UNIVERSITY OF NAIROBI
FACULTY OF ENGINEERING
DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING

HYBRID SOLAR, WIND AND DIESEL GENERATOR POWER SYSTEM DESIGN FOR A TEACHERS TRAINING COLLEGE

PROJECT INDEX: PRJ 111
BY
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F17/1791/2006

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EXAMINER: MR. WALKADE

Project report submitted in partial fulfillment of the requirement for the award of the degree Of
Bachelor of Science in Electrical and Electronic Engineering of the University of Nairobi
Submitted on:
18th May, 2011
DEDICATION

To the Almighty God who kept me breathing, my family who kept me going and all my teachers and friends who showed me the way.
I gratefully acknowledge the support of Dr. Nicodemus Abungu Odero, my project supervisor. He has been of great help and motivation during this process. I also acknowledge Dr. Cyrus Wekesa and my colleagues, Sio Shake, Dancan Njenga, Michael Akeyi and Salim Faraj who challenged me with their input and constructive criticism. I also acknowledge the contribution of Christopher Mukasa for helping in editing of the final draft and Ambia Rahoi who cheered me to the end.
DECLARATION AND CERTIFICATION

Except where indicated otherwise, I certify that the information presented in this report is my original effort and has not been presented before for a degree award in this or any other university to the best of my knowledge.

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ABUBAKAR AIDARUS A.
F17/1791/2006

Date: é é é é é é é é é é é

This report has been submitted to the Department of Electrical and Information Engineering, University of Nairobi with my approval as supervisor:

é é é é é é é é é é é é é é é

Dr. Nicodemus Abungu Odero

Date: é é é é é é é é é é é
The main objective of the project was to design a triple-hybrid solar, wind and diesel generator power system to power a teachers training college in North Eastern Province, an isolated part of Kenya which is impassable during the rainy season. The college has 70 residential houses for the lectures, four hostels, a library, an administration block, an academia, a multipurpose hall, a clinic, a sports pavilion, a swimming pool and street lighting all which needed to be powered. Due to the location of the college, a triple-hybrid generation plant, combining renewable wind and solar energy with diesel fuel supplied by trucks was considered as the most favorable. To size the power system required, an estimation of the load based on Rational Use of Energy (RUE) was carried out and found to be approximately 1000kWh/Day. This was then followed by economic analysis of the three technologies that were to be used in the hybrid system. The discounted costs for diesel generator, wind and solar were found to be Ksh 31.0279/kWh, Ksh 13.2626/kWh and Ksh 31.5878/kWh respectively. To come up with the optimal ratio, a software application was developed and the ratios for diesel generator, wind and solar were found to be 0.2, 0.6 and 0.2 respectively. The cost for these ratios which gave the optimal ratio according to this software application was found to be Ksh 20.48/kWh. This ratio was acceptable considering the system was to be heavily reliable on renewable energy which is quite abundant in this locality. This was followed by sizing of each of the three technologies which make up the hybrid system. The solar farm was to be able to provide a peak load of 54.11785 kW. The wind farm was to be able to provide a peak load of 95.8333kW consisting of four wind turbine with a rating of 25kW each. Four turbines instead of one were to be used for reliability purpose. The diesel generator plant was to consist of two diesel generators with a capacity of 23 kW each and therefore the plant would have a peak load capacity of 46 kW. This would give the whole plant a total peak load of 195.95 kW including a 15% reserve capacity for future load growth. An underground distribution system was then designed. The choice of the distribution was influenced by economic consideration as underground systems are cheaper than overhead distributions in small areas such as this college. The design of the distribution system involved zoning of the college into three zones, design of the layout using AutoCAD and conductor sizing. Each of the zones was supplied with power by a ground mounted sub-station. PVC insulated copper cables were to be used for this project. With this system in place, the college would have an economical, efficient and reliable power supply system.
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<td>PCCU</td>
<td>Power Connection and Control Unit</td>
</tr>
<tr>
<td>CSP</td>
<td>Concentrated Solar Power</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>VAWT</td>
<td>Vertical Axis Wind Turbine</td>
</tr>
<tr>
<td>HAWT</td>
<td>Horizontal Axis Wind Turbines</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>AC</td>
<td>Alternating Current</td>
</tr>
<tr>
<td>MPPT</td>
<td>Maximum Power Point Tracking</td>
</tr>
<tr>
<td>PWM</td>
<td>Pulse Width Modulation</td>
</tr>
<tr>
<td>GMSS</td>
<td>Ground Mounted Sub-Station</td>
</tr>
<tr>
<td>XLPE</td>
<td>Cross-linked polyethylene</td>
</tr>
<tr>
<td>Ksh</td>
<td>Kenya Shilling (lawful currency of Kenya)</td>
</tr>
<tr>
<td>KWh</td>
<td>Kilo Watt hour</td>
</tr>
<tr>
<td>KVA</td>
<td>KiloVolt-Ampere</td>
</tr>
<tr>
<td>O&amp;M</td>
<td>Operation and Maintenance</td>
</tr>
<tr>
<td>REA</td>
<td>Rural Electrification Authority</td>
</tr>
<tr>
<td>REACT</td>
<td>Re-engineering Africa Consortium</td>
</tr>
<tr>
<td>USD</td>
<td>US Dollar</td>
</tr>
<tr>
<td>CL</td>
<td>Lucy Chamber</td>
</tr>
<tr>
<td>C</td>
<td>conductor</td>
</tr>
<tr>
<td>GUI</td>
<td>Graphical User Interface</td>
</tr>
</tbody>
</table>
CHAPTER ONE

INTRODUCTION

1.1 Statement of problem

The project seeks to power a teachers training college in Halugho town in Garissa County. The town does not have electricity and it is at least two hundred kilometres from Garissa which is the nearest town with electricity. After considering both renewable and conventional method of power generation, a triple-hybrid solar, wind and diesel generator was chosen.

1.2 Justification of the chosen power supply system

Garissa Teachers Training College is located in an area that is at least two hundred kilometers from the nearest electricity grid. This is an area whose roads are impassable during the rainy season and thus supply of any kind is usually difficult. Erecting a transmission line of 200 km would be very expensive and hence does not make economic sense. A stand alone diesel generator is also not a good idea on its own, since there would be challenges in supplying fuel during the rainy season. This meant looking at different technologies to power the college. Considering that this is an area that receives considerable radiation every day all year round and the wind speed is also great, triple-hybrid generation plants, combining renewable wind and solar energy with diesel fuel supplied by trucks was considered as most favorable. Such a system would be utilizing infinitely available primary energy source (sunlight and wind). [21]

1.3 Objectives

The objective of this project is to design a triple-hybrid solar, wind and diesel generator power system and distribution power system to power the teachers training college.
1.4 Organization of the Report

This report has been grouped into four main chapters. Chapter two of this report gives the literature review of the components of the hybrid system paying particular attention to each of the three technologies. Chapter three of the report gives a detailed description of the design of the hybrid power system and chapter four gives a detailed description of the design of the power distribution system. Chapter five is on conclusions and recommendations. Section six contains the appendix and section seven contains the list of references.
CHAPTER TWO

LITERATURE REVIEW

2.1 Hybrid system

The Hybrid power system is a complete electrical power supply system that can be easily configured to meet a broad range of remote power needs. There are three basic elements to the system;

a. The power sources.
b. The energy storage technologies.
c. The power management center.

The power sources are a wind turbine, diesel generator and solar arrays. The battery allows autonomous operation by compensating for the difference between power production and use. The power management centre regulates the power production from each of the sources, controls power use by classifying loads, and protects the battery from service extremes.

![Diagram of a hybrid system]

**Figure 2.2.1-1 : Block diagram of a hybrid system**
The certainty of meeting load demands at all times is greatly enhanced by hybrid systems, which use more than one power source. Most hybrids use a diesel generator with PV or wind, because diesel generator provides more predictable power on demand. A battery bank is used in addition to the diesel generator in some hybrids. The battery bank meets the daily load fluctuation, and the diesel generator takes care of the long-term fluctuations. For example, the diesel generator is used in the worst-case weather condition, such as an extended period of overcast skies or when there is no wind for several weeks.

The power connection and control unit (PCCU) provides a central place to make organized connections of most system components. In addition, the PCCU houses the following components:

- Battery charges and discharge regulators.
- Transfer switches and protection circuit breakers.
- Power flow meters.
- Mode controller.

2.2 Wind turbine
A wind turbine is a rotary device that extracts energy from the wind. If the mechanical energy is used directly by machinery, such as for pumping water, cutting lumber or grinding stones, the machine is called a windmill. If the mechanical energy is instead converted to electricity, the machine is often called a wing generator. [4]

Types of Wind Turbines
Wind turbines can rotate about either a horizontal or vertical axis and hence there are two types namely;

- Horizontal axis wind turbines (HAWT)
- Vertical axis wind turbines (VAWT)

2.2.1 Horizontal Axis Wind Turbines (HAWT)
Horizontal axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of tower, and must be pointed into the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which
turns the slow rotation of the blades into quicker rotation that is more suitable to drive an electrical generator.

![Horizontal Axis Wind Turbines (HAWT)](image)

**Figure 2.2.1-1: Horizontal Axis Wind Turbines (HAWT)**

**2.2.2 Vertical Axis Wind Turbine (VAWT)**

Vertical-axis wind turbines (VAWTs) have the main rotor shaft arranged vertically. Key advantages of this arrangement are the turbine does not need to be pointed into the wind to be effective this is an advantage on sites where the wind direction is highly available (variable).

![Vertical Axis Wind Turbine (VAWT)](image)

**Figure 2.2.2-1: Vertical Axis Wind Turbine (VAWT)**
With Vertical Axis Wind Turbine, the generator and the gearbox can be placed near the ground, so the tower does not need to support it, and is more accessible for maintenance. Drawbacks are that some designs produce pulsating torque.

