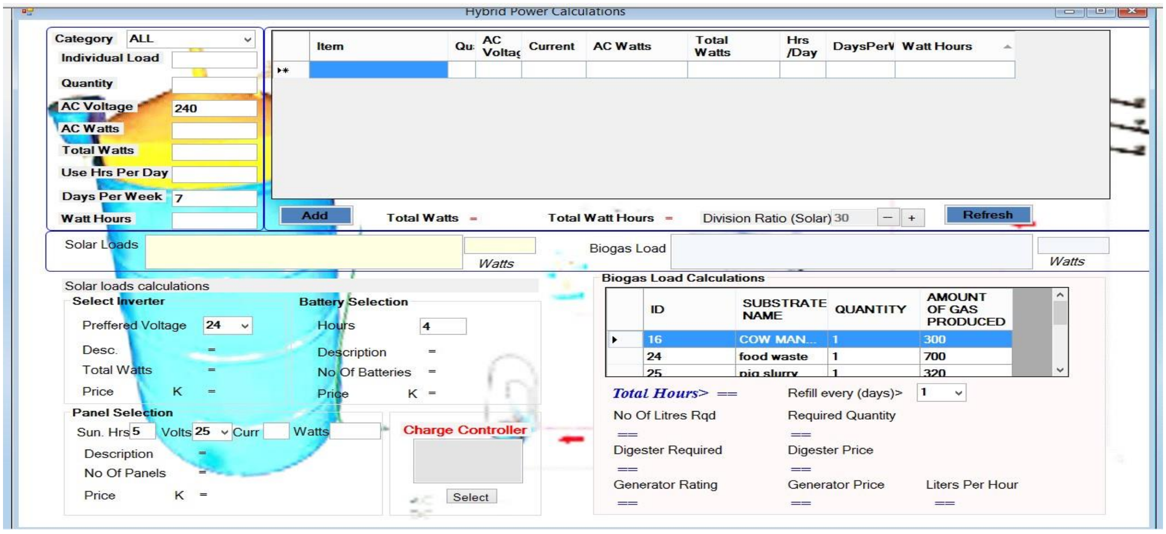


Figure 4.8 solar- biogas calculator interface

In creating this form we used the same design calculation adopted for the solar and the biogas form, however the biogas digester designed was not for cooking but for feeding a generator with specific gas consumption requirement see Table 3.10. The calculator was designed such that the load entered by the user is shared between the two technologies by a possible percentage chosen by the user. If for example the user enters 3 items and choses a 30% percent sharing, a total load sum is computed and 30% of it is compared among the load to choose a combination that would be closer to the 30% of the total load. See Appendix 1 for the code. The flow chart is shown in Figure 4.9.

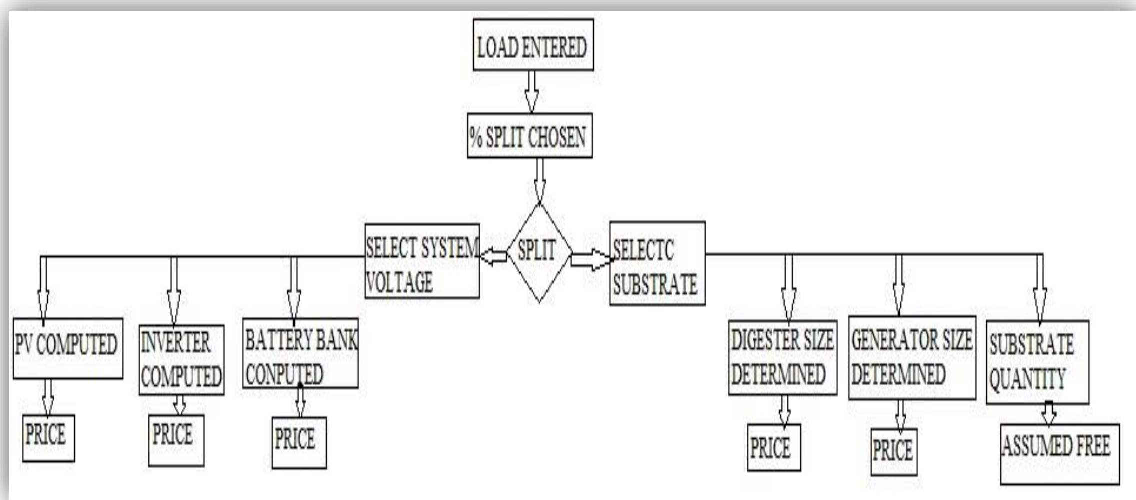


Figure 4.9 solar - biogas Flow chart

Closing remarks

The calculator was basically designed to calculate for possible systems to capture the different needs and desires of the user. These system are: The Solar Photovoltaic System, The Biogas System, the Solar biogas System with biogas being for cooking purposes and the solar – biogas system with biogas being used to power a generator.

CHAPTER FIVE

RESULTS

5.1 Introduction

This chapter shows the results of how the calculator has integrated the adopted calculation in Section 3.1, the substrates characteristics in Section 3.2, the market price survey in Section 3.4, to be able to size up a desired system and give tentative cost estimate

This chapter compares the findings to the material cited in the literature review and to the findings of other researchers who did the same kind of work the results. The chapter also shows the results obtained from the calculator comparing it with a physical system operating in the field. [See Section 3.3.2]

The calculator calculates the solar system, the biogas system and the solar-biogas system with biogas generator. Typical appliance rating from Table 3.0 was considered for input into the calculator.

5.2 Solar calculator

The main aim of the solar calculator, was to show the ability of the calculator to calculate power backup systems and complete off-grid systems and its ability to give a would be purchaser an estimated cost of the major system components excluding accessories and installation charges as this vary greatly from site to site. Compared the physical calculations and those obtained by the calculator.

5.2.1 Power back up system calculation

5.2.1.1 Result 1 - comparing Olympia system with calculator calculations

System details on site

Inverter name	Apollo I 360
Brand	Inverter charger
Size of inverter	850W
Battery name	leoch
Battery type	lead acid battery
Size of battery	100 Ah

Olympia power back up system supplies power to the following loads:

Lg smart	45 W
Lg home theater	5 W
Dstv decoder	10 W

The wattage of the above load were obtained from the name plate of each item. These were imbedded in our calculator in order to size up a system as shown in Figure 5.1. The following results were obtained as shown in Table 5.1

