# HYBRID POWER SYSTEMS OPTIMIZATION FOR COMMERCIAL APPLICATION IN KENYA: A CASE STUDY OF EAST AFRICAN SCHOOL OF AVIATION

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**2019**

# Hybrid Power Systems Optimization for Commercial Application in Kenya: A Case Study of East African School of Aviation

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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**

**2019**

## DECLARATION

This thesis is my original work and has not been presented for a degree in any other university

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**ACKNOWLEGEMENT**

I thank God for the precious gift of life and His mercies. May His name be glorified for His provision and the opportunity to undertake this research with abundant fulfillment.

I wish to give my appreciation to my supervisors; Prof. Joseph N. Kamau, Prof. Robert Kinyua and Dr. Jared H. Ndeda for their invaluable intellectual guidance, insightful ideas, encouragement and worthy instructions. I also wish to thank the East African School of Aviation for granting me the permission to use their institution as a case study for my research work.

Finally, I thank my wife, Alfrida, and our children, Jerome and Mikayla for their support and prayers throughout the research period. I extend the same to my parents Hellen, Reuben Chepkwony and mother in-law Rael Cheboi. They have been my inspiration and motivation to work hard and always strive to make the best out of all circumstances.

## TABLE OF CONTENTS

**DECLARATION** ........ ii
**ACKNOWLEGEMENT** ........ iii
**TABLE OF CONTENTS** ........ iv
**LIST OF TABLES** ........ vii
**LIST OF FIGURES** ........ viii
**LIST OF APPENDICES** ........ ix
**LIST OF ABBREVIATIONS AND NOMENCLATURE** ........ x
**ABSTRACT** ........ xii
**CHAPTER ONE** ........ 1
**INTRODUCTION** ........ 1
1.1 Background ........ 1
1.2 Statement of the Problem ........ 4
1.3 Objectives ........ 4
1.3.1 Main objective ........ 4
1.3.2 Specific objectives ........ 5
1.4 Research Questions ........ 5
1.5 Justification ........ 5
1.6 Scope ........ 6
**CHAPTER TWO** ........ 7
**LITERATURE REVIEW** ........ 7
2.1 Related Studies ........ 7
2.2 Hybrid power systems ........ 9
2.3 Hybrid optimization tools ........ 12
2.4 Theoretical Principles ........ 12
2.4.1 Solar PV Energy ........ 12
2.4.2 Solar Thermal energy ........ 13
2.4.3 Solar Resource Potential Representation ........ 16
2.4.4 Wind energy ........ 19

2.4.5 Economic and financial Analysis ........................................................................ 24
**CHAPTER THREE ........................................................................................ 29**
**METHODOLOGY .......................................................................................... 29**
3.1 Site Description ........................................................................................... 29
3.2 Load Profile Determination ........................................................................... 29
3.2.1 Thermal Fraction Assessment ..................................................................... 31
3.3 Resource Assessment ..................................................................................... 32
3.3.1 Wind Resource Assessment ......................................................................... 32
3.3.2 Wind Turbine Selection ............................................................................... 33
3.3.3 Solar Power System Selection ...................................................................... 34
3.4 Hybrid System Components ........................................................................... 35
3.4.1 The grid ........................................................................................................ 36
3.4.2 The converters .............................................................................................. 36
3.4.3 Wind turbines ............................................................................................... 36
3.4.4 Solar PV Modules ......................................................................................... 36
3.4.5 Solar Water Heating System ......................................................................... 37
3.5 Hybrid system Selection ................................................................................. 37
3.5.1 Load data input ............................................................................................. 38
3.5.2 Wind data resource input .............................................................................. 38
3.5.3 Solar input data ............................................................................................. 39
3.6 Economic Analysis .......................................................................................... 39
**CHAPTER FOUR .............................................................................................. 40**
**RESULTS, ANALYSIS AND DISCUSSION ...................................................... 40**
4.1 Consumption trends and load profile. ............................................................. 40
4.1.1 Sample daily load curves of a typical week in November 2017 ........................ 42
4.1.2 Thermal fraction of the load ........................................................................... 49
4.2 Wind and Solar Resources ............................................................................... 49
4.2.1 Wind power density for the site ...................................................................... 51
4.2.2 Wind Turbine Selection .................................................................................. 52
4.3 Solar Energy for the Site .................................................................................. 53
4.3.1 Solar Power System Selection ........................................................................ 55

4.4 System Simulation....56
4.4.1 Load data input.... 56
4.4.2 Wind data resource input .... 57
4.4.3 Solar input data.... 57
4.5. Simulation Results....58
4.5.1 Solar PV-Wind-Grid Serving Total load of 1864.28 kWh/day .... 58
4.5.2 Wind-Grid Hybrid System for Scaled Load (primary load of 1265.08 kWh/day) .... 60
4.5.3 Wind-Grid-Solar PV-Solar Thermal for the Total Load (1864.2 kWh/day).... 63
4.5.4 Wind-Solar PV-Grid Vs Wind-Solar PV-Grid-Solar Thermal Hybrid Systems .... 65
4.6 Sensitivity Analysis....66
**CHAPTER FIVE .... 67**
**CONCLUSIONS AND RECOMMENDATIONS.... 67**
5.1 Conclusion ....67
5.2 Recommendations ....68
**REFERENCES .... 69**
**APPENDICES.... 74**

## LIST OF TABLES

**Table 1:** Kenya's electricity generation mix ........ 2
**Table 2:** Feed-in-Tariff structure for Projects up to 10 MW ........ 27
**Table 3:** Proposed Net Metering credit settlement ........ 28
**Table 4:** Classes of Wind Power Density and Wind Speed. ........ 33
**Table 5:** Average monthly wind speed ........ 50
**Table 6:** The calculated wind power density values ........ 52
**Table 7:** Monthly average values for GHI ........ 53
**Table 8:** Simulation results for 1864.28 kWh/day ........ 59
**Table 9:** Annualized Costs & NPC for the optimal system ........ 60
**Table 10:** Simulation results for scaled load. ........ 61
**Table 11:** NPC & Annualized costs ........ 61
**Table 12:** SWH Annualized costs and NPCs ........ 64
**Table 13:** Total NPCs & Annualized costs for Wind-Grid-Solar hybrid system ........ 64