2.3 Solar power

Solar power results from the conversion of sunlight into electricity, either directly using photovoltaic cells (PV), or indirectly using concentrated solar power (CSP). CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. PV converts light into electric current using the photoelectric effect. [4]

2.3.1 Solar Photovoltaic Power System

The photovoltaic effect is the electrical potential developed between two dissimilar materials when the common junction is illuminated with radiation of photons. The photovoltaic cell, thus, converts light directly into electricity. The PV effect was discovered in 1839 by French physicist Becquerel. It remained in the laboratory until 1954, when Bell Laboratories produced the first silicon solar cell. It soon found application in the U.S. space programs for its high power capacity per unit weight. Since then it has been an important source of power for satellites. Having developed maturity in the space applications, the PV technology is now spreading into the terrestrial applications ranging from powering remote sites to feeding the utility lines. [4]

The continuing development efforts to produce more efficient low cost cells have resulted in various types of PV technologies available in the market today, in terms of the conversion efficiency and the module cost. The major types are:

- Single-Crystalline Silicon
- Polycrystalline and Semicrystalline
- Thin Films
- Amorphous Silicon

Major advantages of the photovoltaic power are as follows:

- Short lead time to design, install, and start up a new plant.
- Highly modular, hence, the plant economy is not a strong function of size.
- Power output matches very well with peak load demands.
- Static structure, no moving parts, hence, no noise.
- High power capability per unit of weight.
- Longer life with little maintenance because of no moving parts.
- Highly mobile and portable because of light weight.

2.3.2 Present Status

At present, PV power is extensively used in stand-alone power systems in remote villages, particularly in hybrid with diesel power generators. It is expected that this application will continue to find expanding markets in many countries. The driving force is the energy need in developing countries, and the environmental concern in developed countries.

2.4 Industrial diesel power generators

Diesel engines are more suited to continuous running for lengthy periods at higher load ratings and are therefore used more widely for stationary applications.

The use of hooded diesel generators as shown in figure 2.4-1 is becoming increasingly important in industries. These generators provide for low noise levels which reduce noise pollution. The hood also ensures that the generator may be placed outdoors which lowers the cost of installation by eliminating the need to build a generator room.

![Diesel Generator](image)

**Figure 2.3.2-1: Diesel Generator**
2.5 Transformers

Most transformers consist of:

- closed-loop magnetic core on which are wound two or more separate copper coils
- tank in which the corecoil assembly is immersed in cooling and insulating oil
- bushings for bringing the incoming and outgoing leads through the tank or cover [12] [13]

![Ground Mounted Transformer](image)

Figure 2.3.2-1: Ground Mounted Transformer

2.6 Energy storage

Wind power and solar power are rapidly growing and very promising renewable sources of electric energy. But with a large fraction of wind and solar power in the electricity supply network, the stochastic nature of wind and solar power will start to play a significant role. A controllable and non-fluctuating supply is needed to fully secure availability, but this cannot be achieved with wind and solar power alone.

Introducing an energy storage element in connection to a wind and solar power plant changes the spectrum and statistical distribution of the output power. Increasing the amount of storage (power and energy), associated with a wind and solar power plant, will gradually make the output more controllable and predictable. [4]

Energy storage technologies

A variety of technologies are available for storage of energy in the power system. When identifying the most relevant storage solutions it is necessary to include considerations on many relevant parameters, such as: cost, lifetime, reliability, size, storage capacity and environmental impact.
Energy storage technologies for power applications can be divided into three groups:

- Mechanical
- Electro-chemical
- Electromagnetic storage

### 2.7 Power distribution system

An electrical network initiates at the point of generation. Electrical power is generated by converting the potential energy available in certain materials into electrical energy. This is either done by direct conversion of kinetic energy, e.g. wind or water turbines, or solar system or creating steam to drive the turbines, e.g. coal or nuclear boilers. [11]

Overhead lines have the following properties:

**Advantages**
- Less expensive for longer distances
- Easy to locate fault.

**Disadvantages**
- More expensive for shorter distances
- Susceptible to lightning
- Not environment-friendly
- Maintenance intensive
- High level of expertise and specialized equipment needed for installation.

Underground (buried) cable installations are mostly used for power distribution in industrial applications. They have the following properties:

**Advantages**
- Less expensive for shorter distances
- Not susceptible to lightning
- Environment-friendly
- Not maintenance intensive.

**Disadvantages**
- Expensive for long distances
- Can be difficult to locate fault.
CHAPTER THREE

HYBRID POWER SYSTEM DESIGN

This chapter covers the design work that was carried out in designing the hybrid solar, wind and diesel generator power system.

3.1 Load sizing

For determining the required capacity of the hybrid power system, estimating the peak load demand and total kWh/Day were the two aspects of design consideration. Estimating the energy required over the duration selected for the design was the first requirement for the system sizing. In estimating the energy, the Rational Use of Energy (RUE) was employed to ensure that the system is cost effective. [16]

<table>
<thead>
<tr>
<th>Appliances</th>
<th>Watts</th>
<th>Hours used/day</th>
<th>Watts hours/Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling fan</td>
<td>100</td>
<td>8</td>
<td>800</td>
</tr>
<tr>
<td>Coffee maker</td>
<td>600</td>
<td>0.3</td>
<td>180</td>
</tr>
<tr>
<td>Computer</td>
<td>75</td>
<td>2</td>
<td>150</td>
</tr>
<tr>
<td>Computer monitor</td>
<td>150</td>
<td>2</td>
<td>300</td>
</tr>
<tr>
<td>Lights (18 watts energy savers)</td>
<td>10</td>
<td>5</td>
<td>900</td>
</tr>
<tr>
<td>Refrigerator</td>
<td>200</td>
<td>6</td>
<td>1200</td>
</tr>
<tr>
<td>Radio</td>
<td>50</td>
<td>4</td>
<td>200</td>
</tr>
<tr>
<td>Television</td>
<td>100</td>
<td>4</td>
<td>400</td>
</tr>
<tr>
<td>VCR</td>
<td>25</td>
<td>6</td>
<td>150</td>
</tr>
<tr>
<td>Total for 1 house</td>
<td></td>
<td></td>
<td>4,280</td>
</tr>
<tr>
<td>Total for 72 houses</td>
<td></td>
<td></td>
<td>308,160</td>
</tr>
<tr>
<td>Area</td>
<td>Connected load in kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-----------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Library</td>
<td>100.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MPH</td>
<td>50.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Academia</td>
<td>50.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Administration Block</td>
<td>150.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinic</td>
<td>150.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Street lighting</td>
<td>50.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hostels</td>
<td>50.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>50.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Grand total</strong></td>
<td><strong>1,008,160</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3.1-2: Total connected load of the college

<table>
<thead>
<tr>
<th>Area</th>
<th>Connected load in kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Administration block</td>
<td>120.0</td>
</tr>
<tr>
<td>Residential houses (estate)</td>
<td>106.56</td>
</tr>
<tr>
<td>MPH</td>
<td>100</td>
</tr>
<tr>
<td>Academia</td>
<td>80</td>
</tr>
<tr>
<td>Hostel (female and male)</td>
<td>20.0</td>
</tr>
<tr>
<td>Clinic</td>
<td>40.0</td>
</tr>
<tr>
<td>Library</td>
<td>60.0</td>
</tr>
<tr>
<td>Other</td>
<td>53.44</td>
</tr>
<tr>
<td><strong>Total connected Load</strong></td>
<td><strong>580</strong></td>
</tr>
</tbody>
</table>

3.2 Determining the required plant capacity

There college is divided into three zones each, having one ground mounted substation.

**Ground Mounted Substation 1 (GMSS1)**

Connected load = 53.28 kW

Maximum load for GMSS1 = \( \frac{\text{connected load} \times \text{Demand factor}}{\text{Diversity factor}} \) [22]

\[ \text{Maximum load for GMSS1} = \frac{53.28 \times 0.5}{3} = 8.88 \text{ kW} \]

**Ground Mounted Substation 2 (GMSS2)**

Connected load = 53.28 kW
Maximum load for GMSS2 = (connected load × Demand factor)/Diversity factor
Maximum load for GMSS2 = (53.28 × 0.5)/3 = 8.88 kW

**Ground Mounted Substation 3 (GMSS3)**

Connected load = 473.44 kW
Maximum load for GMSS3 = (connected load × Demand factor)/Diversity factor
Maximum load for GMSS3 = (473.44 × 0.55)/1.5 = 173.594 kW

Each of the Ground Mounted Sub- Stations is being fed by a different feeder and therefore the feeders are three in total.

Total max. load for the three feeders = (Max. load for GMSS1 + Max. load for GMSS2 + Max. load for GMSS3)

Total maximum load for the three feeders = 8.88 + 8.88 + 173.594 = 191.354 kW

\[ \text{Factor between the feeders} = \frac{191.354}{1.2} = 159.4622\text{ kW} \]

In the plant design it is desired that the plant should have reserve capacity of 15% above the current maximum demand of the plant for future load growth.

Therefore,

\[ = \text{maxim demand} \times 1.15 = 183.382 \text{ kW} \]

### 3.3 Economic analysis of the different technologies

To come up with the optimal ratio of hybrid power system, the discounted costs/kWh of each of the technologies was calculated. For the economic analysis to be fair, the following costs of the technologies were considered in a fair manner:

- Fuel cost
- Operation and maintenance cost
• Capital cost

3.3.1 Discounted cost analysis for the generator

Initial cost
Cost/kW = $900/kW = 700 × 82 = Ksh 75600
Initial investment, \( I_g = \text{cost/kW} \times \text{plant capacity in kW} \)
Initial investment, \( I_g = 75600 \times 183.382 = 13,863,679.2 \)

The amortization by constant installments “\( A \)” of an initial investment “\( I \)” over a period of “\( n \)” years (20) at constant annual discount rate “\( t \% \)” (10%) is given by:

\[
A_g = I_g \cdot \frac{t}{100} \cdot \left( 1 + \frac{t}{100} \right)^n \left( 1 + \frac{t}{100} \right)^n - 1)
\]

\[
A_g = 13,863,679.2 \cdot \frac{10}{100} \cdot \left( 1 + \frac{10}{100} \right)^{20} = \text{ksh 2,256,249.946}
\]

Calculation of \( KA \)
\[
KA_g = \frac{A_g}{I_g}
\]

\[
KA_g = \frac{2,261,638.9}{13,863,679.2} = 0.1631341
\]

Investment ratio (\( I_{up} \))
\[
I_{up} = \frac{\text{initial investment} (I_g)}{\text{rated power of the production equipment} (P)}
\]

\[
I_{up} = \frac{13,863,679.2}{183.382} = 75600
\]