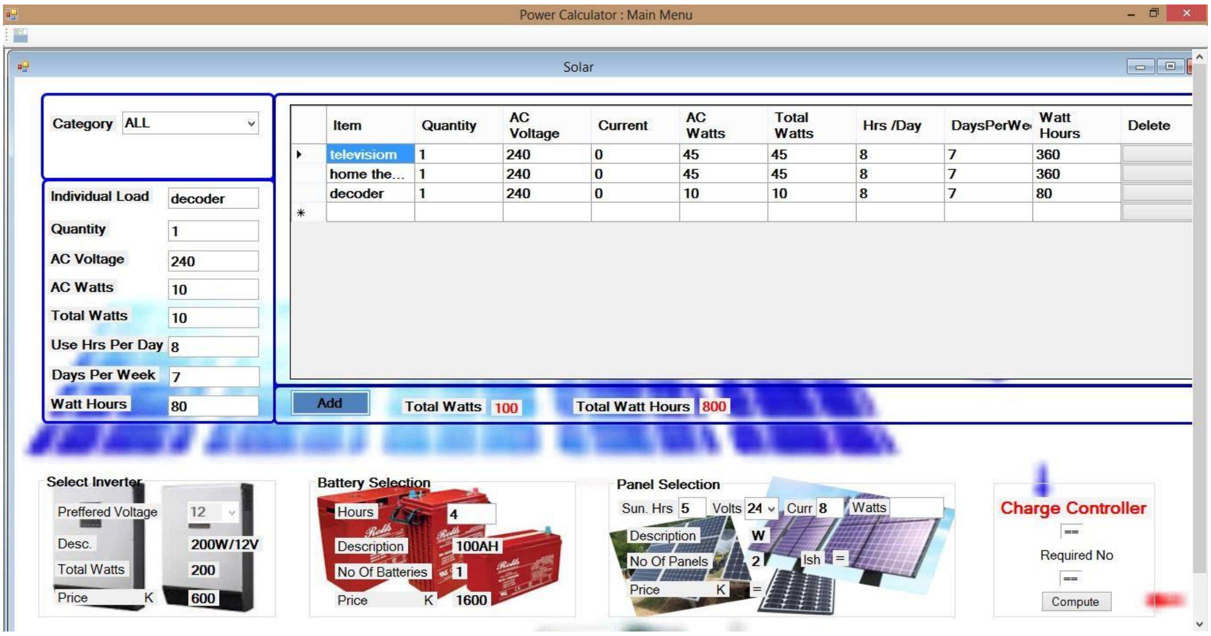


Figure 5.1 Power backup results of Olympia system

Table 5.1 Power Backup calculator results

SYSTEM	QTY	SIZE	Price (ZMW)
Inverter	1	200W/12V	600
Battery	1	100AH	1600
Solar Panel	0	0	0
Charge controller	0	0	0
TOTAL			2200

5.2.2 Solar Photovoltaic system calculation

Electrical appliances (loads) were itemized shown in Table 5.2 with their power ratings and time of operation during the day. The values were inserted in our calculator and obtained the results as shown in Table 5.3

Table 5.2 Typical appliance rating in a house hold

S/N	APPLIANCE	QTY	POWER RATING (W)	HOURLY USE (h)	TOTAL POWER (W)	USAGE
1	Fluorescent lamp	2	40	6	80	outside lights
2	Radio	1	110	6	110	information
3	Laptops	1	65	6	65	work
4	14" Television	1	200	6	200	entertainment
5	Satellite decoder	1	100	6	100	entertainment
6	Deep freezer frost free	1	445	6	445	preservative
7	Lights	10	11	5	110	Inside lights
8	2 Plate cooker	1	2000	1	2000	cooking
	Total				**3110**	

Table 5.3 Solar system calculation Results

SYSTEM	QTY	SIZE	Price (ZMW)
Inverter	1	5kW/48V	K15000
Battery	12	250 Ah	K62400
Solar Panel	24	200W	K 79500
Charge controller	3	40A	K 1950
TOTAL			**K 158,350**

The above system which was sized up by the calculator is sufficient enough to run a 3.11KW load on a daily basis with regards to the period of power usage by each appliance. See Figure 5.2

Figure 5.2 Complete solar solution calculation results

5.2.2.1 Validating calculator's calculation

From section 3.1.and Table 4.0. The solar system was determined as follows.

Total load ………… 3110W

Inverter sizing

3110W * 1.30 = 4030 W

Inverter size selected …….. 5000W/48v as the best available inverter

Battery sizing

3110W/48V = 64.5888 A

Hours of power required 6 hours

Es------64.5888 * 6 = 388.75Ah

TEs….388.75/0.7 = 555.3571 AH

Choose the best available battery…….. 250AH

Number of batteries …………… 555.3571 / 250AH ………. 2.2214 which is rounded off to 3. It is always good practice to oversize a system

Since the system voltage is 48 the number of strings required is 4

Therefore

Total number of batteries is 3* 4 = 12

Panel sizing

Number of sunlight hours 5

5.2.3 Solar system calculation excluding the stove

A solar system was calculated removing the stoves among the appliances just to appreciate how much reduction in system size and cost they would be. The following system was derived. See Table 5.4 and Figure 5.3

Table 5.4 Solar system calculation Results

SYSTEM	QTY	SIZE	Price (ZMW)
Inverter	1	2kW/24V	K 6000
Battery	4	250 Ah	K 20,800
Solar Panel	8	200W	K 9360
Charge controller	3	30A	K 1350
TOTAL			**K 37,510**

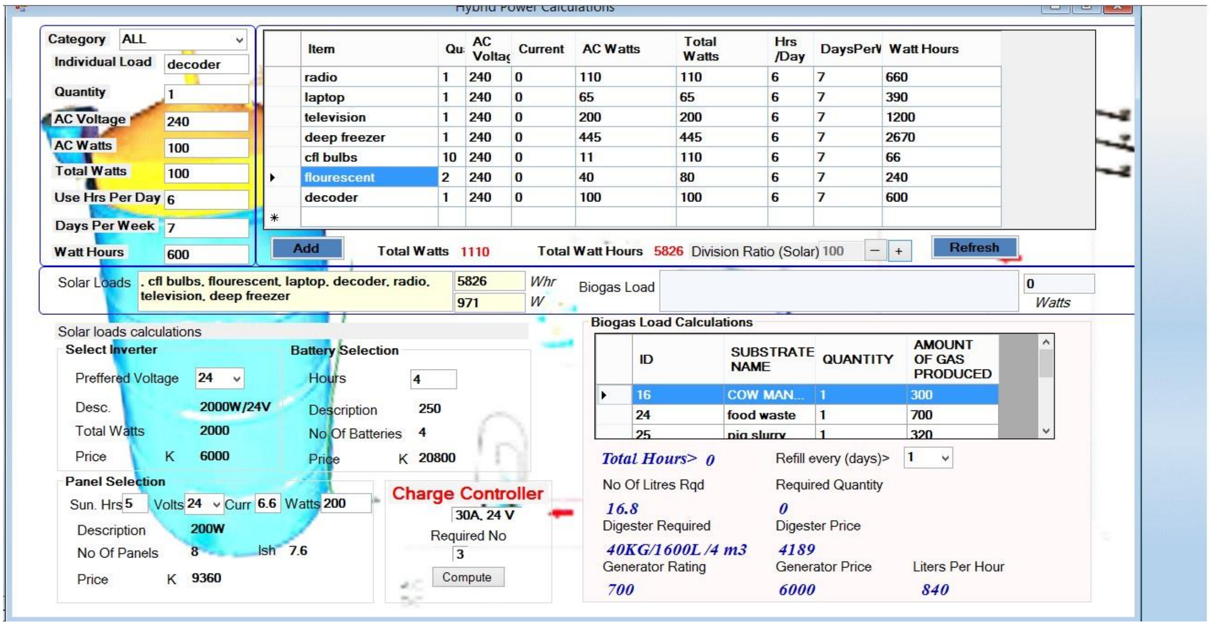


Figure 5.3 Solar calculation results minus stove

5.3 Biogas system for cooking

For the biogas system, the main concern was to determine the ability of the calculator to size up a digester that would satisfy a desired cooking duration. From literature review, it was observed that the digester size and volume is determined by the available substrate: However for this study, a different routes was followed in determining the digester that is to first know the cooking duration and the work back words using methods shown in 3.1.2. Different cooking duration values where inserted in the calculator against a chosen substrate and the digester size was recommended by the calculator. Below are Figures 5.4 and 5.5 showing the results of the calculator.

