DEVELOPMENT OF OPTIMIZATION STRATEGIES FOR A WIND-SOLAR HYBRID SYSTEM: A CASE STUDY OF ST. FRANCIS XAVIER GIRLS SECONDARY SCHOOL IN NAIVASHA, KENYA

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Development of Optimization Strategies for a Wind-Solar Hybrid system: A Case Study of ST. Francis Xavier Girls Secondary School in Naivasha, Kenya

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A Thesis submitted in partial fulfillment for the Degree of Master of Science in Energy Technology in the Jomo Kenyatta University of Agriculture and Technology

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DECLARATION

This Thesis is my original work and has not been submitted for a degree in any other University.

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This Thesis has been submitted for examination with our and approval as University Supervisors.

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DEDICATION

This thesis is dedicated to my Mother, Gladwell Wanjiku, My Wife, My Brothers and Sisters, my Uncles and Auntie for their humble support.

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I would like to thank the Almighty God for His grace and the gift of life throughout this study. I also acknowledge the assistance accorded to me by my supervisors Prof. Kamau, and Prof. Kinyua and IEET staff members. Special thanks also goes to JICA-JKUAT BRIGHT Project for partially funding this study.

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LIST OF ABBREVIATIONS

A	Area
AC	Alternating Current
Ah	Ampere Hour
CDM	Clean Development Mechanism
C_p	Power Coefficient Factor
C_{sc}	Solar Panel Capital Cost and Installation Cost
C_{sm}	Annual Maintenance and Cleaning Cost for solar PV
C_T	Thrust Coefficient Factor
C_{wf}	Installation and Fabrication cost for Wind Turbine
C_{wm}	Annual Maintenance cost for Wind Turbine
DC	Direct Current
GIS	Geographical Information Systems
GLC	Global Land Cover
HOMER	Hybrid Optimization Model for Electric Renewable
HVR	High Voltage Reconnect
I	Real interest rate (5%)
KPLC	Kenya Power & Lighting Company
KWh	Kilowatt hour
LVD	Low Voltage Disconnect
MPPT	Maximum Power Point Tracking
NCAR	National Center for Atmospheric Research

NCER	National Center for Environmental Prediction
NOCT	Nominal Operating Cell Temperature
N_s	Number of solar cells
N_w	Number of wind turbines
PV	Photovoltaic
PWM	Pulse width modulation
SOC	State of Charge
STC	Standard Test Conditions
SRTM	Shuttle Radar Topography Mission
V	Voltage
V	Wind speed (m/s)
y_{proj}	Project lifetime (20 years)
α	Roughness exponential
ρ	Air density
$\bar{v}$	Average wind speed

ABSTRACT

Hybrid power systems are some of the remedies used as an alternative source of energy in Kenya. An integration of wind- solar hybrid systems for energy supply is viewed as a key element of alternative technology. Wind and solar are some of the considerable renewable energy options, both at present as well as in the future due to their availability. Hybrid systems are becoming more convenient ways of harvesting energy from renewable sources when two or more technologies are incorporated and used as one. This study focused on analyzing the performance and development of optimization strategies of a Wind-Solar hybrid system, based on site parameters in St Francis Xavier School Naivasha. The system consists of two wind turbines 900 W each, 30 solar PV modules 100 W_p each arranged into 3 strings of arrays. The system was meant to meet the power load demand in the School. However, power from grid was being used despite the huge investment in renewable energy system. Data on power peak load and power generated from wind and solar PV system was collected by use of data logger for a period of three months. Analytical methods and tool such as Microsoft excel and Hybrid Optimization Model for Electric Renewable software (HOMER) were used for analysis; data was presented in form of bar graphs and curves to give a precise meaning of results. It was found that daily energy demand was 40.5 kWh. Monthly solar energy harnessed was; 98.86 kWh, 94.31 kWh and 120 kWh in February, March and April 2016 respectively. In conclusion, adding 3 kWp solar power and harmonizing the load distribution among three inverters were the best optimization strategies that can be adopted. The findings of this study will be used in future as the reference to estimate available and extractable power from solar and wind power systems as source of renewable energy yearly.

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CHAPTER ONE

INTRODUCTION

1.1 Background of Study

The energy sector is one of areas that are drawing a lot of interest from stakeholders in most of public and private domains in Kenya and the world at large. There has been an exponential growth in sectors which requires energy security for their energy demand, the Kenyan population has also increased. This has led to an increase in the energy demand and thus a need to diversify the available sources of energy. The need to invest in green energy is increasing greatly with the beckoning reward of these investments with carbon credits through the Clean Development Mechanism (CDM) (United Nations, 1998).

Despite high cost of installation, hybrid systems offer several advantages either as a single system from an environmental and cost standpoint. Hybrid systems produce synergistic benefits in which the system efficiencies are typically higher than those individual technologies used separately; some hybrid systems simultaneously improve the quality and availability of power (Jimenez & Lawand, 2000).

A well-designed hybrid system can substantially reduce power dependence on conventional power source from the grid. A Hybrid system is a cost-effective solution to rural electricity needs especially for low power load applications less than 10 kWh/day; Wind/Solar PV Hybrid Systems are very attractive since the peak operating conditions for solar and wind power occur at different times of the day or even during different seasons (Fingersh, Hand & Laxson, 2006).

Currently St. Francis Xavier Girls High uses energy from solar- wind hybrid system, however, they are facing solar wind energy shortage thus need for national grid energy. According to Kumar and Rosen, (2011), it is not theoretically possible to convert more than 29 percent of the sun’s light into energy using for instance crystalline solar cells.

Realistically, the efficiency for a PV panel is likely closer to 24 to 25 percent because of factors like heat and soiling. Therefore, it is necessary to keep solar PV on suitable conditions to ensure that at least 24 percent of solar energy is harnessed. Cells are either mono-crystalline, polycrystalline or amorphous). Mono-crystalline cells have higher efficiency than polycrystalline since they are made from high grade silicon. Its efficiency rate is typically between 15%-20% while the efficiency of polycrystalline is typically between 13%-14% (Steven, Hegedus & Luque, 2003).

Wind is available during the day and at night, this makes wind more preferable for power generation in small or large scale. The Wind turbines requires a minimum wind speed 'cut in' speed before they start producing power. For small wind turbine the cut in speed typically ranges from 2.5 m/s to 4 m/s. After the cut in wind speeds, wind turbine power increases rapidly with increasing wind speed until its start leveling off as it approaches peak power. The available power in the wind is given according to the equation 1 (Manwell, McGowan , & Rogers, 2012).

$$P = \frac{1}{2}\rho A v^3 \quad \text{.......} 1$$

where ρ is the air density, A is rotor Area , v is wind speed

1.2 Statement of the Problem

Increased demand for clean energy and ensuring energy security to oversee Kenya's vision 2030 is possible with the use of solar module (PV systems), wind turbines and other renewable energy sources. The power produced from Wind-Solar hybrid system was considered adequate to meet the power demand for at St Francis Xavier school. However, this was not the case and thus need for national grid power; the study was designed to develop strategy(s) to reduce the dependence on the national grid power and hence maximizing the power production from renewable energy sources (wind and solar).

1.3 Justification of the Study

Power from the grid was relatively expensive as compared to power from the other renewable sources. St. Francis Xavier School stakeholders appreciated the benefit of renewable energy and installed a Wind–Solar hybrid systems in the school. However, power from Wind- Solar hybrid system was not enough and requires power from the grid to meet the power demand in the school. The development strategies for hybrid system identified by the study will optimize power from renewable sources, and reduce the power from the grid. The result of the study substantially improved its performance thus reducing the cost of energy in the school.

1.4 Hypotheses

Development of optimization Strategies for the existing Wind-Solar Hybrid system does not increase the power generation at St Francis Xavier Girls High Naivasha.

1.5 Objectives

1.5.1 Main Objective

The main objective of the study was to explore the optimization strategies for the existing wind-solar hybrid system at St. Francis Xavier Girls High school.

1.5.2 Specific Objectives

The specific objectives of the study were to;

1. Determine the Energy load/demand in St Francis Xavier Girl High school
2. Evaluate the performance of the installed wind solar hybrid system (Energy Production).
3. Determine the potential optimization options for a wind solar hybrid system by simulation.
4. Evaluate the cost of optimized wind solar hybrid system design.

1.6 Study Area

The study focused on wind and solar hybrid system installed at St Francis Xavier Naivasha (coordinate°45'30.1"S 36°28'36.9"E). Figure 1.1 is site location of the case study showing adjacent features.

Figure 1.1: Location map (https://www.google.com/maps/**)**

1.7 Conceptual Frame Work

Figure 1.2 conceptualizes the wind-solar hybrid system design from sources to the load. The system comprises of two wind turbines, 30 solar panels (polycrystalline) and national grid power, converters, charge controllers and batteries connected to appliances.

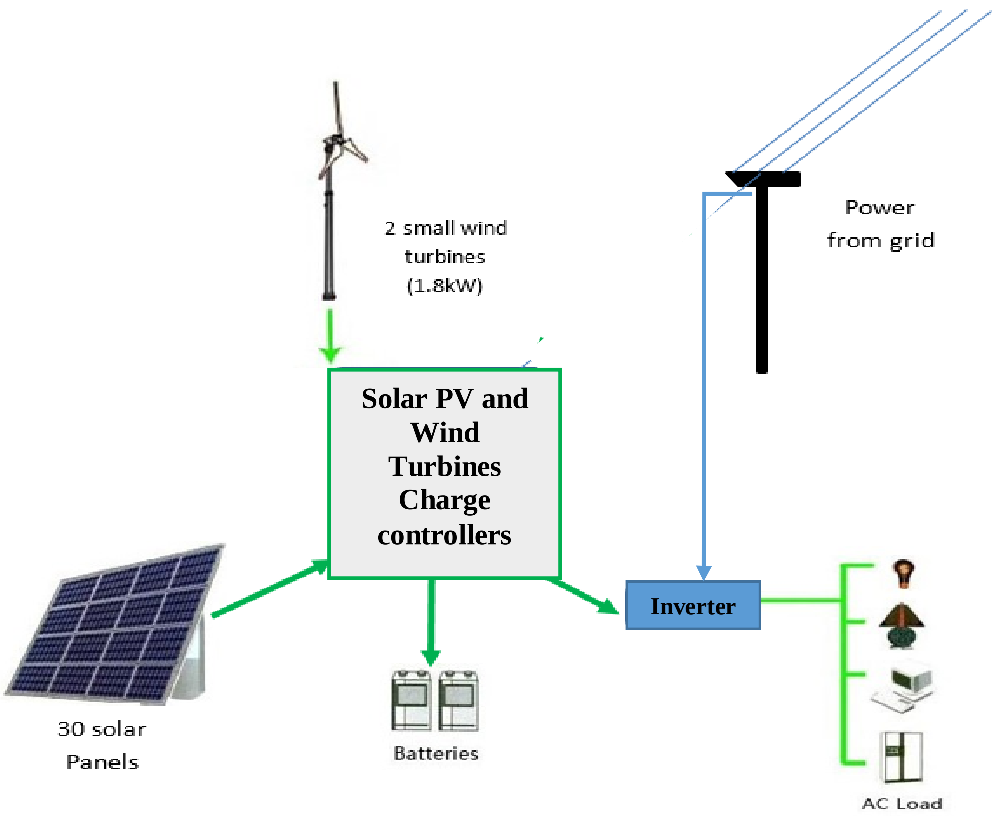

Figure 1.2: Conceptual frame work.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Principles

The direct conversion of wind and solar energy to electricity has advanced markedly over last two decades, significantly reduced prices of photovoltaic modules and Wind turbines due to the availability of incentives in many parts of the world, and has drastically increased its applications especially in third world countries. The design of hybrid power systems depends on specifics of the existing power system, the available renewable sources and the load profile. Given these constraints, there are numerous options including the wind turbine design, amount of wind penetration, inclusion of other renewable power sources, energy storage systems, and the nature of load management. However, the efficiency of wind systems is determined by following factors; wind turbine efficiency which is due to air density, area of the rotor, wind velocity, power coefficient factor (C_p), Thrust Coefficient factor (C_T) (Manwell, McGowan , & Rogers, 2012).

The efficiency of photovoltaic cells of a module is measured under controlled standard test conditions (STC) i.e solar irradiance 1 kW/m^2, cell temperature 25 ºC, air mass 1.5, although the nominal operating cell temperature (NOCT) in its actual applications is much higher than the reference cell temperature 25ºC; the higher NOCT is considered as one of the major causes of reduced efficiency and electrical power output of photovoltaic modules. The applicability and optimum design of the hybrid photovoltaic systems have been investigated by various studies (Ulgen & Hepbasli, 2003; Serrano, Rus & Garcia, 2009; Singh, 2010).

However, the studies on wind-solar hybrid power systems are very limited in Kenya since wind energy applications have only extensively appeared for about less a decade in the Kenyan market.

2.1.1 Solar PV in a Hybrid system

Solar (PV) Modules may provide a useful complement to wind turbines in hybrid power systems. Solar PV modules provide electrical power directly from incident solar radiation, solar PV modules generates DC power source. They usually operate in conjunction with storage and a separate DC bus. In larger systems they may be coupled with PV grid inverters and thus become AC coupled power source. Variations of the solar resource on annual and diurnal scales, as well as on the time scales of front driven weather patterns and the passage of clouds, complicate the design of hybrid systems. The maximum power from the panels is equal to the product of the maximum current and the maximum voltage (Manwell *et al*., 2012).

2.1.2 Solar PV Performance Characterization

Solar PV modules converts irradiance directly to DC electricity, solar PV has no moving parts, therefore they are highly reliable, long lifespan and require little maintenance, mostly they just need to be kept clean and off from shading. Solar PV are rated in terms of peak watts. Power is proportional to irradiance i.e for a PV rated 100 W_p will produce 100 W when the irradiance on the Solar PV is 1 kW/m^2. However, efficiency of module is 80%, it means that when a 100 W solar PV module is used in a battery system, the available power is about 80 W (Jimenez & Lawand, 2000).

2.1.3 Solar PV Capital and Operating Cost

Solar PV are available in a variety of ratings; the cost of PV array is driven by the cost of the modules despite the declining prices due to incentives from the Government. The solar PV are still relatively expensive typically the price of a modules ranges from $4.00 to $5.50 per W_p (Ksh 400- 550) in global market, the module is expected to last for about 20 years (Jimenez & Lawand, 2000). However after incentive by the Kenyan Gorverment and other countries as away of promoting renewabe energy uptake in world, the price of solar module in market has gone low and ranges from 50 Kshs –110 Ksh per W_p as 2017 market price.

2.1.4 Solar Irradiance

The power generated by Solar PV modules is determined by the level of solar radiation falling on the module, the module characteristics and the voltage of the load to which it is connected. Figure 2.1 shows the current–voltage characteristics of a typical PV panel at a given temperature and solar insolation levels.

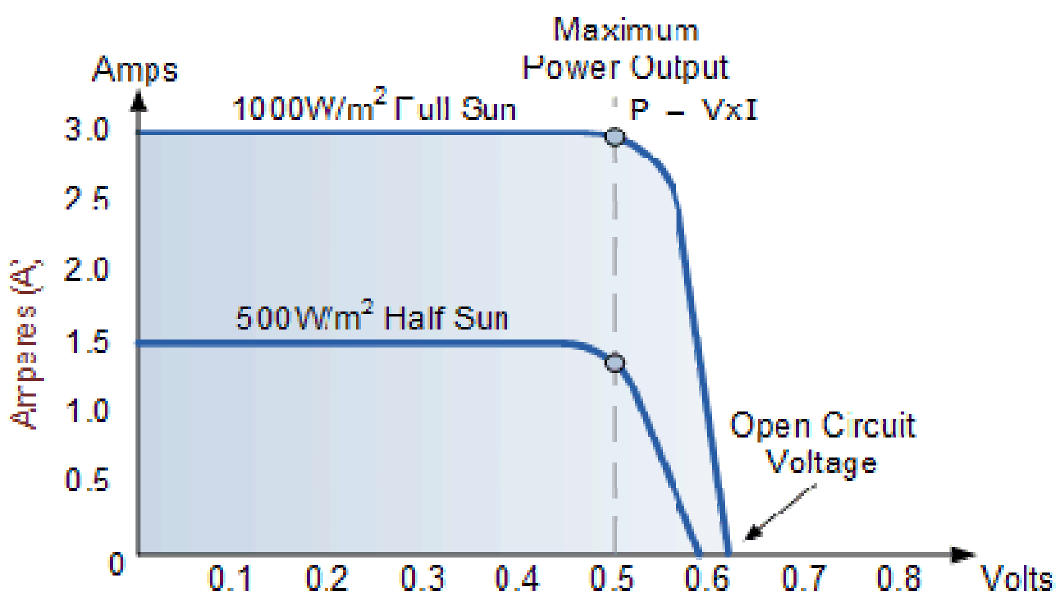

Figure 2.1: Current–voltage characteristics of a typical PV panel

(Source; https://www.google Current–voltage characteristics of a typical PV panel).

2.1.5 Effect of Irradiance on Short Circuit Current (Isc)

Short circuit current is affected by the amount of the irradiances striking on a module, reduced irradiance due to environmental conditions such as clouds, dust or even shading of the cells reduces the current proportionally. However, in case of blocked cells the output power reduces by half. Equation 2 was a modified approach to calculate the charging current in 24V system for a known irradiance (Twidell & Weir , 2006).

$$I_{(24V)} = \frac{I_{(sc)STC}\ x\ irradiance\ (kW/m^2}{1\ kW/m^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..2$$

2.1.6 Wind turbine in a Hybrid systems and Performance Characterization

There are different types of wind turbines that supply DC power as their principal output. These turbines are typically in the smaller size range 10 kW or less. With suitable controls or converters, they may operate in conjunction with AC or DC loads (Manwell *et al.*, 2012).

Wind turbine converts the energy of moving air into useful mechanical or electrical energy, wind turbine needs more maintenance than Solar PV but with moderate wind greater than 4.5 m/s will often produce more energy than similar priced solar panels (Jimenez & Lawand, 2000).

In the process of producing electric energy from wind turbines features, there are numerous energy losses as shown in figure 2.2. At the rotor, there is aerodynamic loss of around 60% of wind power input. Further, there are mechanical losses of around 4% at speed increasers such as gears, and electrical and mechanical losses of around 6% at generator. In total, about 70% of wind power input is lost through wind power generator. Therefore, net electric energy generation is about 30% of wind power input (MoEP, 2015).

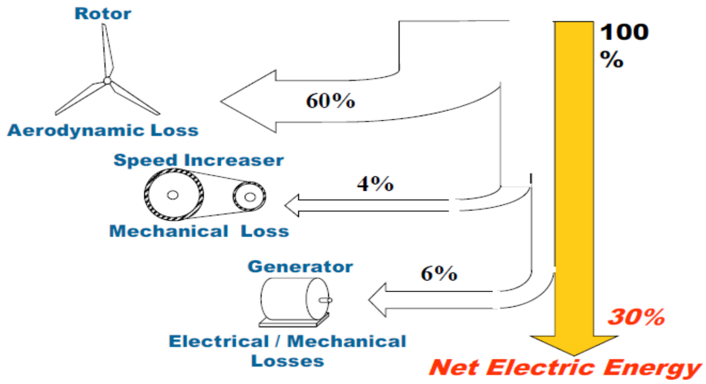

Figure 2.2: Energy losses in wind energy generating turbine (MoEP, 2015).

A wind turbine performance is characterized by its power curve (Figure 2.3) which relates wind turbine power output to the hub height and wind speed. Wind turbines produce much more power at higher wind speeds than at lower wind speeds until the wind speed reaches the cut -out speed (Jimenez & Lawand, 2000).

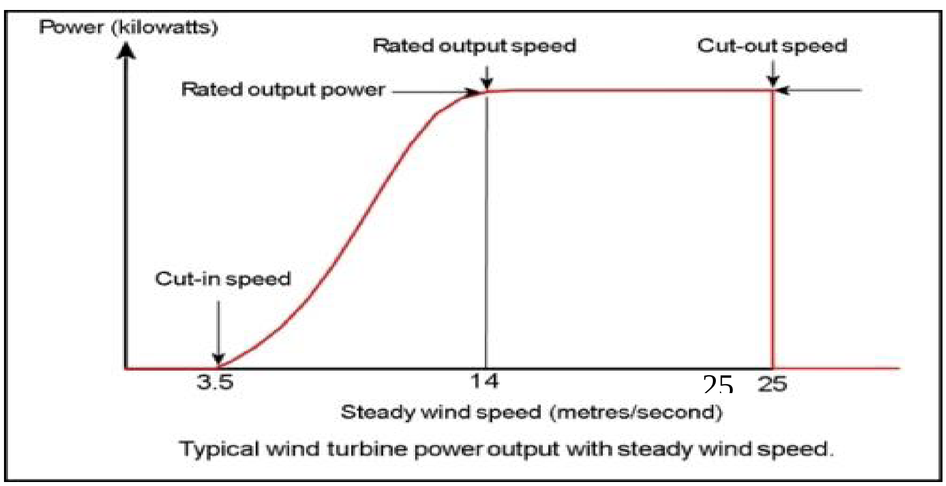

Figure 2.3: Typical wind generator power curve (Jimenez & Lawand, 2000)

2.1.7 Wind Turbine Capital and Operating Cost

Wind turbine prices vary more than Solar PV module prices, similar sized turbine can differ significantly in price due to tower costs based on design and height. Unlike the case of Solar PV, wind turbine offers economies for scale with larger wind turbine costing less per kW than smaller wind turbine, the costs generally range from $2000 per rated kW. Maintenance costs for wind turbine are variable, most small wind turbine requires some preventive maintenance mostly in form of periodic inspection (Jimenez & Lawand, 2000).

2.1.8 Wind Shear

Wind speeds and wind directions can change over a short distance, this occurs either horizontally or vertically and often caused by strong temperature inversions or density gradients in the area. Due to the adjacent feature around Naivasha, this location is subject to wind shear, the wind speed tends to lower at lower heights from the ground and increasing as the height increases (Manwell *et al*., 2012).

2.1.9 Power law

According to Power law, wind speed depend with the heights due the terrerains, the wind speed the near the ground lower as compared to some height above, equation 3 was used to determine the wind speed at height of h_2 m from 6 m and the power excpected (Ulgen & Hepbasli, 2003).

$$v_2 = v_1 \left\{\frac{h_2}{h_i}\right\}^{\alpha} \quad \text{..3}$$

where v_1 (m/s) is the actual wind speed recorded at h_1 (6 m) ,v_2 (m/s) is the wind speed at h_2 (m) and α is roughness exponetial.

2.1.10 Log Law

Wind profile was predicted by logarithmic approach considering natural surfaces were never uniform or smooth and therefore terrains affect the wind speed. The log law was modified to consider mixing at the earth's surface (Manwell *et al*., 2012).

$$V_2 = V_1 \frac{In\left(\frac{h_2}{z_0}\right)}{In\left(\frac{h_1}{z_0}\right)} \quad \text{...}4$$

where v_1 (m/s) is the actual wind speed recorded at h_1 (m),v_2 (m/s) is the wind speed at h_2 (m) and z_0 is roughness length (mm).

2.1.11 Weibull and Rayleigh Probability Density Function.

According Rayleigh and weilbull wind speed probability can be estimated based on the wind data at the monitoring station or using the model called "Weibull distribution" or "Rayleigh distribution" if wind data is not available at the project site. Weibull distribution determines two parameters k and c which represents wind speed, Rayleigh distribution is a special case of weibull distribution where only parameter k and average wind speed is needed (Kantar *et al.*, 2008; Manwell *et al.*, 2012).

$$\text{Weibull} f(V) = \frac{k}{c}\left(\frac{V}{c}\right)^{k-1} \exp[-\left(\frac{V}{c}\right)^{k}] \quad \text{...................................}5$$

$$\text{Rayleigh } f(V) = \frac{\pi}{2}\frac{V}{\bar{V}^2} \exp[-\frac{\pi}{4}\left(\frac{V}{\bar{V}}\right)^{2}] \quad \text{...................................} 6$$

According Rayleigh the average power can be obtained by considering average wind speed as follows

$$\bar{P} = \frac{6}{\pi}.\frac{1}{2}\rho A \bar{v}^3 \text{...}7$$

where ρ : air density, A:rotor area, $\bar{v}$: average wind speed, k: shape factor, c: scale factor.

2.1.12 Hybrid System Overview

Wind Solar hybrid is an electric system that combines wind energy and solar PV energy technologies. Hybrid systems may be standalone/off grid systems or grid tie systems.

The system maximizes energy harnessing protocol when neither the wind nor the solar system is generating energy, most hybrid systems provide power through batteries or without, grid tie systems is capable of supplier national grid eg Kenya power lighting company (KPLC). Alternatively, if the batteries voltage ‘run’ low when wind/solar sources are not producing thus source of power is from nonconventional, either from generator or KPLC (Kenya). Wind – Solar hybrid system consist of the following; Wind turbine, Solar panel (PV), Batteries, Charge controller, Power conditioning equipment, Safety equipment, measuring modulators and sensors.

2.1.13 Monitoring Equipment in a Hybrid system

In a modern wind solar hybrid system, many sensors are used to communicate important aspects of its operations to control the system, a remote control device or data loggers offer monitoring functions (data logging) for various environmental parameter and any additional system related parameters that gives the user an overview of the whole system. These measurements include; Speeds (generator speed, rotor Speed, wind speed, direction of rotation), Electrical Characteristics (grid power, current power factor, voltage grid frequency, ground fault, convertor operation, motion and environmental conditions). Additional parameters that can be monitored are module and ambient temperature, solar radiation, solar irradiation, wind speed (hybrid systems) in some cases also air pressure and air humidity etc.

2.1.14 Battery Bank

In an off grid systems batteries are critical in storing the energy generated and used later when needed. Batteries are rated according to cycles, basically batteries can have shallow cycles which usually ranges from 10.0% to 20.0% of the battery's total capacity or deep cycles up between to 50% to 80%. These classifications depend on the application of the batteries and products specifications (Solar Direct, 2015).

Shallow cycle batteries, are designed to deliver several hundred amperes for a few seconds, and then are quickly recharged. Deep cycle batteries on the other hand, it delivers few amperes for hundreds of hours between charges. These two types of batteries are designed for different applications and should not be used interchangeably; deep-cycle batteries are best suited for PV power systems. The battery's capacity for holding energy is rated in amp-hours there for 1 amp delivered for 1 hour = 1-amp hour (Solar Direct, 2015).

A 12V battery system has an operating normal voltage 12V when fully charged it reaches a maximum of 13.4 and low voltage of 11.5V, the Figure 2.4 and Figure 2.5 shows battery voltage under normal operation (float charging) and daily battery voltage when battery life is ending or the capacity is reducing respectively. Overall cycles are relative to the lifespan of the battery, if the battery is discharged too low the battery lifespan is reduced.