Operation and maintenance cost
O&M cost/kWh = 0.02 × 82 = 1.64

Annual O& = plant capacity in kW × 8760 × O& / 2
Annual O& = 183.382 × 8760 × 1.64 = Ksh 2634539.165
**Calculation of KEM**

\[ KEM_g = \frac{\text{Annual operating & maintenance expenditures}}{I_g} \]

\[ KEM_g = \frac{2634539.165}{13,863,679.2} = 0.190032 \]

**Fuel cost**

Fuel Cost = \( \frac{\text{no. of litres per hour} \times \text{cost of fuel per litre}}{\text{total power generated in one hour in kWh}} \)

\[ \text{Fuel Cost/kWh} = 269 \times 10^4 \times 100 = \text{Ksh}27.98/\text{kWh} \]

Annual fuel cost

\[ \text{Annual fuel cost} = \text{plant capacity} \times 8760 \times \text{Fuel Cost/kWh} \]

\[ \text{Annual fuel cost} = 183.382 \times 8760 \times 27.98 = \text{Ksh}44,947,808.43 \]

\[ \text{FC} = \frac{44,947,808.43}{13,863,679.2} = 3.24213 \]

**The overall discounted cost, \( C \), of a delivered electric kWh is then given by the equation:**

\[ C_g = I_{up}(KA + KEM + FC)/(8760.Fc) \]

\[ C_g = \frac{75600 \times 0.1631341 \times 0.190032 \times 3.24213}{8760 \times 1} = \text{Ksh}31.0279/\text{kWh} \]

**3.3.2 Discounted cost analysis for the wind farm**

**Initial cost**

Cost/kW = $2500/kWh = 2500 \times 82 = \text{Ksh} 205,000

Initial investment \( (I_w) = \text{cost/kW} \times \text{plant capacity in kW} \)

Initial investment \( (I_w) = 205000 \times 183.382 = 37,593,310 \)

**The amortization by constant installments “A” of an initial investment “I” over a period of “n” years (20) at constant annual discount rate “t %” (10%) is given by:**

\[ A_w = I_w \times \frac{\frac{t}{100}}{1 + \frac{t}{100}} \times \frac{n}{1 + \frac{t}{100} - 1} \]
\[ A_w = 37,593,310 \times 10^{10} \times 10^{10} \times 10^{20} = \text{Ksh} \ 4,415,696.087 \]

**Calculation of KA**

\[ KA_w = A_w / I_w \]

\[ KA_w = \frac{4,415,696.087}{37,593,310} = 0.11746 \]

**Investment ratio ( )**

\[ I_{up} = \text{initial investment}/(\text{power of the production equipment}) \]

\[ I_{up} = \frac{37,593,310}{183,382} = \text{Ksh} 205,000/\text{kW} \]

**Operation and maintenance cost**

O & M cost of wind = 0.015 \$/kWh

O & M cost of wind = 0.015 \$/kWh = 0.015 \times 82 = \text{Ksh} 1.23/\text{kWh}

**Calculation of KEM**

Annual operating & maintenance expenditures = \[ \times 8760 \times 0.11746 \]

Annual operating & maintenance expenditures = \[ 183.382 \times 8760 \times 1.23 \]

\[ = \text{Ksh} \ 1,975,904.374 \]

\[ KEM_w = \text{Annual operating & maintenance expenditures}/I_w \]

\[ KEM_w = \frac{1975904.374}{37,593,310} = 0.05256 \]

**The overall discounted cost, C, of a delivered electric kWh is then given by the equation:**

\[ C_w = I_{up} (KA + KEM)/(8760. Fc) \]

\[ C_w = \frac{205,000 \times 0.11746 \times 0.05256}{8760 \times 0.3} = \text{Ksh} \ 13.2626/\text{kWh} \]

3.3.3 **Discounted cost analysis for the solar farm**
Initial cost
The current exchange rate of dollar in Kenya shillings is 82
Cost/kW = $5000/kW = 5000 × 82 = Ksh 410,000
Initial investment \( I_s \) = cost/kW × plant capacity in kW
Initial investment \( I_s = 410000 \times 183.382 = \text{Ksh75,186,620} \)

The amortization by constant installments “A” of an initial investment “I” over a period of “n” years (20) at constant annual discount rate “t %” (10%) is given by:

\[
A_s = I_s \cdot \frac{\frac{t}{100}}{1 + \frac{t}{100}} \cdot \frac{1}{(1 + \frac{t}{100})^n - 1}
\]

\[
A_s = 75,186,620 \cdot \frac{10}{100} \cdot \frac{1}{1 + \frac{10}{100}^{20} - 1} = \text{Ksh 8,831,392.173}
\]

Calculation of \( KA \)

\[
KA_s = \frac{A_s}{I_s}
\]

\[
KA_s = \frac{8,831,392.173}{75,186,620} = 0.11746
\]

Investment ratio ( )

\[
I_{up} = \text{initial investment}/(\text{power of the production equipment})
\]

\[
I_{up} = \frac{75,186,620}{183.382} = \text{Ksh 410,000/kWh}
\]

Operation and maintenance cost
O & M cost of solar = 0.01 $/kWh
Therefore O & M cost of solar = 0.01 × 82 = Ksh 0.82 /kWh

Calculation of \( KEM \)

\[
\text{Annual operating &} = \times 8760 \times \text{O & M} / \text{W}
\]

\[
\text{Annual operating &} = 183.382 \times 8760 \times 0.82
\]

\[
= \text{Ksh 1,317,269.582}
\]

\[
KEM_s = \frac{\text{Annual operating and maintenance expenditures}}{I_s}
\]
\[
KEM_s = \frac{1,317,269.582}{75,186,620} = 0.01752
\]

*The overall discounted cost, \( C \), of a delivered electric kWh is then given by the equation:*

\[
C_s = \frac{I_{up}(K_A + KEM_s)}{(8760 \cdot Fc)}
\]

\[
C_s = \frac{410,000 \cdot 0.117459 \cdot 0.01752}{8760 \cdot 0.2} = \text{Ksh} 31.5878/kWh
\]

**Table 3.3-1: Economic analysis of the different technologies**

<table>
<thead>
<tr>
<th></th>
<th>Generator</th>
<th>Wind</th>
<th>Solar</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial investment</strong></td>
<td>Ksh 13,863,679.2</td>
<td>Ksh 37,593,310</td>
<td>Ksh 57,186,620</td>
</tr>
<tr>
<td><strong>Annualized cost</strong></td>
<td>Ksh 2,256,249.946</td>
<td>Ksh 4,415,696.087</td>
<td>Ksh 8,831,392.173</td>
</tr>
<tr>
<td><strong>Annual O &amp; M cost</strong></td>
<td>Ksh 2,634,539.165</td>
<td>Ksh 1,975,904.374</td>
<td>Ksh 1,317,269.582</td>
</tr>
<tr>
<td><strong>Annual fuel cost</strong></td>
<td>Ksh 44,947,808.43</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Discounted cost/kWh</strong></td>
<td>Ksh 31.0279</td>
<td>Ksh 13.2626</td>
<td>Ksh 31.5878</td>
</tr>
</tbody>
</table>

### 3.4 Determining the composition of the hybrid system

A software application to do the calculation of the various costs for the individual technologies and the hybrid was designed. From the data generated by the software, it was possible to compare the cost of individual technologies against their hybrid and determine the optimal ratio.

The area where the system was to be implemented is in a remote part of the country which experience acute shortage of fuel during rainy seasons. As a result, the percentage of fuel consuming part of the power system was to be kept as low as possible according to Rural Electrification Master Plan 2009 as quoted below;
Delivery of fuel oil in many remote rural areas in North-Western, Northern and North-Eastern Kenya and along the Coast is a serious issue especially during the rainy season. Therefore, the optimal design for power generation in remote areas addresses low or no fuel oil consumption capability in order to enable fuel autonomy during the rainy season. Fortunately, the renewable resource base in these areas permits erecting triple-hybrid generation plants, combining renewable wind and solar energy with diesel fuel supplied by trucks. [21]

To find optimal ratio of the different technologies, iteration method was used. A flow chart was developed as shown in Figure 3.4-1 and an application for analyzing the raw data being fed by user was developed using C++ programming language. [26][27][28]

The application was designed to provide a Graphical User Interface (GUI) where raw data could be entered. The GUI is shown in figure 3.4-2.
Figure 3.3.3-1: Graphical User Interface (GUI)
Calculate constant installment (A), investment ratio (KA), overall discounted cost/kWh (C)

Enter data for Wind power system: constant annual discount rate (t), period of payment in years (n), Initial Investment(I), Annual operating-maintenance expenditures (KE), fuel cost (FC), average annual load factor (Fc) and rated power of the production equipment (P), step (x)

Enter data for Solar power system: constant annual discount rate (t), period of payment in years (n), Initial Investment(I), Annual operating-maintenance expenditures (KE), fuel cost (FC), average annual load factor (Fc) and rated power of the production equipment (P), step (x)

Calculate constant installment (A), investment ratio (KA), overall discounted cost/kWh (C)
Enter data for diesel generator: constant annual discount rate (t), period of payment in years (n), Initial Investment(I), Annual operating-maintenance expenditures (KE), fuel cost (FC), average annual load factor (Fc) and rated power of the production equipment (P), Step (x)

Calculate constant installment (A), investment ratio ( ), KA, overall discounted cost/kWh (C)

Solar ratio = X

Solar Cost = solar ratio × overall discounted cost of solar/kWh

Remainder = 1 – Solar Ratio

Wind Ratio = X

Wind cost = Wind Ratio × overall discounted cost of wind/kWh

Generator Ratio = Remainder – Wind Ratio

Generator Cost = Wind Ratio × overall discounted cost of generator/kWh
Figure 3.3.3-2: flow chart for the optimization code
The data in table 3.4-1 was generated when the raw data was entered at the GUI and graph of the same plotted by the application is shown in Figure 3.4-2.