Assumptions made

- Combustion rate of the burner is 3.145
- The biogas has more than 55% of methane

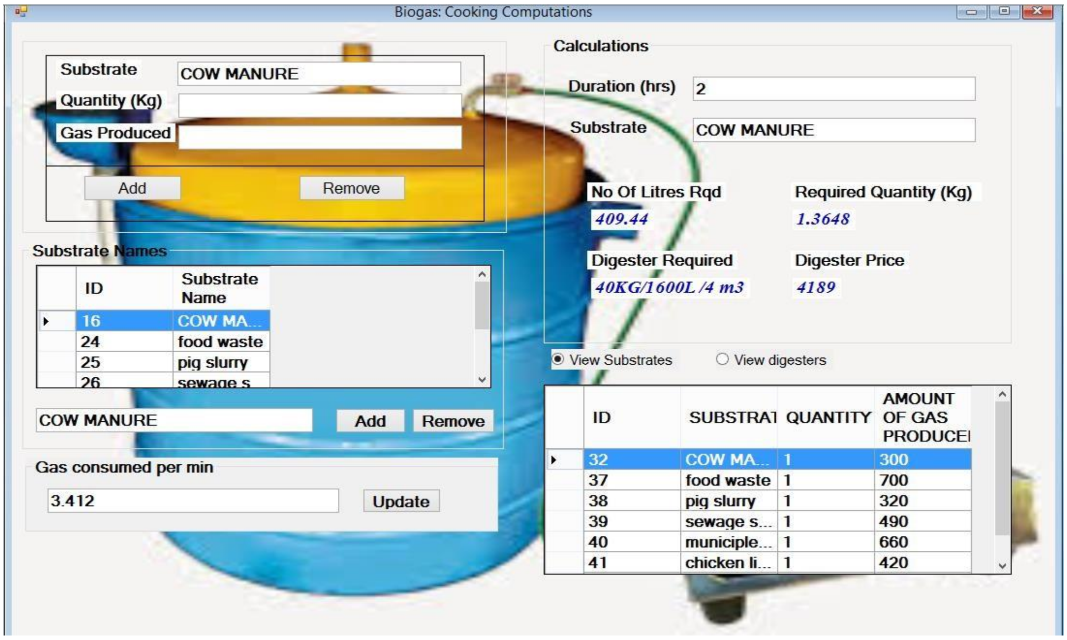


Figure 5.4 biogas for cooking calculation

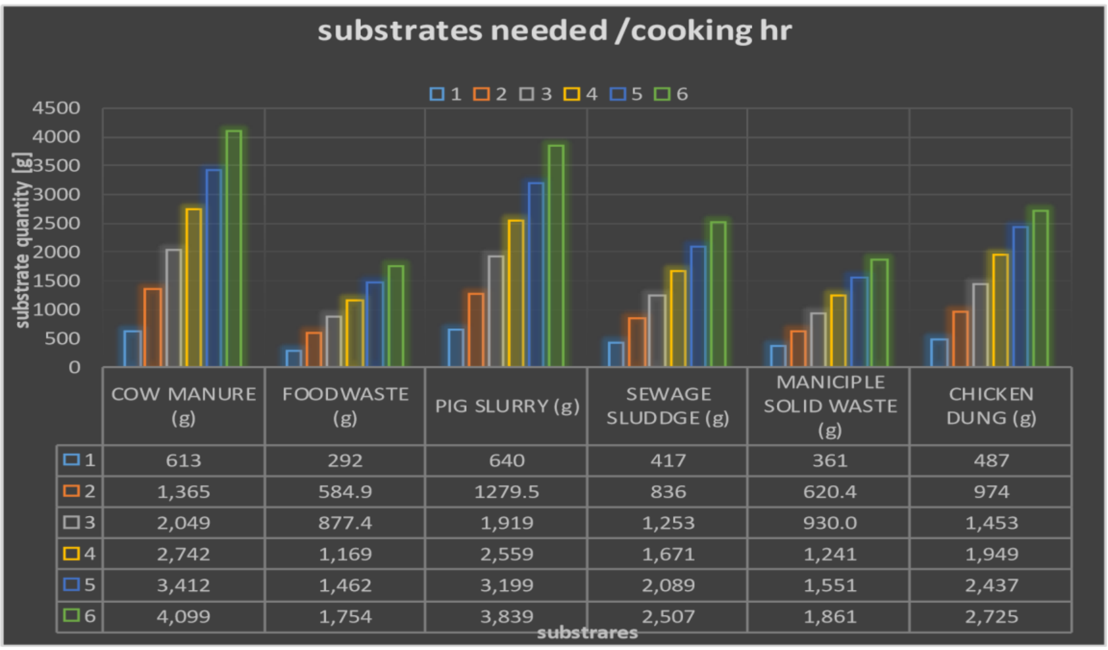


Figure 5.5 substrates needed / cooking hrs

5.5 Solar - Biogas Calculator

The main aim on this form was two-fold:

1 .To determine the possibility of our calculator sizing up a system combining both solar and biogas and consequently give a tentative cost estimates

2. To determine at what percentage of load sharing would be economical for the system choice.

5.4.1 solar – biogas system

From Table 4.1 the load was inserted in our calculator in order to calculate and analyze the energy mix. Figure 5.6 shows the total load entered, the 32 to 68 percent division ratio and the systems calculated and the tentative cost. The results obtained are shown in Table 5.5

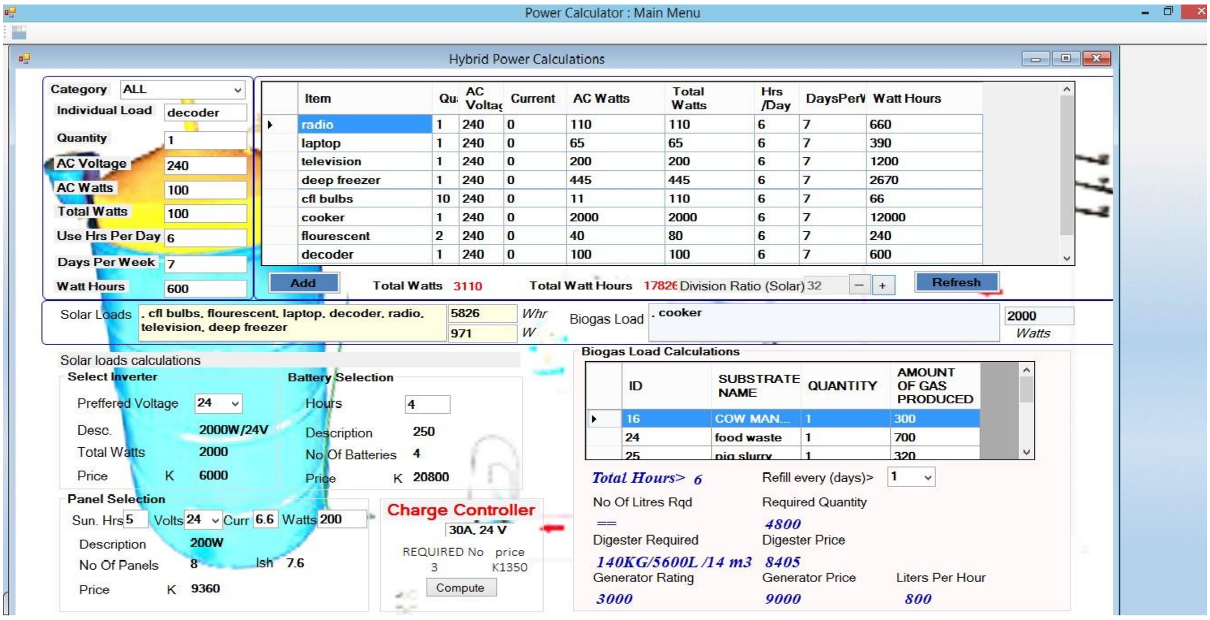


Figure 5.6 Solar biogas generator calculation

Table 5.5 Solar – biogas system calculation Results

SYSTEM	QTY	SIZE	Price (ZMW)
Inverter	1	2kW/24V	K 6000
Battery	4	250 Ah	K 20,800
Solar Panel	8	200W	K 9360
Charge controller	3	30A	K 1350
Generator	1	3000VA	K 9000
Digester	1	14m3	K 8405
TOTAL			K 54,915

CHAPTER SIX
DISCUSSION

6.1 Introduction

This chapter endeavors to discuss the result obtained in chapter 5 on of the four possible systems that the calculator designed with different scenarios. The main objective of this work was to create a calculator that designs solar hybrid systems. The system design started with reviewing literature and formulating design calculations that were bedded in the calculator. Various load profiles were looked at with particular interest on their wattages and hourly use, these were then inserted in the calculator considering various scenarios with main aim of asserting the calculators ability to design workable system.