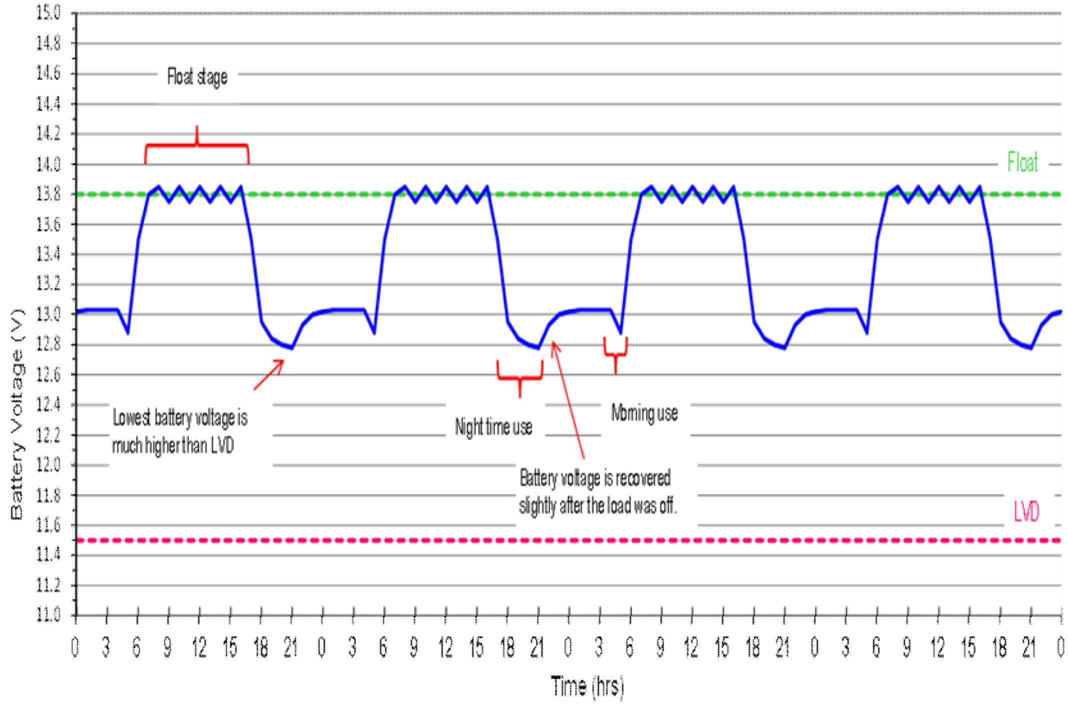

Figure 2.4: Battery voltage under normal operation Float charging.

Figure 2.4 is schema representation of charging process of a normal/healthy battery, during float charging stage the battery is fully charged. However, the charge control allows small quantity of current as result of absorption.

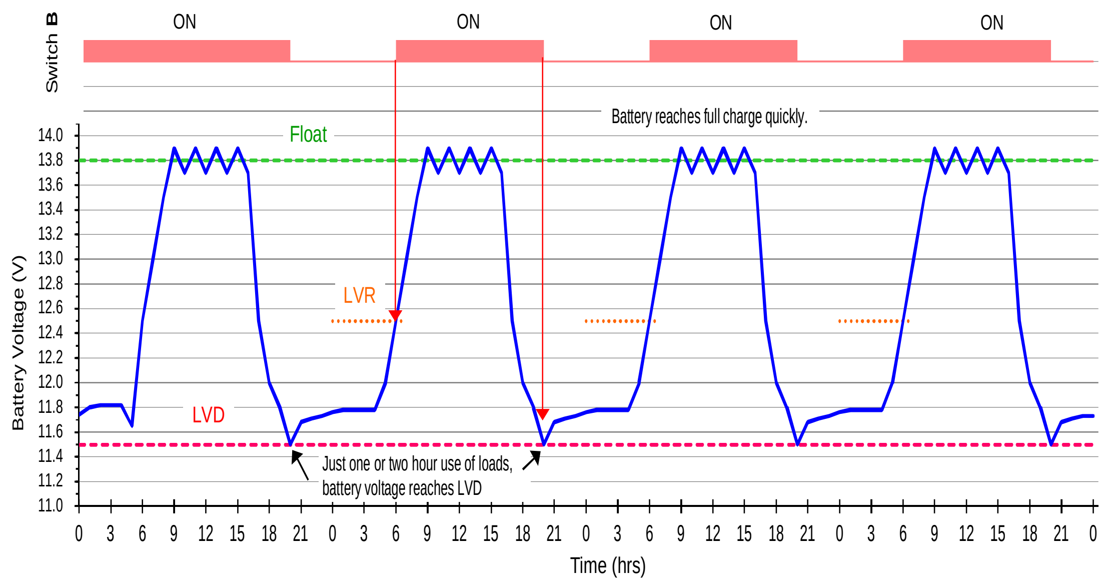

Figure 2.5: Daily battery voltage when battery life is ending.

The schematic Figure 2.5 illustrates the scenario of a "dead" battery zombie state, in this particular case the battery was fully charged within very short time in a sunny day. However, the CC LED indictor show low battery voltage immediately when the load is connected at night or during rainy session.

2.1.15. Power Converter

A power converter is an electronic device used in hybrid power generation to maintain the continuity of energy among AC and DC electrical components. It consists of an inverter and rectifier to perform the conversion from AC to DC and vice versa (Manwell *et al*., 2006).

There are two types of power conversion functions of particular significance for hybrid power systems: Rectifying and inverting rectifiers are commonly used to charge batteries from an AC source. Inverters are used to supply AC loads from a DC source, Plate 2.1 shows the inverter/charger that were used in this study.

Plate 2.1: Inverters/Charger (Mulitplus 24V/3000VA/70A)

2.1.16 Charge Controller

DC electricity generated by a solar PV module flows through a charge controller if the system has batteries. Charge controllers are often also called regulators; however, they do not regulate voltage/current but acts as switch to connect a solar PV module and a battery for charging process, and to connect load and the battery for the use of electricity. The role of charge controllers is to protect batteries since batteries are weak against over charge and over discharge. However, charge controllers are sort of switching devices that have two switches, one in between PV module terminal and battery terminal (Figure 2.6), the other is between load terminal and battery terminal, there are two charge controller technologies maximum power point tracking (MPPT) and Pulse-Width Modulation (PWM) technology, the latest technology allows a better switching control for charging efficiency.

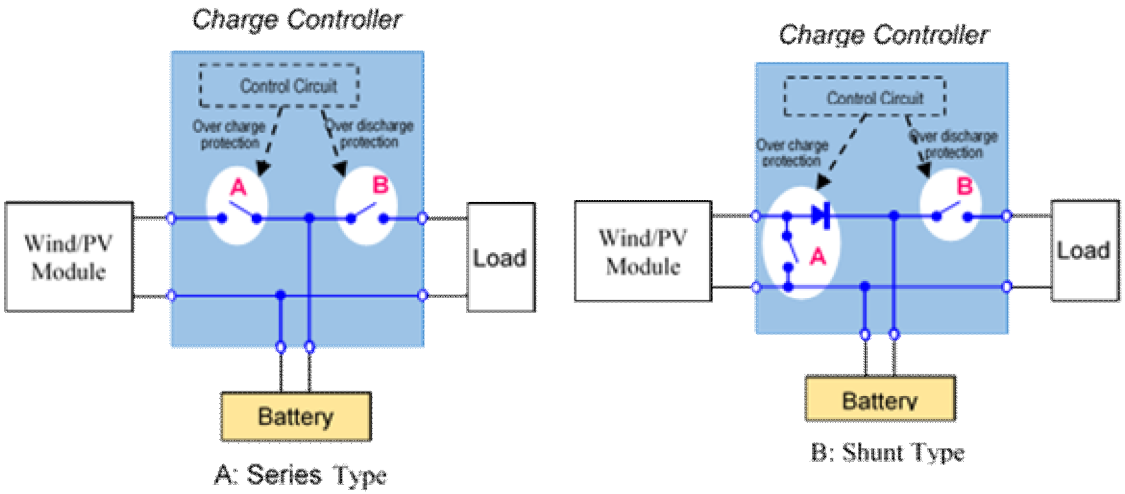

Figure 2.6: Types of charge controllers

However Maximum power point tracking (MPPT) charge controller are more efficient than PWM, MPPT charge controller will track maximum power that can be produced by solar array in case one of the strings/module is shaded or irradiance decreases (Hiwale, Patil, & Vincurkar, 2014).

2.1.17 Power Demand Constrain.

The required power by an appliance is based on wattage (W). Electrical energy is a function of voltage, current and time (equation 8). Equation 9 ensures that the system meets the power demand load, using the power generated from the hybrid system from both wind turbines and solar arrays (Mousa, *et al.*, 2013).

$$\text{Electrical power (W)} = \text{Current (I)} \times \text{Battery Voltage(V)} \quad \text{................8}$$

$$P_0(\text{wind}) + P_0(\text{Solar}) \geq P_{demand} \quad \text{..9}$$

2.1.18 Cost Analysis

The cost of raising the height of turbine and increasing the diameter of rotor can be calculated as follow;

$$\text{Cost of wind turbine} = N_w\, C_{wm} + N_w\,(250h + 2.449r^{2.7} + C_{wf} \qquad \text{..........10}$$

The equation10 can be modified to suit the study. Therefore, equation 11 shows the cost incurred from operation and maintenance of the wind turbine, these cost are a multiple of the number of wind turbines installed (N_w).

$$\text{Cost of wind turbine} = N_w\, C_{wm} + N_w C_{wf}\left(\frac{1 \times (1+i)^{y_{proj}}}{(i=1)^{y_{proj}-1}}\right) \qquad \text{................ 11}$$

where N_w is number of wind turbines, $C_{wm,}$ the annual maintenance cost for wind turbine, C_{wf} installation and fabrication cost for wind turbine, y_{proj}, the project lifetime (20 years) and i, the real interest rate (5%).

Calculation of the cost incurred when finding the optimal design and placement of the solar arrays, considers the capital and maintenance costs, the cost being a multiple of the optimal number of solar arrays (N_s).

$$\text{Cost of Solar} = N_s\, C_{sm} + N_s C_{sc}\left(\frac{1 \times (1+i)^{y_{proj}}}{(i=1)^{y_{proj}-1}}\right) \qquad \text{.......................... 12}$$

where N_s is the number of solar cells, C_{sm}, the annual maintenance and cleaning cost for solar panel and C_{sc}, the Solar panel capital cost and installation cost (Mousa, Diabat, & Fath, 2013).

2.1.19 Cost of Energy

CoE is calculated using the following equation 13 (Fingersh, , *et al*., 2006).

$$\mathrm{CoE} = \frac{(\mathrm{FCR}) \times \mathrm{ICC}}{\mathrm{AEP_{net}}} + \mathrm{AOE} \quad \ldots\ldots\ldots\ldots\ldots\ldots \; 13$$

where; CoE is levelized cost of energy (Ksh/kWh), FCR is fixed charge rate per year, ICC is initial capital cost, AEP_{net} net annual energy production (kWh/yr), AOE annual operation.

$$\mathrm{AOE} = \mathrm{LLC} + \frac{(O\&M + LRC)}{\mathrm{AEP_{net}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots 14$$

where; LLC is land lease cost, O&M is levelized cost, and LRC is levelized replacement/overhaul cost. Alternative approach for calculating cost of energy unit by KPLC monthly electricity bill was adopted.

2.2 Previous Work Relevant to the Study

2.2.1 Solar Energy Kenya

Omwando *et al*. (2013) investigated the solar energy potential in Nakuru between longitudes 35°28'and 35°36'East and latitudes 0°12'and 1°10'South. An altitude of 1859 m above the sea level. The insolation values were measured for Nakuru municipality; the minimum recorded monthly value was 4.8 kWh/m^2/day. The results show that Nakuru region has a moderate and high solar energy potential, with an average daily insolation of 6.9 kWh/m^2. The maximum value recorded was 9.8 kWh/m^2/day in February 1997, and in the same year maximum value recorded was 4.8 kWh/m^2. Solar energy within Nakuru region has the expected energy output calculated from month to month and season to season in kWh/m^2 as in figure 2.7 (Omwando, Kinyua, Ndeda, Marigi, & Kibwege, 2013).

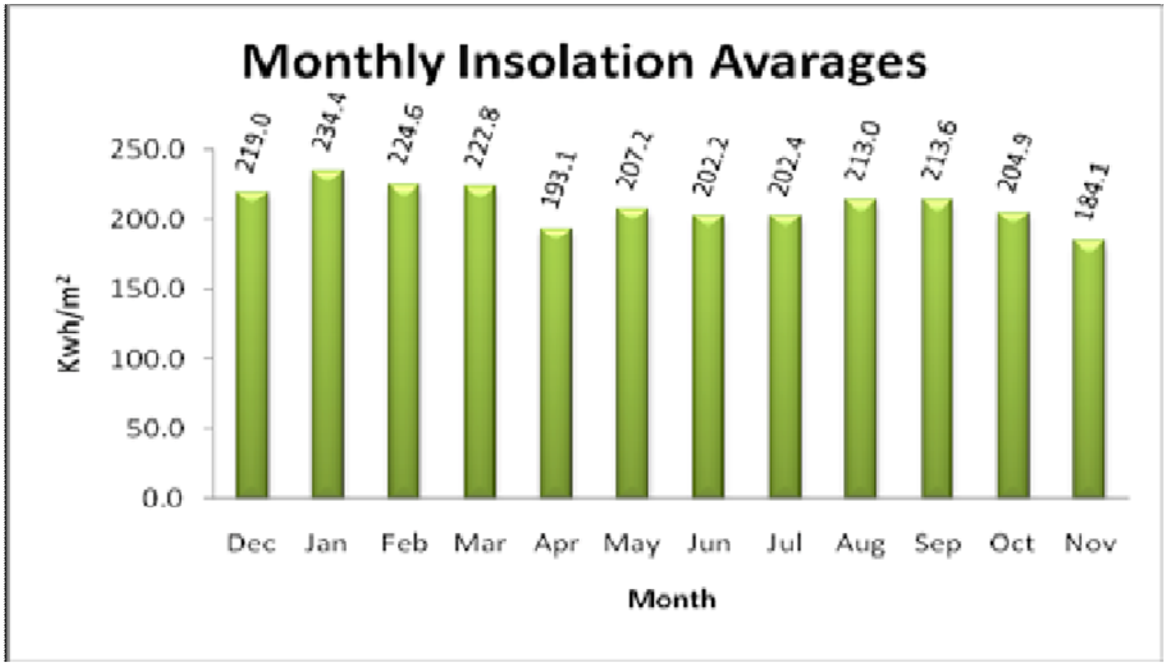

Figure 2.7: Monthly solar energy availability in Nakuru (Omwando et al., 2013).

2.2.2 Wind Parameters in Kenya

Wind is moving air, the energy in wind comes from the sun when the sun shines, and it heats the Earth. Land usually absorbs and releases energy more quickly than water. The air over the land gets hotter than the air over the water. The warm air rises and cooler air rushes in to take its place. Wind energy has a wide application in day to day life, such cooling.

WinDForce Ltd, 2013 carried out an assessment for development of wind Atlas for Kenya. The assessment was carried out in Geographical Information systems (GIS) environment using wind mast datasets, NCEP/NCAR Reanalysis, Shuttle Radar Topography Mission (SRTM) Digital Elevation Model and Global Land Cover (GLC,

2000) datasets. Table 2.1 shows wind speeds for potential areas in Kenya at height of 80 m above the ground.

Table 2.1: High wind potential regions in Kenya assessed from the Meso map-study (WinDForce Ltd, 2013).

No.	Province	County	Potential Area (km^2)	Long term Wind Mean Speeds at 80m (m/s)	
				Minimum value of mean annual wind speed	Maximum value of mean annual wind speed
1	Eastern	Marsabit	75,596	4.96	8.47
2	Rift Valley	Turkana	68,314	2.73	6.6
3	North-Eastern	Wajir	53,413	5.64	6.53
4	North-Eastern	Garissa	44,459	5.77	7
5	Coast	Tana River	38,610	5.32	7.02
6	Eastern	Isiolo	24,881	5.8	6.84
7	Rift Valley	Samburu	21,102	5.49	6.57
8	Coast	Kilifi	12,310	5.29	7.41
9	Rift Valley	Baringo	10,942	4.8	6.3

The wind speed for entire Kenya was categorized as Class I (greater than 8.5 m/s), Class II (7.5 m/s - 8.5 m/s), Class III (6.5 m/s – 7.5 m/s) and Class IV (6m/s – 6.5 m/s) (WinDForce Ltd, 2013; Rahul, Mohammand, Neelu, Deepshikha, Kiva, Mungai, 2018).

At 100 m above the ground, it was observed that Marsabit in Eastern division has the largest potential area with a maximum of mean annual wind speed of 9.27 m/s and minimum of mean annual wind speed of 5.32 m/s followed by similar wind speeds in Turkana County in Rift Valley province. Geographically, in Central provinces, counties such as Nyeri experiences fairly good wind speeds with maximum value of mean annual wind speed of 7.44 m/s covering a potential area of 3359 sq km followed by Kirinyaga with 7.41 m/s and 1481 sq km. In the Rift Valley province, counties such as Turkana has maximum potential area of 61353 sq km with maximum of annual mean wind speed of 7.11 m/s followed by Nakuru with 29286 sq km and 6.52 m/s.

Figure 2.8 show a map of Kenya illustrating regions experiencing different wind speeds at height of 100 m which represented in different colour code. Green colour represents most part of Kenya followed by yellow which indicate average wind speeds 7.0 m/s -7.5 m/s (Rahul, *et al.*, 2018).

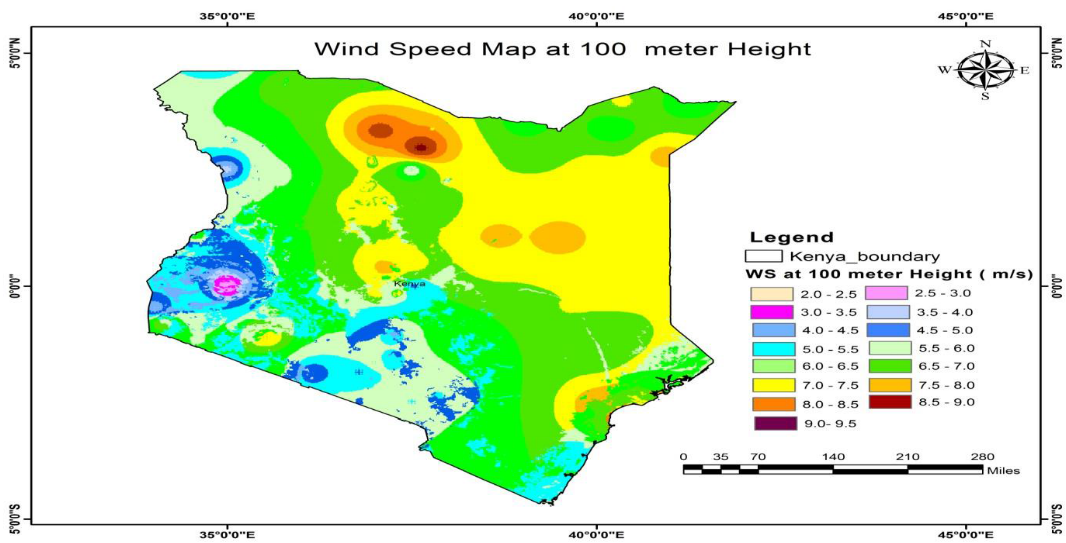

Figure 2.8: Wind Speed Map of Kenya at 100 m above the ground (WinDForce Ltd, 2013).

Marsabit recorded lowest monthly average wind speed of 7.440 m/s which was registered in December 2002 while August 2002 recorded the highest average wind speed of 14.490 m/s (Kamau *et al.*, 2010). The average wind speeds at St. Francis Xavier site was 3.54 m/s at height of 10 m (Maina *et al*., 2016).

CHAPTER THREE

INTRODUCTION

This chapter focus on the research design, methodology and procedures that were employed to measure and gather data for energy generation from wind turbine and solar PV, irradiance, energy usage from the grid and load demand/consumption at St. Francis Xavier Girls School for February, March and April 2016.

3.1 Materials and method.

Power monitoring equipment were installed at the site. These included; wind sensor kit, Data logger, and analyzing software.

Daily electrical energy demand was determined with aid of electrical power equation 8, the wind solar hybrid system performance and power demand were analyzed using equations 2, 15 and 16. The solar wind hybrid performance was characterized through simulation of data from Solar PV and wind turbines in various channels obtained in data logger, total power from each channel was determined.

The wind shear, power law was used to estimate the power output based on elevation height of the wind turbine tower as in equation 3.

In a previous study (Mishra, Panigrahi & Kotharin, 2014), realize the system configuration by use of HOMER software. Thus stimulating and optimizing the best solution for a hybrid system and generated a report incorporating all the aspects of a wind-solar system; therefore, HOMER software was chosen as a research tool to assist in optimizing the system in this study.

3.1 Study Design.

Experimental designs (section 3.2.1 & 3.2.2) was used to study the power generated by the wind solar hybrid system for a period of three months. Power generated by the wind turbine and the solar PV was stored in battery bank and inverters/chargers were used to supply AC power output.

The study adopted the design as follows; three inverters/chargers were connected to sanatorium, laboratories, classes, library, and staff room, dining hall, administration, classes and dormitory and to the computer room. The grid power was incorporated in system as standby to recharge the system when there was no or little power from renewable sources (wind and solar). Power from all three sources was fed into the data logger which recorded the following; Temperature, Voltages, Currents, Wind speeds, irradiance and power density.

3.2 The Experiment Setup

St. Francis Xavier School Wind Solar Hybrid System consisted of thirty Solar photovoltaic modules (polycrystalline) on roof, two wind turbines installed at 6 m height (fixed-guyed), three AC-DC inverters and wind sensor, the following procedure was used to collect data.

Figure 3.1 illustrate the experimental setup data collection procedure for solar, wind, grid power and other measurements input. Data logger internalizes all measurements and store in memory disk/card into a comma separated values (CSV) file.

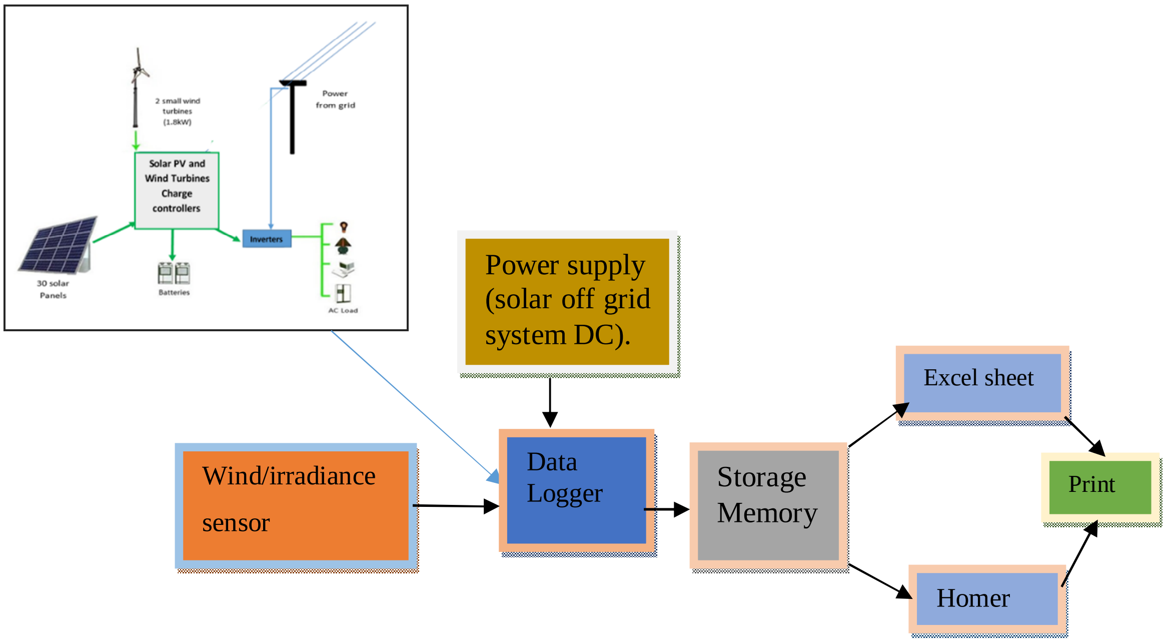

Figure 3.1: Hybrid system experimental setup.

3.2.1 Small wind Turbines

Two small wind turbines each rated 0.9 kW were existing, 1.8 kW power was expected to be generated from the two wind turbines at 6 m height. Wind turbines were connected to two charge controllers (C/C) that switches ON-OFF when charging the batteries. Data logger interpreted current data as voltage (V) in channel CH9 and CH10 for WT1 and WT2 respectfully. Converting the raw data to current the ratio of 4V:50A was considered at channel CA09 and CA10, the ratio was based on manufactures' manual (Hioki, 2018)

$$Power\ (W) = V_{Bat}\ x\ I_{Iwind} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 15$$

Plate 3.1 illustrates two wind turbines used in the study, growing trees (terrains) was observed.

Plate 3.1: Wind Turbines at St. Francis Xavier Girls School

The data logger was configured to measure macro amperes node/amplitude, and corresponded to the cut-in wind speeds. The wind anemometer was installed several meters apart, where terrains could have caused wind turbulence compromising the wind speeds measured and that one captured by the wind turbines.

3.2.2 Solar PV

Thirty Solar PV modules (polycrystalline) each 100 Wp, were arranged in 3 sets of array in parallel and series connection (2 modules in series 5 set of 2 in parallel) these sets were connected to three charge controllers (C/C). Plate 3.2 illustrated the Solar PV installation used in this study.

Plate 3.2: Solar PV at St. Francis Xavier Girls School

Figure 3.2 illustrate the schematic configuration of the Solar PV into three arrays as they are mounted on roof top.

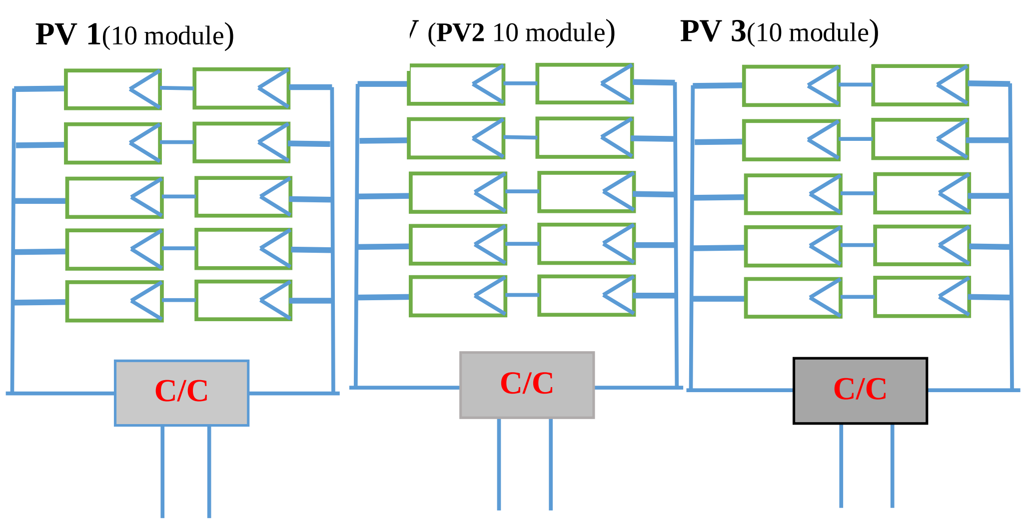

Figure 3.2: Schematic arrangement of array for St. Francis Xavier Girls School

Data for wind speed, and irradiance for power calculation was recorded per second and measurement was done determining the charging current and voltage flowing through the charge controllers and inverters. Data logger was configured into 17 channels (CH), CH 01,03,11,12 and 13 representing wind speed, Irradiance (W/m^2), PV_1, PV_2 and PV_3 respectively.