# LIST OF FIGURES

**Figure 1a**: Logger with 3 Phase 4 wire connections ............................................................... 30

**Figure 2**: Hybrid system configuration..................................................................................... 35

**Figure 3:** Energy Time of use at the site ................................................................................. 41

**Figure 4**: load profile & energy Usage for Saturday, 25th Nov. 2017 ...................................... 42

**Figure 5:** Load profile & energy Usage for Sunday, 26th Nov. 2017 ....................................... 43

**Figure 6**: Load Profile & energy Usage for Monday, 27th Nov. 2017...................................... 44

**Figure 7:** Load Profile & energy Usage for Tuesday (Public holiday), 28th Nov. 2017............ 45

**Figure 8**: load Profile & energy Usage for Wednesday, 29th Nov. 2017 .................................. 46

**Figure 9:** Load Profile & energy Usage for Thursday 30th Nov. 2017. .................................... 47

**Figure 10:** Load Profile & energy Usage for Friday, 1st Dec 2017 .......................................... 48

**Figure 11**: Typical Daily load profile for EASA....................................................................... 49

**Figure 12**: Probability density function at 30 m height. .......................................................... 50

**Figure 13**: Cumulative Distribution Function for the site at 30 m height................................. 51

**Figure 14**: Power curves for different nominated wind turbines ............................................. 53

**Figure 15**: GHI for the site curtesy of NASA .......................................................................... 54

**Figure 16**: Monthly Hourly Average Global Irradiance on PV array....................................... 55

**Figure 17**: Input load data for the site ...................................................................................... 56

**Figure 18**: Input data for the wind resources for the site ......................................................... 57

**Figure 19**: Input data for the Solar GHI resources for the site ................................................. 58

**Figure 20**: Unscaled HPS Wind Generation, Grid Purchases, Load & Grid Sales for a week ... 62

**Figure 21**: Scaled HPS Wind Generation, Grid purchases, Load & Grid Sales for a week ....... 63

**Figure 22**: Hybrid power system annual productions.............................................................. 65

**Figure 23**: Sensitivity analysis graph (Optimal System plot with COE Superimposed) ........... 66

## LIST OF APPENDICES

**Appendix I:** Consumption Data for EASA. .................................................................74
**Appendix II:** Hummer H24.5- (100 kW) Data sheet and Power Curve ..........................95
**Appendix III:** Data sheet for Canadian MaxPower........................................................97
**Appendix IV:** Solar Water Heating System Specifications ...........................................98
**Appendix V:** ERC Hot water demand guidelines..........................................................99
**Appendix VI:** SWH Calculations Baseline...................................................................100
**Appendix VII:** SWH Cash flows & NPC calculations..................................................101
**Appendix VIII:** Power Usage Research Questionnaire for EASA. ..............................102

## LIST OF ABBREVIATIONS AND NOMENCLATURE

| | |
|---|---|
| **AC** | Alternating Current |
| **COE** | Cost of Energy |
| **CI1** | Commercial Industrial Class 1 |
| **DC** | Direct Current |
| **EASA** | East African School of Aviation |
| **ERC** | Energy Regulatory Commission of Kenya |
| **IFC** | International Finance Corporation |
| **GIS** | Geographic information system |
| **GHI** | Global Horizontal Irradiance |
| **GTI** | Grid Tie Inverter |
| **HAWT** | Horizontal Axis Wind Turbine |
| **HOMER** | Hybrid Optimization of Multiple Energy Resources |
| **HPS** | Hybrid Power Systems |
| **HRES** | Hybrid Renewable Energy System |
| **IRENA** | International Renewable Energy Agency |
| **KPLC** | Kenya Power and Lighting Company |
| **KSh** | Kenya Shilling |
| **kWh** | Kilowatt-hour |
| **LPSP** | Loss of power supply probability |

| | |
|---|---|
| **MATLAB** | Matrix Laboratory |
| **MW** | Megawatt |
| **MWh** | Megawatt-hour |
| **NASA** | National Aeronautics and Space Administration |
| **NPV** | Net Present Value |
| **NPC** | Net Present Cost |
| **NREL** | National Renewable Energy Laboratory |
| **O&M** | Operation and Maintenance |
| **PGMT** | Power Generation and Transmission Master Plan, Kenya |
| **PSCAD** | Power System Computer Aided Design |
| **PV** | Photovoltaic |
| **REA** | Rural Electrification Authority |
| **REN** | Renewable Energy |
| **RECP** | Renewable Energy Cooperation Program |
| **RES** | Renewable Energy Sources |
| **SPP** | Simple Payback Period |
| **SWH** | Solar Water Heating |
| **USD** | US Dollar |
| **VAWT** | Vertical Axis Wind Turbine |

**ABSTRACT**

Hybrid power systems consist of at least two energy sources deployed to serve a common load. Renewable energy resources are largely dependent on weather and/or time of day and this gives them the disadvantage of low availability, unreliability, instability and high cost of energy. Hybrid Power Systems are designed to address individual weaknesses of deployed energy resources. In this study, design and optimization of wind-solar and grid hybrid power system was done in order to determine its viability in meeting a specific load of a commercial consumer in Kenya. East African School of Aviation (EASA) was selected as a case study because it is a midsized learning institution with diverse and reasonably high energy demand typical of a commercial consumer. It did therefore provide a suitable case study for developing a viable hybrid power system for similar energy consumers. This research was thus focused on designing an optimized Wind-Solar PV-Solar Thermal and Grid power system to meet local energy demand of EASA in Nairobi Kenya. This objective was met by carrying out site energy demand assessment, resource assessment, power system components selection and simulation using a simulation software (HOMER). The peak load, base load and daily average energy consumption were found to be 177 kW, 60 kW and 1864.28 kWh/day respectively. Local energy resource assessment for the site established that solar resource potential is high and suitable for most solar energy applications. Wind energy on the other hand was found to be a Class 1 category which denotes a poor wind resource regime. System simulation and optimization gave positive results for wind-solar and grid hybrid systems. The most optimal system was composed of Wind-Solar PV-Solar Thermal-Grid energy sources with a Net Present Cost and Cost of Energy of KSh 68,927,127 and KSh 7.38/kWh respectively. The Cost of Energy is lower than the utility charges for a commercial consumer charged under the method CI1. Further, this system has a Simple Payback Period of 4.93 years hence making it an attractive project to undertake. The study revealed that hybrid power system utilizing grid connected local energy resources can provide low cost power hence the same can be adopted by commercial consumers with similar energy demands.