<table>
<thead>
<tr>
<th>Ratios</th>
<th>Solar Cost/kWh</th>
<th>Wind Cost/kWh</th>
<th>Gen Cost/kWh</th>
<th>Hybrid cost/kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-0.20, W-0.20, G-0.60</td>
<td>31.59</td>
<td>13.26</td>
<td>31.02</td>
<td>27.58</td>
</tr>
<tr>
<td>S-0.20, W-0.40, G-0.40</td>
<td>31.59</td>
<td>13.26</td>
<td>31.02</td>
<td>24.03</td>
</tr>
<tr>
<td>S-0.20, W-0.60, G-0.20</td>
<td>31.59</td>
<td>13.26</td>
<td>31.02</td>
<td>20.48</td>
</tr>
<tr>
<td>S-0.40, W-0.20, G-0.40</td>
<td>31.59</td>
<td>13.26</td>
<td>31.02</td>
<td>27.7</td>
</tr>
<tr>
<td>S-0.40, W-0.40, G-0.20</td>
<td>31.59</td>
<td>13.26</td>
<td>31.02</td>
<td>24.15</td>
</tr>
<tr>
<td>S-0.60, W-0.20, G-0.20</td>
<td>31.59</td>
<td>13.26</td>
<td>31.02</td>
<td>27.81</td>
</tr>
</tbody>
</table>
Figure 3.4-3: graph for generated data

Table 3.4-2: Composition of the hybrid plant

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Capacity of source in kWh/Day</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind farm</td>
<td>600</td>
<td>60</td>
</tr>
<tr>
<td>Solar farm</td>
<td>200</td>
<td>20</td>
</tr>
</tbody>
</table>
After the composition of the hybrid power system was decided on, the design of the various
technologies was carried out in the subsequent sections.

3.5 Wind farm sizing

3.5.1 Determining wind farm capacity
Units of energy in kWh/Day to be produced by the wind farm are 600kWh as shown in table 3.1-1.
Load factor of a wind farm = 0.3 [25]
Units of energy in kWh/Day to be produced by the wind farm = maximum demand × load factor × 24
Therefore;
Maximum demand = Units of energy in kWh/Day to be produced by the wind farm/ (load factor × 24)
Maximum demand = 600kWh/ (0.3 × 24) = 83.333kW
It is desired that the plant to have a plant reserve of 15% of the current maximum demand.
Therefore;
Wind farm capacity = 83.333 × 1.15 = 95.8333kW

3.5.2 Calculating the number turbines ( ) needed
It is proposed that for this project a turbine of 25kWₚ from West Wind be used. The turbine has the
following features:
Turbine Diameter, $D_T = 33.5$ ft
Height = 80 ft
Hub height = 84 ft

Number of turbines = plant capacity/turbine capacity = 3.8333 ≈ 4
When several turbines are installed in clusters, the turbulence due to the rotation of blades of one
turbine may affect the nearby turbines. In order to minimize the effect of this rotor induced turbulence,
a spacing of 3 $D_T$ to 4 $D_T$ was provided within the rows, where $D_T$ was the rotor diameter. [8]
Clearance from any structure (fall zone) = $h_T + D_T = 84 + 33.5 = 117.5$ ft
Spacing within the same row, \( S_R = 4 \times D_T = 4 \times 33.5 = 134 \text{ ft} \)

Inter row spacing = 10 \( D_T = 335 \text{ ft} \)

Length of a row, \( L_R = S_R (N_{TR} - 1) \)

\[ L_R = 143 \times 4 - 1 = 429 \text{ ft} \]

Wind turbines of various sizes are available commercially. Small machines are often used for standalone applications like domestic or small scale industrial needs. Since generation of considerable quantities of power was needed, four wind turbines were clubbed together and installed in clusters, forming a wind farm or wind park. There were several advantages in clustering wind machines:

- Installation
- Operation
- Maintenance

Moreover, four smaller wind turbines instead of one big wind turbine were chosen for reliability reasons. If one of the small ones developed mechanical problems, the rest would continue functioning and thus total blackout would be avoided unlike when a single turbine is providing all power. This kind of configuration also allowed for maintenance without power interruption.

The wind farm was to be laid out as indicated in figure 3.3-1.
Figure 3.5.2-1: layout of the wind farm plan

Figure 3.5.2-2: layout of the wind farm in three dimensions
3.6 Solar farm sizing

3.6.1 Solar farm capacity sizing

The PV array sizing was done according to "Wind and Solar Power System, design, Analysis and Operation" by Mukund R. Patel. [4]

Units of energy in kWh/Day to be produced by the solar farm are 200kWh as shown in table 3.1-1.

\[
\int_{6 \text{ p.m.}}^{8 \text{ a.m.}} (\text{solar radiation} \cdot \text{conversion efficiency}) \, dt = \\
\int_{6 \text{ p.m.}}^{8 \text{ a.m.}} (\text{loads + losses power charge} + \text{shunt power}) \, dt + \int_{6 \text{ p.m.}}^{8 \text{ a.m.}} (\text{loads and losses}) \, dt
\]

Or, in discrete time intervals of constant load and source power,

\[
\sum_{6 \text{ p.m.}}^{8 \text{ a.m.}} (\text{solar radiation} \cdot \text{conversion efficiency}) \Delta T = \\
\sum_{6 \text{ p.m.}}^{8 \text{ a.m.}} (\text{loads + losses power charge} + \text{shunt power}) \Delta T + \sum_{6 \text{ p.m.}}^{8 \text{ a.m.}} (\text{loads and losses}) \Delta T
\]

Total load + loss = solar farm capacity × no. of radiation hours × Conversion efficiency of the module

Units of energy in kWh/Day to be produced by the solar farm = 200kWh

A total loss of 20% for the whole system in conversion and due other losses was assumed.

Six hours of radiation was assumed

\[200 + (200 \times 0.2) = \text{solar farm capacity} \times 6 \times 0.85\]

Therefore;

Solar farm capacity = \[(200 + (200 \times 0.2)) / (6 \times 0.85)\] = 47.059 kW

The solar farm is desired to have a reserve capacity of 15% of the current size required \[22\]

Solar farm capacity = current solar farm capacity × 1.15

**Solar farm capacity = 47.059 × 1.15 = 54.11785 kW**

3.6.2 Calculation of number and layout of solar modules

Rating of each PV module = 100Wp

No. of PV modules required = \[(54.11785 \times 1000) / 100\] ≈ 541

No of PV modules per array = 34
No. of PV arrays = \( \frac{541}{34} = 15.917 \approx 16 \)
No. of rows = 2
No. of arrays per row = \( \frac{16}{2} = 8 \)

### 3.6.3 Layout of the solar farm

The Layout of the solar firm was done is such a way that there would be no shading effect as a result of one row casting shade on the other.

![Figure 3.6.3-1: layout of the solar farm](image)

### 3.6.4 Charge controllers

Since the brighter the sunlight, the more the voltage the solar cells produce, the excessive voltage could damage the batteries. A charge controller is used to maintain the proper charging voltage on the batteries. As the input voltage from the solar array rises, the charge controller regulates the charge to the batteries preventing any overcharge. There are two types of charge controllers;

- Pulse Width Modulation (PWM)
- Maximum Power Point Tracking (MPPT)

For this project MPPT is recommended because it matches the solar panel voltage output to that of the battery voltage to insure maximum charge (amps). [15]

Determining rating

Charge controller rating = (No. of arrays per row × No of PV modules per array × rated power of PV module)/(rated voltage of PV module × No of PV modules per array)

Charge controller rating = \( \frac{100 \times 34 \times 8}{(12 \times 34)} = 66.667A + 20\% = 80A \)
Determining number of controllers needed

No. of charge controllers needed = rows = 2

3.6.5 Inverter

The power electronic circuit used to convert DC into AC is known as the inverter. The term “converter” is often used to mean either the rectifier or the inverter. The DC input to the inverter is from PV power modules and then it gives out AC voltage.

Determining the rating and number of inverters needed

The peak power that solar power system provides is 40 kW for five hours or less than 40 kW for more hours. For reliability purpose three pure sine wave inverters of 20kW each were used. This configuration would allow for routine maintenance and repairs incase of mechanical problem without interference with normal service.

The specification of the inverter is given in table 3.4.3-2.

<table>
<thead>
<tr>
<th>Table 3.6-1: inverter specification</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power rating</strong></td>
</tr>
<tr>
<td>DC Input</td>
</tr>
<tr>
<td>Voltage</td>
</tr>
<tr>
<td>Range</td>
</tr>
<tr>
<td>AC Output</td>
</tr>
<tr>
<td>Voltage</td>
</tr>
<tr>
<td>Regulation</td>
</tr>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>Load power factor</td>
</tr>
<tr>
<td>Harmonic distortion</td>
</tr>
<tr>
<td>Overload capacity</td>
</tr>
<tr>
<td>Crest factor</td>
</tr>
</tbody>
</table>
In addition to the above features it should also have at least the following;

- High reliability should exceed 20 years
- Industrial grade- built to operate in extreme environments
- Low audible noise
- High efficiency Transistor Bridge
- Long life led indicators
- Remote status panel
- Microprocessor based alarms

### 3.6.6 Mounting system

**Design consideration of mounting system**

In general, there are two types of PV mounting system configurations utilized in large scale solar developments;

- Fixed tilt
- Single axis tracking mounting structures.

Fixed tilt mounting systems are typically rack mounted systems with the panels installed at a fixed angle, normally at or near the latitude of the site to maximize for annual energy production (see Figure 3.4.4-1 below). Single axis tracking systems employ an actuator system that rotates an axel so that the panels track the sun from east to west over the course of a day. The trade-offs between these two systems include:

- Fixed tilt systems are lighter in weight, are less expensive, and produce less energy per installed kW on an annual basis than a single axis tracking system;
- Single axis tracking systems are heavier (requiring deeper piers for footings), more expensive, and produce more energy per installed kW on an annual basis than a fixed tilt system.

Since both weight and pier depth are critical design criteria for avoiding both deeper pier depths and differential settlement, a fixed tilt mounting structure is recommended for use at this site.
3.7 Battery bank sizing

The battery is supposed to provide a back up equivalent to 20% of the total capacities of the two renewable technologies. This would take care of slight variations while the generator will take care of the large variations.

Battery Bank (AH) = \( \frac{E_{\text{bat}}}{d_{\text{disch}} \cdot V_{\text{disch}} \cdot \text{DoD}_{\text{allowed}} \cdot N_{\text{bat}}} \)

Where;

- \( E_{\text{bat}} \) = energy required from the battery per discharge,
- \( d_{\text{disch}} \) = efficiency of discharge path, including; inverters, diodes, and wires, etc.
- \( V_{\text{disch}} \) = average cell voltage during discharge,
- \( \text{DoD}_{\text{allowed}} \) = maximum Depth of Discharge allowed for the required cycle life, and
- \( N_{\text{bat}} \) = number of batteries in parallel.