Data logger interpreted all data as voltage (V), converting voltage to current. A ratio of (4V:50A) was considered based on manufacturer recommendation. Channel (CA), CA12, 13 and 14 represent current from each PV channel. PV current and battery voltage was considered as the power (Hioki, 2018).

$$\text{Power (W)} = V_{Bat} \times I_{IPV} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 16$$

$V_{Bat.}$ Battery Voltage (Channel CA08), I_{IPV} PV currents (channel CA 12, 13 and 14).

Table 3.1 illustrates modules specifications that were used in the study and thus used to calculate the power of the solar arrays.

Table 3.1: Solar PV polycrystalline module Specification (Solinc East Africa Limited)

Module Rating	**100 W**		**STC**
I_{sc}	6.3A	Irradiance	1.0 kW/m^2
I_{mp}	5.82A	Temperature	25^{0}c
V_{mp}	17.2V	AM	1.5
V_{oc}	21.7 V	Efficiency	80%
P_{max}	100.1W	Vendor/Installer	Chloride Exide

3.2.3 Power Storage and Distributions

The Power was stored in battery banks, there were 24 pieces of Gaston 2 V 1200 Ah, the total battery capacity was calculated as 57.6 kWh. Inverters were used to convert DC to AC power (Plate 2.1), the inverters specification were 24V/3000VA/70A (Vectron Energy, MultiPlus), and three inverters/charger were considered in this study.

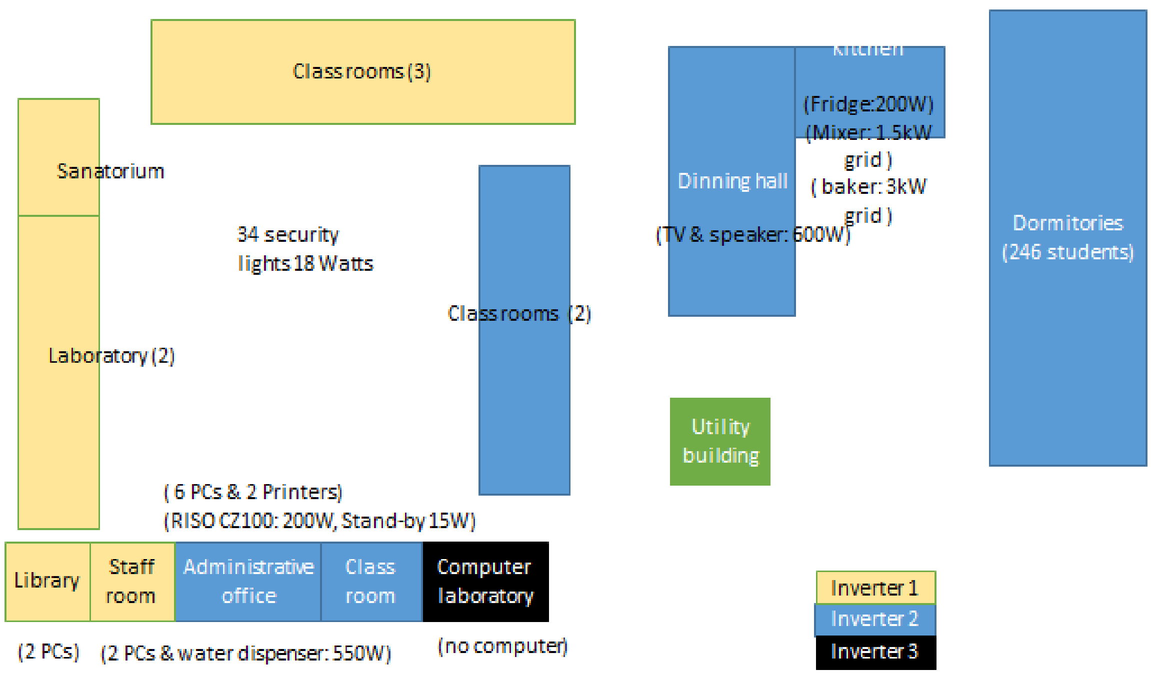

Figure 3.3: Distribution layout for St. Francis Xavier Girls School

Figure 3.3 show the load distribution to the Inverters/charger; Inverter 1 was connected to sanatorium, laboratories, classes (2A, 3A, 3B, 4A, and 4B), library, and staff room. Inverter 2 was connected to dining hall, administration block, classes (1A, 1B, 2B) and dormitory. Inverter 3 is connected to computer room however during the time of study there were no computers.

3.3 Data collection and sampling

Data for energy generation from wind turbine and solar PV, irradiance, energy usage from the grid was measured per second by use of data logger as a tool (hybrid system monitoring instrument) for a period of three months for 24 hours i.e February, March and April 2016. The energy demand load was recorded in Channel CH15, CH16 and CH17 of the data logger (Plate 3.3) as raw data, converting raw data to an energy data the following ratios was considered {0-4-10V:0-100-250} (Hioki, 2018).

Vectron Energy MultiPlus 24V/3000VA/70A are type of Inverter/Charger which are programmable (Plate 2.1); their reading was in channel CA15, CA16 and CA17 this indicated energy data converted to demand/load charging/discharging current in reference to the system batteries bank.

Plate 3.3: Data logger

3.4 Data Analysis

The statistical analysis was done by use of Excel (Microsoft office) and the average, summation power was determined, hence daily energy production was calculated. HOMER software was used in the systems optimization and for cost effectiveness. The result was used to evaluate the best economical options for optimizing power generation.

CHAPTER FOUR

RESULTSAND DISCUSSIONS

4.1 Introduction

This chapter presents the results, analysis and discussion were precise to the objective of the study.

4.2 Daily Energy Load.

Daily Energy demand analysis in St. Francis Xavier girls was done based on AC-DC Inverters/Chargers data recorded by a data logger. An energy consumption analysis was conducted and identified 14 categories of appliances, the usage hours per appliances in every category was defined and total energy demand was calculated.

Table 4.1 presents the list of electrical appliances used in St. Francis Xavier Girls School. Secondly daily energy load demand/consumption was analyzed for 24 hours from three Inverters/Chargers; 1, 2 and 3, as an alternative to determine the actual energy consumption as it was measured and recorded by data logger in channel CA15, CA16 and CA17 respectively during the study period.

Table 4.1: List of Appliances and energy demand.

S/N	Appliances	Power rating (W	Units	Hour(s)	Energy(kWh)	S/N	Appliance	Power rating (W)	Units	Hours	Energy(kWh)
1	Security	18	38	11	7.524	8	Computers	60	5	8	2.4
2	Dormitories Bulbs	18	36	5	3.24	9	Printers 1(standby 15w	200	1	2	0.4
		20	21	5	2.1		Riso-CZ100)	15	1	6	0.09
3	Freezer	200	1	12	2.4	10	Printers 2(standby 2w	250	1	3	0.75
							HP Laser Jet	2		5	0.01
4	Dining bulbs	40	16	5	3.2	11	Water Dispenser	550	1	6	3.3
5	Classes bulbs	18	24	4	1.728	12	TV/Decoder	110	1	4	0.24
6	Offices bulbs	20	8	4	0.64	13	Speakers	600	2	4	4.8
7	Laptops	40	4	4	0.64	14	DVD	5	1	4	0.02
			kWh/day		21.47				kWh/day		12.01
			Total Energy Demand		33.48		kWh/day				

Table 4.2 (a, b & c) summarizes the average load power. Inverters/Chargers rated 3 kVA were evaluated by analyzing power flow per second from each were obtained. Inverter 2 indicated higher power demand flow of 4.6 kW beyond its rated capacity of 3 kW and no power demand from Inverter 3, this causes an overload to the system.

Table: 4.2 (a): Average weekly power load in February 2016.

	Week 1 February	Week 2 February	Week 3 February	Week 4 February
Inverter 1(3kW)	1.21 kW	0.68 kW	0.77 kW	0.48 kW
Inverter 2(3kW)	4.06 kW	4.30 kW	4.56 kW	2.26 kW
Inverter 3(3kW)	0.00 kW	0.00 kW	0.00 kW	0.00 kW

Table: 4.2 (b): Average weekly power load in March 2016.

	Week 1 March	Week 2 March	Week 3 March	Week 4 March
Inverter 1(3kW)	0.53 kW	0.75 kW	0.57 kW	0.49 kW
Inverter 2 (3kW)	3.44 kW	4.34 kW	3.66 kW	2.54 kW
Inverter 3 (3kW)	0.00 kW	0.00 kW	0.00 kW	0.00 kW

Table: 4.2 (c): Average weekly power load in April 2016.

	Week 1 April	Week 2 April	Week 3 April	Week 4 April
Inverter 1 (3 kW)	0.49 kW	0.70 kW	0.03 kW	0.39 kW
Inverter 2 (3 kW)	4.60 kW	0.83 kW	0.88 kW	0.87 kW
Inverter 3 (3 kW)	0.00 kW	0.00 kW	0.00 kW	0.00 kW

Figure 4.1 (a) shows the average power demand flow from Inverter 1, 2 and 3 respectively the consumption is relative to the appliances in table 4.1. The average power peak load recorded by inverters/charger was 0.79 kW, 3.8 kW and 0.0 kW respectively.

In this particular month in February 2016 Inverter 2 was operating at 3.8 kW beyond its rated capacity of 3.0 kVA, more than 27 % allowable operation tolerance these was due appliances that were in use at the same time.

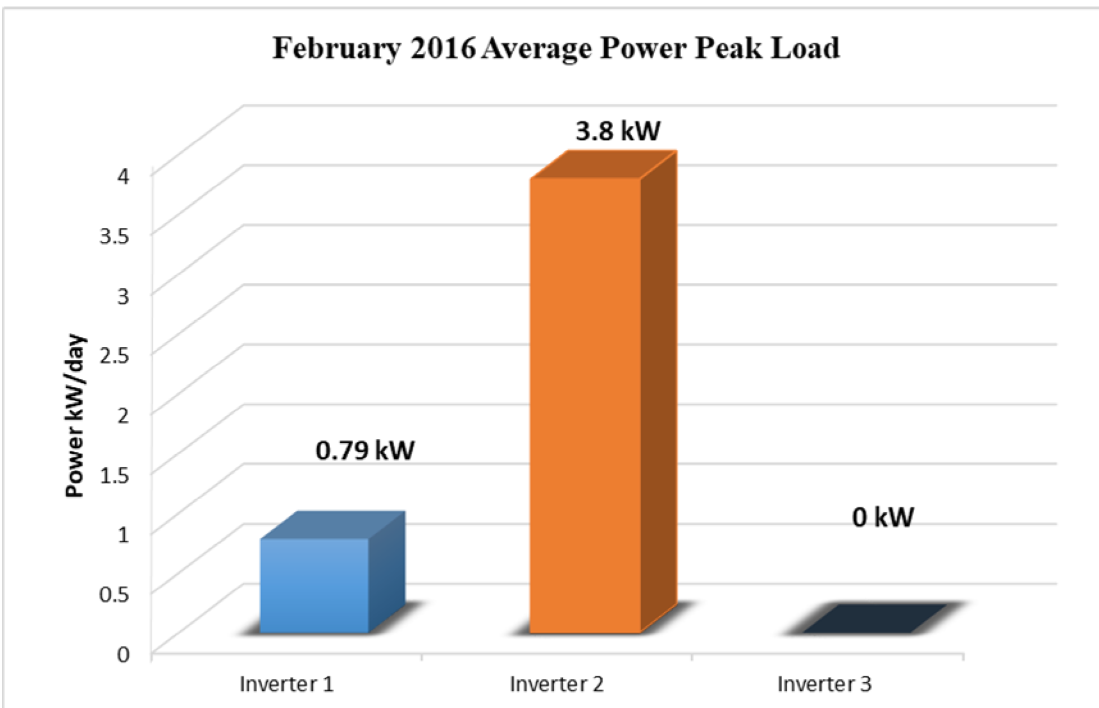

Figure 4.1 (a): Average power demand in three inverters/chargers in February 2016.

Figure 4.1 (b) shows the average power demand flow from Inverter/charger 1, 2 and 3 respectively as per the consumption of the appliances in table 4.1. The average power peak load recorded by the inverters/chargers was 0.58 kW, 3.56 kW and 0.0 kW per month respectively. In this particular month (March 2017) the study result shows Inverter 2 was overloaded beyond its nominal capacity of 3.0 kVA, the overload was about 19 % more than allowable operation tolerance of Mulitplus Inverter/charger. This may be due to too many appliances switched ON at same time leading to higher total power peak.

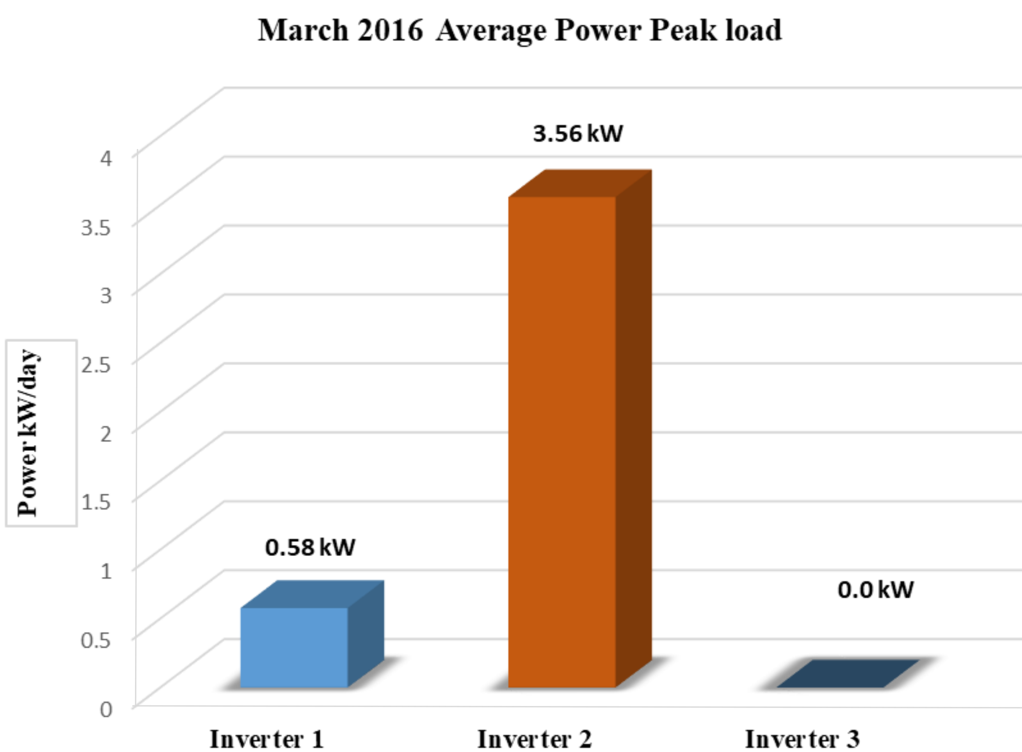

Figure 4.1 (b): Average power demand in three inverters/charger in March 2016.

Figure 4.1 (c) shows the average power demand flow from Inverter/charger 1, 2 and 3 respectively as the consumption of the appliances in table 4.1. The average power peak load recorded from Inverters was 0.40 kW, 1.54 kW and 0.0 kW per month respectively. In this particular month (March 2016) inverters/chargers 1, 2 and 3 the result shows the Inverter/charger were operating below their rated capacity of 3.0 kVA. This could have resulted to higher energy consumption from wind-solar in month of February 2016 which recorded higher energy demand if there was no overload.

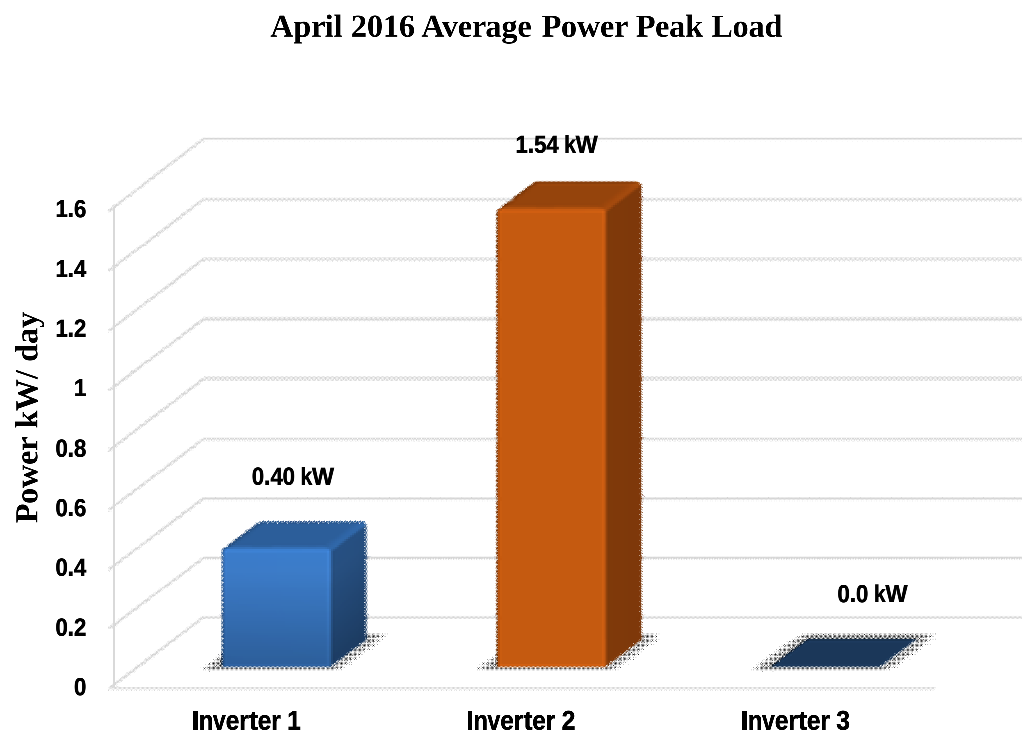

Figure 4.1 (c): Average power demand in three inverters/charger in April 2016.

The Figure 4.2 indicates weekly power peak load distribution among three inverters/chargers. In month of February 2016; Inverter 1, indicated higher power peak load of 1.21 kW in week 1 as compared to 0.46 kW in week 4. During week 4 the school was closed for the midterm holiday. Inverter 2, indicated slightly higher power peak load of 4.56 kW in week 3, week 1 (4.06 kW) week 2 (4.30 kW) respectively while in week 3 it recorded lower power peak load of 2.26 kW, same percentage consumption drastically reduced during midterm holiday by inverter/charger 1. However, inverter/charger 3 recorded zero percentage load demand, these was because there were no electrical appliances in computer laboratory.

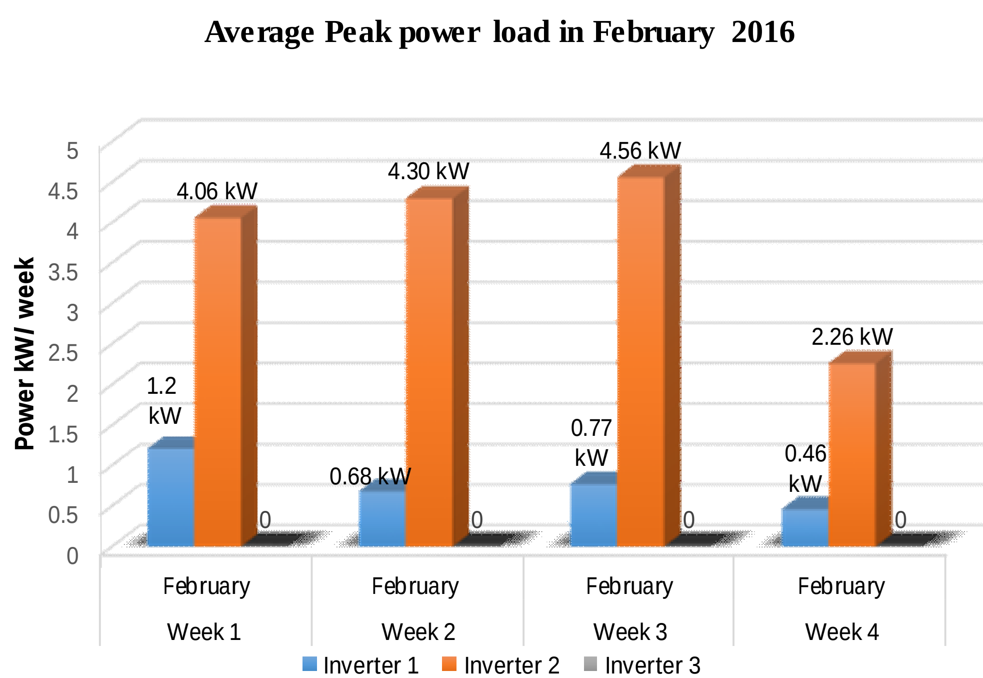

Figure 4.2 (a): February weekly power load Inverter/Charger 1, 2 & 3

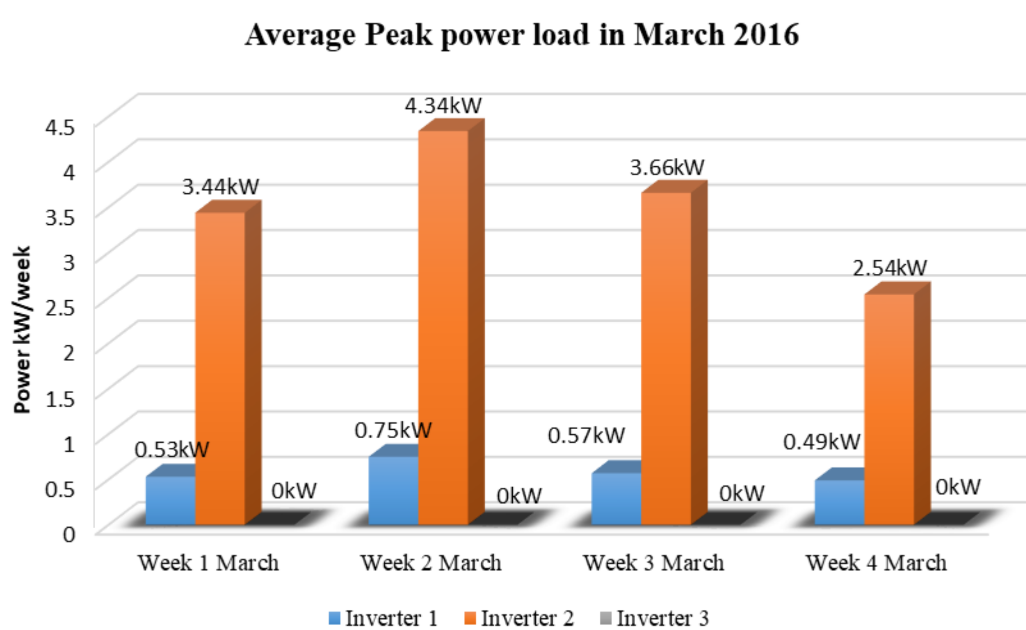

Figure 4.2 (b): March weekly power load Inverter/Charger 1, 2 & 3

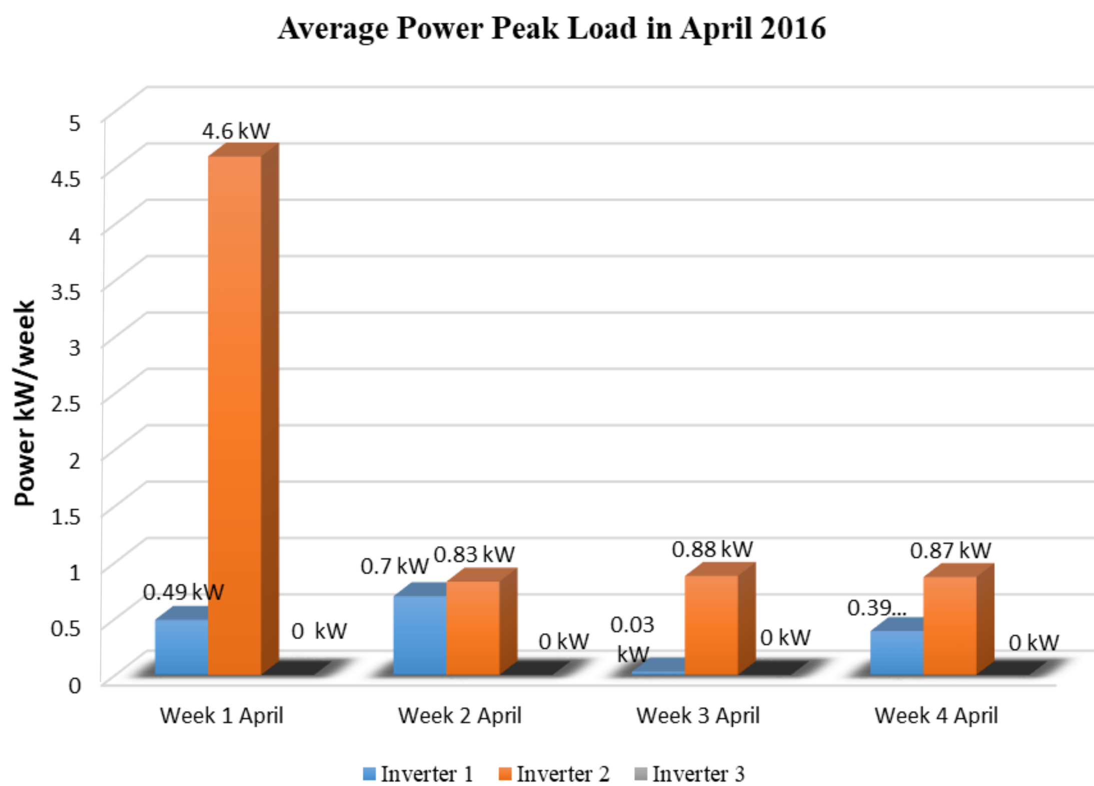

Figure 4.2 (c): April weekly power load Inverters/Charger 1, 2 & 3.

Figure 4.3 (a & b) shows the daily load curve for Inverter/Charger 1, 2 and 3, Inverter/charger 2 indicated highest peak loads as compared with other inverters/chargers in February and march 2016. From these observations, it is clear that quite a number of appliances were connected to inverters 2. Implying that load distribution was not equally distributed and this overloaded inverter 2 while inverter 3 indicated no power demand, meaning no load/appliance(s) was connected to this inverter/charger 3.