6.2 Solar calculator

6.2.1 Power back up system calculation

From the data given to the calculator a system was calculated which consisted of 200W inverter and a battery size of 100Ah. The cost being a total of K2000. Comparing the calculated values with the physical system there was a disparity on the size of the inverter. However, the market locally does not have 250 W inverters which would explain how the owner was given the smallest inverter available on the market. A power simulation was done where it was made to run on battery for a period until an indicator showed low battery. The period of backup was 8.hrs 37min. This result showed that the battery size recommended by the calculator was near accurate with regards to the backup period. (Figure. 5.1)

6.2.2 Solar Photovoltaic system calculation

The loads selected to input in the calculator are loads typically found in a house hold and saved as a good source to see the type of system the calculator would design. Section 4.1.2.1 showed the calculations validating the system designed by the calculator. From the results it was observed that the calculator was able to design a typical system that would be installed to run 3.1 KW load to run for 6hrs.from the data base of the system components the calculator was able to retrieve the information and provide cost of the of the designed system.

6.2.3 Solar system calculation minus stove

From the load selected in Table 5.1. It was observed that after removing the cooker unit the cost of the system reduced significantly.

6.3 Biogas system for cooking calculation

On the biogas for cooking form. If the gas consumption rate for a particular burner is known, the amount of biogas required for a particular cooking duration can be calculated. Also we can know the amount of substrate required for chosen substrate taking into consideration the gas production characteristics of the substrates.

For a particular cooking duration the substrate type does very little to change the digester size.

6.3 Solar - Biogas Calculator

Comparing the solar system and the solar biogas generator system, the solar system, for a total load wattage of 3110W is more expensive compared to the solar - biogas system with same load wattage at 70 /30 division ration.

A combination of solar system and biogas system for cooking reduces the cost significantly from both the purely load on solar system and load on solar – biogas generator system

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction

This chapter present the conclusions and recommendations drawn from the study. The conclusions have been presented to reflect achievements of each specific objective and for clarity purposes

7. 2 Conclusions

The following conclusion have been drawn from the study on the design of the Solar biogas hybrid calculator:

i. To determine the ability of the calculator of the calculator to calculate power back up systems and complete off grid systems.

- The calculator was able to size up a backup system that would much an already installed system.
- Knowing the loads that are required to be powered, the calculator was able to size up a solar system and give cost estimates of the individual components of the solar system.

ii. To determine the ability of the biogas to size up a digester that would satisfy a desired cooking duration

- Knowing the cooking duration and the substrates available the digester size and its estimated cost was determined, the substrates quantity required was also determined. A cooking period of 2 hrs was inserted and cow manure as substrate chosen. A 4 m^3 digester costing K 4,189 was designed and 1.3648 kg substrate quantity was determined.

iii. To determine the possibility of our calculator sizing up a system combining both solar and biogas and consequently give tentative cost.

- A load was selected consisting of fluorescent lamps, radio, laptop, 14” television, satellite decoder, deep freezer frost free, lights, and a 2 plate cooker, making a total wattage of 3.11kW and a Watt Hour usage of 17.826 kWh. The load parameters were imbedded in the software and a 32 % division between Solar and Biogas was selected. A system consisting of the following was designed: 2000W/24V inverter costing K 6000, 4* 250Ah Battery costing K20,800, 8 * 200 W solar panels costing K 9000, a 14 m3 digester costing

K8,405 and a 3 kVA biogas generator costing K8405. For the Biogas digester for cooking, a cooking period of 2 hrs was inserted and cow manure as substrate chosen. A 4 m3 digester costing K 4,189 was designed and 1.3648 kg substrate quantity.

7.3 Recommendations

The following recommendations where drawn from the study

i. The solar and biogas component that are sized up by the calculator must always be updated by the organization using it, to suit their business in terms of the kind of systems they have and there cost.
ii. More research should be carried out to show how levelized cost analysis can be included in the system taking into account the wear and tear and operation cost of the system that has been designed.
iii. More research needs to be carried out to show at what percent of load sharing would be more economical for the combination of the two technologies.

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APPENDICES

Appendix I Quotations

I.1 Radian stores quotation

Radian
Inspiring Trust . Since 1991
Radian Stores Retail Ltd

Radian Stores Retail Limited.
P.O.Box 30318, Lusaka, Zambia.
Tel: (211) 220686/ 238451

QUOTATION

Customer Details:

To: NECOR ZAMBIA LTD
Address: LUSAKA
Contact: 0977408164

Quotation Details:

Date: 08/09/2017
Quote No: 20170908 - 04
Quote Validity: 7 DAYS

Qty	Description	Item Price (KR)	Gross Total (KR)
01	T-BOLT SOLAR PANEL POLY -SR156P - 250W	1,700.00	1,700.00
01	LEOCH SOLAR BATTERY - 12V - 250AH	3,465.00	3,465.00
01	LEOCH SOLAR BATTERY - 12V - 100AH	1,445.00	1,445.00
01	T-BOLT HYBRID INVERTER -SOL. & AC CHARGER -IVS-1000VA	1,840.00	1,840.00
01	FORTUNER STANDARD INVERTER / HOME UPS-24V-2000VA	3,150.00	3,150.00
01	FORTUNER STANDARD INVERTER / HOME UPS-12V-850VA	1,445.00	1,445.00
		Sub Total:	13,045.00
		Discount:	
		Net Total:	**13,045.00**

Note: - All Prices are inclusive of 16% VAT.
- This is not a Tax Invoice & thus will not be accepted as proof of payment.

Issued By: ALPHA
(On behalf of Radian Stores Retail Ltd)

Received By:
Sign:
Date:

LG PHILIPS OLYMPUS Midea DEFY

I.2 Id Solar Quotation

solar solutions

You need Power - We offer Solutions

QUOTATION

No. 222

Date: 30-09-2016

id Solar Solutions
4483 Katima Mulilo Road, Kalundu
Lusaka, Zambia

Mobile: +260 (978) 676 937 / (09 SUNPOWER)
Email: sales@idsolarsolutions.com

TPIN: 1002975074

Zanaco **Bank, Acacia Branch**
Account Numbers:
05161676500192 (ZMW)
05161676500293 (USD)

Customer Details

Name: MCCOR (Yasaya)

Address:

Phone: Cell: 0977407164

Email: [illegible]

Currency used: USD / ZMW / ......

Item Code	Description of Product	Qty	Item Price excl. VAT	Total Price excl. VAT	VAT 16%	Total Price incl. VAT
1	AGM 220Ah	1	3500	3500	–	3,500

Goods supplied remain the property of id Solar Solutions UNTILL PAID FOR IN FULL

USD quotations have a validity of 2 weeks, they can be paid in ZMW by using the BOZ exchange rate on date of payment.
ZMW quotations have a validity of 1 day.

Payment terms:
100% upfront for component sales
80% upfront on orders and installations.