Battery Bank Capacity = \( \frac{800000 \times 0.2}{0.8 \times 1 \times 384 \times 3} \) = 173.611 AH

The reason why three battery banks of equal capacity were used is for reliability. In case one of them fails the other two can continue providing power till the damaged battery bank is replaced.
### 3.8 Generator sizing

The generator is to provide power for five hours per day starting from 6.00 pm to 11.00 pm when power usage is at its peak. Total peak load to be provided by the generator is 200kWh/Day as shown in Table 3.1-1.

Generator size = 200kWh/5h = 40kW

A reserve capacity of 15% is desired, therefore;

Required generator capacity = 40 × 1.15 = 46 kW

It is recommended that two generators of 23 kW be installed in parallel. This configuration allows for usage of one generator when the load demand is low and both generators when load demand is high. It also allows maintenance to be carried out without power interruption.

<table>
<thead>
<tr>
<th>Prime power</th>
<th>23kW (25kVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connect type</td>
<td>3-phase and 4 wire</td>
</tr>
<tr>
<td>Frequency</td>
<td>50Hz</td>
</tr>
<tr>
<td>Voltage</td>
<td>230/400 (adjustable)</td>
</tr>
<tr>
<td>Voltage control</td>
<td>AVR</td>
</tr>
<tr>
<td>Power factor</td>
<td>0.8 lagging</td>
</tr>
<tr>
<td>Excitation mode</td>
<td>Brushes self-Excitation</td>
</tr>
<tr>
<td>Insulation glass</td>
<td>H/H</td>
</tr>
<tr>
<td>Protection Grade</td>
<td>Ip21-23</td>
</tr>
</tbody>
</table>
3.9 Power connection and control unit

The power connection and control unit (PCCU) provides a central place to make organized connections of most system components. In addition, the PCCU houses the following components:

- Battery charges and discharge regulators.
- Transfer switches and protection circuit breakers.
- Power flow meters.
- Mode controller.

The plant has a total capacity of 195.95 kW which 95.83 kW is from the wind farm, 54.11 kW is from the solar farm and 43.0 kW is from the diesel generator. However, it is desired that the controller be able to handle an extra 20% future growth as buying another one in case of growth does not make economic sense.
CHAPTER FOUR

POWER DISTRIBUTION SYSTEM DESIGN

4.1 Distribution Layout

The distribution system layout was done using AutoCAD as shown in figure 4.2-1. The area was divided into three zones, with each zone being powered by one ground mounted substation.

![Distribution System Layout](image)

*Figure 3.6.6-1: plan of distribution system of the Teachers Training College*

4.2 Ground Mounted Substation (GMSS)

Step-up transformers would be utilized to raise the voltage of the generated electricity from 0.415 kV to 11 kV. The step-up transformers would be located next to the Power Connection and Control Unit (PCCU). They are two in number and each should be rated 600 kVA. This enables the effective and
efficient transmission of electricity in the whole area with minimized power loss. Step Ī down transformers would be utilized to drop the voltage of the transmitted electricity from 11kV to 0.430kV. These are three in number. Ground Mounted Substation 1 (GMSS1) is rated 100 kVA; Ground Mounted Substation 2 (GMSS2) is rated 100kVA and Ground Mounted Substation 3 (GMSS3) is rated 500kVA. The secondary side voltage is 430 so as to cater for voltage drop. This ensures that the consumer receives 3 phase power at each Ground Mounted Sub Station which is then fed to the service turrets as 3 phase and then to the building as single phase.

4.3 Type of power distribution system

Underground power distribution system was chosen for this project. This is because the area under consideration is a small area, a college; therefore it makes more economical sense to use underground system. On deciding the type of distribution system, radial and networked circuits were considered. Radial power distribution system is being proposed for this project. [11]

![Radial Power Distribution System](image)

**Figure 3.6.6-1: Radial Power Distribution System**

The distribution power system reticulation is shown in figure 4.3-1.

4.4 Conductor sizing

After considering both XLPE and PVC conductors which are the ones usually used for low voltage power distribution, PVC insulated type was chosen for economic reasons although XLPE conductor have higher current carrying capacity for the same size.

The following formulae were applied to size the conductors between the Ground Mounted Sub-Stations (GMSS) and the Lucy Chambers and between the Lucy Chambers and the buildings:
4.4.1 Full load current calculation

\[ I = \frac{x}{\sqrt{x}} \times 0 \ A \]

Or

\[ I = \frac{x}{\sqrt{x}} \ A \]

A slightly larger conductor size (plus 20%) was chosen for safety aspects, and to provide for the higher than usual current, which may be experienced during starting of electric motors. [11]

Then once the full load current was determined, the right conductor size was chosen from manufacturer’s tables for copper conductors. See appendix A and appendix B. [11]

A 4-core PVC-insulated copper cable for conductors between GMSS and the Lucy Chambers and Single-core PVC-insulated cables with stranded copper conductors for conductors between Lucy Chambers and the residential houses.

The conductors connecting the Lucy Chambers and clinic, library, administration blocks, academia, and multipurpose hall is 4-core PVC-insulated copper cable.

4.4.2 Calculation of voltage drop

\[ V = \text{full load current} \times \text{length of conductor} \times \text{voltage drop/ampere/metre} \]

The values for voltage drop/ampere/metre were read from manufacturer’s tables for copper conductors against the chosen conductor size.

4.4.3 Calculation of percentage (%) voltage drop

\[ \% \text{voltage drop} = \frac{\text{voltage drop}}{\text{voltage drop/metre}} \times 100 \]

Definition of acronyms used in the tables

GMSS = Ground Mounted Sub-Substation
GMSS1 = the number identifies the GMSS
L.C = Lucy Chamber
L.C1.1 = the first number (L.C.1.1) identifies the Ground Mounted Sub-Station (GMSS1) while the second number (L.C.1.1) identifies the Lucy Chamber

C = conductor length

C1.1.2 = the first number (C1.1.2) identifies the GMSS, the second number (C1.1.2) identifies the Lucy Chamber, the third number (C1.1.2) identifies the house number.

To calculate the conductor sizes for the distribution system, the peak loads that were collected from my colleagues who are doing the wiring for the different building as tabulated in table 4.4-1 were used.

<table>
<thead>
<tr>
<th>Building</th>
<th>Peak load (kVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principle’s House</td>
<td>41.667</td>
</tr>
<tr>
<td>Departmental Head’s House</td>
<td>37.222</td>
</tr>
<tr>
<td>Lecturer’s House</td>
<td>35.778</td>
</tr>
<tr>
<td>Library</td>
<td>270</td>
</tr>
<tr>
<td>Administration Block</td>
<td>260</td>
</tr>
<tr>
<td>Multipurpose Hall (MPH)</td>
<td>234.6</td>
</tr>
<tr>
<td>Academia</td>
<td>250</td>
</tr>
<tr>
<td>Sports Pavilion</td>
<td>38</td>
</tr>
<tr>
<td>Hostel</td>
<td>230</td>
</tr>
</tbody>
</table>

Example of how the calculation was done for C1.1;

\[ I = \frac{1}{\sqrt{s}} \times P = 299.864A + 20\% = 359.84A \]

Conductor size = 300 mm

Voltage drop = 0.189 × 10 × 359.84 × 67 = 4.56V

% voltage Drop = \frac{4.56}{359.84} × 100 = 1.06%

The other calculations for rest of the conductors were carried in a similar way and tabulated in table 4.4-2, table 4.4-3 and table 4.4-4.

Each Lucy Chamber is connecting six houses each with a single phase. To balance the load between the three phases (i.e. the Red, the Yellow and the Blue phases), each of the phases is feeding two
houses and hence the coloring to show which ones are being fed by which phase. The conductors which are colored black are three phase conductors.

Table 4.4-2: Characteristics of conductors of zone 1 which is being fed by GMSS1

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<tr>
<th></th>
<th>Length of conductor (m)</th>
<th>Full load current (A)</th>
<th>Conductor size (mm)</th>
<th>Voltage drop (V)</th>
<th>%Voltage drop</th>
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<td>Full load current (A)</td>
<td>Conductor size (mm²)</td>
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<td>% voltage drop</td>
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<td>175.37</td>
<td>120</td>
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</tr>
<tr>
<td>L.C2.5</td>
<td></td>
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<td></td>
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<tr>
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<td>1.22</td>
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<td>95</td>
<td>3.79</td>
<td>1.55</td>
</tr>
<tr>
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<td>23.2</td>
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<td>70</td>
<td>2.36</td>
<td>0.96</td>
</tr>
<tr>
<td>C2.5.44</td>
<td>39</td>
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<td>70</td>
<td>3.97</td>
<td>1.62</td>
</tr>
<tr>
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<td>175.379</td>
<td>70</td>
<td>5.11</td>
<td>2.09</td>
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<td>C2.5.46</td>
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<td>3.16</td>
<td>1.29</td>
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<td>1.28</td>
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<td></td>
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<tr>
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<td>1.62</td>
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<td>120</td>
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<td>2.27</td>
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<tr>
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<td>1.71</td>
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<td>70</td>
<td>4.08</td>
<td>1.67</td>
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<tr>
<td>C2.6.63</td>
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<td>175.78</td>
<td>70</td>
<td>2.26</td>
<td>0.93</td>
</tr>
<tr>
<td>C2.6.64</td>
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<td>188.34</td>
<td>120</td>
<td>5.72</td>
<td>2.34</td>
</tr>
<tr>
<td>C2.6.1</td>
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<td>188.34</td>
<td>240</td>
<td>4.80</td>
<td>2.04</td>
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Table 4.4-3: Characteristics of conductors of zone 3 which is being fed by GMSS3
<table>
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<tr>
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<th>139.1</th>
<th>118.13</th>
<th>120</th>
<th>5.72</th>
<th>1.36</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3.4.1.73</td>
<td>31.0</td>
<td>179.64</td>
<td>70</td>
<td>3.23</td>
<td>1.35</td>
</tr>
<tr>
<td>C3.4.1.74</td>
<td>30.2</td>
<td>179.64</td>
<td>70</td>
<td>3.15</td>
<td>1.32</td>
</tr>
<tr>
<td>C3.5.ML1</td>
<td>72.6</td>
<td>370.10</td>
<td>240</td>
<td>5.68</td>
<td>1.32</td>
</tr>
<tr>
<td>C3.6.ML2</td>
<td>82.4</td>
<td>370.10</td>
<td>240</td>
<td>6.43</td>
<td>1.50</td>
</tr>
<tr>
<td>C3.7.Academia</td>
<td>111.0</td>
<td>402.80</td>
<td>240</td>
<td>9.42</td>
<td>2.19</td>
</tr>
<tr>
<td>C3.8.LH1</td>
<td>145.7</td>
<td>370.10</td>
<td>240</td>
<td>11.38</td>
<td>2.65</td>
</tr>
<tr>
<td>C3.9.LH2</td>
<td>151.3</td>
<td>370.10</td>
<td>240</td>
<td>11.82</td>
<td>2.75</td>
</tr>
<tr>
<td>C.3.10.1.Clinic</td>
<td>222.7</td>
<td>435.00</td>
<td>300</td>
<td>18.31</td>
<td>4.26</td>
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</table>
Figure 4.3-1: Power distribution system reticulation
CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION
The objective of the project, which was designing of hybrid solar, wind and diesel generator power system and power distribution system to power the teachers training college, was met.