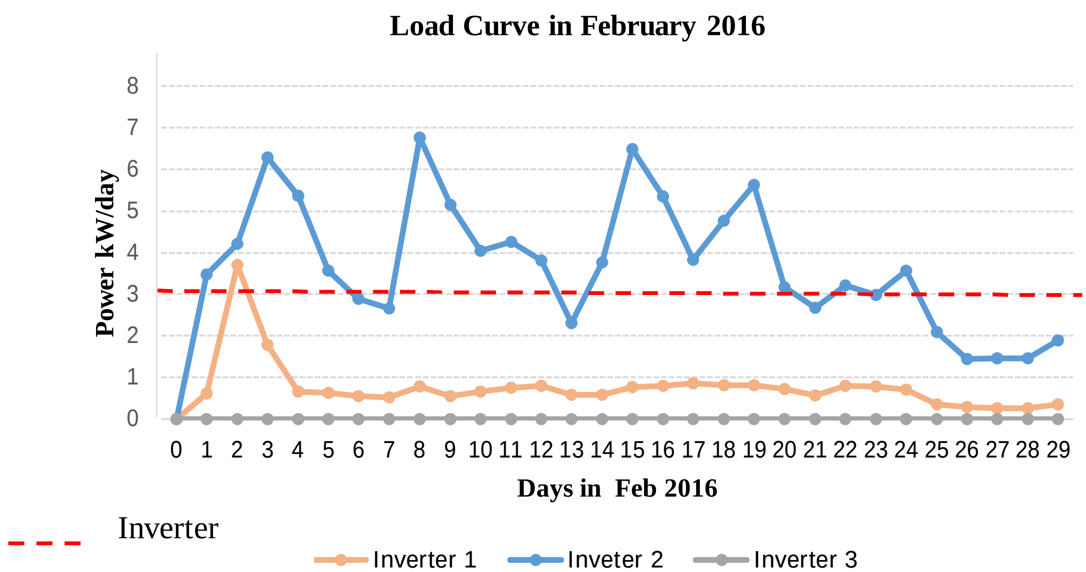

Figure 4.3 (a): Inverter/Charger Load curve in February 2016.

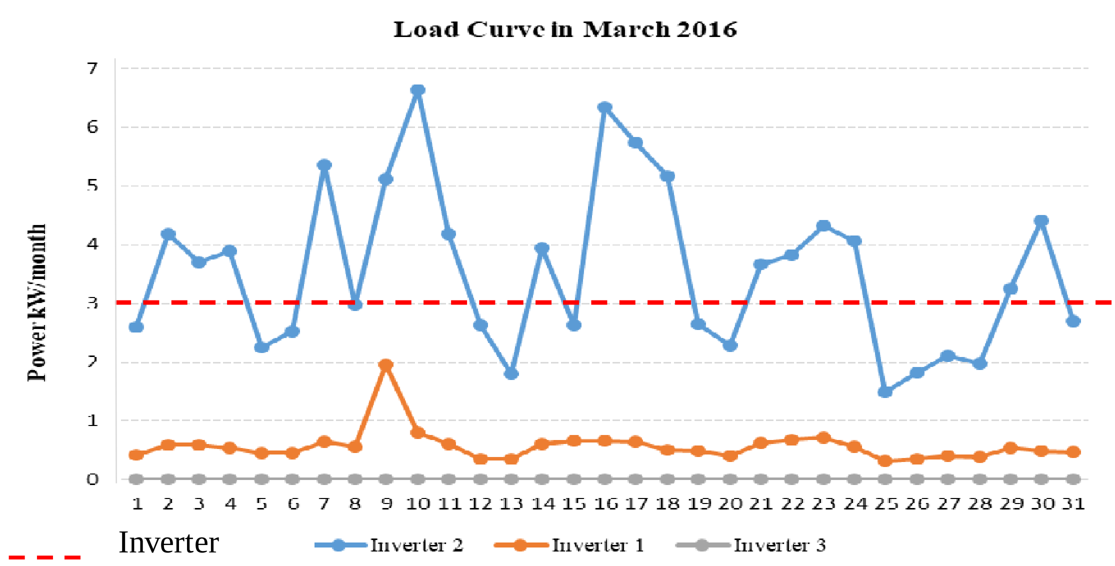

Figure 4.3 (b): Inverter/charger Load curve in March 2016.

Figure 4.3 (c) indicated the power consumption reduced drastically, all inverters/chargers were operating below the rated capacity. During this month the school had closed for April holiday therefore few appliances were ON for a few hours causing this scenario. However, on 4th April there was acute energy consumption, presumably some appliances such as (lights, photocopier, printers and computer) were in operation for more hours than usual and students were preparing for end of term examinations, thus spending more study hours.

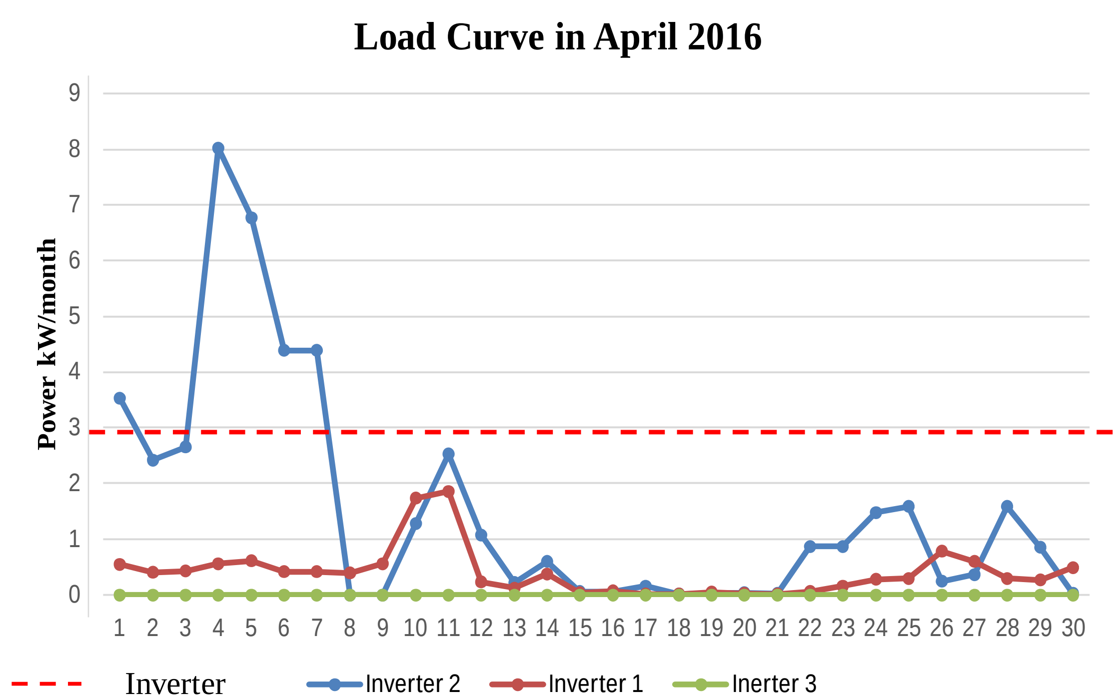

Figure 4.3 (c): Inverter/Charger Load curve in April 2016.

Figure 4.4 (a, b, &c) shows monthly power demand (peak load) curves recorded from three Inverters/charger, the actual curves suggested high rated appliances were used/connected and prolonged consumptions.

Figure 4.4 (a) illustrates the summation of the load peak from three inverters/charger; result show that the average power peak recorded in month of February 2016 was 8.0 kW against Inverter/chargers total rated power peak of 9 kW.

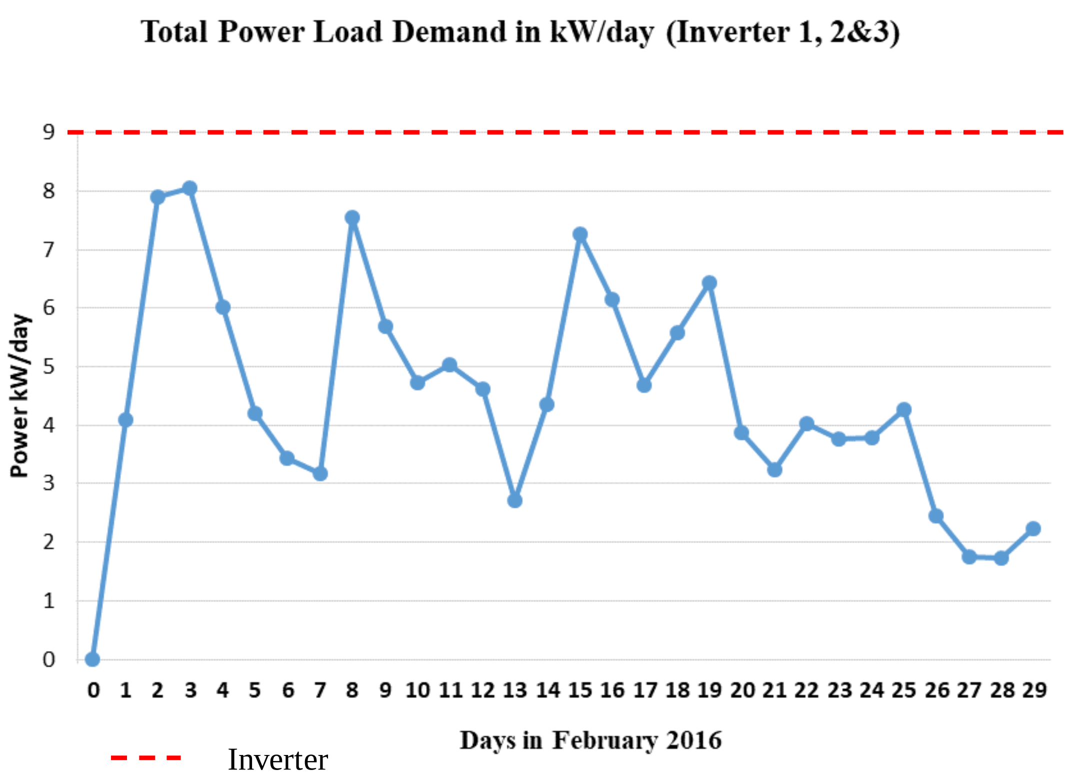

Figure 4.4 (a): Total Power load Demand in February 2016.

Figure 4.4 (b) illustrates the summation of the load peak from three Inverter/charger. The results show that power peak recorded in month of March 2016 was 7.4 kW against inverter/chargers total rated power peak of 9 kW.

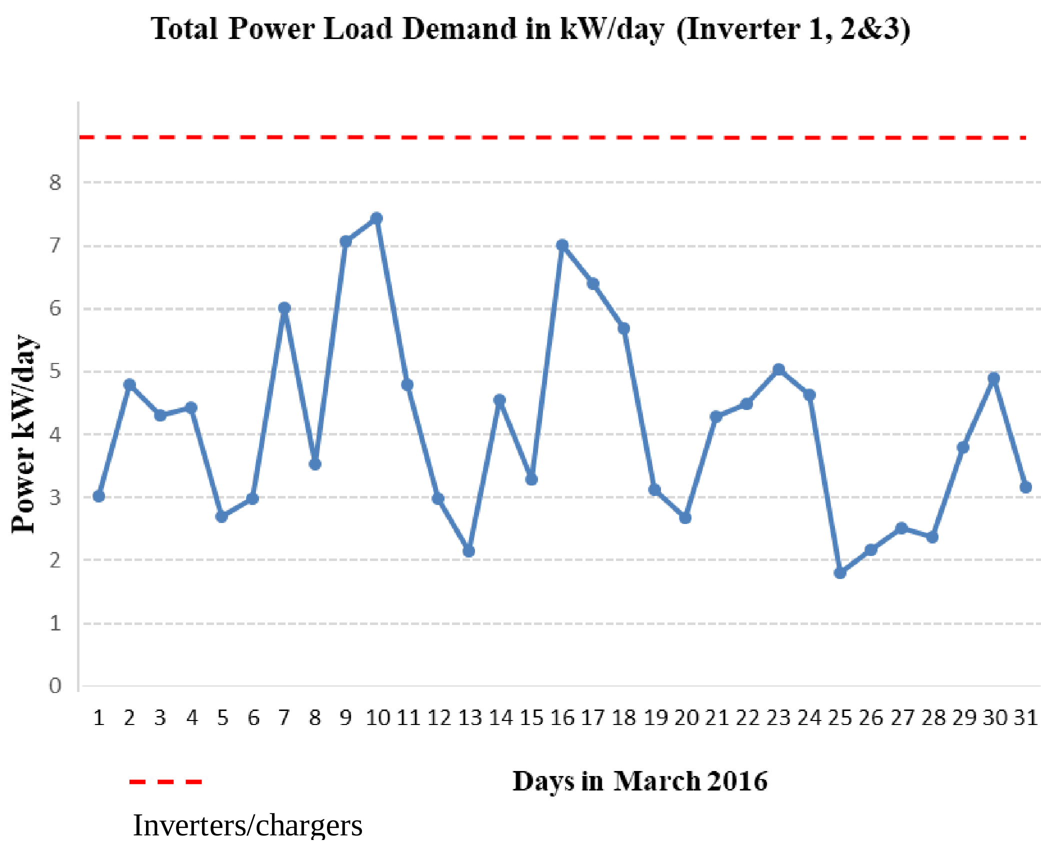

Figure 4.4 (b): Total Power load Demand in March 2016.

Figure 4.4 (c) illustrates the summation of the load peak from three Inverter/charger, result show that the Average power peak recorded in month of as April 2016 was 8.6 kW against inverter/chargers total rated power peak of 9 kW, April 2016 recorded a higher power peak value as compared to February and March the same year.

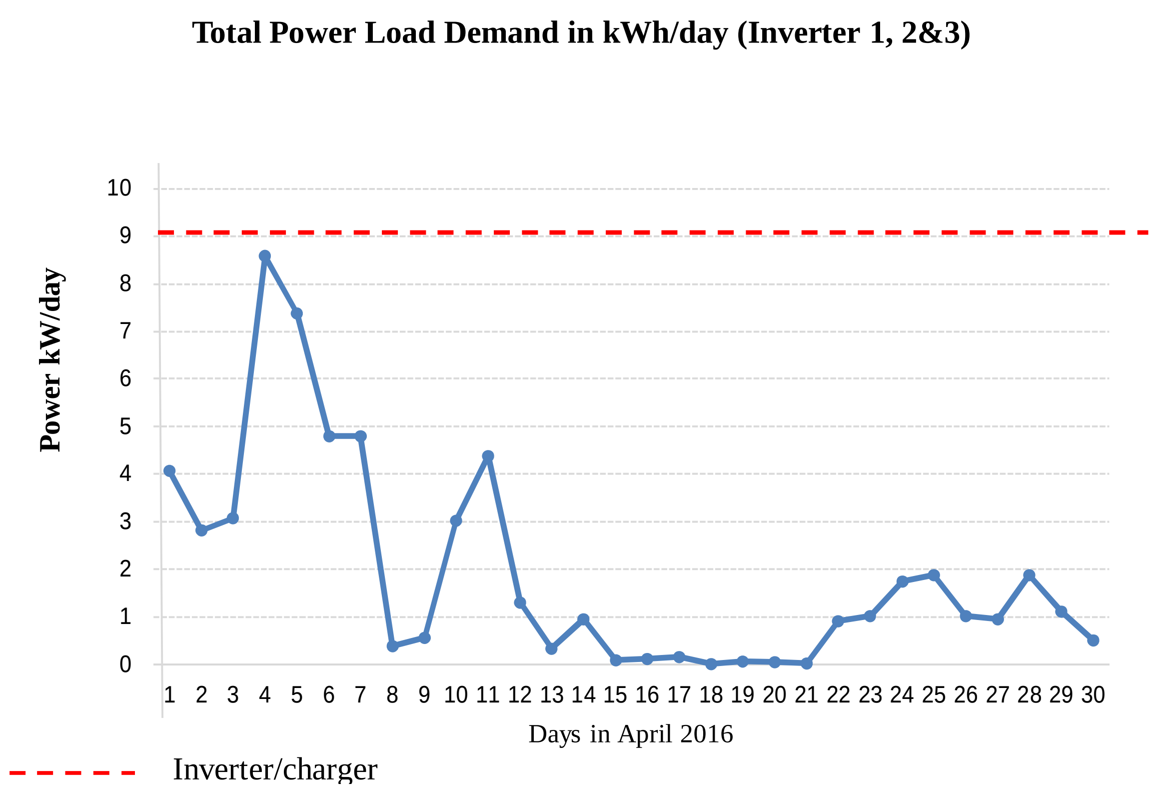

Figure 4.4 (c): Total Power load Demand in April 2016.

The Figure 4.5 summarizes the energy demand in this particular site. In February more units of energy were consumed which was the highest value of energy units (1492.68 kWh) during the sampled period, while April recorded lowest energy consumption.

The study found that there was an overload in Inverter 2, power load harmonization was required. Load harmonization will be achieved by reducing the number of classrooms, /appliances that are powered by the Inverter 2. It would be ideal to dedicate Inverter 3 to serve dormitories, and classrooms block 2. Inverter 2 to supply classroom block 2&3, sanatorium, laboratories, library and staffrooms as in Figure 3.3.

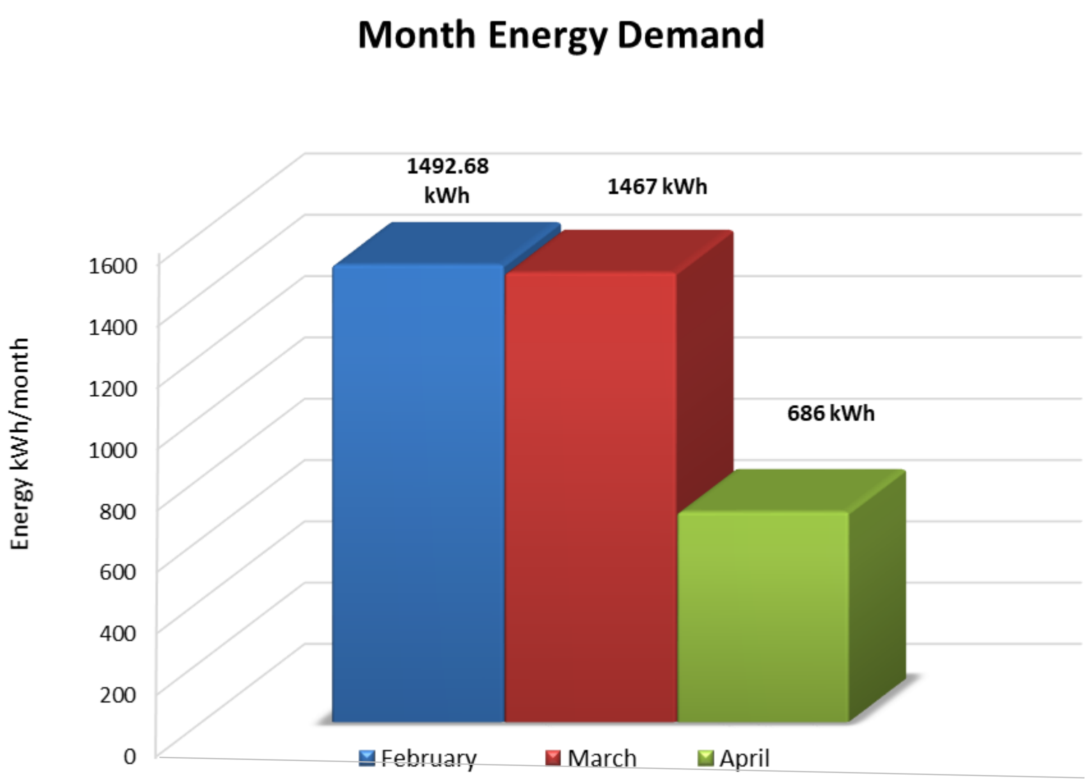

Figure 4.5: Energy demand for February, March and April 2016.

4.2 Power Production and system performance

4.2.1 Solar PV Power output.

Thirty solar modules polycrystalline were considered in this study. The rating of each was 100 W_p. The site parameters were the same and installation is explained in section (3.2.2). At least seven sunshine hours were considered from 0900hr to 1600hr where irradiance greater than 0.25 kW/m^2 was recorded.

Figure.4.5 (a, b & c) illustrates average daily insolation for 7 hours in month of February, March and April respectively. Highest insolation of 6.48 kWh/m^2 and lowest of 2.81 kWh/m^2 was recorded in February 2016. Omwando *et al.* (2013) results shows that Nakuru regions has a moderate to high solar energy potential, with an average daily insolation of 6.9 kWh/m^2 which was almost the same as that obtained in this study. The study recorded insolation of 6.475 kWh/m^2 in the month of February a deviation of 0.425 kWh/m^2 was noted, deviation of these results from previous researches was contributed by effects of global warming, efficiency and accuracy of measuring tools.

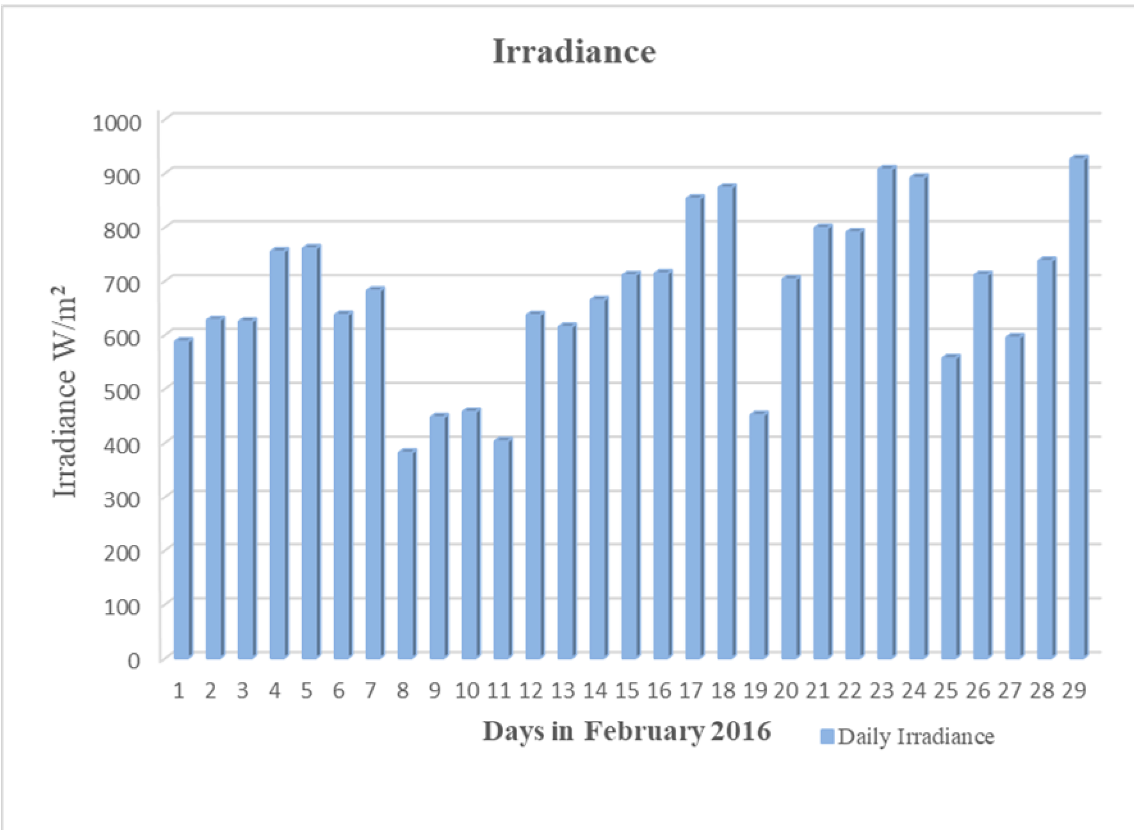

Figure 4.6 (a): Daily Irradiance (W/m^2) for February 2016.

In March 2016 (Figure 4.6 b) the highest average insolation recorded was 5.99 kWh/m^2 at irradiance 855.71 W/m^2 and lowest was 2.46 kWh/m^2 at irradiance of 351.43 W/m^2.

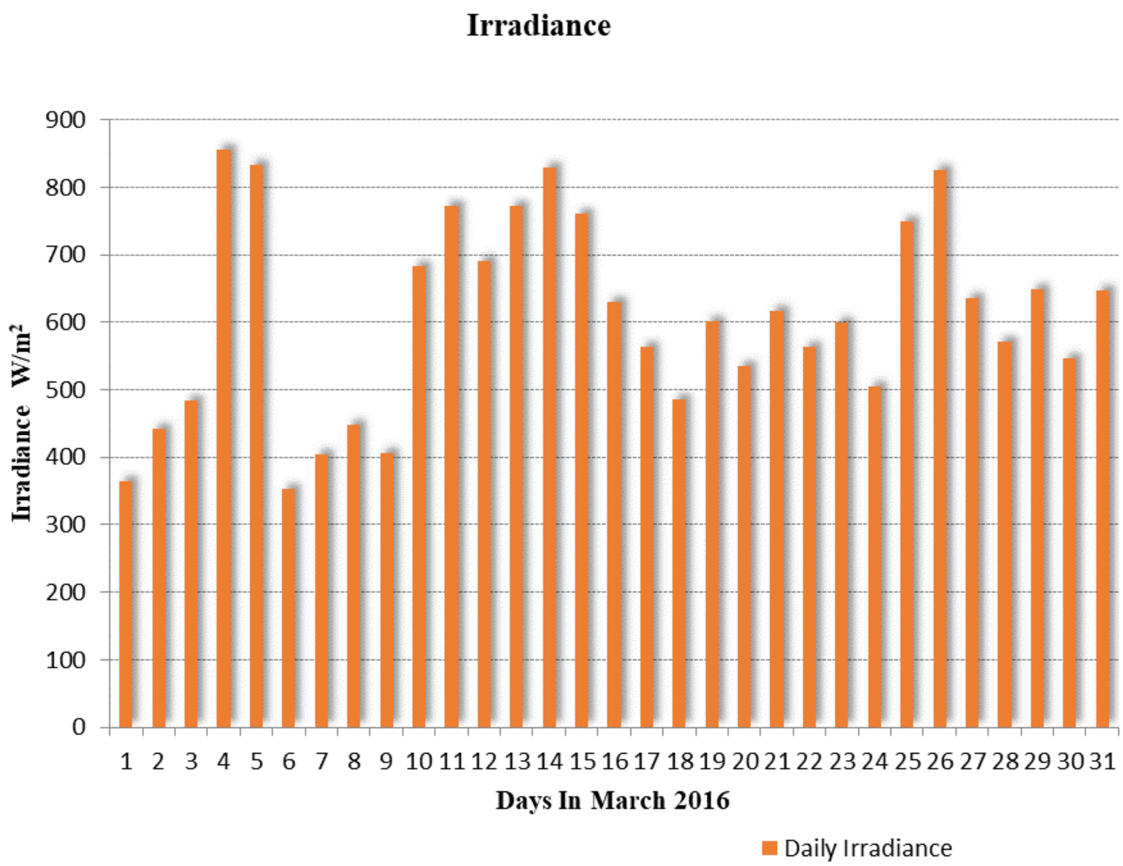

Figure 4.6 (b): Daily Irradiance (W/m^2) in March 2016.

Figure 4.6 (c) illustrates irradiance in April 2016 highest recorded insolation was 6.11 kWh/m^2 at irradiance of 872.85 W/m^2 and the lowest was 1.21 kWh/m^2 at irradiance of 172.86 W/m^2. The insolation was different from results for year 2010 as reported by Omwando *et al*. (2013).