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background

With the consistent expansion of energy access and demand as a result of human population growth and industrialization, pressure is equally increasing on the available energy resources. Fossil based energy resources like petroleum, coal and natural gas have finite reserves that can be exhausted within human time scale (Covert, Greenstone & Knittel, 2016). In addition, exploitation of conventional energy resources is accompanied by adverse environmental impacts like greenhouse gas emissions and climate change. These concerns have prompted the development and deployment of renewable sources of energy (RES) in order to mitigate effects of climate change together with the risk of depletion of fossil-based resources. Wind and solar energy resources suffer from intermittence hence making them unreliable sources of energy. This poses challenges to increasing grid penetration of renewable energy (Chow, Belongie & Kaissl, 2015).

Despite much technological advancement in RES like solar, wind, geothermal, small hydro, tidal wave and biomass, conventional sources still provide the least cost of electricity (Covert et al., 2016). Although the conventional power sources provide the least cost of electricity, they have high levels of emissions compared to the RES which have low or no emissions. In locations where the potential of RES is high, it is possible to have the least cost of electricity based on the same without the addition of conventional energy sources.

In order to overcome the inherent weaknesses of the different types of energy resources, hybrid power systems have been designed and developed (El-Tous & Hafith, 2014). An optimal mix of various energy sources can result in acceptable level of emissions and affordable cost of electricity. Hybrid system optimization therefore provides a means for supplying clean and affordable power to users. These systems can be developed through combination of two or more sources of energy based on their availability in a given location and their potential.

Demand for electricity in Kenya has been steadily growing in the last 5 years. According to the Ministry of Energy & Petroleum Report (2016), access to electricity was at 23% in 2012 and in 2016, it was at 55%. This growth has been experienced in the domestic, small commercial and large commercial sectors though at varying rates. Connection to the end users is implemented through central grid or off-grid systems for remote locations. As the demand for electricity continues to grow, so must the supply of electricity. The main sources of electricity in Kenya now are hydro, thermal, geothermal, wind, solar and biomass. The national generation mix in terms of installed capacity consist of 64.4% RES and 35.6% fossil-based energy resources (KPLC, 2015). Generation of electricity from available energy resources must be increased if a 100% access to electricity by the population is to be met. The process of availing electricity must be done prudently by designing viable and competitive power systems that utilize local energy resources optimally. Table 1 shows installed capacity and annual electricity generation mix in Kenya.

**Table 1: Kenya's electricity generation mix**

| Sources of Power Generation | | Installed Capacity | | Annual Generation | |
|---|---|---|---|---|---|
| | | MW | Percentage | GWH | Percentage |
| Renewable | Hydro | 821 | 35.1 | 3787 | 38.58 |
| | Geothermal | 632 | 27 | 4608 | 46.95 |
| | Solar | 1 | 0 | 0.79 | 0.01 |
| | Wind | 26 | 1.1 | 56.7 | 0.58 |
| | Cogeneration | 28 | 1.2 | 0.31 | 0.003 |
| | Total | 1508 | 64.1 | 8452.8 | 86.123 |
| Fossil Fuels | Thermal | 833 | 35.6 | 1296 | 13.2 |
| | Imports | 0 | 0 | 67 | 0.69 |
| | Total | 833 | 35.6 | 1363 | 13.89 |
| Installed Capacity & Generated Units | | 2341 | 100 | 9815.8 | 100 |

**Source: (KPLC, 2015)**

Kenya is endowed with vast amounts of RES like solar, wind, hydro, geothermal and biomass but with varied distribution across the country. A hybrid system composed of two or more of these available resources can be developed to add on to the existing generation capacity either on grid or off-grid. Energy resource potential of each of these sources must be carried out so that suitable combination can be selected for development of a hybrid system in a given location. Meteorological data compiled from a local weather station over a given period of time may be used to estimate solar and wind energy potential. Local river flow at different times of the year can be measured and analyzed for estimation of hydro power potential of a location.

Kenya lies within the equator and does enjoy long hours of sunshine throughout the year across the whole country (Oloo, Strobbl, &Olang, 2016). Solar can therefore form a significant component of a hybrid system in any location of the country. Wind energy can be utilized in places of high wind speeds. The ministry of energy has developed a wind atlas with shortlisted sites of high wind energy potential (ERC, 2013). The information can be used as a guide for determining wind resource potential but specific site resource assessment must be carried out before an actual investment is done. Small hydro potential in Kenya is estimated at 3000 MW but only 30 MW of this has been exploited. Geothermal energy has an attractive potential of 10000 MW while Biomass also has a significant potential in providing sustainable energy.

In Kenya, the cost per kWh of electricity charged by KPLC for CI1 consumer range between Ksh 15 and Ksh 20 while off-grid cost of electricity can be as high as Ksh 80/kWh (ERC-IFC, 2015). Remote locations are best connected to electricity through mini grid systems due to the high cost of construction of transmission lines from far off generation centers (Lukuyu & Cardell, 2014). Off-grid power systems utilize local energy resources to supply power to the immediate communities. A blend of resources may be used in order to efficiently and effectively generate power with costs comparable to grid rates. Where off-grid power systems are used to provide electricity for essential services in remote places to precede a planned grid expansion, the installation should be made grid-tie ready.