The power system design included load sizing, plant sizing, economic analysis of the three technologies and finally the plant design. The solar system has a peak load capacity of 54.12 kW, the wind farm has a peak load capacity of 95.833 kW and the diesel generator has a peak load capacity of 46 kW. This gives the plant a total peak load capacity of 195.953 kW. This plant is able to provide at least the 1000kWh/Day needed by the college and also meet a maximum demand of 195.953 kW. This capacity of the plant includes a reserve capacity of 15% above the current maximum demand to cater future load growth.

The power distribution system design included: dividing the college into three zones, sizing of the transformers, designing the distribution layout and sizing of the conductors. All these objectives were achieved.

5.2 RECOMMENDATIONS
It was not possible to finish some parts of the design which are important to the project due to time constraints and therefore it is recommended that they should be finished in future work for the successful completion of the project. These are the areas which were not covered.

5.2.1 Protection system
Protection system design is very important to any power plant as it is capital intensive and therefore protection is very important to ensure that the specified life span of the system is met.
5.2.2 Power factor correction

Power factor correction was not done in the concluded work due lack of time and it is therefore recommended that it be done in future works.
APPENDICES

6.1 APPENDIX A: Current carrying capacity of Single-core PVC-insulated copper conductors

<table>
<thead>
<tr>
<th>Rated Area (mm²)</th>
<th>Nominal Diameters</th>
<th>Current Ratings</th>
<th>Volt Drop (mV/Am)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D₁ (mm)</td>
<td>D₂ (mm)</td>
<td>Nominal Mass (kg/km)</td>
</tr>
<tr>
<td>25</td>
<td>5.95</td>
<td>11.94</td>
<td>566</td>
</tr>
<tr>
<td>35</td>
<td>7.00</td>
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<td>469</td>
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<tr>
<td>50</td>
<td>8.15</td>
<td>15.15</td>
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<td>9.79</td>
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<td>830</td>
</tr>
<tr>
<td>95</td>
<td>11.54</td>
<td>18.04</td>
<td>1160</td>
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<td>120</td>
<td>12.96</td>
<td>20.24</td>
<td>1413</td>
</tr>
<tr>
<td>150</td>
<td>14.39</td>
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<tr>
<td>185</td>
<td>16.10</td>
<td>24.80</td>
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<td>240</td>
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<td>27.81</td>
<td>2725</td>
</tr>
<tr>
<td>300</td>
<td>21.45</td>
<td>30.75</td>
<td>3175</td>
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<tr>
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<td>53.45</td>
<td>11050</td>
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</table>

Note: (1) D₁ is the diameter over the conductor.
(2) D₂ is the diameter over the PVC sheath.
## 6.2 Appendix B: Current carrying capacity of 3- and 4-core PVC-insulated copper cable

<table>
<thead>
<tr>
<th>Cable Size (mm²)</th>
<th>Ground (A)</th>
<th>Bnts (A)</th>
<th>Air (A)</th>
<th>Impedance (Ω/km)</th>
<th>Volt Drop (mV/km/m)</th>
<th>1-Phase Circuit Rating (A)</th>
<th>t₁₀ - 3c (mm)</th>
<th>t₁₀ - 4c (mm)</th>
<th>d - 3c (mm)</th>
<th>d - 4c (mm)</th>
<th>D₁₀ - 3c (mm)</th>
<th>D₁₀ - 4c (mm)</th>
<th>Approx. Mass</th>
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<td>9.33</td>
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<td>62.20</td>
<td>69.13</td>
<td>12950</td>
</tr>
</tbody>
</table>

*Note: The data provided is a summary of current carrying capacity for different cable sizes, with columns for ground, number of conductors, air gap, impedance, voltage drop, current ratings, and physical properties such as nominal diameter and approximate mass.*
6.3 APPENDIX C: The layout of the teachers training college
6.4 APPENDIX D: Optimization code
#include <math.h>
#include <stdlib.h>
using namespace System;
using namespace System::ComponentModel;
using namespace System::Collections;
using namespace System::Windows::Forms;
using namespace System::Data;
using namespace System::Drawing;
using namespace Microsoft::Office::Interop::Excel;

#pragma once

namespace Aidarus {

/// <summary>
/// Summary for Form1
/// </summary>
///
/// WARNING: If you change the name of this class, you will need to change the
/// 'Resource File Name' property for the managed resource compiler tool
/// associated with all .resx files this class depends on. Otherwise,
/// the designers will not be able to interact properly with localized
/// resources associated with this form.
///
/// </summary>
public ref class Form1 : public System::Windows::Forms::Form
{
public:
Form1(void)
{
    InitializeComponent();
    //
    // TODO: Add the constructor code here
    //
}

    static int count;
    static int button_press = 0;
    static double gen_cost, wind_cost, solar_cost, optimal_cost;
    static double wind_ratio, solar_ratio, gen_ratio;
    static System::Collections::SortedList^ listsolar = gcnew System::Collections::SortedList();
    static System::Collections::SortedList^ listgen = gcnew System::Collections::SortedList();
    static System::Collections::SortedList^ listwind = gcnew System::Collections::SortedList();
    static System::Collections::SortedList^ listoptimal = gcnew System::Collections::SortedList();
    static System::Collections::SortedList^ listlabel = gcnew System::Collections::SortedList();
    static int total;
    static bool m_bGraph = false;

private: System::Windows::Forms::TextBox^ Plant_capacity;

public:

private: System::Windows::Forms::Label^ label9;
private: System::Windows::Forms::TextBox^ Unit_step;

private: System::Windows::Forms::Label^ label10;
private: System::Windows::Forms::Button^ button2;
    static bool m_bFill_table = false;

protected:

/// <summary>
/// Clean up any resources being used.
/// </summary>
///
~Form1()
{
    if (components)
    {
        delete components;
    }

private: System::Windows::Forms::ListView^ listView1;
private: System::Windows::Forms::ColumnHeader^ Gen_cost;
private: System::Windows::Forms::ColumnHeader^ Wind_cost;
}
private: System::Windows::Forms::ColumnHeader^ Solar_cost;
private: System::Windows::Forms::ColumnHeader^ Optimal_cost;
private: System::Windows::Forms::GroupBox^ groupBox1;
private: System::Windows::Forms::Label^ label1;
private: System::Windows::Forms::Label^ label2;
private: System::Windows::Forms::Label^ label3;
private: System::Windows::Forms::Label^ label15;
private: System::Windows::Forms::Label^ label14;
private: System::Windows::Forms::Label^ label6;
private: System::Windows::Forms::Label^ label17;
private: System::Windows::Forms::Label^ label18;
private: System::Windows::Forms::TextBox^ Interest_rate;
private: System::Windows::Forms::TextBox^ O_M;
private: System::Windows::Forms::TextBox^ Constant_instalment;
private: System::Windows::Forms::TextBox^ Initial_cost;
private: System::Windows::Forms::TextBox^ Repayment_period;
private: System::Windows::Forms::TextBox^ Fuel_cost;
private: System::Windows::Forms::TextBox^ P_C;
private: System::Windows::Forms::TextBox^ Rated_power;
private: System::Windows::Forms::RadioButton^ radioButton1;
private: System::Windows::Forms::RadioButton^ radioButton3;
private: System::Windows::Forms::RadioButton^ radioButton2;
private: System::Windows::Forms::Button^ button1;

protected:

private:

/// <summary>
/// Required designer variable.
/// </summary>
System::ComponentModel::Container ^components;

#pragma region Windows Form Designer generated code
/// <summary>
/// Required method for Designer support - do not modify
/// the contents of this method with the code editor.
/// </summary>
void InitializeComponent(void)
{
    this->listView1 = (gcnew System::Windows::Forms::ListView());
    this->ratios = (gcnew System::Windows::Forms::ColumnHeader());
    this->wind_cost = (gcnew System::Windows::Forms::ColumnHeader());
    this->solar_cost = (gcnew System::Windows::Forms::ColumnHeader());
    this->optimal_cost = (gcnew System::Windows::Forms::ColumnHeader());
    this->button2 = (gcnew System::Windows::Forms::Button());
    this->unit_step = (gcnew System::Windows::Forms::TextBox());
    this->label10 = (gcnew System::Windows::Forms::Label());
    this->plant_capacity = (gcnew System::Windows::Forms::TextBox());
    this->label9 = (gcnew System::Windows::Forms::Label());
    this->button1 = (gcnew System::Windows::Forms::Button());
    this->radioButton3 = (gcnew System::Windows::Forms::RadioButton());
    this->radioButton2 = (gcnew System::Windows::Forms::RadioButton());
    this->radioButton1 = (gcnew System::Windows::Forms::RadioButton());
    this->fuel_cost = (gcnew System::Windows::Forms::TextBox());
    this->p_c = (gcnew System::Windows::Forms::TextBox());
    this->rated_power = (gcnew System::Windows::Forms::TextBox());
    this->O_M = (gcnew System::Windows::Forms::TextBox());
    this->constant_instalment = (gcnew System::Windows::Forms::TextBox());
    this->initial_cost = (gcnew System::Windows::Forms::TextBox());
    this->repayment_period = (gcnew System::Windows::Forms::TextBox());
    this->interest_rate = (gcnew System::Windows::Forms::TextBox());
    this->label18 = (gcnew System::Windows::Forms::Label());
    this->label17 = (gcnew System::Windows::Forms::Label());
    this->label16 = (gcnew System::Windows::Forms::Label());
    this->label15 = (gcnew System::Windows::Forms::Label());
    this->label14 = (gcnew System::Windows::Forms::Label());
    this->label13 = (gcnew System::Windows::Forms::Label());
this->label2 = (gcnew System::Windows::Forms::Label());
this->label1 = (gcnew System::Windows::Forms::Label());
this->groupBox1->SuspendLayout();
this->groupBox1->ResumeLayout();