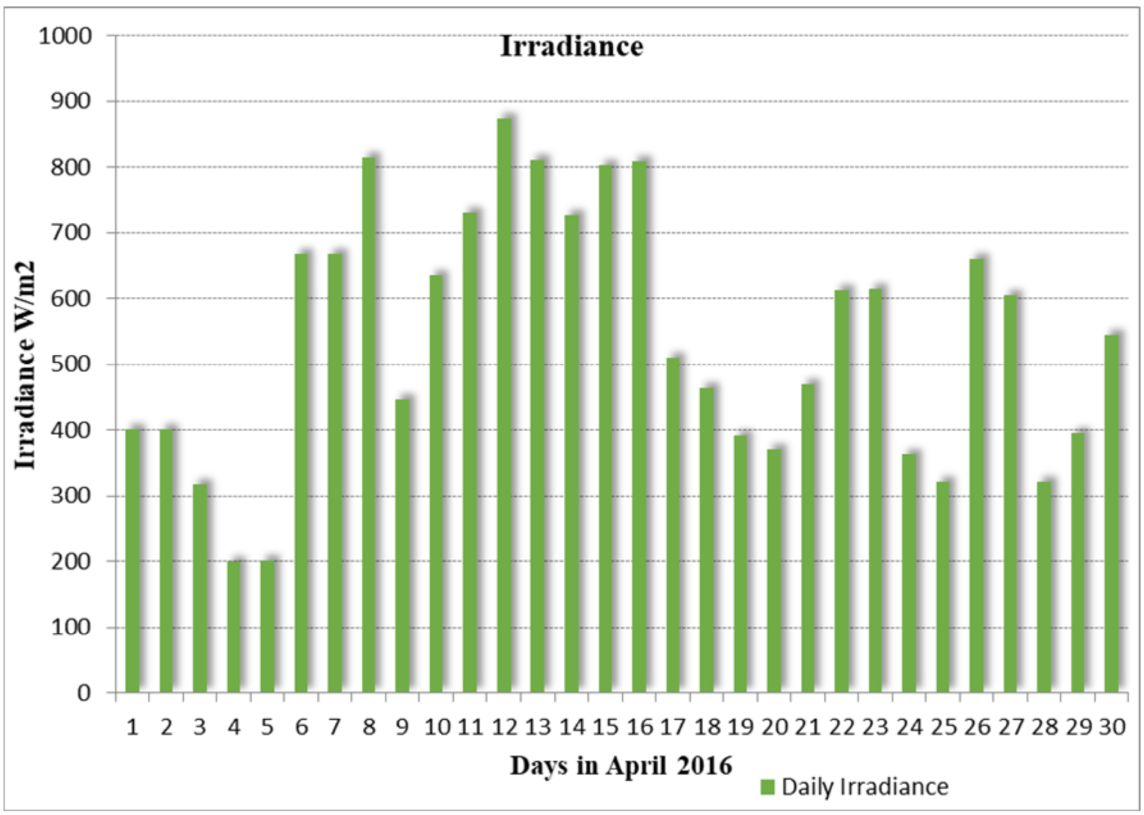

Figure 4.6 (c): Daily Irradiance (W/m^2) in April 2016.

Figures 4.7 (a, b & c) show energy generated from solar arrays; PV 1, PV 2 and PV 3 respectively. Solar PV 2 array indicated higher performance, PV 2 recorded energy production of 3.48 kWh in a day that recorded irradiance of 390 W/m^2as compared with PV 1 and PV 3 which recorded 1.89 kWh and 1.58 kWh respectively during the same day.

The output power was calculated from the respective currents times corresponding battery voltage using equation 15. At normal conditions a solar PV module of 100 Wp produced 80% power as per the rating, at an irradiance of 1000 W/m^2. Module rated 100 Wp has I_{sc} of 6.4 A at 1000 W/m. Reducing irradiance affects the current proportionally, thus at 400 W/m^2 irradiance corresponded currents were 2.48 A as an output (Mohammad *et al.*, 2016).

A single array comprised of two sets of modules connected in series and five modules in parallel (Figure 3.2), increasing the I_{sc} five times, i.e Isc = 31.5 A at STC.

$$I_{(24v)} = \frac{31.5\text{A x } 0.65 \text{ kW/m}^2}{1 \text{ kW/m}^2} = 20.475 \text{ A(equ.2)}$$

At an average irradiance of 0.65 kW/m^2 the output current is 20.475 A. Based on this output current, power generated per hour was 540.54 W and daily energy output was 3.78 kWh.

$$\text{Power (W)} = 26.4 \text{ V}_{\text{Bat V}} \text{ x } 20.475\text{A} = 540.54 \text{ W Per hour (equ.16)}$$

Hence daily energy production = 540.54 +540.54+540.54 +540.54+540.54 +540.54+ 540.54 = 3783.78 Wh (seven hours of sunshine).

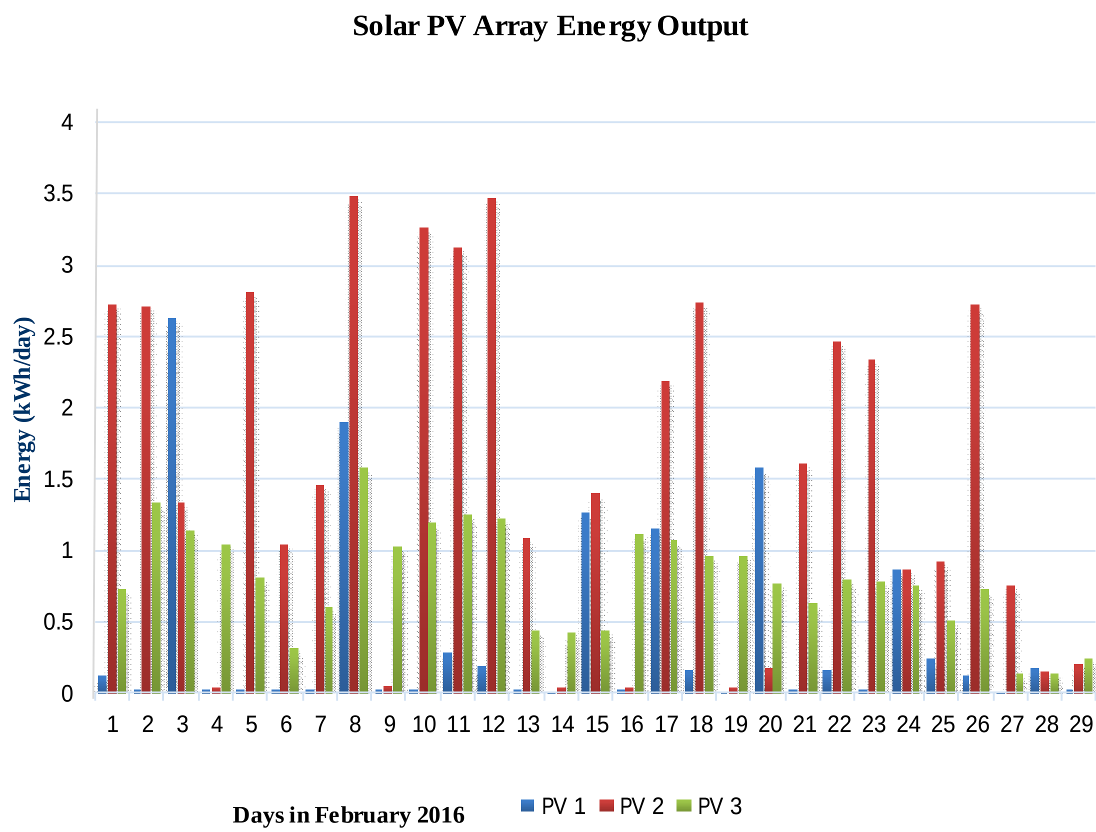

Figure 4.7 (a): Daily solar PV array energy productions for February 2016.

The results indicated that Solar PV array energy production was not equal contrary to researcher's expectations. Array PV 2 generated more units of energy on 16th March, and this was an advantage of using MPPT charge controller. Solar array PV1 and PV 3 was connected to PWM charge controller thus shading/soiling reduced energy generation drastically because PWM does not track maximum power point.

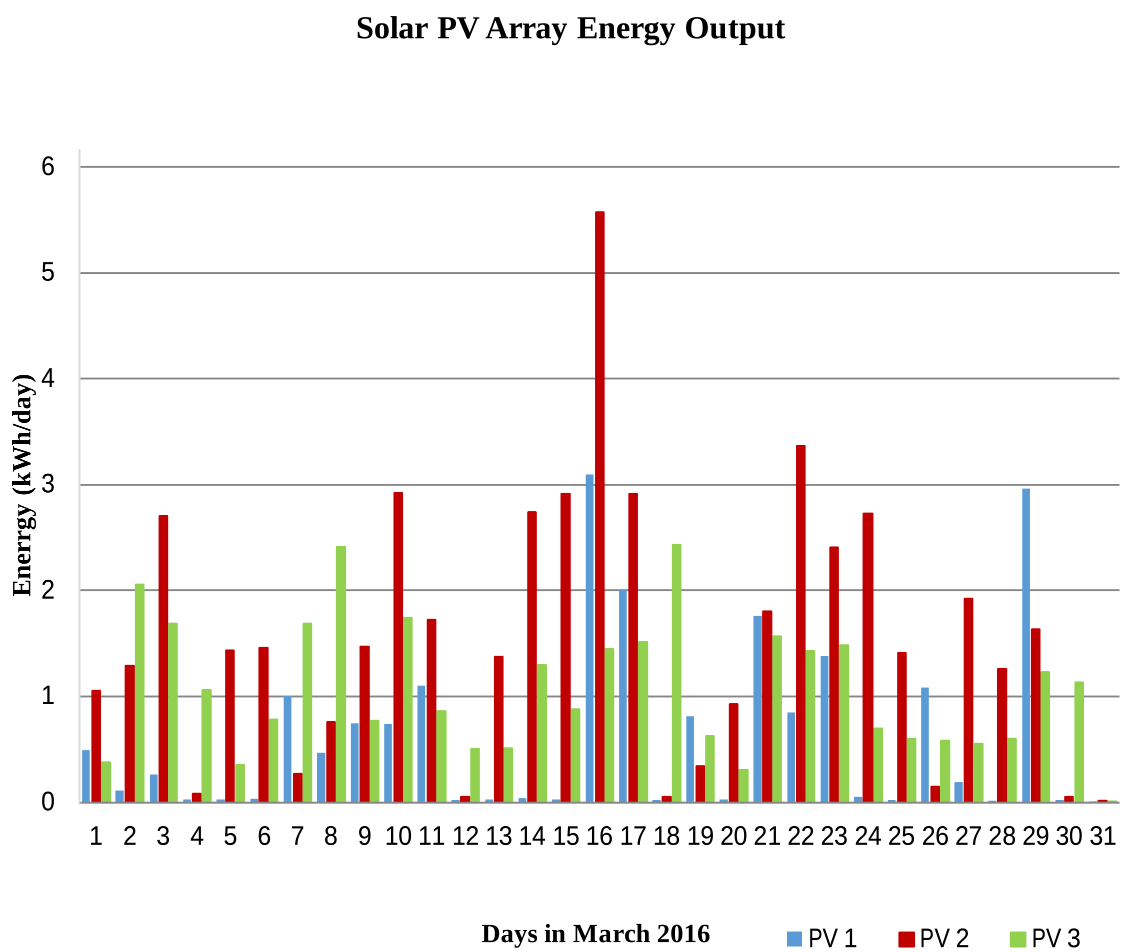

Figure 4.7 (b): Daily solar PV array energy productions in March 2016.

In Figure 4.7 (c) it was observed that April 2016 was quite cloudy as compared to February and March the same year and therefore less irradiance was recorded, same results as shown by Omwando *et al.*, (2013) this affected total daily energy generated. However, energy generation from 12th to 25thApril 2016 was observed being quite low as compared to February and March, this was because there was less consumption /loads and the battery was charged fully.

The charger controller regulated amount of power loaded to the battery at absorption and at float states, thus less energy was measured even though more energy was available to be generated. The charge controllers disconnected solar PV from charging process when the batteries attain full charge (Hiwale, Patil, & Vincurkar, 2014).

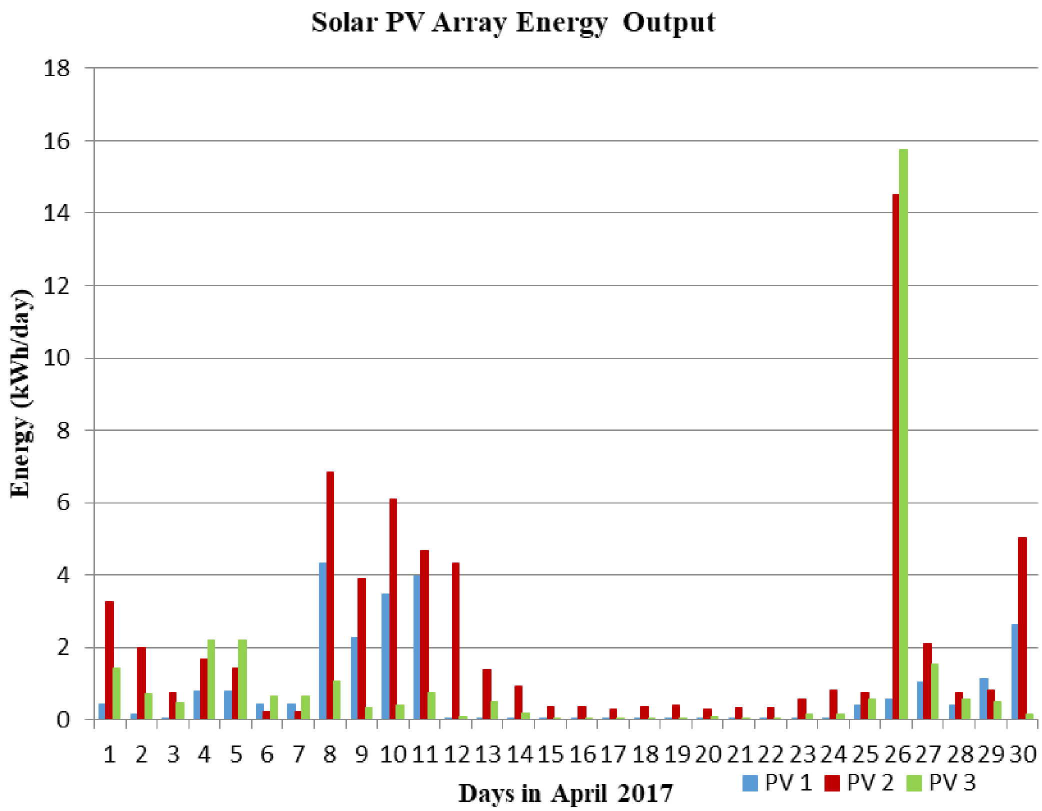

Figure 4.7 (c): Daily solar PV array energy productions in April 2016.

Figure 4.8 (a) illustrates monthly energy production analyzed and a summary of three set of arrays PV 2, PV 3 and PV 1. PV 2 recorded 45.22 kWh/month, 23.07 kWh/month, and 11.10 kWh/month respectively, contrary to researcher's expectations because the arrays were subjected to same parameters and orientation (Plate 3.2). Use of MPPT charge controller contributed to 45.22 kWh/month energy production from solar PV 2 as discussed by Hiwale *et al*. (2014).

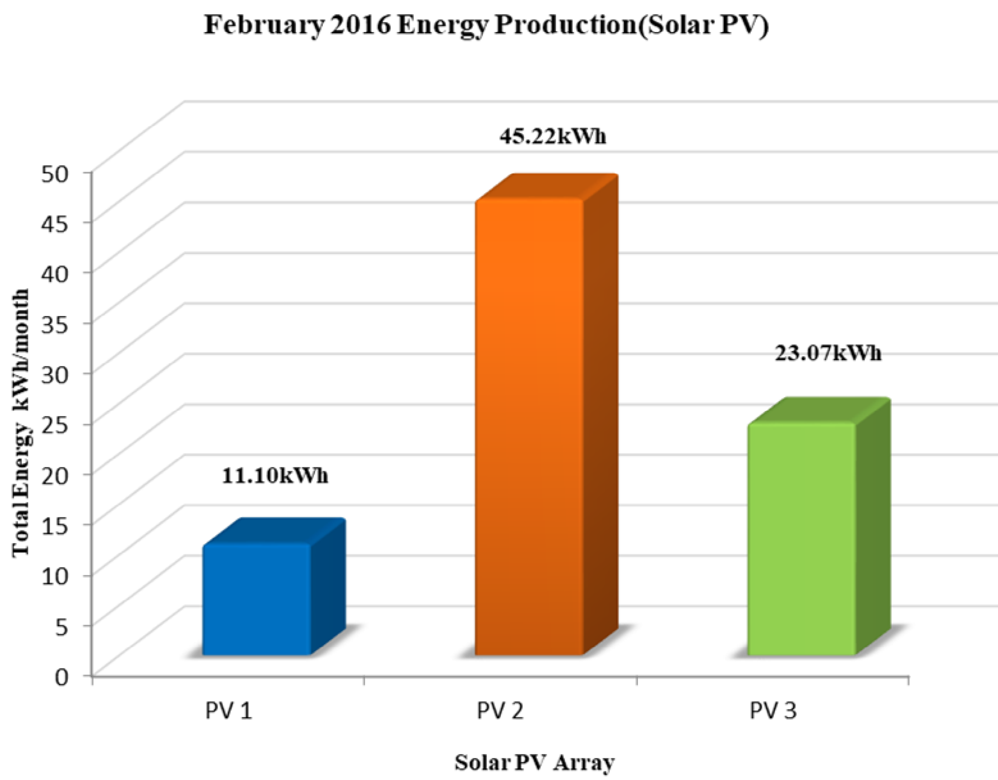

Figure 4.8 (a): Monthly energy from solar PV1, PV 2, and PV 3 in February 2016.

Figure 4.8 (b) shows a monthly energy production a summary of three arrays PV 2, PV 3 and PV 1. PV2 recorded 47.13 kWh/month, 30.82 kWh/month and 16.36 kWh/month respectively, contrary to researcher's expectations because the arrays were subjected to same parameters and orientation (Plate 3.2). The MPPT charge controller contributed to 47.13 kWh/month energy production from solar PV2 (Hiwale *et al*., 2014).

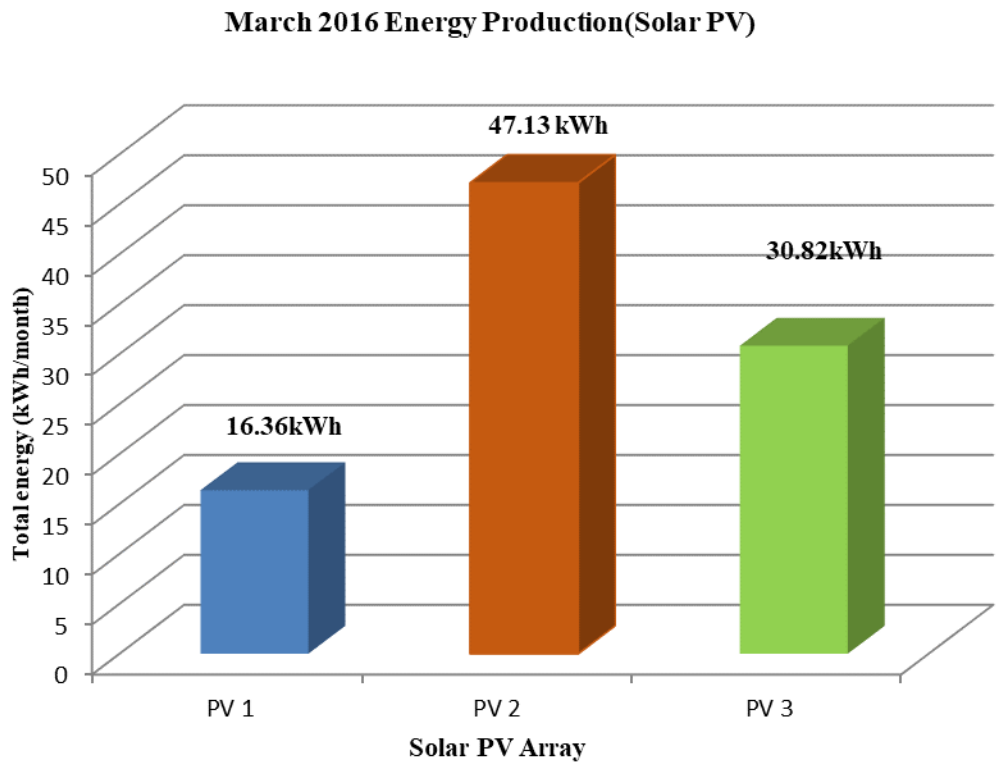

Figure 4.8 (b): Monthly energy from solar PV1, PV 2, and PV 3 in March 2016

Figure 4.8 (c) explains monthly energy production analyzed and a summary of energy production from three arrays PV 2, PV 3 and PV 1. PV2 recorded 65.29 kWh/month, 35.77 kWh/month, and 19.70 kWh/month respectively contrary to researcher's expectations because the arrays were subjected to same parameters and orientation (Plate 3.2). It was contributed by use MPPT charge controller leading to energy generation of 47.13 kWh/month from solar PV2 (Hiwale *et al*., 2014).

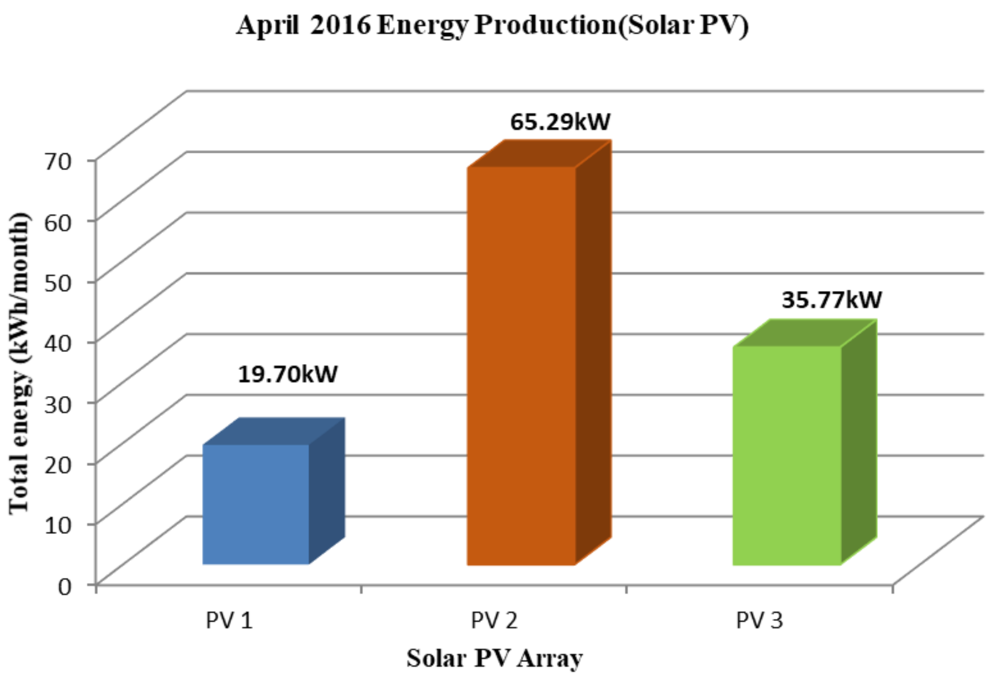

Figure 4.8 (c): Monthly energy from solar PV1, PV 2 and PV 3 in April 2016

4.2.2 Solar Power Output Projection.

During the sampled period by this study, February was found to have the highest insolation and highest energy demand in St. Francis Xavier Girls School, therefore the result for February was used to project solar PV power output. A solar system designer can predicate power generation for a system in Naivasha region based on the results recorded by this study, the approach below can be used to estimate power generation. February recorded a maximum and minimum irradiance of 0.925 kW/m^2 and 0.381 kW/m^2 respectively. Assuming batteries were at normal voltage of 24.6 V. Daily power/energy generation predication would be calculated as follows;

$$I_{(24V)} = \frac{31.5A \text{ x } 0.925 \text{ kW/m}^2}{1 \text{ kW/m}^2} = 29.14 \text{ A(equ.2)}$$

$$\text{Maximum Power (W)at STC} = 26.4\ V_{VBat}\ x\ 29.14\ A\ \ x\ 80\%$$
$$= 4.01\ \text{kW per day [7 hours]equ.16}$$

$$I_{(24V)} = \frac{31.5A\ x\ 0.381\ kW/m^2}{1\ kW/m^2} = 12.00\ A(equ.2)$$

$$\text{Minimum Power (W)at STC} = 26.4\ V_{VBat}\ x\ 12.00\ A\ \ x\ 80\%$$
$$= 1.77\ \text{k W per day [7 hours]equ.16}$$

where 31.5 A is the total maximum I_{sc} of the solar PV considered by the study at STC, V_{Bat} is the terminal voltage of the battery in charging process, $I_{(24)}$ is the current of a 24 V system.

Monthly Solar PV energy generation with reference to the available irradiance was taken as the sum of energy generated and recorded in the three channels, and recorded as 79.39 kWh/month in February. In contrast to the expected energy production at average irradiance and float voltage which was calculated to 109.71 kWh. This was about 28% deviations from the actual power/ energy production, this was due to various technical aspects such as; voltage drop as results of cable resistance, charge controller regular disconnect and other miscellaneous powers losses.

4.3 Wind Power output.

To appreciate the wind profile in Naivasha, the study related the performance of same wind turbines as it would have operated at different parameter in Marsabit, where other studies show that the wind profiles were attractive to energy generation from wind (WinDForce Ltd, 2013; Kamau, Kinyua , & Gathua, 2010).

To calculate the Rayleigh distribution and electricity production from turbines in Naivasha site as discussed by Maina *et al.* (2016) that average wind speeds at St. Francis Xavier Naivasha was 3.54 m/s at height of 10 m equation 3, average wind speed at 6m was 3.34 m/s. Therefore, Rayleigh equation 6 was used to determine the distribution as shown in appendix 2 and illustrated in Figure 4.9. Comparing the power curve and value ‘c’ with actual wind speeds encountered in Naivasha and Marsabit. Naivasha was experiencing relatively low wind speeds, where the wind speeds distribution was characterized by a ‘shape parameter’ k at typical site k = 2. Parameter “k” was therefore it is estimated as 1.5 because Naivasha has a wider ranging of distribution. From this study it was observed that wind generator unreliable as a single power source (Khennas, Dunnett & Piggott, 2003).