Grid tied mini grid systems provide a host of advantages to the main grid. An optimized, grid ready hybrid system can provide affordable power to remote communities at the present while upon grid connection in the future, the same system will add into the net available power in the main grid. If managed properly, integration of mini grid systems to the main grid will hasten the process of development of a smart grid with significant component of renewable energy sources. It is therefore worth taking all measures to design the most suitable hybrid system for exploiting local energy resources.

## 1.2 Statement of the Problem

Electricity generation using local energy resources is faced with two major constraints of high cost of production and reliability of supply. Local energy resources like solar, wind and small hydro suffer from intermittency and seasonal variations. Deployment of individual local energy resources could present a large supply and demand mismatch due to variability of supply coupled with demand fluctuation. Energy buffering technologies like battery storage, pumped hydro, pressurized air among others may be used to match demand to supply. Storage technologies however are still expensive and would cause the overall cost of energy to be high and less competitive. Hybridizing local energy resources with complementing availability patterns can help in addressing the problem of demand versus supply mismatch at competitive costs. The key issues in designing a hybrid power system therefore are understanding local energy resource potential, defining demand trends, quantifying the costs of conversion technologies and finally integrating all components in the most optimal way possible.

## 1.3 Objectives

### 1.3.1 Main objective

The main objective of this study was to design and optimize Wind-Solar PV-Solar Thermal and Grid hybrid power system for commercialization in Kenya by determining both the technical and the economic feasibilities.

### 1.3.2 Specific objectives

1. To estimate the wind and solar resource potential at the site
2. To determine the load profile for site
3. To size and optimize a hybrid power system for meeting the specific load of the site using a simulation software (HOMER)
4. To determine the Net Present Cost (NPC), Cost of Energy (COE) and the Simple Payback Period (SPP) of the Hybrid Power System.

## 1.4 Research Questions

1. What is the resource potential for wind and solar in the site?
2. What is the load profile of the institution?
3. What is the composition of an optimized system that meets the institution's load demand?
4. What is the NPC, COE and SPP of the system?
5. What is the outcome of the sensitivity analysis for the system?

## 1.5 Justification

Business entities are continuously pressed to find ways of lowering their operational costs in order to be competitive both locally and regionally. Among the most significant components of such operating costs is the power bill. The cost of energy from the utility provider in Kenya for commercial industrial consumer (CI1) ranges between Ksh 15/kWh and Ksh 20/kWh. The fluctuation in the cost of energy is majorly influenced by fuel charge levy which varies depending on the level of thermal generation component during a billing period. In addition to contribution to high energy cost, thermal energy generators are associated with emission of harmful greenhouse gases to the atmosphere. Power from the grid is not very reliable so that companies and institutions are tasked to install diesel-based backup generators.

There is need therefore to explore both the technical and economic viability of local energy resources' deployment to meet on site power demand of a commercial consumer. A properly designed hybrid power system exploiting local energy resources can confer several benefits to the consumer and the economy in general. Among these benefits are; reduction of energy bills by utilizing free from nature resources, reduction of emission of harmful greenhouse gases to the atmosphere, improvement of the voltage profile of the distribution lines hence reduction in distribution loses and the overall increase of renewable energy proportion of the national generation mix.

### 1.6 Scope

The research will focus on hybrid power system comprising Solar PV, Solar thermal, and Wind to meet the load for EASA in Nairobi. The school offers diploma and certificate courses in the field of aviation. The institution has students' hostels and an estate department with several housing units for staff. The institution's power demand is mainly from lighting, running learning equipment in their workshops, air conditioning, borehole pump, swimming pool pump and thermal load in the form of water heating.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Related Studies

There are several studies that have been conducted on hybrid power systems in Kenya and in other countries (Contreras, 2015; Lukuyu & Cardell, 2014; Prodromidis, 2014; Tazvinga, 2015 & Khoury, 2016). These studies have focused on utilizing local energy resources such as wind, solar, hydro, geothermal, biomass and diesel to meet several operation objectives. Characteristics like reliability, stability, cost of energy and renewable energy fraction have been used in determining viability of a hybrid power system. Quite a number of the research results have been published. The following paragraphs present a review of some of these research works.

Faten, Mohamed and Hanaa, (2012) carried out a study and designed a hybrid power system based on Solar PV, wind generator and fuel cell storage. Their objective was to efficiently serve an electric load of a small-scale desalination unit and a tourism motel in Hurghada, Egypt. Four renewable energy power systems were analyzed in order to select the most optimum of them. The energy systems considered were; PV-wind hybrid system, stand-alone wind system, stand-alone photovoltaic system and PV-wind-fuel cell hybrid system. HOMER simulation software was used to size, optimize and estimate the costs of the proposed systems. Their results indicated that the PV-wind power hybrid system was the most viable and reliable among the four system configurations for meeting the load for the selected site.

Gagari, Ramananda and Sudip, (2012) used PSCAD software to simulate the operational characteristics of a hybrid power system composed of hydro and wind power. They identified load sharing, voltage stability and environmental conditions as critical attributes of the system. The output of the wind and hydro generators were connected to the same bus to serve a common load. Depending on load demand, both generators provided useful power but failed when the load was larger than the combined output. The load was also met in the absence of one generator provided the output limit of the available generator was not exceeded. The study concluded that hybrid power systems provide high quality power based on complementarity of different generators used.

Pandley & Aditi, (2016) modeled and simulated a grid connected PV-Wind hybrid power system using MATLAB/SIMULINK. Both the PV and Wind systems were connected in parallel and then to the grid through an inverter whose gate pulse was controlled. The objective was to analyze the grid voltage and current to determine Total Harmonic Distortion (THD). From the study, a low magnitude of 1.63% for THD was obtained. The research concluded that a properly designed hybrid power system with the necessary conditioners can be integrated to the grid without much harm to the overall system.