// listview1

this->listview1->Columns->AddRange(gcnew System::Array< System::Windows::Forms::ColumnHeader^ >({
    (gcnew System::Windows::Forms::ColumnHeader(gcnew cli::array<System::String^{3}>{{"Gen Cost"}, {"Wind Cost"}, {"Solar Cost"}, {"Optimal Cost"}})),
    (gcnew System::Drawing::Point(53, 42)),
    gcnew System::Windows::Forms::ColumnHeader(gcnew cli::array<System::String^{3}>{{"listview1"}}),
    (gcnew System::Drawing::Size(466, 184)),
    gcnew System::Windows::Forms::ColumnHeader(gcnew cli::array<System::String^{2}>{{"TabIndex"}}),
    gcnew System::Drawing::Size(0),
    gcnew System::Drawing::ImageBehavior(false),
    gcnew System::Windows::Forms::ColumnHeader(gcnew cli::array<System::String^{3}>{{"View"}}),
    (gcnew System::Drawing::Size(0)),
    gcnew System::Windows::Forms::ColumnHeader(gcnew cli::array<System::String^{2}>{{"SelectedIndexChanged"}}),
    gcnew System::EventSubEventHandler(gcnew System::EventSubEventHandler(gcnew cli::array<System::String^{3}>{{"listview1_SelectedIndexChanged"}}))});

// ratios

this->ratios->Text = L"Ratios S-W-G-";
this->ratios->Width = 120;

// gen_cost

this->gen_cost->Text = L"Gen Cost/kWh";
this->gen_cost-> TextAlign = System::Windows::Forms::HorizontalAlignment::Center;

// wind_cost

this->wind_cost->Text = L"Wind Cost/kWh";
this->wind_cost-> TextAlign = System::Windows::Forms::HorizontalAlignment::Center;

// solar_cost

this->solar_cost->Text = L"Solar Cost/kWh";
this->solar_cost-> TextAlign = System::Windows::Forms::HorizontalAlignment::Center;

// optimal_cost

this->optimal_cost->Text = L"Hybrid Discounted Cost";
this->optimal_cost-> TextAlign = System::Windows::Forms::HorizontalAlignment::Center;

// groupbox1

this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Button2);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::UnitStep);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Label10);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Plant_capacity);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Label9);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::RadioButton3);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::RadioButton2);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::RadioButton1);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Fuel_cost);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::PC_C);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Rated_power);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Q_M);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Constant_installment);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Initial_cost);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Repayment_period);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Interest_rate);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Label18);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Label7);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Label16);
this->groupBox1->Controls->Add(gcnew System::Windows::Forms::Label15);}
this->radioButton3->AutoSize = true;
this->radioButton3->Location = System::Drawing::Point(23, 75);
this->radioButton3->Name = L"radioButton3";
this->radioButton3->Size = System::Drawing::Size(101, 17);
this->radioButton3->TabIndex = 18;
this->radioButton3->Text = L"Solar Cost";
this->radioButton3->UseVisualStyleBackColor = true;
// radioButton2

this->radioButton2->AutoSize = true;
this->radioButton2->Location = System::Drawing::Point(24, 52);
this->radioButton2->Name = L"radioButton2";
this->radioButton2->Size = System::Drawing::Size(83, 17);
this->radioButton2->TabIndex = 17;
this->radioButton2->Text = L"Wind Power";
this->radioButton2->UseVisualStyleBackColor = true;
// radioButton1

this->radioButton1->AutoSize = true;
this->radioButton1->Checked = true;
this->radioButton1->Location = System::Drawing::Point(24, 29);
this->radioButton1->Name = L"radioButton1";
this->radioButton1->Size = System::Drawing::Size(104, 17);
this->radioButton1->TabIndex = 16;
this->radioButton1->TabStop = true;
this->radioButton1->Text = L"Diesel Generator";
this->radioButton1->UseVisualStyleBackColor = true;

// Fuel_cost

this->Fuel_cost->Location = System::Drawing::Point(248, 311);
this->Fuel_cost->Name = L"Fuel_cost";
this->Fuel_cost->Size = System::Drawing::Size(100, 20);
this->Fuel_cost->TabIndex = 15;

// F_c

this->F_C->Location = System::Drawing::Point(248, 281);
this->F_C->Name = L"F_C";
this->F_C->Size = System::Drawing::Size(100, 20);
this->F_C->TabIndex = 14;

// Rated_power

this->Rated_power->Location = System::Drawing::Point(248, 249);
this->Rated_power->Name = L"Rated_power";
this->Rated_power->Size = System::Drawing::Size(100, 20);
this->Rated_power->TabIndex = 13;

// O_M

this->O_M->Location = System::Drawing::Point(248, 221);
this->O_M->Name = L"O_M";
this->O_M->Size = System::Drawing::Size(100, 20);
this->O_M->TabIndex = 12;

// Constant_instalment

this->Constant_instalment->Location = System::Drawing::Point(248, 191);
this->Constant_instalment->Name = L"Constant_instalment";
this->Constant_instalment->Size = System::Drawing::Size(100, 20);
this->Constant_instalment->TabIndex = 11;

// Initial_cost

this->Initial_cost->Location = System::Drawing::Point(248, 162);
this->Initial_cost->Name = L"Initial_cost";
this->Initial_cost->Size = System::Drawing::Size(100, 20);
this->Initial_cost->TabIndex = 10;

// Repayment_period
//
// this->Repayment_period->Location = System::Drawing::Point(248, 132);
// this->Repayment_period->Name = L"Repayment_period";
// this->Repayment_period->Size = System::Drawing::Size(100, 20);
// this->Repayment_period->TabIndex = 9;
//
// Interest_rate
//
// this->Interest_rate->Location = System::Drawing::Point(248, 104);
// this->Interest_rate->Name = L"Interest_rate";
// this->Interest_rate->Size = System::Drawing::Size(100, 20);
// this->Interest_rate->TabIndex = 8;
//
// label8
//
// this->label8->AutoSize = true;
// this->label8->Location = System::Drawing::Point(21, 311);
// this->label8->Name = L"label8";
// this->label8->Size = System::Drawing::Size(82, 13);
// this->label8->TabIndex = 7;
// this->label8->Text = L"Fuel Cost/kWh:";
//
// label7
//
// this->label7->AutoSize = true;
// this->label7->Location = System::Drawing::Point(21, 281);
// this->label7->Name = L"label7";
// this->label7->Size = System::Drawing::Size(160, 13);
// this->label7->TabIndex = 6;
// this->label7->Text = L"Average annual load factor (PA):";
//
// label6
//
// this->label6->AutoSize = true;
// this->label6->Location = System::Drawing::Point(20, 249);
// this->label6->Name = L"label6";
// this->label6->Size = System::Drawing::Size(256, 13);
// this->label6->TabIndex = 5;
// this->label6->Text = L"Rated power of the production equipment (P) in kW:";
//
// label5
//
// this->label5->AutoSize = true;
// this->label5->Location = System::Drawing::Point(21, 221);
// this->label5->Name = L"label5";
// this->label5->Size = System::Drawing::Size(63, 13);
// this->label5->TabIndex = 4;
// this->label5->Text = L"Q & M Cost/kWh:";
// this->label5->Click += gcnew System::EventHandler(this, &Form1::label5_Click);
//
// label4
//
// this->label4->AutoSize = true;
// this->label4->Location = System::Drawing::Point(20, 191);
// this->label4->Name = L"label4";
// this->label4->Size = System::Drawing::Size(108, 13);
// this->label4->TabIndex = 3;
// this->label4->Text = L"Constant Instalments:";
//
// label3
//
// this->label3->AutoSize = true;
// this->label3->Location = System::Drawing::Point(20, 162);
// this->label3->Name = L"label3";
// this->label3->Size = System::Drawing::Size(117, 13);
// this->label3->TabIndex = 2;
// this->label3->Text = L"Initial Investment/kW:";
//
// label2
//
// this->label2->AutoSize = true;
// this->label2->Location = System::Drawing::Point(21, 132);
// this->label2->Name = L"label2";
private: System::Void button1_Click(System::Object^ sender, System::EventArgs^ e) {
    System::Globalization::CultureInfo^ MyCI = gcnew System::Globalization::CultureInfo("en-US",false);
    m_bFill_table = false;
    if (count == 0) {
        radioButton2->Checked = true;
        radioButton1->Checked = false;
        count++;
            double inv = System::Convert::ToDouble(Initial_cost->Text);
            double annual_disc = System::Convert::ToDouble(Interest_rate->Text);
            double r_power = System::Convert::ToDouble(Rated_power->Text);
            double repay_period = System::Convert::ToDouble(Repayment_period->Text);
            double const_inst = calc_const_instalment(inv, annual_disc, repay_period, r_power);
            // Constant installment -> Text = const_inst.ToString("F02", MyCI);
            double initial_inv = r_power * inv;
            double lup = initial_inv/r_power;
            double op_m = System::Convert::ToDouble(O_M->Text);
            double annual_op_m = r_power * 8760 * op_m;
            double KE = annual_op_m/initial_inv;
            double ann_load_ftr = System::Convert::ToDouble(F_C->Text);
            double fuel_cost = System::Convert::ToDouble(Fuel_cost->Text);
            double annual_fuel_cost = r_power * 8760 * fuel_cost;
            double FC = annual_fuel_cost/initial_inv;
            double disc_cost = (inv*4*r_power + total_kWh_lifespan*(op_m +
            fuel_cost);
double cost_kWh = total_cost/total_kWh_lifespan;
//gen_cost = cost_kWh/ann_load_ftr;
//gen_cost = cost_kWh;
if(Plant_capacity->Text != "+")
{
    double capacity = System::Convert::ToDouble(Plant_capacity->Text);
    if(capacity > 0) gen_cost *= capacity;
}
else
{
    radioButton2->Checked = false;
    radioButton1->Checked = true;
    count--;
    MessageBox::Show(L"Enter all the required data first.");
}
else if (count == 1)
{
    radioButton3->Checked = true;
    radioButton2->Checked = false;
    count++;
    if (Initial_cost->Text != "" && Interest_rate->Text != "" && 
        Repayment_period->Text != "" && O_H->Text != "" && F_C->Text != "")
    {
        double inv = System::Convert::ToDouble(Initial_cost->Text);
        double annual_disc = System::Convert::ToDouble(Interest_rate->Text);
        double r_power = System::Convert::ToDouble(Rated_power->Text);
        double repay_period = System::Convert::ToDouble(Repayment_period->Text);
        double const_inst = calc_const_instalment(inv, annual_disc, 
                                                  repay_period, r_power);
        Constant_instalment->Text = const_inst.ToString("F02",MyCI);
        double initial_inv = r_power * inv;
        double KA = const_inst/initial_inv;
        double lnp = initial_inv/r_power;
        double op_m = System::Convert::ToDouble(O_M->Text);
        double annual_op_m = r_power * $760 * op_m;
        double KE = annual_op_m/initial_inv;
        double ann_load_ftr = System::Convert::ToDouble(F_C->Text);
        //double fuel_cost = System::Convert::ToDouble(Fuel_cost->Text);
        double annual_fuel_cost = r_power * $760 * fuel_cost;
        double FC = annual_fuel_cost/initial_inv;
        double disc_cost = lnp*(KA*KE)/($760*ann_load_ftr);
        wind_cost = disc_cost;
        if(Plant_capacity->Text != "+")
        {
            double capacity = System::Convert::ToDouble(Plant_capacity->Text);
            if(capacity > 0) wind_cost *= capacity;
        }
    }
else
{
    radioButton3->Checked = false;
    radioButton2->Checked = true;
    count--;
    MessageBox::Show(L"Enter all the required data first.");
}
else if (count == 2)
{
    radioButton1->Checked = true;
    radioButton2->Checked = false;
    count = 0;
    if (Initial_cost->Text != "" && Interest_rate->Text != "" && 
        Repayment_period->Text != "" && O_H->Text != "" && F_C->Text != "")
    {
        double inv = System::Convert::ToDouble(Initial_cost->Text);
        double annual_disc = System::Convert::ToDouble(Interest_rate->Text);
        double r_power = System::Convert::ToDouble(Rated_power->Text);
        double repay_period = System::Convert::ToDouble(Repayment_period->Text);
        double const_inst = calc_const_instalment(inv, annual_disc,
repay_period, r_power;
    Constant_instalment->Text = const_inst.ToString("F02", MyCI);
    double initial_inv = r_power * inv;
    double KA = const_inst/initial_inv;
    double tgp = initial_inv/r_power;
    double op_m = System::Convert::ToDouble(D_m->Text);
    double annual_op_m = r_power * 8760 * op_m;
    double KE = annual_op_m/initial_inv;
    double ann_load_ftr = System::Convert::ToDouble(F_C->Text);
    //double fuel_cost = System::Convert::ToDouble(Fuel_cost->Text);
    //double annual_fuel_cost = r_power * 8760 * fuel_cost;
    //double FC = annual_fuel_cost/initial_inv;
    double disc_cost = tgp*(KA+KE)/(8760*ann_load_ftr);
    solar_cost = disc_cost;
    if(Plant_capacity->Text == "")
    {
        double capacity = System::Convert::ToDouble(Plant_capacity->Text);
        if(capacity > 0) solar_cost *= capacity;
    }
    m_bFill_table = true;
    }
    else
    {
        radioButton1->Checked = false;
        radioButton3->Checked = true;
        count = 2;
        MessageBox::Show(L"Enter all the required data first.");
    }
}