Availability (Estimated Delivery/Installation Period):

Sub Total	3500
VAT	–
Total (incl. VAT)	3500

I.3 Davies & Shirtliff quotation

QUOTATION

DAVIS & SHIRTLIFF

Davis & Shirtliff Ltd
Plot 14702, Lumumba Rd
P O Box FW112, Lusaka, ZAMBIA
Tel/Fax: +260-211-288 010/1
Lusaka@zm.dayliff.com

Date: 24-Apr-17
Ref. No.: 05/Q/2016/ CRM

Customer:
NECOR ZAMBIA
P.O. Box
Lusaka
Email:

Attention:
Cell No.:

Availability: Ex-Stock Subject to prior Sales
Payment Terms In the absence of an approved credit facility, full upfront payment will be required

TRANSACTION DETAILS
SUPPLY ONLY

ITEM No.	EQUIPMENT	Qty	Unit Rate	Disc	VAT Rate	Amount
	Equipment:					
1	Opti Electo 2000, 1600 Watts Inverter Pure sinewave 24VDC input, 240Vac Output	1	7,500	25%	0%	5,625
					TOTAL, ZMW	5,625

NOTE:
The system quote is based on the estimated loading below
1 Only loads that do not produce heating may be utilised in event of power outage. Where applicable, unnecessary loads should be avoided
2 Quotation

Warranty: Equipment is covered by a 12-month manufacturer's warranty from date of delivery. This covers for failures related to manufacturing faults. It specifically excludes any failures due to factors beyond our control, such as failures due to electrical surges, incorrect operation or if any unauthorised repairs are attempted. Please refer to any of our technical staff for the recommended protection and operation instructions for your equipment to ensure trouble-free use

VAT ANALYSIS

Rate	Amount	VAT
0%	5,625	0
16%	0	0

Quotation Prepared by
Brian Siakweenda
Sales Engineer
Cell: 0968-330566 ----------------
Email: Brian.Siakweenda@dayliff.com

QUOTATION

DAVIS & SHIRTLIFF *know H2Ow through experience* Davis & Shirtliff Ltd Plot 14702, Lumumba Rd P O Box FW112, Lusaka, ZAMBIA Tel/Fax: +260-211-288 010/1 Lusaka@zm.dayliff.com	Date: 20-Jun-17 Ref. No.: BS/Q/2016/ CRM
Customer: NECOR ZAMBIA LTD P.O. Box Lusaka Attention: Cell No.:0977408164 Email:	**Availability:** Ex-Stock Subject to prior Sales **Payment Terms:** In the absence of an approved credit facility, full upfront payment will be required

TRANSACTION DETAILS
SUPPLY ONLY

ITEM No.	EQUIPMENT	Qty	Unit Rate	Disc	VAT Rate	Amount
1	**Equipment:** EFECTO 3000 2400watts Inverter Pure sinewave 24VDC input, 240Vac Output	1	8,300	25%	0%	6,225
					TOTAL, ZMW	6,225

NOTE:

The system quote is based on the estimated loading below

1 Only loads that do not produce heating may be utilised in event of power outage. Where applicable, unnecessary loads should be avoided

2 Quotation is for supply only

Warranty: Equipment is covered by a 12-month manufacturer's warranty from date of delivery. This covers for failures related to manufacturing faults. It specifically excludes any failures due to factors beyond our control, such as failures due to electrical surges, incorrect operation or if any unauthorised repairs are attempted. Please refer to any of our technical staff for the recommended protection and operation instructions for your equipment to ensure trouble-free use

VAT ANALYSIS	Rate	Amount	VAT
	0%	6,225	0
	16%	0	0

Quotation Prepared by
Brian Siakweenda
Sales Engineer
Cell: 0968-330566 ....
Email: Brian.Siakweenda@dayliff.com

QUOTATION

DAVIS & SHIRTLIFF — know H₂Ow through experience Davis & Shirtliff Ltd Plot 14702, Lumumba Rd P O Box FW112, Lusaka, ZAMBIA Tel/Fax: +260-211-288 010/1 Lusaka@zm.dayliff.com	Date: 22-May-17 Ref. No.: BS/Q/2016/ CRM
Customer: NECOR ZAMBIA P.O. Box Lusaka Attention: Cell No.: Email:	**Availability:** Ex-Stock Subject to prior Sales **Payment Terms:** In the absence of an approved credit facility, full upfront payment will be required

TRANSACTION DETAILS

SUPPLY ONLY

ITEM No.	EQUIPMENT	Qty	Unit Rate	Disc	VAT Rate	Amount
1	Equipment: Opti Efecto 5000, 4000 Watts Inverter Pure sinewave 48VDC input, 240Vac Output	1	15,700	25%	0%	11,775
					TOTAL, ZMW	11,775

NOTE:

The system quote is based on the estimated loading below

1 Supply only

Warranty: Equipment is covered by a 12-month manufacturer's warranty from date of delivery. This covers for failures related to manufacturing faults. It specifically excludes any failures due to factors beyond our control, such as failures due to electrical surges, incorrect operation or if any unauthorised repairs are attempted. Please refer to any of our technical staff for the recommended protection and operation instructions for your equipment to ensure trouble-free use

VAT ANALYSIS	Rate	Amount	VAT
	0%	11,775	0
	16%	0	0

Quotation Prepared by

Brian Siakweenda

Sales Engineer

Cell: 0968-330566 ....

Email: Brian.Siakweenda@dayliff.com

I.4 Puxin Biogas generator quote

PUXIN SHENZHEN PUXIN TECHNOLOGY CO. LTD

PUXIN

Shenzhen Puxin Technology Co. Ltd

Addr: 1-2nd floor, Bldg 4, Masha Xuda High-tech. Industry Park , 49 Jiaoyu North Rd , Gaoqian, Pingdi , Longgang, Shenzhen, P. R. China

E-mail: info@puxintech.com Website: http://www.puxintech.com

PUXIN Biogas Generators
Biogas Generators for family Size biogas plant

Item Number	1500W	3000W
Specifications Photos		
Type	Biogas Generator	Biogas Generator
Rated Power	1500W	3000W
Max. Power	1800W	3500W
Frequency	50HZ	
DC Output	12V 8.3A	
Generator Type	Brass,copper generator, Single Cylinder, 4-stroke, Air-cooled	
Engine Type	168FG	188FG
Starting method	Electric starting	Electric starting
Ignition System	T.C.I.	
Engine oil capacity(L)	Add 0.6L oil before using	Add 1.1L oil before using
Gas consumption(m^3/h)	1.05	2.1
Continue Working Time	Cooling after continuous operation 4 hours	
Standard Equipment	European two-holed socket with cover / American three-hole socket	
	1, AC, 220V single-phase	

1

PUXIN **SHENZHEN PUXIN TECHNOLOGY CO. LTD**

	2, DC 220V single-phase)+105	
Dimensions	610*440*455mm	700*525*560mm
Weight	40kgs	75kgs
Suitable gas	Biogas	
Price	USD470	USD765

Biogas Gas requirements

1- Biogas no less more than 65% Methane(CH4)
2- Gas pressure: 2KPA ~ 6KPA
3- Biogas should be processed by desulfuring and dehydration before entering into the generator sets.(Otherwise, it will damage the engine cylinder, spark plug and other parts.) The warranty will not cover damaged cause wrong operation.

Parameter of Biogas Generator Set

Prime power/Standby power	10KW
Standby power	11KW
Rated Speed	1500RPM
Rated Frequency	50Hz
Rated Voltage	400V
Phase	AC 3-Phase, 4 wire
Voltage Stability	≤±1%
Shock mitigation system	High elastic rubber shock absorbe
Voltage transient	≤±20%
Structure mode	All-in-one
Voltage Stable time	≤1.5s
Current fluctuation	≤0.5%
Current Stability	≤5%
Current transient	≤±10%
Current Stable time	≤5s
Current fluctuation	≤0.5%
Colour	your choice
Certificates	ISO 9001:2008, CE

2

Warranty	1 year or 1500 running hours which arrives first
Compression ratio	Open
Control system	Automatic alarm system
Size	1950*950*1500(plywood case)
EX WORKS PRICE	US$6,894.00
CHP System	US$2,651.00
Total price	US$9,545.00

Appendix II Puxin Biogas Digester

II.1 General introduction of PUXIN Assembly Biogas Plant.