Nagaraj, Thirugnanamurthy, Rajput and Panigrahi, (2016) used MATLAB to analyze the performance of different combinations of energy technologies with different capacities. The objective of their study was to design a system that addresses the problem of energy resource fluctuation at a minimum cost. They focused on total energy produced per year, the cost per unit of energy, and the availability of power for specific load throughout the year. They found out that, addition of PV, wind turbines or storage capacities does not solve the problem of fluctuation and neither does it help in reducing the cost of energy. For the location under study, wind and solar resources were found to complement each other hence leveraging on this characteristic led to lower cost per unit of energy.

Okinda and Odero, (2016) carried out a research to find out an optimal system configuration of solar PV-wind hybrid system to serve a load in northern Kenya. They confirmed that wind and solar resource regimes for the site were complementary and therefore were good candidates for hybridization. Sizing and optimization results presented a competitive cost of energy (of USD 0.20), at a loss of power supply probability (LPSP) of 10%. They however noted that the cost optimal configuration was not the resource optimal solution. This was determined by comparing a Solar PV system with a sun tracking system with one without. The sun tracked system delivered power at a higher energy cost but with a lower LPSP.

Most studies have focused on hybrid system operation, sizing and optimization for different configurations of micro-hydro, diesel, wind, solar PV and battery storage to meet different objectives. Despite these configurations meeting their operating objectives like stability, reliability and clean energy fraction, their cost of energy is still higher than their local market energy tariffs. Additionally, there has not been adequate research on solar thermal incorporation in a hybrid power system. This study therefore seeks to size and optimize a hybrid power system consisting of solar thermal, solar PV and wind to serve a specific load with the aim of minimizing storage requirements hence reducing the overall cost of energy.

## 2.2 Hybrid power systems

A hybrid power system (HPS) is composed of two or more sources of power used to generate electricity for meeting a common load. Such a power system combines renewable energy and traditional generators like diesel generators. Hybrid renewable energy system (HRES) on the other hand uses renewable energy sources only. The different sources of energy have unique characteristics that either limit or promote their usage. In a hybrid power systems design, such resource characteristics are considered and optimized in order to overcome their weaknesses (El-Tous & Hafith., 2014).

Generally, a power system consists of different components integrated together to fulfill its functions. Such components include; generators, transmission, conditioners and the loads. Generators are conversion devices for harnessing available energy resources in the required form. Transmission equipment is for transporting generated power to the load center. Generated power may need to be regulated and conditioned to suit the end use devices by means of conditioners like storage, converters and rectifiers.

Hybrid power systems may be implemented through central grid connection (on-grid) or as a stand-alone power generating system (off-grid). A grid connected HPS may be designed to operate on island mode when there are faults in the main grid. Off-grid power systems operate independent of the central grid and generate power from local energy resources. Inclusion of renewable energy resources (RES) like wind and solar with a lot of intermittence introduces instability to the central grid (Ma, 2015). It is therefore necessary to employ effective resource forecasting methods and intelligent power electronic regulators to ensure smooth integration to the grid.

Economic viability of a hybrid power system is dependent on proper assessment of available energy resources, development status of conversion technology and the main goals of a power project. The desire to reduce fossil-based fuels to generate electricity because of the harmful nature of their exploitation process makes RES an attractive alternative for generating power (Covert et al., 2016). HPS provides a good opportunity for the use of renewable energy to supply electricity cost effectively if proper optimization for its components is done. Where the cost of carbon emissions and other greenhouse gases to the environment is accounted for, the viability of RES increases significantly. Additionally, the use of locally available energy resources enhances energy access and security.

Emission of greenhouse gases in power generation is associated with the combustion of fossil fuels for power generation (Sandeep & Kumar, 2013). Emission level is defined by the amount of greenhouse gas released to the environment per kWh of electricity generated. Emissions Factor (EF) is used to describe the amount of pollutants released per unit of generated power by a power system. The Kenya Grid has an EF of about 0.5 $tCO_2eq/MWh$ (NEMA, 2014). Emissions level varies depending on the level of penetration of renewable energy sources in the generation mix. A conscious effort must be made from the planning stage of a power system to comply with acceptable level of emissions requirements or otherwise generate an emission free energy. Prevailing energy policy instruments could be used to encourage or force compliance to reduce greenhouse gas emissions.

Remote communities may be supplied with electricity through off-grid HPS where construction of central grid is expensive or difficult due to the local terrain (Contreras, 2015). Grid connection in Kenya is presently at 60% while off-grid connection is only at 0.08% of installed capacity (KPLC, 2014). This implies that 40% of Kenyans who are not yet grid connected have a paltry 20 MW of electricity between them. Off-grid HPS therefore has a niche in expanding access to electricity in Kenya. The government of Kenya through the Rural Electrification Authority (REA) has carried out a study to determine potential sites for off-grid power systems development for potential investors (ERC, 2015).

Based on the distributed nature of renewable energy resources, hybrid power systems may need to be distributed as well according to potential and availability. This characteristic makes the viable scale of their development to range from several watts to a few megawatts' installations (Prodromidis, 2014). The unique hybrid power system size is determined by the load to be served, nature of available energy resources, economic as well as environmental constraints. Rigorous analysis of interrelationships between these factors that determine the design of an HPS needs to be done in order to come up with an efficient and effective outcome. This process is called optimization.

With the need to widen energy availability and access, the process must be economically and financially sound and sustainable. This need is more urgent when renewable energy resources are to be deployed to generate energy. Though the current costs for RES development has come down, the levelized cost of electricity for the different generation technologies varies from one region to the other (Timmons et al., 2014). Their deployment in a hybrid system must therefore be optimized in order to make the overall cost of generation comparable or better than for conventional systems.

Project lead time for HPS is comparatively shorter due to their modular nature (IRENA, 2015). Deployment of HPS does provide a path for quick access to electricity in addition to low cost of electricity. Future load demand increase will easily be met by addition of more generation units. Power generation units utilizing local energy resources should be optimized in order to meet the project's goals. Variation in energy resource distribution and availability across a geographical location needs careful study in determining the level of penetration of a particular resource in the generation mix. It is therefore necessary to carry out a study on a hybrid system optimization that takes such reality into account.