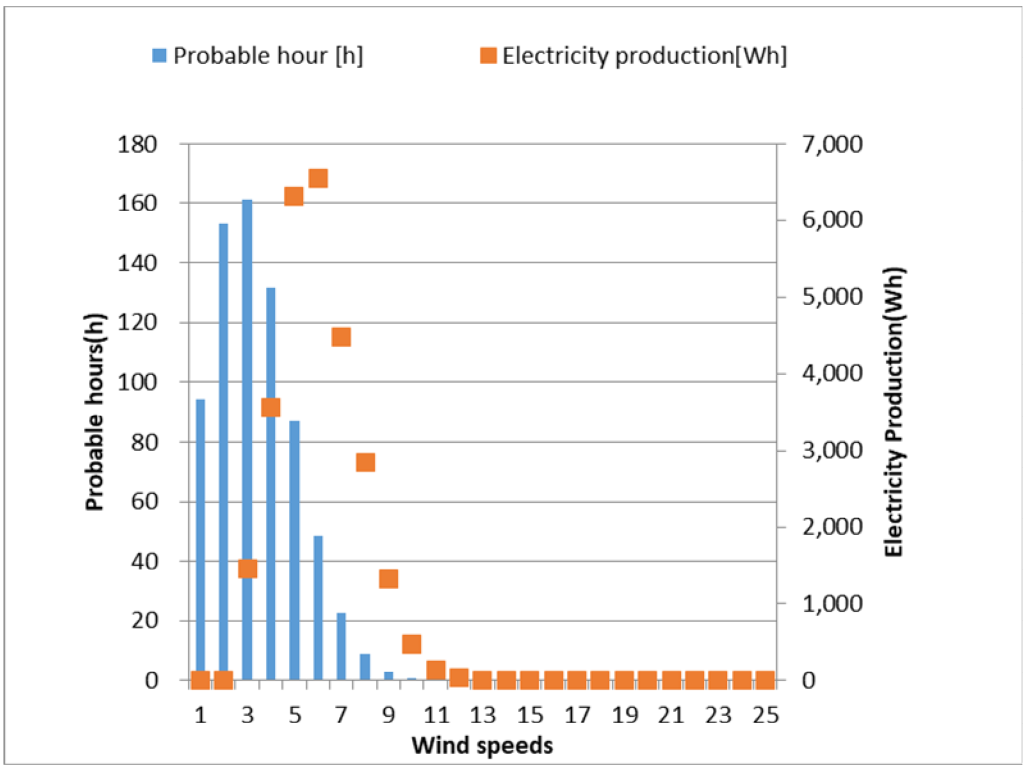

Figure. 4.9: The Rayleigh distribution and electricity production in Naivasha

Marsabit recorded lowest monthly average wind speed of 7.44 m/s which was registered in December 2002 while August 2002 recorded the highest average wind speed of 14.49 m/s (Kamau *et al.*, 2010). Considering Marsabit annual wind speeds of 9.4 m/s, Rayleigh distribution of the same wind turbine is represented in Figure 4.10 where test data such as air mass, atmospheric pressure was assumed to be the same.

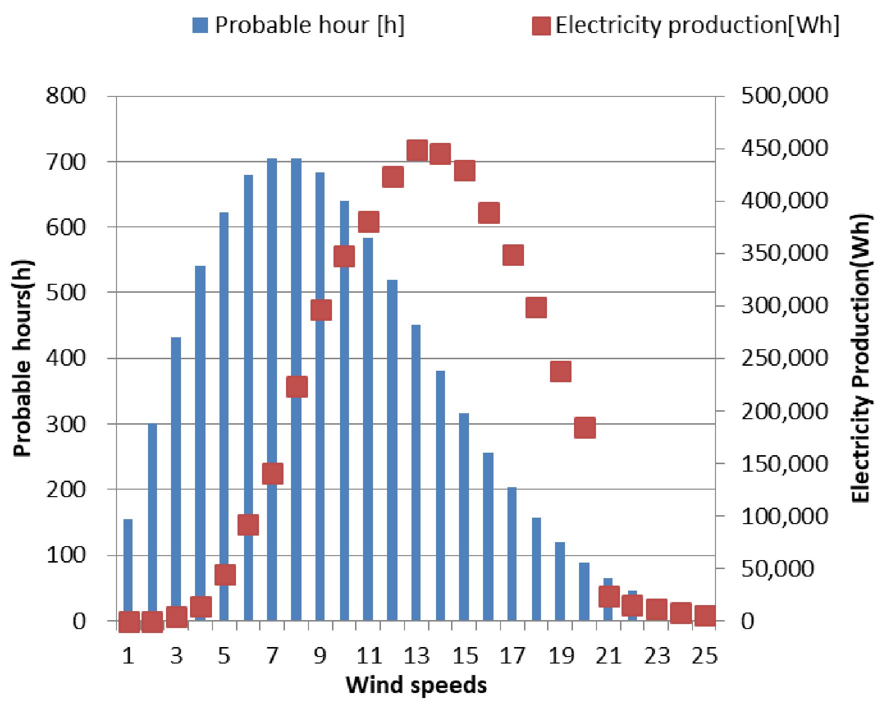

Figure 4.10: The Rayleigh distribution and electricity production in Marsabit.

Based on the wind speeds at this site in Naivasha, turbine WT_1 recorded energy generation, as compared to WT_2 which from the results no energy was generated (Appendix 1). These was contributed by low wind speeds, surrounding terrains and wind patterns (Maina *et al*., 2016) or turbine generator was faulty thus the operations of generator/wind charge controller could further be investigated.

In Figure 4.11 (a) is a summary of actual power harnessed from the wind as daily counts in month of February 2016. The maximum energy generated was 2.4 kWh/day as result of a good wind profile observed on 29th February 2016. Wind speed operated within the cut-in and cut-out speeds at 2.5 m/s and 12 m/s respectively of this particular wind turbines, generator produced maximum energy as explained by Kamau *et al.* (2010).

Wind turbine (WT_1) performance and energy generation was observed being below manufacturer's explanation on power curve compared to WT_2 as the subjected to same parameters. Other factors contributing to low performance are discussed in subheading 4.3.1.

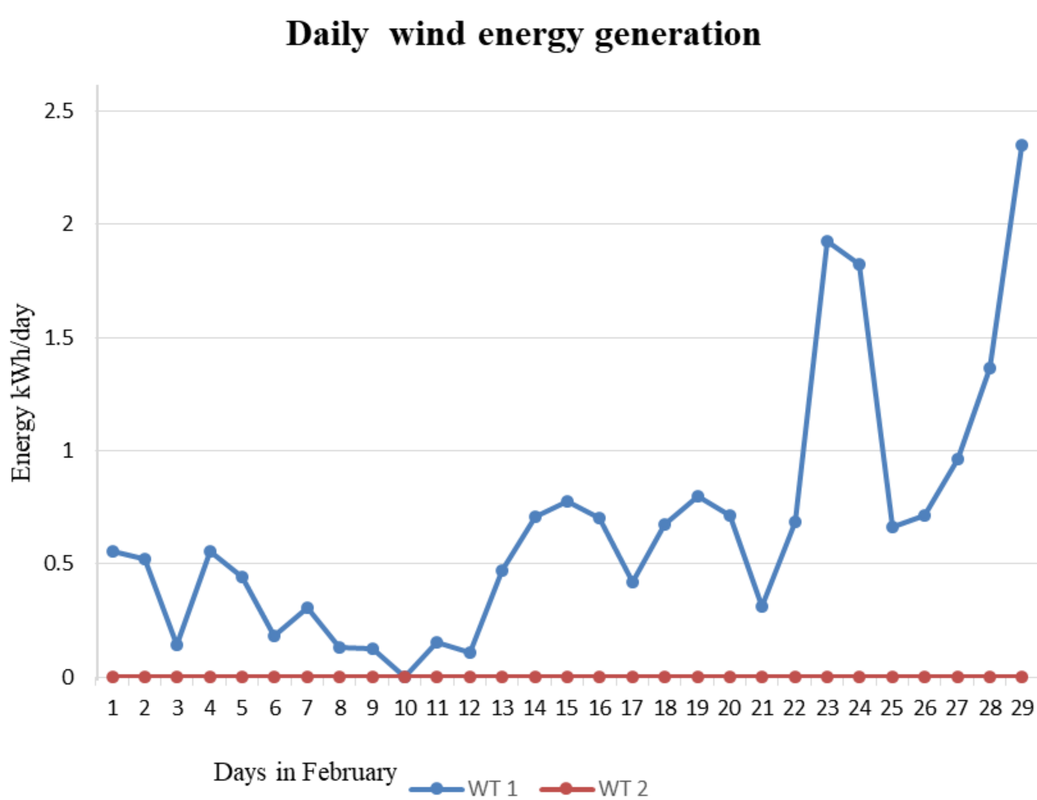

Figure 4.11 (a): Total daily wind energy generation in February 2016.

In Figure 4.11 (b) is a summary of actual power harnessed from the wind as daily counts in month of March 2016. The maximum energy generated was 2.4 kWh/day as result of a good wind profile observed on 4th March 2016. Wind speed operated within cut-in speeds of particular wind turbine, generator produced maximum energy as explained by Kamau *et al*. (2010).

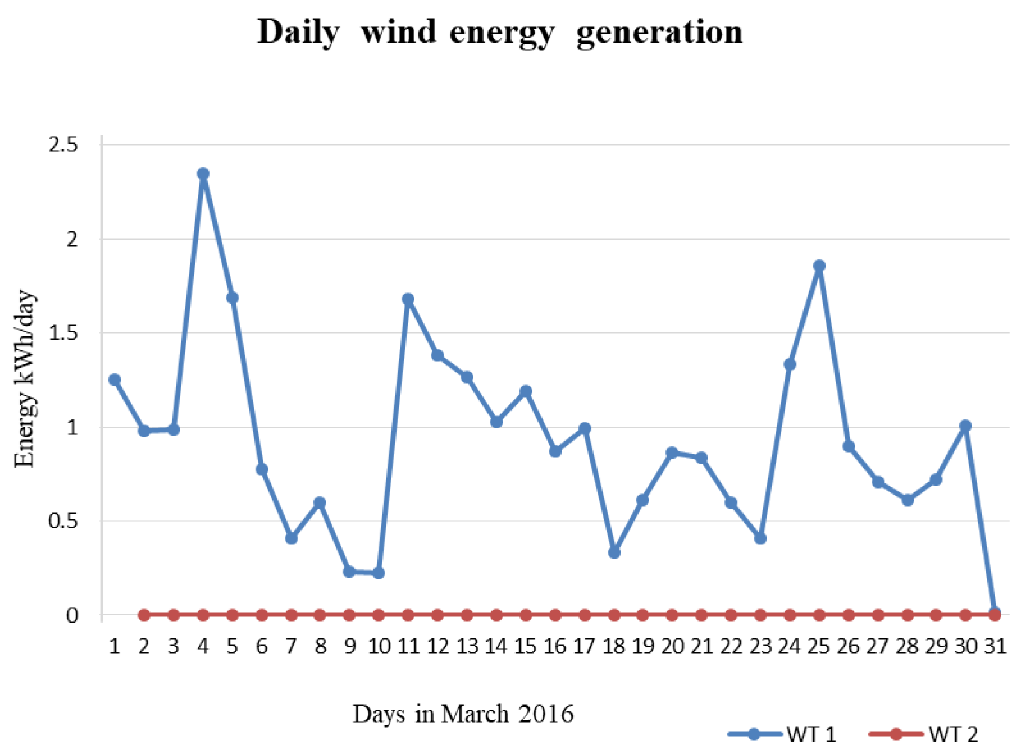

Figure 4.11 (b): Total daily wind energy generation in March 2016

In Figure 4.11 (c) is a summary of actual power harnessed from the wind by the wind turbine as daily counts in month of April 2016. The maximum energy generated recorded was 6.6 kWh/day this was as result of a good wind profile observed on 26th & 27th April 2016. The study shows that on 26th and 27th April, the wind speeds pattern throughout these days it was more attractive for energy was generation.

Wind turbine that is operating within cut-in and cut-out wind speeds contributes to maximum energy generation as explained by Maina *et al.* (2016); Kamau *et al.* (2010).

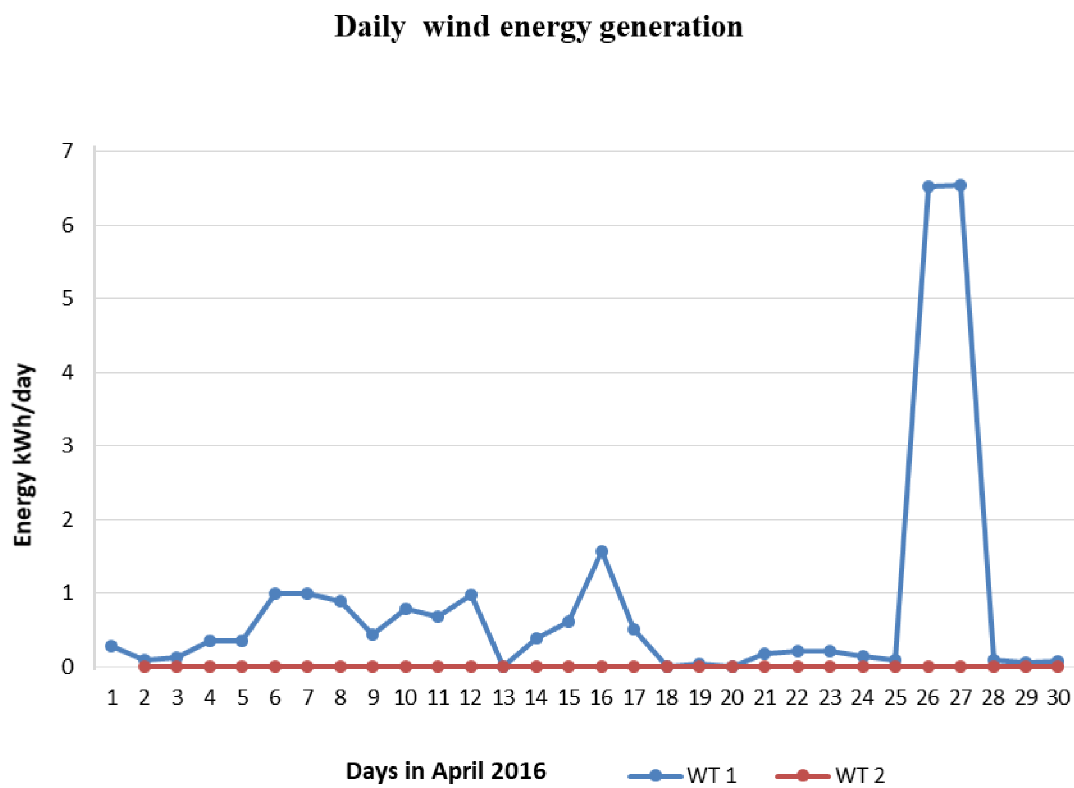

Figure 4.11 (c): Total daily wind energy generation in April 2016

The monthly energy production is discussed in the Figure 4.12 (a, b & c). Despite turbine's low performance, monthly energy production of 19.37 kWh was recorded during the sampled month of February. WT_1 recorded 19.37 kWh and WT_2 production was 0.0 kWh. The study suggests that WT_2 generator/wind charge controller was faulty thus no power was generated.

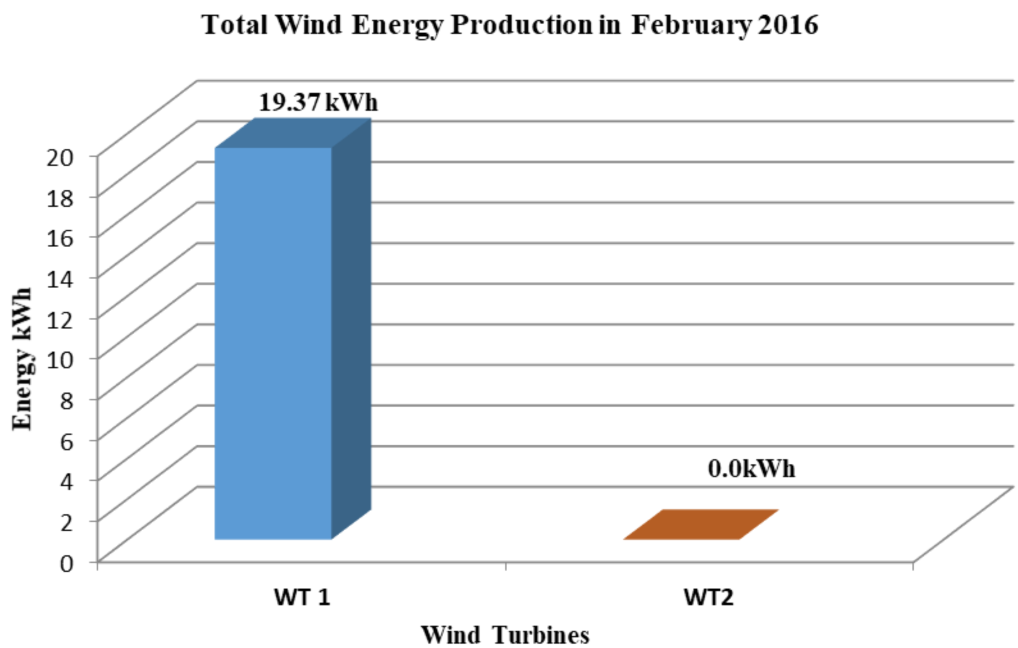

Figure 4.12 (a): Monthly Wind turbine energy production in February 2016.

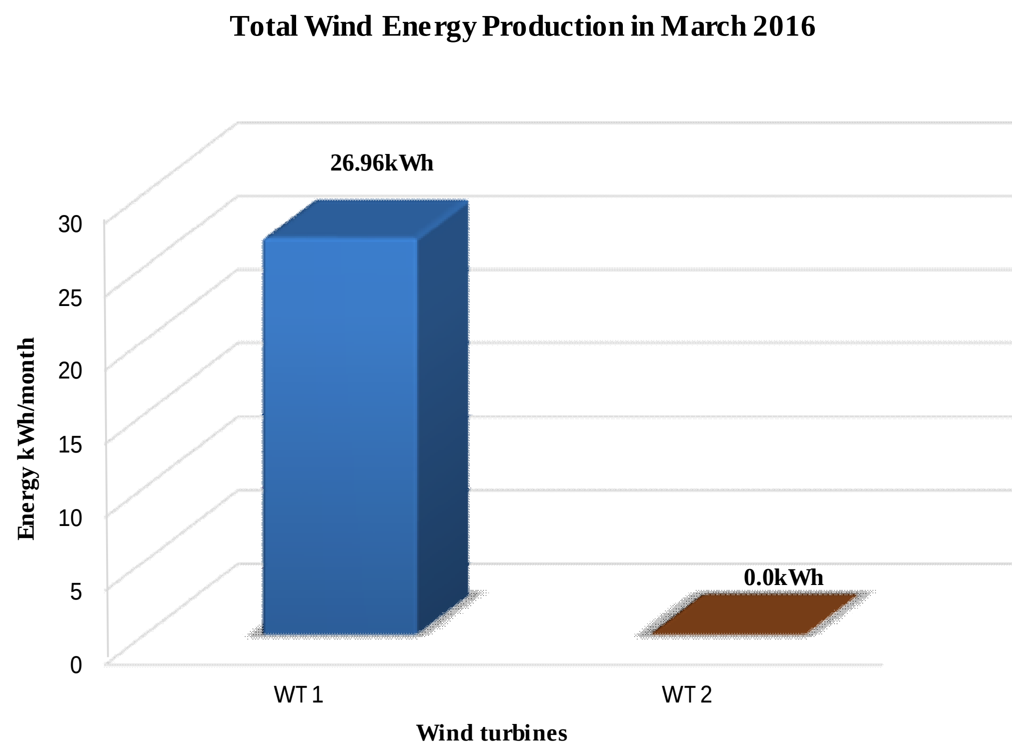

Figure 4.12 (b): Monthly Wind turbine energy production in March 2016.

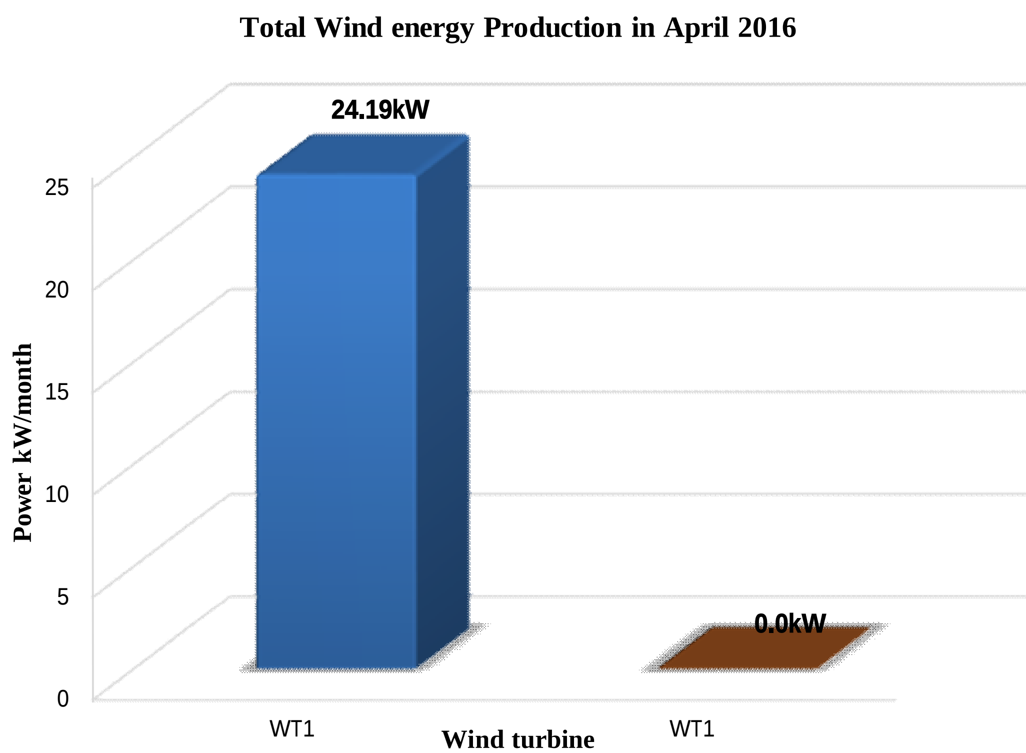

Figure 4.12 (c): Monthly Wind turbine energy production in April 2016.

The wind generator power production was observed be very low, March 2016 WT_1 recorded highest energy generation while no energy was generated from WT_2.

In this scenario the power generated by wind turbine was observed as dependent on the availability of other power sources. The charging current from grid power (KPLC) is usually stable when it's available as compared to current generated by solar/wind turbines. Thus grid power would dominate the charging process, because most of the time the grid power is ON and available.

When cut in wind speed was attained for turbine to starting generating the batteries were at absorption or float state, only a float charging current was required by the system or even no charging current. Thus charge controller switches OFF the turbine by shunt mode (short circuit breaks). From the raw data it was observed that at some points wind speeds reached a highest wind speed of 11.5 m/s and lowest was 0.2 m/s, however no power was recorded from wind turbine WT_2.

4.3.1 Site Survey.

The turbines were spaced 6 m apart and in the surrounding environs, tall trees and structures were observed. The obstructions by these obstacles caused turbulence, which affected the performance of turbines depending on wind directions. Obstructions such as building and trees drastically reduce the energy available from wind (Manwell *et al.*, 2012).

Terrain was not so conducive for the installed wind turbines. They were installed near taller building than the height of turbines and at least 4 m away from the buildings, thus affecting in manner the blades capture wind flow aerodynamically because of the fixed pitch angle.

Raising the height of wind turbines tower for at least by additional 4m this would optimize power generation, at this height the wind turbine will capture wind speeds with less turbulence. In addition, windmills can be ideal for these sites/institutions, this will save energy needed to run electrical pump installed in St. Francis Xavier School.

4.4 Energy from the Grid.

Grid power was primarily as a backup source, when there was little power harnessed from the renewable sources the grid will supply. The Switching ON/OFF was configured manually, therefore making the system difficult to operate automatically. Switching the grid power ON was done when Inverters/chargers disconnects the system due to low battery voltage or overloading as discussed in section 4.1. The curves in figure 4.12 (a, b

& c) shows daily power frequency from grid power, in months of February, March and April. April 2016 the grid power consumed was 715.54 kWh/month units of energy, in month of February and March it recorded higher grid power consumption of 754.09 kWh/month and 738.06 kWh/month respectively. However maximum average energy in February was 50 kWh/day.

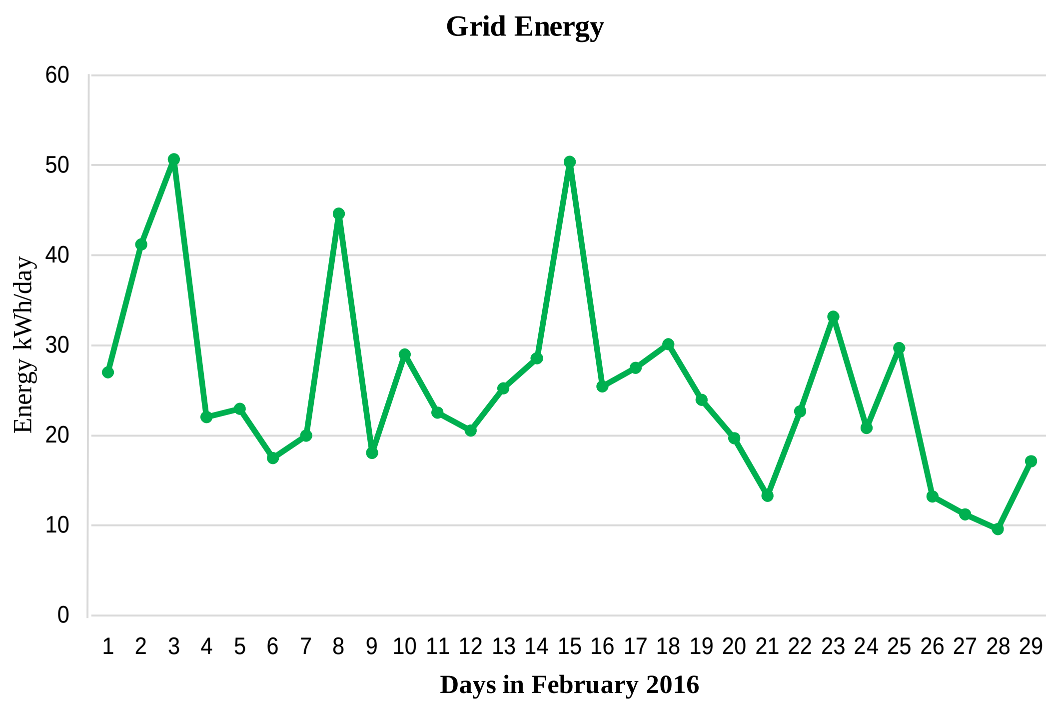

Figure 4.13 (a): Grid energy in February 2016

Figure 4.13 (b) shows that March recorded actuate energy consumption of 92 kWh/day on 16th March 2016, during this day the results show that many activities were taking place, which included use of heavy machine i.e welding. It was observed from the grid power/load curve that the minimum power recorded was 10 kWh/day in February.