//fill the data //after all the costs for solar, wind and generator have been provided //calculate all the values to fill the table if(m_bFill_table == true)
{
    double s_cost, w_cost, g_cost, remainder, step, R;
    int reciprocal;
    listView1->Items->Clear();
    ListViewItem *listviewItem;
    if (Unit_step->Text != ":") step = System::Convert::ToDouble(Unit_step->
Text);
    else step = 0.25;
    if (step > 0 && step <= 0.25)
    { 
        reciprocal = 1/step;
    } else
    {
        MessageBox::Show(L"The units should be above 0 and less than 0.25. The default unit shall be used ");
        reciprocal = 1/0.25;
    }
    int counter = 0;
    listLabel->Clear();
    listSolar->Clear();
    listGen->Clear();
    listWind->Clear();
    listOptimal->Clear();
    for (int i = 1; i < (reciprocal-1); i++)
    {
        remainder = reciprocal-i;
        double R = (double)i/reciprocal;
        for (int j = 1; j < remainder; j++)
        {
            double J = (double)/reciprocal;
            double rem = remainder/reciprocal;
            String* str_L = I.ToString("F02", MyCI);
            String* str_J = J.ToString("F02", MyCI);
            String* str_R = R.ToString("F02", MyCI);
            String* msg = L"S="+str_I", W="+str_J", G="+str_R;
            listLabel->Add(counter, msg);
            listviewitem = new ListViewItem(msg);
double calcConstInstallment(double inv, double annDisc, double n, double rPower)
{
    double result;
    result = inv*rPower*(annDisc/100)*pow((1+annDisc/100), n)/(pow(1+rPower, n)-1);
    return result;
}

void RunExcel()
{
    // create the excel workbook
    Excel::Application* exApp = gcnew Excel::ApplicationClass();
    // add a workbook
    Workbook* exWb = exApp->Workbooks->Add(Type::Missing);
    // Delete the last two worksheets
    safe_cast<Worksheet*>(exWb->WorkSheets[3])->Delete();
    safe_cast<Worksheet*>(exWb->WorkSheets[2])->Delete();

    // Create a variable for the active worksheet's tracking handle
    // (First Worksheet is the default active one)
    Worksheet* exWs = safe_cast<Worksheet*>(exApp->ActiveSheet);

    // Rename the active worksheet
    exWs->Name = "Charts";

    // Make a line chart
    MakeLineChart(exWs, 2, 1);

    // Show the workbook
    exApp->Visible = true;
}

void MakeLineChart(Worksheet* ws, int row, int col)
{
    int xPos = (col+9)*48; // Col width 48 points. Chart starts in 3rd
    int yPos = row*9; // Row height = 9, Chart starts in 2nd row
    double optimalVal = 0;
    double solarVal = 0;
    double windVal = 0;
    double genVal = 0;
    String* ratio;
String" title = "Graphs for simulated data;"

//1. Format two Worksheet columns to two decimalplaces for chart data
ws->Range[#B1:C1, Type: Missing]->EntireColumn->NumberFormat = "#0.00";

//2. Reset the three Worksheet data column widths to better fit data
ws->Range[#A1, Type: Missing]->EntireColumn->ColumnWidth = 25;
ws->Range[#B1:E1, Type: Missing]->EntireColumn->ColumnWidth = 15;

// Put Column titles on the chart
ws->Cells[row-1, col] = "Ratios";
ws->Cells[row-1, col+1] = "Solar Cost/kWh";
ws->Cells[row-1, col+2] = "Wind Cost/kWh";
ws->Cells[row-1, col+3] = "Gen Cost/kWh";
ws->Cells[row-1, col+4] = "Hybrid cost/kWh";

//4. Extract the data from two SortedLists and put it on the chart
IDictionaryEnumerator* ide = listoptimal->GetEnumerator();
IDictionaryEnumerator* ide2 = listwind->GetEnumerator();
IDictionaryEnumerator* ide3 = listgen->GetEnumerator();
while (ide->MoveNext()) {
    ide2->MoveNext();
    ide3->MoveNext();
    ratio = ide->Key->ToString();
    optimalval = Convert::ToDouble(ide->Value);
    solarval = Convert::ToDouble(ide2->Value);
    windval = Convert::ToDouble(ide3->Value);
    genval = Convert::ToDouble(ide4->Value);
    ws->Cells[row, col] = ratio;
    ws->Cells[row, col+1] = solarval;
    ws->Cells[row, col+2] = windval;
    ws->Cells[row, col+3] = genval;
    ws->Cells[row, col+4] = optimalval;
    row++;
}

//5. Create a ChartObject Collection for the Worksheet
ChartObjects* chObj = safe_cast<ChartObjects*>(ws->ChartObjects(Type: Missing));

//6. Add the ChartObject to the collection at(x, y, width, height) in points
// Width = 350 to prevent title from wrapping
ChartObject* chObj = chObj->Add(xPos, yPos, 350, 300);

//7. Create a chart from the ChartObject
Chart* ch = chObj->Chart;

//8. Create a Range object & set the data range.
total += row;
String" str_range = "B2:E"+total;
Range* rn = ws->Range[str_range, Type: Missing];

//9. Do the chart
ch->ChartWizard([n->CurrentRegion, Source
   XlChartType::xlLine, //Gallery
   Type::Missing, //Format
   XlRowCol::xlColumns, //Plot by
   1, //Category Labels
   1, //Series Labels
   true, //Has Legend
   title, //Title
   "Ratios", //Category Title
   "cost/kWh", //Value Title
   Type::Missing); //Extra Title

//10. Tell it the chart type again - initially comes up as a "lineMarked" type
ch->ChartType = safe_cast<XlChartType*>(XlChartType::xlLine);

//11. Position the Chart Legend from the side to the bottom
ch->Legend->Position = XlLegendPosition::xlLegendPositionBottom;
private: System::Void button2_Click(System::Object^ sender, System::EventArgs^ e) {
    if(m_bGraph == true)
        RunExcel();
    else MessageBox::Show("Submit data first.");
}
private: System::Void pictureBox1_Click(System::Object^ sender, System::EventArgs^ e) {
}
LIST OF REFERENCES

9. C.N. Rasmussen "Improving wind power quality with energy storage"
10. Mick Sagrillo, Sagrillo Power & Light "Planning Your Wind System" Improving the Wind Resource at Your Site - windletter the monthly newsletter of the american wind energy association Volume 26 Issue No. 2
16. Estimating PV System Size and Cost by The Infinite Power of Texas, SECO Fact Sheet No. 24
22. Principles of power systems
23. Model Ordinance for Small Wind Energy Systems Ordinance Rockingham Planning Commission
24. “Economic Analysis of Renewable Energy-Based Electrification” class notes of Power Systems by Dr. C. Wekesa, Department of Electrical and Information engineering, University of Nairobi
27. Steve Quallin “Practical c++ programming” O’Reilly & Associates, Inc. 2003