### 2.3 Hybrid optimization tools

Optimization may be done using established softwares like HOMER or computational tools like MATLAB, Octave and Excel. Economic and environmental parameters are the key input quantities used in the optimization tools. These tools utilize suitable algorithms and mathematical models in order to select an efficient power system with balanced attributes. Optimization process involves simulation of different combination of resources and comparing the outcome to acceptable operating conditions. These conditions could be pre-set by means of benchmarking to achieve desired goals e.g., levelized cost of electricity (LCOE), emissions level and net present value.

### 2.4 Theoretical Principles

#### 2.4.1 Solar PV Energy

Solar energy is obtained from the sun's radiation to the earth. The focus of this study includes the conversion of solar radiation to electricity by means of solar photovoltaic cells. The most common solar PV technology in use today is the silicon PN-junction solar cell. It is a relatively mature technology whose costs have come down considerably over the past 10 years. Between 2010 and 2014 alone, the cost of solar PV declined by 50% (IRENA, 2014). The LCOE for utility scale Solar PV systems fell by half in the same period, from around Ksh 32/kWh to Ksh 16/kWh globally (IRENA, 2014). The conversion efficiencies of solar PV cells have improved between 10% and 40% at present and has been a major contributor to the declining costs of Solar PV technology.

Solar PV systems can be designed for small scale home use as well as utility scale for grid connection. At the core of a solar PV system is the solar cell. Several solar cells may be connected in series or in parallel to increase voltage and current output respectively. Multiple cells are connected together to make a module, while several modules are connected together to form a PV array depending on the desired output. Commercially available solar PV modules have power ratings ranging from a few watts for simple lighting to a few kW for running typical household equipment.

Radiation from the sun is converted to electricity by the solar cell of a PV system. Between 10% and 40% of the sun's radiation is converted to electricity depending on the quality of equipment used. Much of the sun's radiation is absorbed in the form of heat thus necessitating equipment design that can withstand resultant temperatures. Output from a PV system is dependent on the amount of radiation incident on its surface. The variation of incident radiation from the Sun during the day and across the yearly seasons influence the productivity of a PV system. A mathematical formula containing significant parameters for power output from a PV system is given by Equation 2.1 (Kolhe, Agbossou, Hamelin& Bose, 2003).

$$P_{solar} = P_{STC} f_{PV} \left(\frac{G_T}{G_{STC}}\right) \left[1 + a_p (T_C - T_{STC})\right] \qquad 2.1$$

Where $P_{STC}$ is power from PV panels at standard test conditions, $f_{PV}$ is derating factor, $G_T$ (W/m$^2$) is the incident radiation, $G_{STC}$ (W/m$^2$) is radiation in standard test conditions (1000W/m$^2$) and $a_p$ is the temperature coefficient which influence PV system performance according to the real time temperature of the system.

In addition to PV modules, a Solar PV power system is composed of more components with vital roles in delivering power in the form, quantity and quality desired. These components include inverters, charge controllers, cabling and the load. Each of these components must be properly designed and sized in order to achieve the systems design goals (Kumar & Kumar, 2016).

### 2.4.2 Solar Thermal energy

Solar thermal technology uses sun's energy to generate thermal energy with minimal emissions. This thermal energy may be used to heat water, other fluids and solid storage materials which are used as medium of transferring the same energy. Thermal heat from the sun can be stored in the form of Sensible Heat (SH) or Latent Heat (LH) depending on the properties of a chosen storage material (Kumar & Shukla, 2015). Water is a good material for storing heat in the form of SH because of its high specific heat capacity and availability (Kumar & Shukla, 2015). Solar water heating therefore provides a means for harnessing sun's heat energy for various applications such as industrial heating, space heating and domestic hot water demand.

Different technologies are available for harvesting the sun's heat energy but all utilize the same principle; to employ a collector, heat exchanger, heat transfer medium, heat storage system and a monitoring system. The main types of solar collectors are; flat plate collectors, evacuated tube collectors and concentrated solar collectors. Flat plate collectors are the simple, low cost and effective type of collectors suitable for moderate heating while the evacuated tubes and concentrated collectors are more complex, costlier but more efficient thermal heat receivers.

Solar collectors have radiation absorbing surfaces or plates. The radiant flux striking a plate is given by; $\mathbf{t}_{\mathbf{cov}}A_PG$, where G is the irradiance on the collector, $A_P$ is the exposed area on the plate and $\mathbf{t}_{cov}$ is the transmittance of the glazing. Only a fraction $\alpha_p$ of this flux is absorbed. The heated plate is hotter than the environment hence it loses heat at a rate $\frac{(T_p-T_a)}{R_L}$ where; $R_L$ is the resistance to heat loss from the plate at temperature ($T_p$) to the environment at temperature ($T_a$).

The net heat flow in the plate is given by Equations 2.2a and b (Twidell & Weir, 2006)

$$P_{net} = \tau_{cov}\alpha_P A_P G - \frac{(T_P-T_a)}{R_L} \quad \ldots\ldots 2.2a$$

$$P_{net} = A_P\,[\tau_{cov}\alpha_P G - U_L(T_P - T_a)\,] \quad \ldots\ldots 2.2b$$

Where $U_L$ is the overall heat loss coefficient given by; $\frac{1}{A_p R_L}$

The two Equations (2.2a and 2.2b) are referred to as Hottel-Whillier-Bliss equations which illustrate the parameters that influence performance of a collector. One set of the parameters is related to the transmission and absorption of heat while the other set is related to retention and movement of heat (Twidell & Weir, 2006). The equation can be simplified through circuit analysis of a solar collector in order to determine its operating conditions like efficiency and stagnation temperature. Stagnation temperature is the maximum possible temperature that can be attained by a collector.

Solar Water Heating (SWH) system can be used as an energy generator for harnessing heat from the sun which is stored in the form of sensible heat. Heated water is consumed at desired temperature when needed from a storage tank. It is also possible to use hot water to supply thermal load by means of heat exchangers if there is such a demand. Inlet water temperature, storage water temperature and the hot water demand in liters per day are vital parameters used for designing a SWH system.