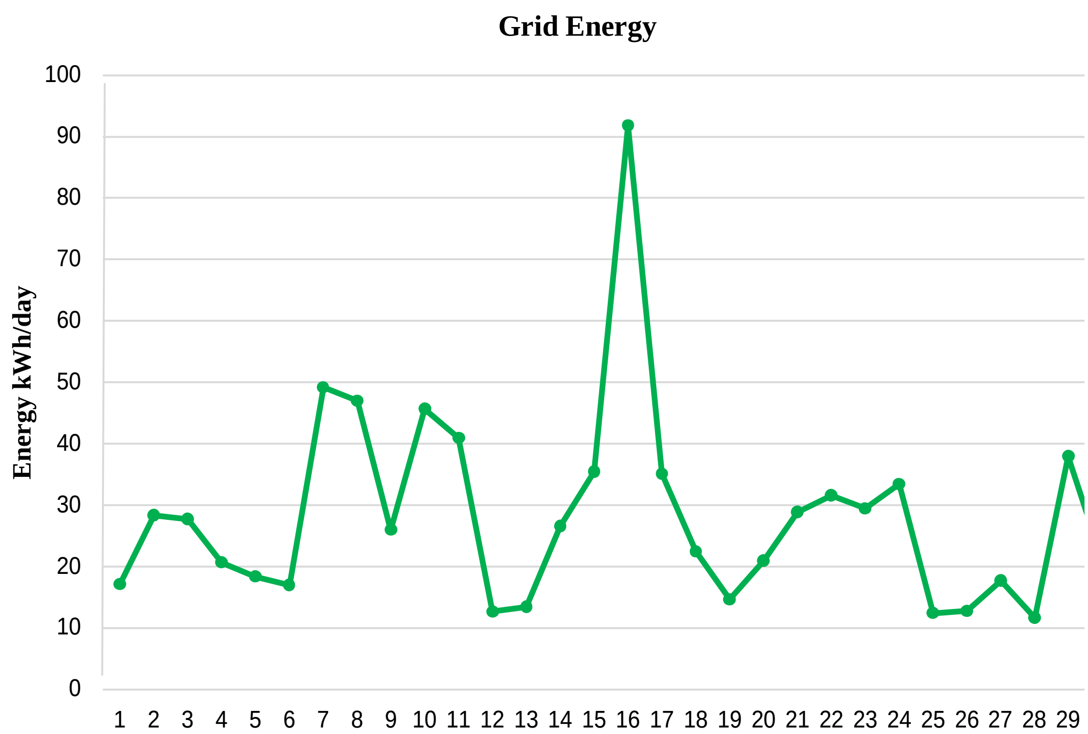

Figure 4.13 (b) Grid Energy March 2016

Figure 4.13 (c) summarizes April 2016 results and recorded three days with high energy consumption 9th, 10th and 26th April recorded 85 kWh/day, 90 kWh/day and 90 kWh/day respectively, it was observed that in three consecutive months there was several days with high energy consumption this was due of routine maintenance activities which involved use of heavy electrical machines.

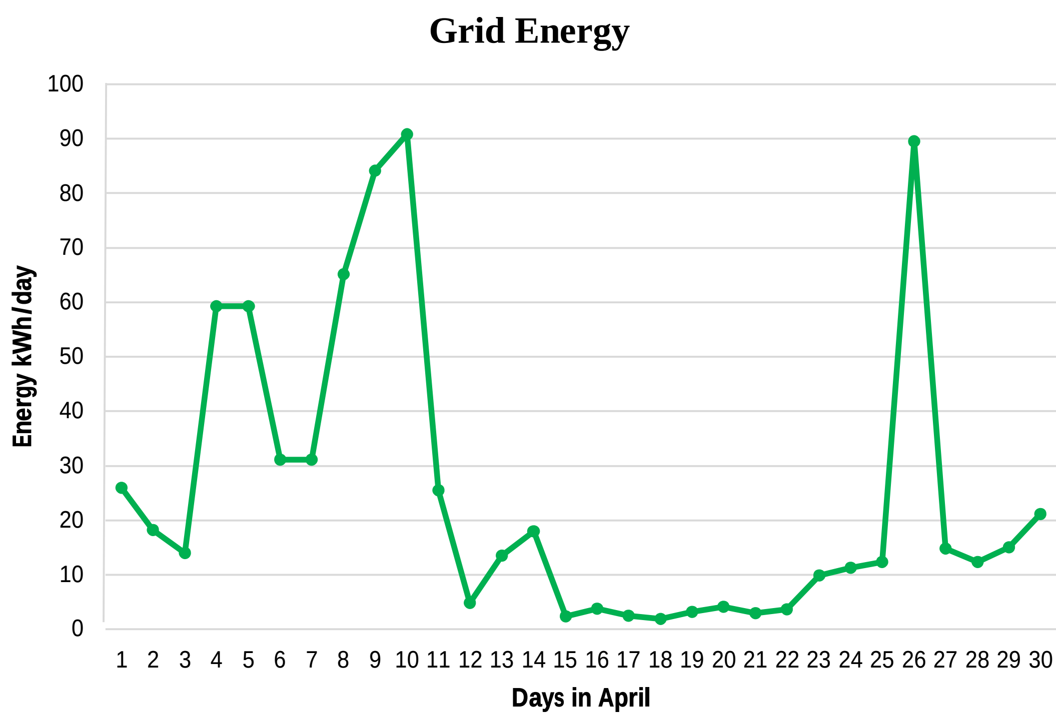

Figure 4.13 (c): Grid Energy in April 2016.

4.5 Solar, Wind and Grid Energy Trend

In this study, it was revealed that power was received from three sources; solar PV, grid energy and wind turbines recording 98.68 kWh, 738.06 kWh and 19.29 kWh respectively as summarized in the Figure 4.14 (a) in February. Grid energy contributed to 86.62% of total energy consumed in February 2016 thus solar and wind energy did not meet the energy demand.

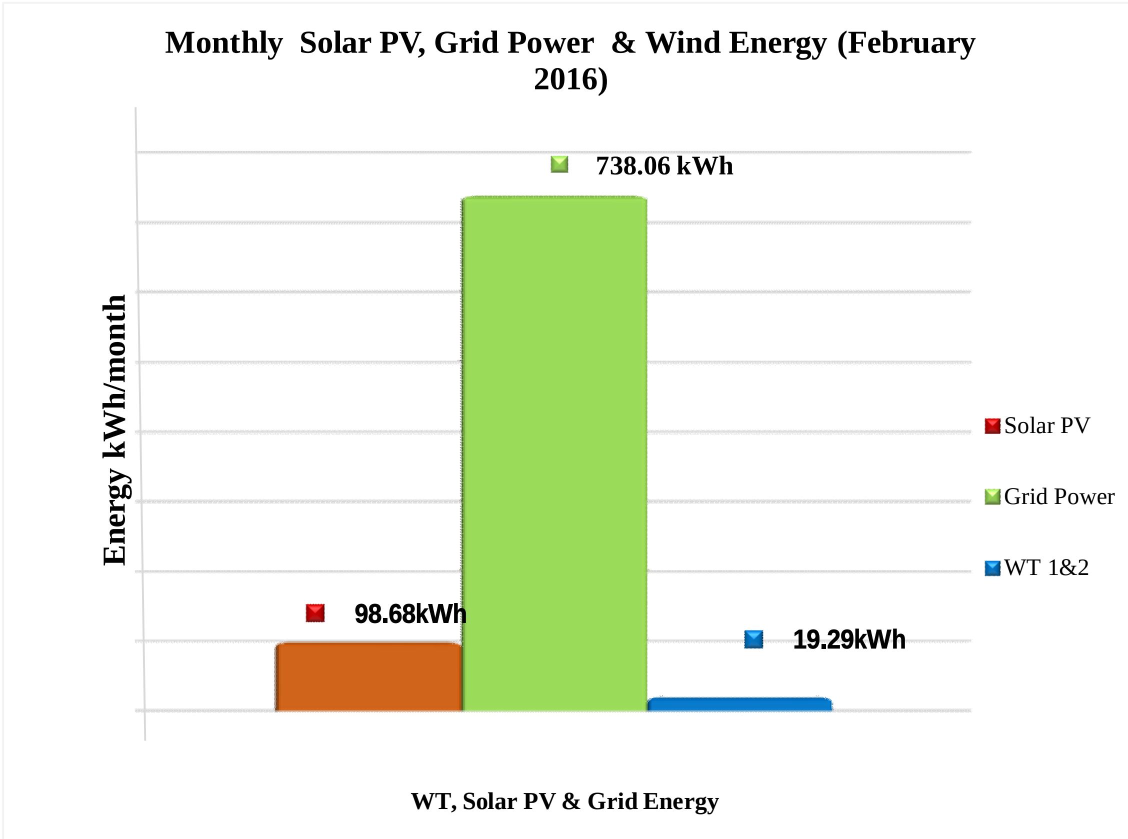

Figure 4.14 (a): Monthly Solar PV, Grid and Wind energy sources in February 2016.

In March 2016 at least 754.09 kWh units of energy was received from the grid power as compared to the rest of the energy sources. At least 86.26%, 10.97% and 2.77% of energy was received/harnessed from the Grid energy, solar PV and wind turbines respectively. From Figure 4.14(b) it was observed the 86.26 % (754.09 kWh) consumed was received from the grid because energy from solar and wind did not meet the demand.

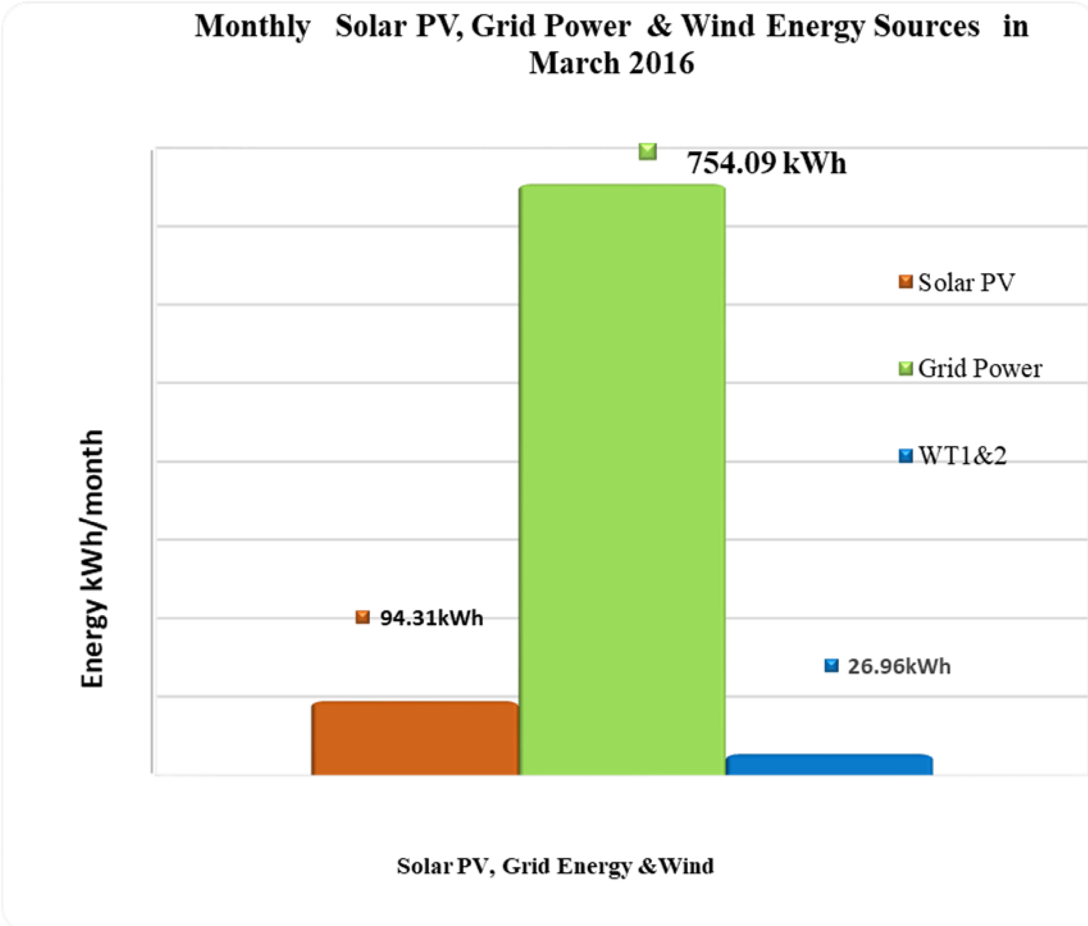

Figure 4.14 (b): Monthly Solar PV, Grid and Wind energy sources in March 2016.

In April 2016 at least715.54 kWh units of energy was received from grid energy as compared to rest of the energy sources. At least 83.15%, 14.03% and 2.81% of energy was received/harnessed from the grid power, solar PV and wind turbines respectively.

This results indicated 83.15% of consumed energy was received from the grid, and it implied that energy from solar and wind did not meet the demand.

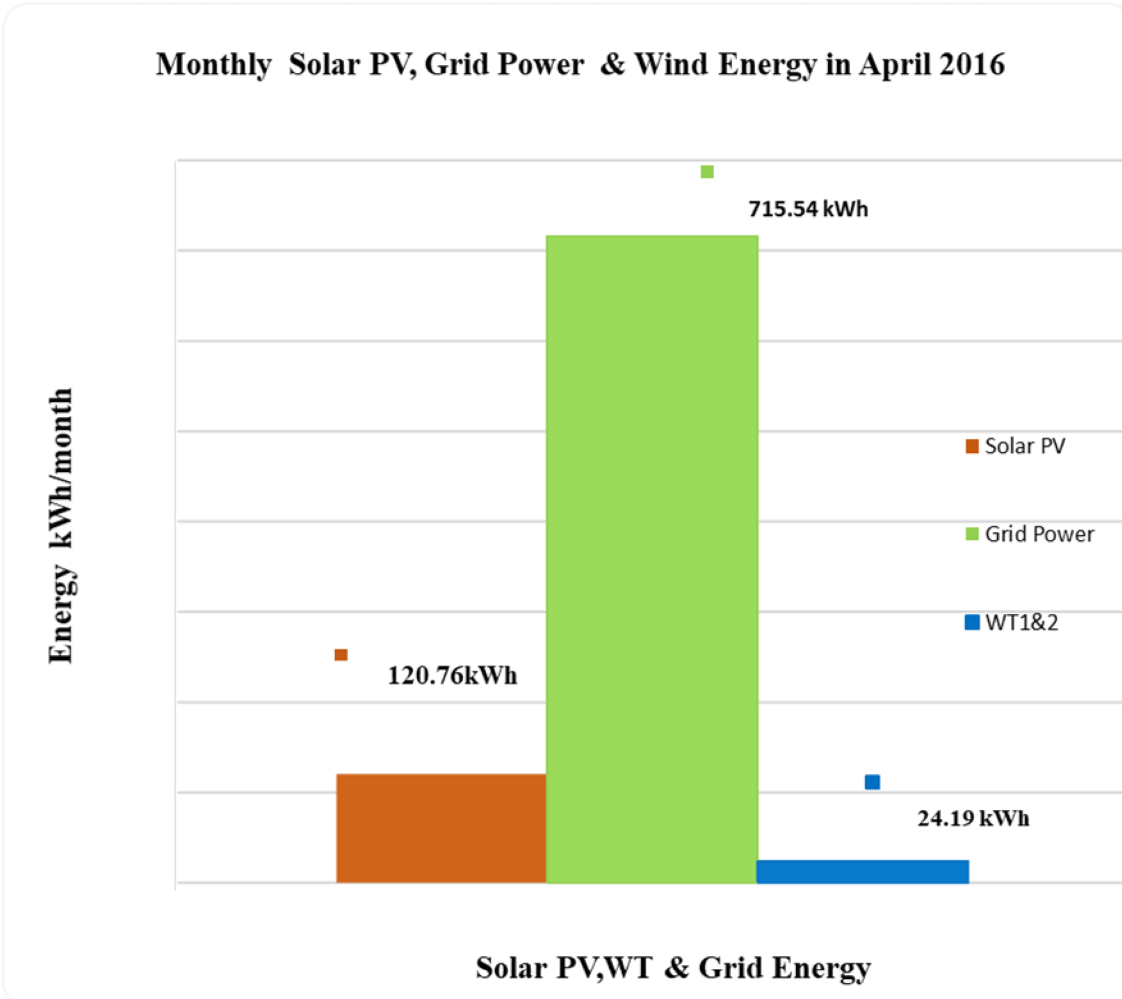

Figure 4.14 (c): Monthly Solar PV, Grid and Wind energy sources in April 2016.

Figure 4.15 (a) explains energy generation trend from three sources, based on these results it was observed that grid power dominated the consumption trend where a maximum of 50 kWh/day was recorded. While energy generated from solar and wind recorded a maximum of 7.1 kWh/day and 1.9 kWh/day in February 2016.

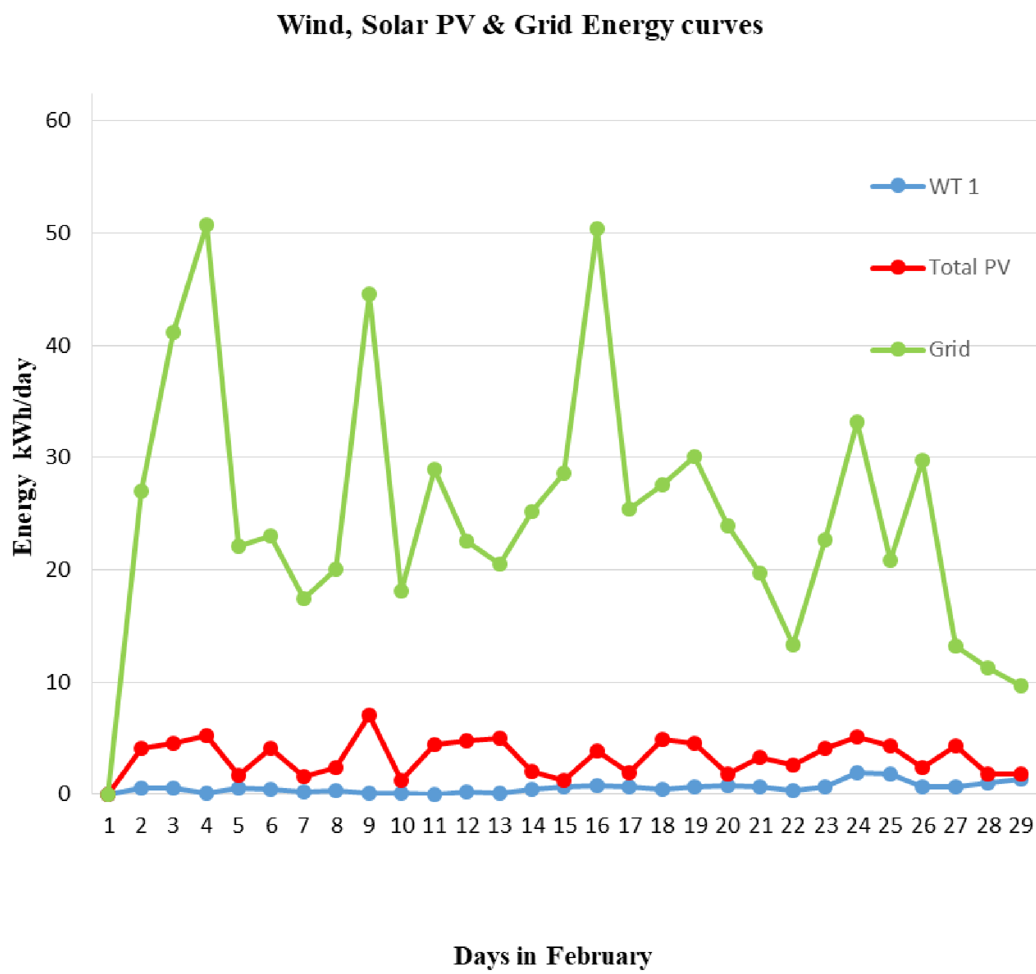

Figure 4.15 (a): Superimposed Wind, Solar and Grid energy curves in February 2016.

In March 2016 results, it was observed that there was daily fluctuation in energy consumption. The power from grid dominated the system as a main power source, maximum of 91 kWh and minimum of 12 kWh of energy was received from the grid while only a maximum of 10 kWh was generated from solar.

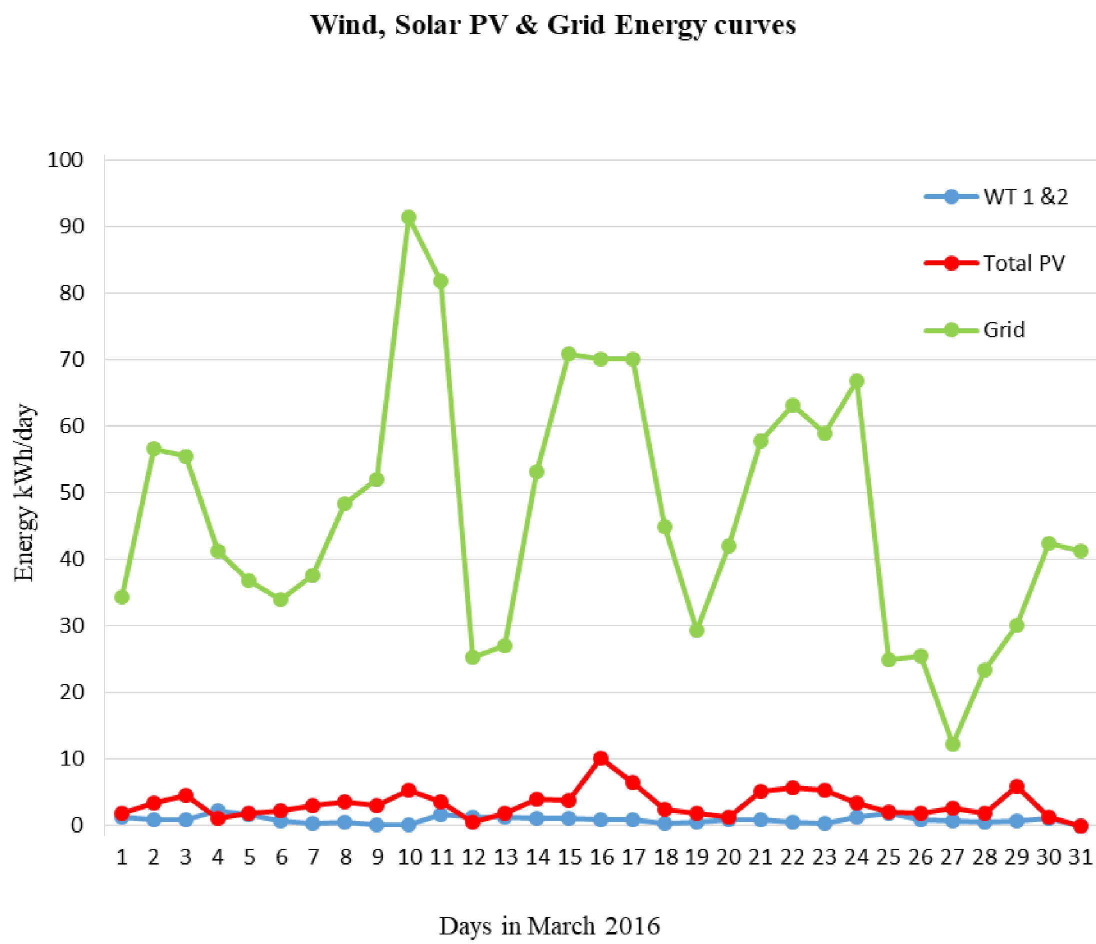

Figure 4.15 (b): Superimposed Wind, Solar and Grid energy curves in March 2016.

A consumption of 90 kWh/day on 10th April 2016, was received from the grid, 9.9 kWh/day and 0.8 kWh/day was generated from solar and wind respectively. Energy consumption received from grid reduced to a minimum of 1.9 kWh/day and 0.4 kWh/day which was generated from solar system on 11th and 25th April 2016. The study observed that lower energy consumption was due to fact that the school was not in session.

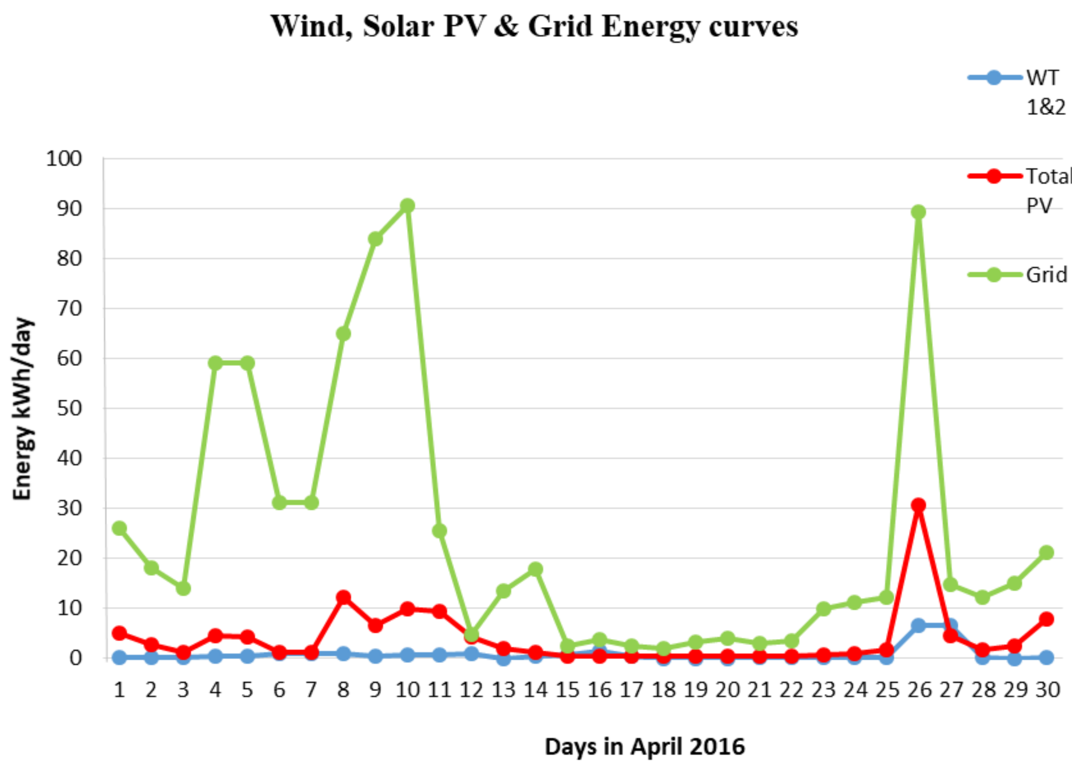

Figure 4.15(c): Superimposed Wind, Solar and Grid energy curves in April 2016.

4.6 Batteries and Charge Controller

The performance of solar PV system was technically triggered by the available power in a storage (battery bank). Charge controllers operating principal monitors the states of charge (SOC) of a battery and thus protecting the battery. The status of the batteries was also examined and found to be in normal state of 85% battery's healthiness at the beginning of the sampled period of the study. However, after monitoring the system after 12 months, the batteries were observed to have reduced its capacity. Due to increased energy demand in St. Francis Xavier Girls School, there was a need to look for additional power sources and harmonization of load distribution to sustain the energy demand.

Due to overloading of the inverter(s) the system allowed the grid power to take over the load demand and frequently charged the batteries because of stable grid power charging current than current from solar PV and wind turbines. Therefore, the charge controller disconnects the solar PV power to protect the batteries from overcharge and discharge. When the irradiance was higher and a lot of power generation was expected from solar PV, the batteries were already at float charge state and very small amount energy (absorption current) was required to fill the batteries (Steven, Hegedus, & Luque, 2003).