(1) MATERIAL SPECIFICATION

- Inlet and outlet of digester: Stainless steel
- Mental supporting frame: Galvanized iron
- Hollow sunlight sheet of green house: PE

(2) EXCELLENT SAFETY FEATURE

There is no safety problem of the biogas digester, each digester is installed with pressure releaser, when biogas pressure in the digester is too big, and biogas will flow into atmosphere through pressure releaser.

(3) ODORLESS

The biogas fermentation process happens in the sealed membrane digester and biogas is collected and desulfurized and be used, so there is no smell for the unit.

(4) TEMPERATURE FOR BIOGAS FERMENTATION

Normal temperature: 10 -30 Celsius

Middle temperature: 30 -35 Celsius

Higher temperature: 50-55 Celsius

Note: the temperature is not higher than 60 Celsius

II.2 CE certificate for Puxin Assembly Biogas System

USG

CERTIFICATE

Of Conformity

Certificate No.	:	USG2016030113C
Applicant	:	Shenzhen Puxin Technology Co., Ltd. 2nd floor, Bldg 4, North Jiaoyu Rd.49#, Gaoqiao, Pingdi, Longgang, Shenzhen, P.R.China
Manufacturer	:	Shenzhen Puxin Technology Co., Ltd. 2nd floor, Bldg 4, North Jiaoyu Rd.49#, Gaoqiao, Pingdi, Longgang, Shenzhen, P.R.China
Product	:	Assembly Biogas System
M/N	:	PX-ABS-3.4M3 、 PX-ABS-1.2M3 、 PX-ABS-15M3 、 PX-ABS-66M3、PX-ABS-260M3、PX-ABS-1380M3
Trademark	:	N/A
Test Standard	:	EN 60204-1: 2009 EN ISO 12100:2010

When tested as specified, the submitted sample complies with the Low Voltage Directive 2006/95/EC and 2006/42/EC Directive.
The certificate is applicable to the test products mentioned above. It is only valid in connection with the test report number: USG2016030113R.

CE

Bruce Zhao

Date:Mar 01, 2015

Shenzhen USG Technology Co.,Ltd.

Block A, Anle Industrial Zone, Hangcheng Road, Xixiang Town, Shenzhen, China
Tel: 86-755-26458601 Fax: 86-755-61653962 www.szdezhuo.com

II.3 Puxin family size assembly biogas plant PX-ABS-3.4M3& PX-ABS-1.2M3

(1) Application

It makes you treat your organic waste locally, use the biogas for cooking and electricity, feed your garden with nutritious liquid fertilizer, save on your energy bill and garbage disposal fee!

It is the ultimate solution for families, restaurants, hotels and resorts to treat their organic wastes (food waste, sewage sludge and animal manure etc.)

TECHNICAL DATA

Waste Treatment Capacity:

Raw material	Maximum (Kg/d) for 3.4m3 model	Maximum (Kg/d) for 1.2m3 model
Food waste	25	8.3
Pig manure	45	15
Cow manure	60	20
Chicken manure	26	8.6
Human manure	32	10.6
Vegetable	65	21.6

Output: Biogas 0.6 m3 or 2m3/day and Clean natural liquid fertilizer, biogas is family daily cooking and lighting purpose.

PS: The product is convenient for commercialization: It can be easily carried, displayed on exhibitions and supermarkets, and be delivered in cardboard boxes.

Capable dealers are welcome!

Special size products can be manufactured when order in Batch.

No.	Greenhouse volume (m3)	Dimension of digester (cm)	Water level (m)	Fermentation capacity （m^3）	Gas storage (m^3)
1	1.2	L120*W81*H120	0.65	0.6	0.4
2	3.4	L156*W120*H195	1	1.7	1.0

II.4 Puxin medium size assembly biogas plant PX-ABS-15M3, PX-ABS-66M3

Application

It is designed for livestock farm, Slaughter house and food processing plant to treat their organic wastes and waste water; for restaurants, hotels, and campus and residence community to treat their organic wastes (food waste, sewage sludge and animal manure etc.)

TECHNICAL DATA

Waste capacity:

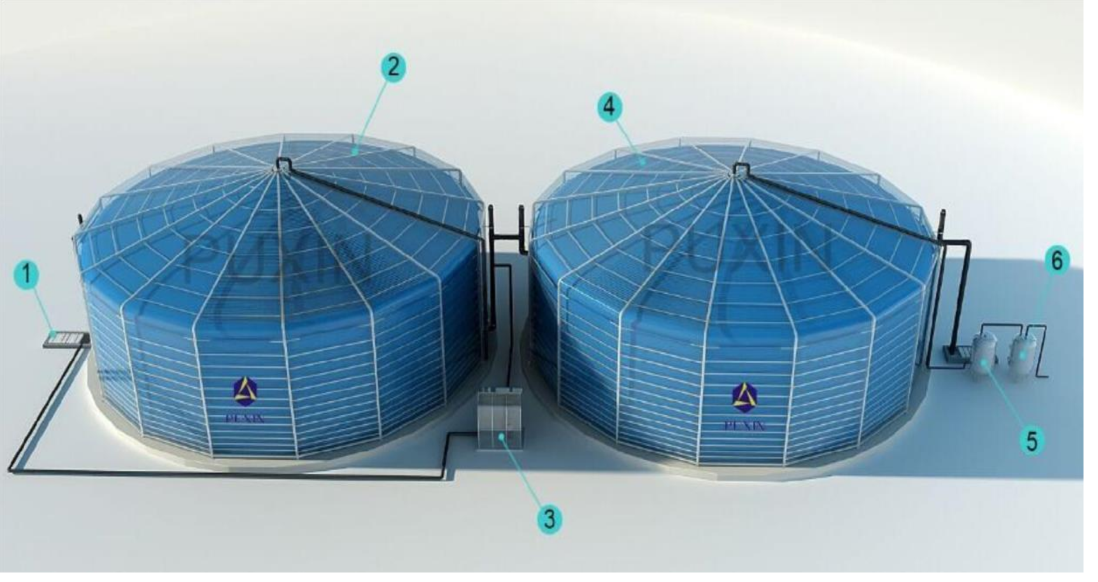
Raw material	Maximum (Kg/d) for 15M3(A) model	Maximum (Kg/d) for 15M3(B) model	Maximum (Kg/d) for 66M3 model
Food waste	125	180	702

Pig manure	225	324	1263
Cow manure	300	432	1684.8
Chicken manure	130	187	729.3
Human manure	160	230.4	898.6
Vegetable	325	468	1825.2

Output: Biogas 10 to 15m3 per day and 56m3 per day and organic liquid fertilizer, it can produce 22.5KWH and 84KWH of electricity per day or can be used for cooking purpose.

No.	Greenhouse volume (m3)	Dia. of digester (m)	Height (M)	Water level (m)	Fermentation capacity（m3）	Gas storage （m3）
1A	15.0	3	2.5	1.25	8.8	4.9
2B	15.0	3	2.5	2	12.7	2.5
3	66.0	6	3	2	50	10

II. 5 Puxin large size assembly biogas plant PX-ABS-260M3, PX-ABS-1380M3



① Pretreatment tank ② First stage digester ③ Circulation pump ④ Second stage digester ⑤⑥ Biogas dehydrator and desulfurizer

Application

It is designed for medium and large farm, medium and large amount of waste water or medium and large size of MSW treatment.

TECHNICAL DATA

Waste capacity:

Raw material	Maximum (Ton/d) for 260m3 model	Maximum (Ton/d) For 1380m3 model
Food waste	2.8	12.5
Pig manure	5	22.5
Cow manure	6.7	30
Chicken manure	2.9	13.5
Human manure	3.6	17
Vegetable	7.3	32.5

Output: Biogas 200m3 per day and 1000m3 per day and organic liquid fertilizer, it can produce 300KWH and 1500KWH of electricity per day or can be used for cooking purpose.