Hot water demand per day is estimated based on set parameters of temperature of the inlet water and that of water at the storage tank. Temperature variation of water in the storage tank is monitored at predefined time intervals to effectively account for temperature fluctuations as a result of usage. If occurrences are recorded via a controller as when the temperature of water in the storage tank is below minimum, a booster heater is turned on. A booster heater is served by electric power or fuel-based steam or hot water generator like a boiler. The length of time the booster heater runs is used to determine the amount of energy needed in addition to that which is supplied directly by the sun.

In order to select a suitable water heating system, hot water demand at a site is estimated based on the type of consumer, inlet water temperature, outlet water temperature as well as the quantity of water required in litres. Quantity of hot water demanded can be reasonably determined by estimating the number of users and appliances in most dominant functional room in a standardized building (Piertese-Quirjins, Loon, Beverloo, Blom & Vreeburg, 2014). Based on this practice, ERC has developed guidelines for hot water demand for different types of buildings in Kenya (see Appendix V). It is desired that water temperature in the storage tank be at a minimum of $60^{o}C$ to prevent growth and multiplication of harmful *legionella* bacteria in the system (Levesque, Lavoie & Jean 2014*)*. If hot water is utilized at a temperature other than $60^{o}C$, adjustment is made to demand at $60^{o}C$. Equation 2.3 is used to adjust and relate demand at another temperature to demand at $60^{o}C$.

$$D_{(T)} = D_{(60)} \frac{T - T_i}{(60 - T_i)} \quad \text{......2.3}$$

Where; $T$ is desired water temperature, $T_i$is the inlet water temperature.

Total energy required per day to meet hot water demand is given by Equation 2.4.

$$L = V\rho c\left(T_{(60)} - T_i\right) \quad \text{......2.4}$$

Where; $V$ is volume of water, $\rho$ is density of water and $c$ is the specific heat capacity of water.

A Solar Water Heating system collector area must be determined in order to select a size that can meet the desired demand. Total energy harnessed by a collector is directly proportional to the area exposed to the sun's radiation. For sheltered collectors such as the flat plate collectors, thermal heat capture is related to its material properties such as transmittance, absorptivity and resistance to heat loss. Equation 2.5 gives a simplified relationship between irradiance and the collector area size.

$$A_C = \frac{L}{\eta_{solar} . I_{av}} \quad \text{......2.5}$$

Where; $A_C$ is the collector area, $\eta_{solar}$ is the collector efficiency and $I_{av}$is the average daily insolation.

### 2.4.3 Solar Resource Potential Representation

Solar resource data may be obtained through onsite measurements using appropriate instruments at defined time intervals. Direct Normal Irradiance (DNI) is measured using Pyrheliometer while total Global Horizontal Irradiance (GHI) is measured using a Pyranometer. Local and global meteorological stations continually collect solar radiation data which may be used in designing systems that are affected by Solar. Solar radiation available over a given location varies from hour to hour depending on the sun's position at different times of the day and the amount of cloud cover.

In order to predict a Solar PV system electricity output during design stage, it is preferable to estimate hourly electricity production using available solar radiation data. However, if only the monthly mean daily irradiance data is available, hourly mean irradiance should be estimated (Suh and Choi, 2017). There are empirical models that have been developed for estimating hourly Solar Irradiance from available monthly mean daily irradiance data. Equation 2.6 shows a model for estimating extraterrestrial horizontal radiation according to Duffie and Beckman (2013).

$$\bar{G}_o = \frac{12}{\pi} G_{on} \left[\cos\phi \cos\delta \left(\sin\omega_2 - \sin\omega_1\right) + \frac{\pi(\omega_2 - \omega_1)}{180°} \sin\phi \sin\delta\right] \text{..........2.6}$$

Where:

$\bar{G}_o$= the extraterrestrial radiation averaged over a time step [kW/m$^2$]

$G_{on}$ = the extraterrestrial normal radiation [kW/m$^2$]

$\phi$ = latitude angle for the location [°]

$\delta$ =declination angle [°]

$\omega_1$ = the hour angle at the beginning of the time step [°]

$\omega_2$ = the hour angle at the end of the time step [°]

Solar resource data give the average amount of radiation striking a horizontal surface at the bottom of the atmosphere (same as the earth's surface) in each time step. The ratio of the earth's surface radiation to the extraterrestrial radiation over a given time step is called the Clearness Index as described by Equation 2.7 (Duffie & Beckman, 2013).

$$K_T = \frac{\bar{G}}{\bar{G}_o} \text{..........2.7}$$

Where:

$\bar{G}$ = the global horizontal radiation over the earth's surface averaged over a time step [kW/m$^2$]

$\bar{G}_o$ = the extraterrestrial radiation averaged over the time step [kW/m$^2$]

Solar radiation reaching the earth's surface has two components; beam and diffuse radiations. Beam radiation reaches the earth surface without scattering by the atmosphere while diffuse radiation reaches the earth's surface after its direction has been changed by the atmosphere. The total of beam and diffuse radiation is called global solar radiation which is expressed by Equation 2.8 (Duffie & Beckman, 2013).

$$\bar{G} = \bar{G}_b + \bar{G}_d \text{..........2.8}$$

Where:

$\bar{G}_b$ = the beam radiation [kW/m$^2$]

$\bar{G}_d$ = the diffuse radiation [kW/m$^2$]

Where solar resource data is available as global radiation and it is necessary to find either beam or diffuse components. Erbs, Klein and Duffie, (1982) developed a model that gives diffuse radiation as a function of clearness index as shown in Equation 2.9.

$$\frac{\bar{G}_d}{\bar{G}} = \begin{cases} 1.0 - 0.09K_T & for\ K_T \leq 0.22 \\ 0.9511 - 0.1604K_T + 4.388K_T^2 - 16.638K_T^3 + 12.336K_T^4 & for\ 0.22 < K_T \leq 0.8 \\ 0.165 & for\ K_T > 0.80 \end{cases} \quad ......2.9$$

For purposes of designing a system that utilizes solar power, it may be appropriate to determine the amount of radiation striking a tilted surface. In order to calculate the amount of radiation striking a tilted surface, it may be assumed that the diffuse radiation is made up of three components; isotropic, circumsolar and horizon brightening components. Isotropic diffuse radiation comes equally from all parts of the sky while circumsolar originates from the direction of the sun and the Horizon component emanates from the horizon.