The study observed that there were three different types of charge controller i.e (PMW and MPPT) from different manufacture, where technical specification varies with products. Array PV 2 was connected to MPPT charge controller which has ability to maximize the power generation (Hiwale, Patil, & Vincurkar, 2014). Disconnecting and reconnecting changing process was not simultaneous this caused unbalanced terminal voltage and rate of charging. Solar PV string(s) may be active even if other strings have already been disconnected when the batteries are fully charged or low voltage disconnect(LVD) was reached and the availability of grid power charged the battery frequently thus more cycle in day. This process reduces the lifespan of the batteries and eventually damages the batteries.

4.7 Simulation of Load Profile.

The monthly average irradiance, wind speeds, daily average energy demand results were used to simulate the best design of a solar-wind hybrid system. Hybrid Optimization Model for Electric Renewable (HOMER) realized an average energy demand of 40.5kWh/day for the sample period (February, March and April). Figure 4.16, 4.17 and 4.18 illustrates load profiles in February, March and April 2016 respectively, the peak load demand was noted to start from 5am and 6am huge load demand was recorded between 6pm and 11pm every day.

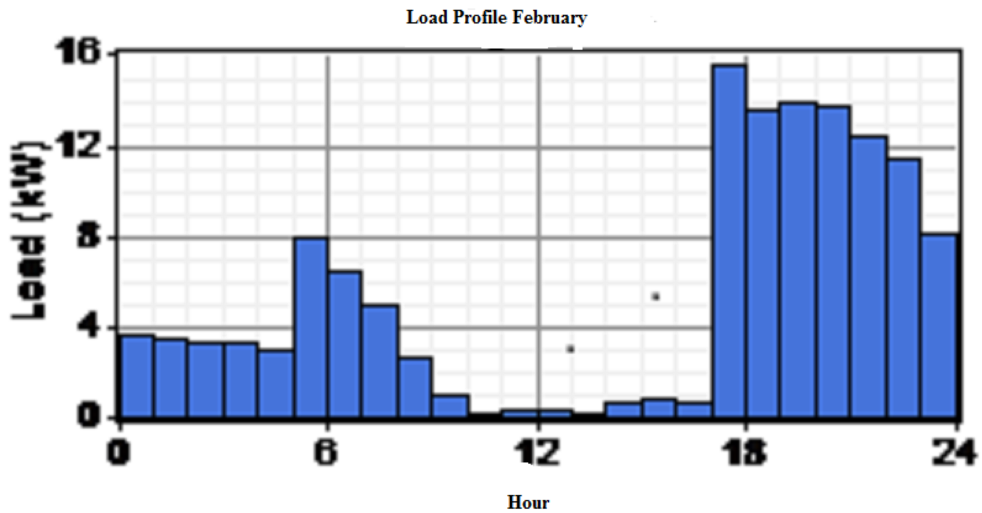

Figure 4.16: Daily Load profile for St. Xavier Girls School February 2016

Figure 4.17 illustrate simulated load profile for March, the results shows that the high demand was recorded in early morning between 5am to10am and between evening 6pm for March.

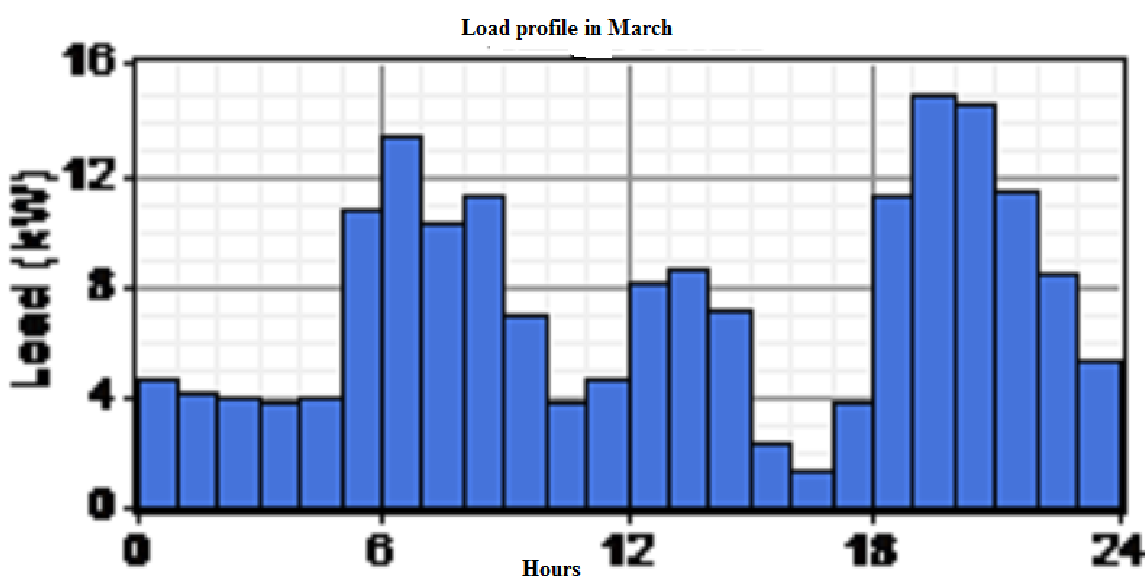

Figure 4.17: Daily Load profile for St. Xavier Girls School March 2016.

Figure 4.18 illustrates simulated load profile for April 2016. It was observed that load demand for April 2016 increased between 5 am to 10 am every day, while 5 am recorded a maximum power peak of 17 kW.

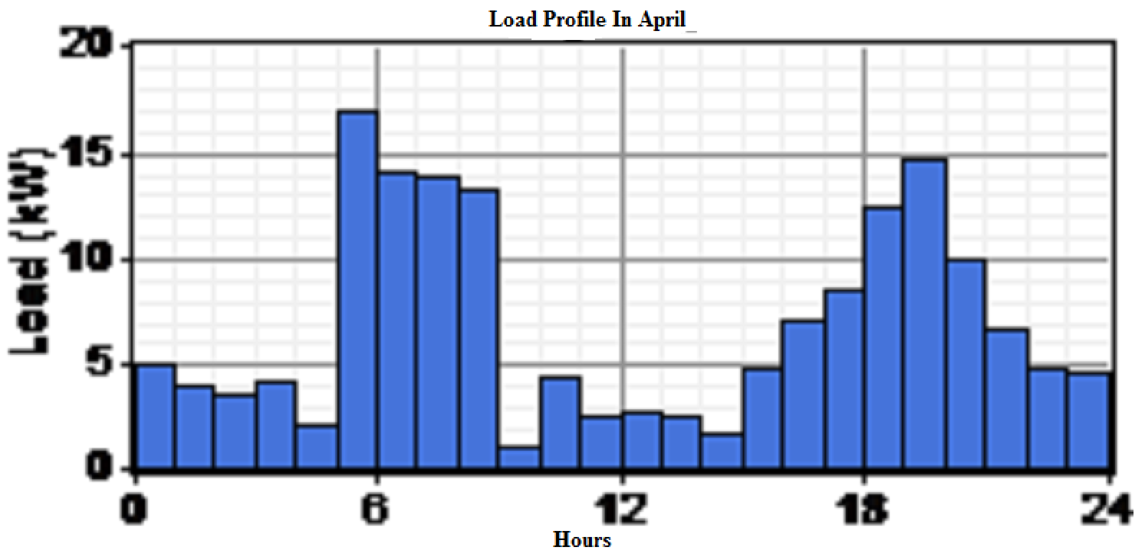

Figure 4.18: Daily Load profile for St. Xavier Girls School for April 2016.

The study observed 72 options simulated by using HOMER, the study chose the best hybrid option that resembled Solar-Wind hybrid system at the institution based on the total cost of implementing similar project simulated using HOMER. From the results simulated using HOMER it was observed that battery capacity installed at the institute was lower (25.9 kWh) than simulated battery capacity (35 kWh) considering lowest possible DoD of 50 % and discharging efficiency of 90%. Operating an off grid Solar-Wind hybrid system with low battery capacity will reduce the life span of the battery this is because system will make more cycles per day and tend to discharge below recommended DoD.

4.8 Payback period, Sizing and Cost of Modification of Solar- Wind System

4.8.1 Payback period

The wind-solar hybrid system in St Xavier girls' school total cost of installation was Ksh 3.49 million, and estimated annual maintenance cost of Ksh 20,000. This cost was based on the prevailing market cost of solar equipment in the year 2010. However, the study found that same capacity of wind – solar hybrid system would cost 2.36 million.

The highest energy consumption was recorded as1492.68 kWh/month; while the average annual energy consumption was 17912.16 kWh/year. The Solar Wind hybrid system generated an average of 128.06 kWh per month thus annual generation of 1536.76 kWh/year. However, operating on solar wind hybrid system to meet the load demand of 17912.16 kWh/year, the annual saving is calculated as follows;

Cost of electricity per unit 22 Ksh (including tax levy and other fee)

Annual Savings;$= 17{,}912.16\ \text{kWh} \times \frac{22\ \text{ksh}}{\text{kWh}} = 394{,}067.52\ \text{Ksh}$ (annual saving- annual maintenance) $= 394{,}067.52\ \text{Ksh} - 20000\ \text{Ksh} = 374{,}067.52\ \text{Ksh}$

$$\text{Payback period} = \frac{\text{Total cost of installation (wind solar hybrid system)}}{\text{Annual saving}}$$

$$\text{Payback Period} = \frac{2{,}640{,}000}{374{,}067.52} = 7.06\ \text{years}$$

The Solar-Wind hybrid system investment will breakeven after 7.06 years based on a constant energy demand and value of money.

4.8.2 Solar PV Array Sizing

Figure 4.18 schematically explain conceptual design approach of solar system, battery capacity with reference to load demand. From Table 4.1 total energy demand was calculated as 33.48 kWh/day. Currently 19.5 kWh/day was generated from already installed system and additional of 13.98 kWh/day was needed to meet daily energy demand.

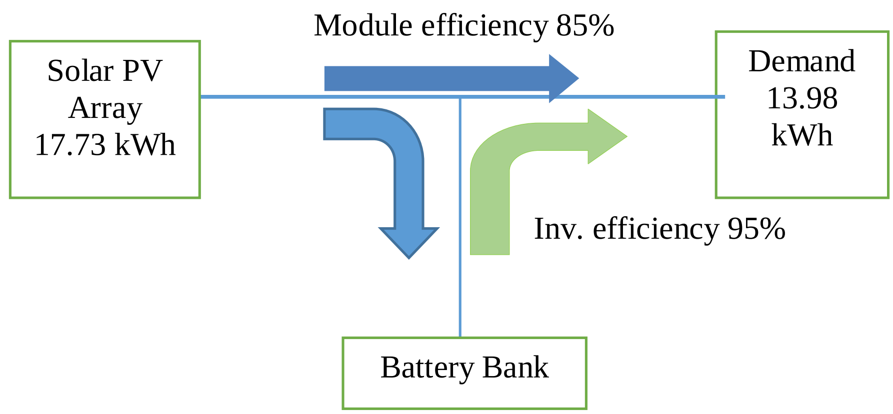

Figure 4.19: Solar PV design conceptualization.

Power output required from solar array considering the inverter efficiency 95% and Module efficiency 85% and battery efficiency 80%. The average insolation for the sampled months was 6.475 kWh/m^2, thus energy generated for 7 hours per day.

Array power output in 7 h $= \frac{17730 \text{ Wh} \times 100 \times 100}{95 \times 85 \times 7\text{h}} = 3136.6 \text{ W}_p$.

Modules rated 250W_p (polycrystalline) would be suitable for the system, Number of modules required $\frac{3136.6 \text{ w}}{250 \text{ W}} = 12.5 \equiv 12$ modules rated 250 W_p.

As 2015 the market price of solar PV is Ksh 60 per watt.

4.8.3 Wind Turbine sizing

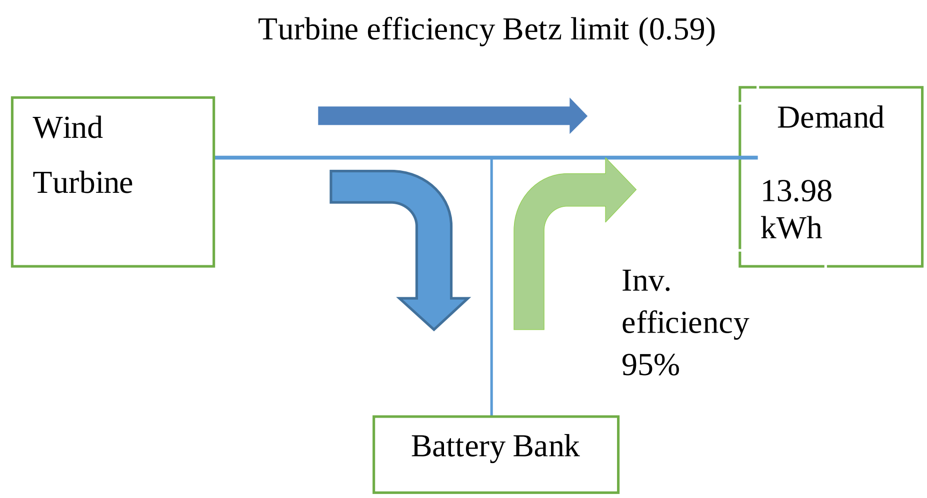

Figure 4.20: Wind turbine design conceptualization.

A design of wind turbine(s) that can generate at least 24.5 kWh, when operating at St. Francis Xavier's wind parameters to meet the energy demand will be needed. The power output results from wind turbines in sampled site was not desirable, however the wind pattern was observed to meet minimum threshold for wind turbines. Turbines have low efficiency due to moving parts and is prone to breakdown and thus annual maintenance cost is usually high as compared to solar PV**.**

4.8.4 Battery Bank Sizing

Simulated load profile using HOMER (figure 4.16, 4.17 and 4.18), load energy demand between 5pm to 7am per day was calculated as 118.1 kWh, 129.5 kWh, and 120.8 kWh for February, March and April 2016 respectively. The battery capacity should be 100% of energy demand; thus 129.5 kWh was selected because it was the highest capacity needed among the sampled months February, March and April which was used to size the battery capacity at DOD of 50% and one day of autonomy.

$$\frac{129500\text{AVh}}{48\text{V}} = 2697.9 \text{ Ah(System battery capacity)}$$

The capacity of battery at St. Francis Xavier Girls High school was noted to be lower than what simulation suggested, however the batteries cannot be added to the current installation because old batteries will deteriorate the healthiness of new batteries and they can only be upgraded once.

4.8.5 Cost of Modification of Solar- Wind System.

Table 4.3 summarizes the bill of quantities for the cost of modification identified by the study that can implemented to increase the power and reduce dependency from grid power. Cost of materials was based on vendor's price list of 2016.

Table 4.3: Bill of Quantities

Item	Quantity	Rating	Connection(series x parallel)	Cost(Ksh)
Solar PV	12	$250W_p$	2 strings; 2series x 6 parallel	180,000
MPPT Charge Controller	1	150/45		30,000
Materials				15,000
Installation				10,000
			Actual Total cost	235000
			Capital required	235000

The table 4.3 is a summary of the bill of quantities for adopted modification of solar-wind hybrid system.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The chapter focus on summary of discussions pointing out the conclusions and recommendations based on findings of the study. The researcher draws and presents the summary conclusions and recommendations systematically as the objectives of the study. Which were to; determine the energy load/demand in St Francis Xavier Girl High school, evaluate the performance of the installed wind solar hybrid system (Energy Production), determine the potential optimization options for a wind solar hybrid system by simulation, evaluate the cost of optimized wind solar hybrid system design.

5.2 Conclusions

The results indicate that the institution’s monthly energy consumption was within the domestic energy usage at an average of 40.5 kWh/day.

The site was observed to have a sufficient solar energy of 6.48 kWh/m^2, 5.99 kWh/m^2 and 6.11 kWh/m^2 in February, March, and April 2016 respectively. It was very ideal for solar PV systems with monthly energy generation was 98.68 kWh, 94.31 kWh and 120.76 kWh in month of February, March and April 2016 respectively.

The study show that wind turbine generated maximum of 6.6 kWh/day and a total monthly energy generation 19.26 kWh, 26.96 kWh and 24.19 kWh in February, March and April 2016 respectively.

Study identified the best optimization strategies was to add 3 kWp solar power at cost of about 235,000 Ksh and harmonizing load distribution among the inverters to ensure the peak load does not exceed inverter rating of 3 kVA.

5.3 Recommendations

A professional monitoring system to be installed to provide real time information/performance remotely for a solar-wind hybrid system, thus giving an alarm when overloading or strange operation happens with system.

Professional battery monitoring system to be installed to stabilize and normalize state of charge (SOC). The system administrator will be able respond before the system fails and hence prolonging battery lifespan.

The study recommend replacement of PMW with MPPT charge controllers from same manufacturer, this will ensure efficiency in charging and maximum power tracking mechanism.

The study recommends that the grid power to be isolated from solar-wind hybrid and operate independently, thus grid power to be used only when there is insufficient solar wind power and as backup in cloudy weather or in case of overuse.

REFERENCES

Fingersh, L., Hand, ,. M., & Laxson, A. (2006). *Wind Turbine Design Cost and Scaling Model,*. Cole Boulevard: National Renewable Energy Laboratory.

Hioki. (2018). *Hioki.* Retrieved from: https://www.manualslib.com/manual/ 1228108/ Hioki-Lr8431-20.html.

Hiwale, A. S., Patil, M. V., & Vincurkar, H. (2014). An Efficient MPPT Solar Charge Controller. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 7*(3), 10505-10511.

Jimenez, A. C., & Lawand, T. (2000). *Renewable Energy for rural schools,* Cole Boulevard: National Renewable Energy Laboratory.

Kamau, J. N., Kinyua , R., & Gathua, J. K. (2010). 6 years of wind data for Marsabit, Kenya average over 14 m/s at 100 m hub height; an analysis of the wind energy potential. *Renewable Energy , 35*(6), 1300.

Kantar, Y. M., & Usta , I. (2008). Analysis of wind speed distributions function derived from minimum cross entropy principles as better alternative to Weibull function. *Energy conversion management*, *49,* 962-973.

Khennas, S., Dunnett, , S., & Piggott, H. (2003). *Small Wind Systems for Rural Energy Services,* New Delhi: Dorwyn Ltd.

Kumar, R., & Rosen, M. A. (2011). A Critical Review of Photovoltaic-Thermal Solar Collectors. *Applied Energy,* 306-3614.

Maina, A. W., Kamau, J. N., Timonah, N., Nishizawa, Y., & Saoke, C. (2016). Wind Power Potential Analysis Based on Different Methods fitted in Weibull and Rayleigh models for Wind patterns in Juja and Naivasha. *International*

Journal of Innovative Research in Science Engineering and Technology., *5*(1), 24.

Manwell, J., McGowan , J. G., & Rogers, A. L. (2012). *Wind Energy Explained; Theory, Design and Application*,Washington: John Wiley and sons Ltd.

Mishra, S., Panigrahi, C. K., & Kothari, D. P. (2016). Design and simulation of a solar–wind–biogas hybrid system architecture using HOMER in India. *International Journal of Ambient Energy*, *37*(2), 184-191.

MoEP. (2015). *Guideline for Wind Power:* Unpublished guidelines; Nairobi: Ministry of Energy and Petroleum.

Mohammad , R. M., Hashim, H., Chandima, G., Mohd, A. R., Mohammad, I., R.,Shahrooz, H.(2016) Power loss due to soiling on solar panel; A revew. *Renewable and Sustainable Energy Reviews*, *56*, 1307-1316.

Mousa, K., Diabat, A., & Fath, H. (2013). Optimal design of a hybrid solar- wind power to drive a small- size reverse osmosis desalination plant. *Desalinition and water Treatment*, 3421.

Omwando, L. M., Kinyua, R., Ndeda, J. O., Marigi, S. N., & Kibwege, J. K. (2013). Investigation of Solar Energy Potential in Nakuru Kenya,. *Baraton Interdisciplinary Research Journal, 3*(2), 29-40.

Rahul, K. Kandoi, M, Ziaulhaq, A. Neelu, K.M. Deepshikha, S. Kiva, I. & Mungai, K. (2018). Scalling up of Wind Energy Development Plans in Kenya. Retrieved from https://www.windforceanagement.com/uploads/articles/rahul kumar kandoi scaling up of wind energy development plans in Kenya 963709. pdf

Serrano, E., Rus, G., & Garcia, M. (2009). Nenotechnology for sustainable Energy. *Renewable and Sustainable Energy Reviews*, 2372-2384.

Singh, K. (2010). *Implementation Guide for Renewable Energy*, India: Thapar University, Patiala.

Solar Direct, (2015). Bringing Renewable Technology Down to Earth. Retrieved from: http://www.solardirect.com/pv/batteries/batteries.htm.

Steven, H. & Luque, A. (2003). *Handbook of Photovoltaic Science and Engineering*,West Sussex, England: John Wiley & Sons Ltd.

Twidell, J., & Weir , T. (2006). *Renewable Energy Resources*, New York: Taylor & Francis.

Ulgen, K., & Hepbasli, A. (2003). A Study on Evaluating the Power Generation of Solar-Wind Hybrid Systems in Izmir, Turkey. *Energy Sources*, *25*(3), 241-252.

United Nations, (1998). *Kyoto Protocol to the United Nations Framework convention on Climate Change*. Kyoto: United Nations.

WinDForce Ltd. (2013). *Wind Secotor prospectus -Kenya*. Retrieved from: http://www.renewableenergy.go.ke/assetuplds/files/Wind%20Sector%20Prospectus%20Kenya.pdf.

APPENDICES

Appendix 1: Total energy from wind, solar, KPLC and load demand in February 2016.

	kWh/day	kWh/day	kWh/day	**kWh/day**	**kWh/day**	**kWh/day**	**kWh/day**		**(kWh/day)**
Date	**WT 1**	WT 2	PV 1	**PV 2**	**PV 3**	**Total PV**	**KPLC**	**Total Power**	**Load D.**
01/02/2016	0.553089	0	0.125	2.724123	0.723194	4.1252845	2.248955	6.37423923	3.392494
02/02/2016	0.521344	0	0.022	2.706716	1.331487	4.5811841	3.433369	8.01455306	5.439048
03/02/2016	0.141677	0	2.633	1.335824	1.142476	5.2529791	4.223905	9.47688399	5.458939
04/02/2016	0.553089	0	0.017	0.037943	1.040929	1.6486771	1.839119	3.48779641	5.932466
05/02/2016	0.444958	0	0.024	2.812849	0.807702	4.0894037	1.915533	6.00493688	3.399359
06/02/2016	0.179362	0	0.016	1.040518	0.314437	1.5506185	1.455145	3.00576395	2.676625
07/02/2016	0.309305	0	0.016	1.45893	0.602118	2.3864636	1.66745	4.05391327	2.643364
08/02/2016	0.128407	0	1.894421	3.483534	1.57913	7.085492	3.717176	10.802668	4.928853
09/02/2016	0.12769	0	0.015127	0.049517	1.02542	1.2177537	1.506002	2.72375531	5.639537
10/02/2016	0	0	0.014934	3.258203	1.191025	4.4641613	2.414996	6.87915699	4.12771
11/02/2016	0.152986	0	0.283791	3.124261	1.254502	4.8155403	1.875522	6.69106221	4.433708
12/02/2016	0.107646	0	0.183749	3.469531	1.225681	4.9866062	1.711456	6.69806232	3.880808
13/02/2016	0.472164	0	0.023045	1.080887	0.432044	2.0081398	2.102549	4.11068933	2.347072
14/02/2016	0.706892	0	0.013565	0.041663	0.421662	1.1837818	2.38322	3.56700219	4.727423
15/02/2016	0.775542	0	1.266243	1.395409	0.429709	3.8669029	4.200564	8.06746692	5.117502
16/02/2016	0.704369	0	0.015966	0.039087	1.112318	1.8717394	2.118157	3.98989667	6.055991
17/02/2016	0.417099	0	1.152878	2.186541	1.075593	4.8321119	2.294899	7.1270105	3.844388
18/02/2016	0.672435	0	0.156358	2.743948	0.958438	4.5311788	2.50852	7.03969926	4.603256
19/02/2016	0.800257	0	0.014208	0.038475	0.963517	1.8164576	1.997736	3.81419387	6.338345
20/02/2016	0.716101	0	1.583701	0.167869	0.759742	3.2274139	1.643393	4.8708074	3.005403
21/02/2016	0.314327	0	0.016784	1.613659	0.628087	2.5728565	1.109976	3.68283291	2.639088
22/02/2016	0.687291	0	0.164494	2.469781	0.788995	4.1105607	1.892109	6.00266997	3.245809
23/02/2016	1.923288	0	0.019963	2.332969	0.778837	5.0550575	2.766509	7.82156659	2.885034
24/02/2016	1.824742	0	0.859543	0.861763	0.748552	4.2945989	1.733912	6.02851116	2.918494
25/02/2016	0.664813	0	0.243159	0.914542	0.504007	2.3265214	2.47793	4.8044516	3.774705
26/02/2016	0.716484	0	0.124879	2.724123	0.723194	4.2886795	1.100534	5.38921388	2.327407
27/02/2016	0.965036	0	0.014083	0.748246	0.128533	1.8558977	0.934463	2.79036055	1.246321
28/02/2016	1.363852	0	0.169156	0.150572	0.127408	1.810989	0.803331	2.61431975	1.166011
29/02/2016	2.349454	0	0.017628	0.205147	0.246689	2.8189188	1.429192	4.24811051	1.90402
Max	2.349454	0	2.633002	3.483534	1.57913	7.085492	4.223905	10.802668	6.338345
Min	0	0	0.013565	0.037943	0.127408	1.1837818	0.803331	2.61431975	1.166011
Mean	0.6653	0	0.382766	1.559194	0.795359	3.4026197	2.120884	5.52350327	3.796524
Total Power Prod.	19.2937	0	11.10022	45.21663	23.06542	98.67597	61.50562	160.181595	110.0992

Appendix II: Calculation of Rayleigh distribution and the electricity production.

Annual wind speed in Naivasha =				3.34	[m/s]	
	Rayleigh distribution					
V [m/s]	Probability	Probable Hours [h/month]	Power Naivasha [W]	Electricity production [Wh/month]		
1	0.131	94	0	0		
2	0.212	153	0	0		
3	0.224	161	9	1,460		
4	0.183	131	27	3,567		
5	0.121	87	72	6,309		
6	0.067	48	136	6,543		
7	0.031	23	199	4,483		
8	0.012	9	317	2,835		
9	0.004	3	434	1,322		
10	0.001	1	543	482		
11	0.000	0	651	145		
12	0.000	0	814	39		
13	0.000	0	995	9		
14	0.000	0	1,167	2		
15	0.000	0	1,356	0		
16	0.000	0	1,519	0		
17	0.000	0	1,718	0		
18	0.000	0	1,899	0		
19	0.000	0	1,990	0		
20	0.000	0	2,080	0		
21	0.000	0	362	0		
22	0.000	0	344	0		
23	0.000	0	353	0		
24	0.000	0	362	0		Electricity Production/day
25	0.000	0	371	0		
				27,195	[Wh/month] =→	76 [Ah/day]
				27	[kWh/month	