No.	Greenhouse volume (m3)	Dia. of digester (m)	Height (M)	Water level (m)	Fermentation capacity （ m3）	Gas storage （m3）
1	260.0	7.88	5.5	4	200	39.8
2	1380	16	7.46	5	1000	200

Appendix III Source code for the calculator

```
 using      System;      using      System.Collections.Generic;      using
System.ComponentModel;  using  System.Data;  using  System.Drawing;  using
System.Linq;   using   System.Text;   using   System.Windows.Forms;   using
System.Data.OleDb;

namespace PowerCalculator
    {
    public partial class Solar : Form
    {              string  GasPerMin  =  string.Empty;               string
SelectedSubstrate = string.Empty;         int Hours = 0;
        double  MaxBatteryPrice  =  0;              OleDbConnection  CONN;
int  RowCounter  =  0;            double  TotalWatts  =  0;           double
TotalWattHrs = 0;          double Amphours2 = 0;         public Solar()
        {
            InitializeComponent();
        }



        private void txtQuantity_TextChanged(object sender, EventArgs e)
        {             try
        {                                            txtTotalWatts.Text   =
(double.Parse(txtQuantity.Text)                                         *
double.Parse(txtWatts.Text)).ToString();
            }             catch             {
            }             finally
            {
            }
        }
        private void txtWatts_TextChanged(object sender, EventArgs e)
        {             try              {
                txtTotalWatts.Text = (double.Parse(txtQuantity.Text) *
 double.Parse(txtWatts.Text)).ToString();
            }                 catch                 {                 }
finally
            {
            }
        }
```

```
        private void txtHrsPerDay_TextChanged(object sender, EventArgs
e)
        {           try           {
                txtWattHours.Text = ((double.Parse(txtWatts.Text) *
       double.Parse(txtHrsPerDay.Text)                                *
double.Parse(txtDaysPerWeek.Text)) /
 7).ToString();
            }               catch               {             }
finally
            {
            }
        }
        private void txtDaysPerWeek_TextChanged(object sender, EventArgs
e)
        {           try           {
                txtWattHours.Text = ((double.Parse(txtWatts.Text) *
double.Parse(txtHrsPerDay.Text)  *  double.Parse(txtDaysPerWeek.Text))  /
7).ToString();
            }           catch
            {           }           finally
            {
            }
        }

        private void txtTotalWatts_TextChanged(object sender, EventArgs
e)
        {           try           {
                txtWattHours.Text = ((double.Parse(txtWatts.Text) *
double.Parse(txtHrsPerDay.Text)  *  double.Parse(txtDaysPerWeek.Text))  /
7).ToString();
            }               catch               {             }
finally
            {
            }
        }
        private void btnAdd_Click(object sender, EventArgs e)
        {
```

```
            dataGridView1.Rows.Add(1);
            dataGridView1.Rows[RowCounter].Cells[0].Value               =
txtIndLoad.Text                                                          ;
dataGridView1.Rows[RowCounter].Cells[1].Value     =     txtQuantity.Text;
dataGridView1.Rows[RowCounter].Cells[2].Value      =      txtVoltage.Text;
dataGridView1.Rows[RowCounter].Cells[3].Value            =            "0";
dataGridView1.Rows[RowCounter].Cells[4].Value     =     txtWatts.Text     ;
dataGridView1.Rows[RowCounter].Cells[5].Value    =    txtTotalWatts.Text;
dataGridView1.Rows[RowCounter].Cells[6].Value   =   txtHrsPerDay.Text    ;
dataGridView1.Rows[RowCounter].Cells[7].Value    =    txtDaysPerWeek.Text;
dataGridView1.Rows[RowCounter].Cells[8].Value = txtWattHours.Text;
            RowCounter = RowCounter + 1;
 TotalWattHrs    =    TotalWattHrs    +    double.Parse(txtWattHours.Text);
lblTotalWattHours.Text      =    TotalWattHrs.ToString();    TotalWatts    =
TotalWatts   +   double.Parse(txtTotalWatts.Text);   lblWattsTotal.Text   =
TotalWatts.ToString();
            SelectInverter();
            DetermineBattery();
        }
        private void btnCalculate_Click(object sender, EventArgs e)
        {
         }
        private void CalulateTotalWAttHours()
        {
            double Total= 0;             int i;
            for (i = 0; i <= RowCounter-1; i++)
            {
                Total = Total +
 double.Parse(dataGridView1.Rows[i].Cells[8].Value.ToString()) ;
            }
            lblTotalWattHours.Text = Total.ToString();


         }
        private void SelectInverter()
        {
```

```
            string sql = "select * from Inverters where Voltage = " +
        cmbPrefferedVoltage.Text + " and watts > " + lblWattsTotal.Text +
" order by   watts";
            CONN.Open();
            OleDbCommand  cmdGetInverter  =  new  OleDbCommand(sql,  CONN);
OleDbDataReader  DR  =  cmdGetInverter.ExecuteReader();                 if
(DR.HasRows)
            {
                DR.Read();
                lblInverterDesc.Text    =    DR["Description"].ToString();
lblInverterWatts.Text                     =          DR["Watts"].ToString();
lblPrice.Text = DR["Price"].ToString();
            }             else
                MessageBox.Show("No     Inverter     Can     meet     these
Specifications",
"Inverter",  MessageBoxButtons.OK);
            CONN.Close();


                     }
        private void ShowSubstrateGasProduced()
        {
            Form1 f2 = new Form1();
            string  query  =  "select  S.ID,substrateName  as  [SUBSTRATE
NAME], quantity as         QUANTITY, producedGasLiters as [AMOUNT OF GAS
PRODUCED] from substrates S,     litersPerSubstrate  L  where  S.ID  =
L.substrateID";             f2.ShowGridData(query, CONN, dataGridView2);
        }
        private void Solar_Load(object sender, EventArgs e)
        {
            CONN                          =                          new
OleDbConnection("Provider=Microsoft.Jet.OLEDB.4.0;Data
       Source=C:\\PowerCalculator\\PowerCalculator.mdb");
            cmbPrefferedVoltage.Text = "24";             CONN.Open();
            string   sql   =   "select   gaspermin   from   gaspermin";
OleDbCommand cmdGetRate = new OleDbCommand(sql, CONN);
            OleDbDataReader DR = cmdGetRate.ExecuteReader();
            DR.Read();
GasPerMin = DR[0].ToString();
CONN.Close();
```

```
ShowSubstrateGasProduced();
            cmbCategory.Text = "COOKING";
        }
        private void ShowHideRelevant()
        {
            if (lblCompType.Text.ToUpper() != "SOLAR ONLY")
            {
                if (cmbCategory.Text == "COOKING")
                {                               btnAdd.Visible = false;
groupBox1.Hide();                                       groupBox2.Hide();
groupBox3.Hide();                     gbxBiogas.Show();

                }                         else                          {
btnAdd.Visible = true;                                  groupBox1.Show();
groupBox2.Show();                                       groupBox3.Show();
gbxBiogas.Hide();
                }


            }
        }
        private void PanelsComputation()
        {
            if (txtSunlightHours.Text != "" && txtPanelcurrent.Text !=
"")
            {
                lblPanelDesc.Text   =   txtPanelWatts.Text   +   "W";
double Panelvoltage = 0;
                if (double.Parse(cmbPanelVoltage.Text) >= 12 &&
 double.Parse(cmbPanelVoltage.Text) <= 24)
                {
                    Panelvoltage = 12;
                }                 else
                {
                    Panelvoltage = 24;
                }
                double   X   =   double.Parse(txtSunlightHours.Text)   *
      double.Parse(txtPanelcurrent.Text);
                double Y = Math.Truncate( Amphours2 / X) + 1;
```

```
                lblNoOfPanels.Text           =           (Y           *
(double.Parse(cmbPrefferedVoltage.Text) /
 Panelvoltage)).ToString();
            }
        }

        private void label13_Click(object sender, EventArgs e)
        {
         }
        private double GetMaxBatteryPrice(OleDbConnection CON)
        {
            CON.Open();             double MaxPrice = 0;
            string sql = "select max(Price) from Battery";
            OleDbCommand cmdGetMaxAmpHrs = new OleDbCommand(sql, CON);
            OleDbDataReader DR = cmdGetMaxAmpHrs.ExecuteReader();
            DR.Read();
MaxPrice = double.Parse(DR[0].ToString()); CON.Close(); return MaxPrice;
        }
        private double GetMaxAmpHours(OleDbConnection CON)
        {
            CON.Open();             double MaxAmpHrs = 0;
            string    sql    =    "select    max(AmpHours)    from    Battery";
OleDbCommand cmdGetMaxAmpHrs = new OleDbCommand(sql, CON);
            OleDbDataReader DR = cmdGetMaxAmpHrs.ExecuteReader();
            DR.Read();
            MaxAmpHrs          =          double.Parse(DR[0].ToString());
CON.Close();             return MaxAmpHrs;
        }
        private void txtHours_TextChanged(object sender, EventArgs e)
        {
            DetermineBattery();
        }
        private void DetermineBattery()
        {             try             {
                double AmpHours = 1.3 * (TotalWatts /
 (double.Parse(cmbPrefferedVoltage.Text)))                          *
double.Parse(txtHours.Text);                     if (GetMaxAmpHours(CONN) >
AmpHours)
```

```
                    {
                        Amphours2 = AmpHours;
                        string sql = "select * from battery where AmpHours > 
" + AmpHours
 + "  order by AmpHours";
                        CONN.Open();
                        OleDbCommand  cmdGetBattery  =  new  OleDbCommand(sql, 
CONN);                                              OleDbDataReader   DR   = 
cmdGetBattery.ExecuteReader();                        if (DR.HasRows)
                        {
                            DR.Read();
                            lblBatteryDesc.Text                            = 
DR["Description"].ToString();
lblNoOfBatteries.Text = 
 (double.Parse(cmbPrefferedVoltage.Text) /    12).ToString();
                            lblBatteryPrice.Text                           = 
(double.Parse(DR["Price"].ToString()) * 
 double.Parse(lblNoOfBatteries.Text)).ToString();
                            CONN.Close();
                        }                 }                 else
                    {
                        CONN.Close();
                        Amphours2 = GetMaxAmpHours(CONN);
                        lblBatteryDesc.Text                                = 
(GetMaxAmpHours(CONN)).ToString();                          if (AmpHours % 
double.Parse(GetMaxAmpHours(CONN).ToString()) > 0)
                        {


                            lblNoOfBatteries.Text                          = 
((Math.Truncate((AmpHours / 
      double.Parse(GetMaxAmpHours(CONN).ToString())))+1)               * 
      (double.Parse(cmbPrefferedVoltage.Text) / 12)).ToString();
                        }                     else
                        {
                            lblNoOfBatteries.Text = ((Math.Round((AmpHours / 
      double.Parse(GetMaxAmpHours(CONN).ToString())),       0))        * 
      (double.Parse(cmbPrefferedVoltage.Text) / 12)).ToString();
                        }
```

```
                    lblBatteryPrice.Text =
        (double.Parse(GetMaxBatteryPrice(CONN).ToString())           *
        double.Parse(lblNoOfBatteries.Text)).ToString();

                }
            }                catch                 {                 }
finally
            {
            }
        }
        private void groupBox3_Enter(object sender, EventArgs e)
        {

        }
        private  void  txtPanelWatts_TextChanged(object  sender,  EventArgs
e)
        {
            string  sql  =  "select  *  from  Panels  where  watts>=  "  +
txtPanelWatts.Text+ "  order by Price ";
            CONN.Open();
            OleDbCommand  getPricePpanel  =  new  OleDbCommand(sql,  CONN);
OleDbDataReader  DR  =  getPricePpanel.ExecuteReader();                if
(DR.HasRows)
            {
                DR.Read();
                lblEstimatedPanelPrice.Text = DR["Price"].ToString();
            }
            CONN.Close();
            PanelsComputation();
        }

        private    void    txtPanelcurrent_TextChanged(object    sender,
EventArgs e)
        {
            PanelsComputation();
        }
```

```
        private   void   cmbCategory_SelectedIndexChanged(object   sender,
EventArgs e)         {
            ShowHideRelevant();


        }
        private      void      dataGridView2_CellClick(object      sender,
DataGridViewCellEventArgs
      e)
        {
            SelectedSubstrate =
 dataGridView2.Rows[e.RowIndex].Cells[0].Value.ToString();
            if  (SelectedSubstrate  !=  string.Empty  &&  txtHrsPerDay.Text
!= "" &&  GasPerMin  != string.Empty)
            {
                SolarComputer();
            }         }
        public void labelHybrid(string MyText)
        {
            lblCompType.Text = MyText;
        }
        public void HideShowBioGas()
        {
            if (lblCompType.Text == "SOLAR ONLY")
            {
                gbxBiogas.Hide();


            }
            else             {
                gbxBiogas.Show();
            }         }
        private void SolarComputer()
        {
            if  (SelectedSubstrate  !=  string.Empty  &&  txtHrsPerDay.Text
!= "" &&
 GasPerMin != string.Empty)
            {
                Form1 F = new Form1();
```

```
                CONN                           =                       new
OleDbConnection("Provider=Microsoft.Jet.OLEDB.4.0;Data
 Source=C:\\PowerCalculator\\PowerCalculator.mdb");
                F.GetParameters(txtHrsPerDay.Text,     SelectedSubstrate,
GasPerMin);                 F.AMOUNTSCALCULATOR(CONN,SelectedSubstrate);
lblQuanityREquired.Text          =          F.RequiredAmountSubstrate();
lblNoOfLiters.Text              =              F.RequiredGasCapacity();
lblDigesterDesc.Text             =              F.DigesterDescription();
lblDigesterPrice.Text = F.DigesterPrice();


            }
        }
        private   void   dataGridView1_CellContentClick(object   sender,
       DataGridViewCellEventArgs e)
        {


        }
        private     void     dataGridView1_CellClick(object     sender,
DataGridViewCellEventArgs
       e)
        {
            if (e.ColumnIndex == 7)
            {


            }
        }
        private void dataGridView1_RowsRemoved(object sender,
 DataGridViewRowsRemovedEventArgs e)
        {             try
            {                  double TOTAL = 0;                  double
TOTAL2 = 0;                 int R = 0;
                for (R = 0; R <= dataGridView1.Rows.Count - 2; R++)
                {
                    TOTAL = TOTAL +
       double.Parse(dataGridView1.Rows[R].Cells[5].Value.ToString());
TOTAL2 = TOTAL2 +
       double.Parse(dataGridView1.Rows[R].Cells[8].Value.ToString());
//lblWattsTotal.Text      =      (double.Parse(lblWattsTotal.Text)      -
```

```
        double.Parse(dataGridView1.Rows[e.RowIndex].Cells[6].Value.ToStrin
g())).ToStrin
 g() ;
                }
                TotalWattHrs = TOTAL2;                      TotalWatts =
TOTAL;
                lblWattsTotal.Text          =          TOTAL.ToString();
lblTotalWattHours.Text = TOTAL2.ToString();

            }           catch           {
            }           finally
            {
            }
        }
        private void btnMenu_Click(object sender, EventArgs e)
        {
            frmMainMenu F = new frmMainMenu();
            F.Show();

        }
        private void rectangleShape2_Click(object sender, EventArgs e)
        {

        }

    } }
```