There are three other factors that are vital in estimating the amount of radiation falling on a tilted surface and they are; ratio of beam radiation on a tilted surface to beam radiation on horizontal surface as given by Equation 2.10; anisotropy index which is a measure of atmospheric transmittance of beam radiation (Equation 2.11); and horizon brightening factor (Equation 2.12) (Duffie & Beckman, 2013).

$$R_b = \frac{\cos\theta}{\cos\theta_z} \quad ......2.10$$

Where $\theta$ and $\theta_z$ are the incidence and Zenith angles respectively.

$$A_i = \frac{\bar{G}_b}{\bar{G}_o} \quad ......2.11$$

$$f = \sqrt{\frac{\bar{G}_b}{\bar{G}}} \quad ......2.12$$

A model known as HDKR developed from the works of Hay, Davies, Klucher and Reindl may be used to estimate total radiation falling on a tilted surface by incorporating features of Equations 2.6 to 2.12. HDKR model is shown by Equation 2.13 (Duffie & Beckman, 2013)

$$\bar{G}_T = (\bar{G}_b + \bar{G}_d A_i)R_b + \bar{G}_d(1 - A_i)\left(\frac{1+\cos\beta}{2}\right)\left[1 + f\,sin^3\left(\frac{\beta}{2}\right)\right] + \bar{G}\rho_g\left(\frac{1-\cos\beta}{2}\right) \quad \text{2.13}$$

Where $\beta$ and $\rho_g$ are slope of the surface in degrees and ground reflectance in % respectively.

### 2.4.4 Wind energy

Wind energy is converted to electricity by means of wind turbines. Wind turbines convert the wind's kinetic energy to a turbine's rotational power. The rotating shaft of a wind turbine is coupled to an electric generator. There are two types of wind turbines in use today, i.e. the horizontal axis wind turbines (HAWT) and the vertical axis wind turbines (VAWT). Horizontal axis wind turbines have their rotational axis parallel to direction of wind flow and the ground.

The power in the wind is given by the Equation 2.14 (Manwell, McGowan & Rogers, 2002)

$$P = \frac{1}{2}\rho A v^3 \quad \text{2.14}$$

Where $\rho$ ($kg/m^3$) is the density of air, A ($m^2$) is the rotor swept area and v is wind velocity.

The density of air varies with altitude and reduces with increase in height due to pressure drop at higher altitudes. It is therefore possible to estimate air density as a function of altitude and vital parameters defined as;

$P_0$= Standard atmospheric pressure at sea level, 105325 Pa

$T_0$= Standard temperature at sea level, 288.15 K

$g$ = earth's gravitational acceleration, 9.8066 m/s$^2$

$L$= temperature lapse rate, 0.0065 K/m

$R$= Ideal gas constant, 8.31447 J/(mol.K)

$M$= Molar mass of dry air, 0.0289644 kg/mol

Temperature at altitude $h$ is given by Equation 2.15.

$$T = T_0 - Lh \qquad (2.15)$$

Pressure at altitude $h$ is given by Equation 2.16.

$$p = p_0 \left(1 - \frac{Lh}{T_0}\right)^{\frac{gM}{RL}} \qquad (2.16)$$

Density of air at altitude $h$ may then be estimated using the molar form of ideal gas as shown in Equation 2.17.

$$\rho = \frac{pM}{RT} \qquad (2.17)$$

It is not possible to convert all the power in the wind into a wind turbine kinetic energy but only a fraction of it is. Albert Betz established that the theoretical maximum efficiency (power coefficient) of any wind turbine design is 59% (Manwell et al.,2002). This is known as The Betz limit or Betz law. A practical wind turbine will have a power coefficient well below the Betz limit with values between 0.30 and 0.45 (Manwell et al., 2002). By considering the other factors in a complete wind turbine system like gearing, bearing and generator losses and so on, only 10-30% of the power in the wind is ever converted to useful power. It is therefore necessary to factor in the power coefficient in Equation 2.14 so that the extractable power from the wind is as given by Equation 2.18.

$$P_{avail} = \frac{1}{2}\rho \mathrm{A} v^3 C_p \qquad (2.18)$$

Where; $C_p$ is the coefficient of performance of a wind turbine.

From Equation 2.14, it is clear that power from a wind turbine is highly dependent on the wind speed. There are two critical wind speeds that are important in the design and operation of a wind turbine, i.e. the cut-in speed and the cut-out speed. The cut-in speed is the minimum wind speed required to get power output from a turbine. The wind turbine blades may turn at speeds lower than the cut-in speed but no power is generated. The cut-out speed on the other hand is the maximum speed above which the turbine is not safe to operate. For most turbines, the cut-out windspeed is 25 m/s and higher speeds are considered unsafe for turbine operation. In order to enhance a wind turbine's productivity, control mechanisms have been developed to allow for safe operations at speeds above 25 m/s. The control mechanism also ensures a smooth power output from the wind generator (Feng & Sheng, 2014).

A wind turbine generator power output varies due to variation in wind speed with time. The wind generator performance is also determined by its design characteristics such as efficiency. A combination of local wind regime factors and the technical characteristics of a wind turbine influences how much power is generated by a wind generator or wind farm. The capacity factor is a parameter that may be used to determine productivity of a wind power system. This is given by the ratio of actual annual energy output to the equivalent annual energy output generated at name plate capacity of the generator. The average capacity factor for wind generators considered for farms in Europe and US range between 21% and 30% (Boccard, 2009). The capacity factor has an impact on the LCOE of a wind power system where high capacity factor translates to lower LCOE.

#### 2.4.4.1 Wind resource potential

Primary data for wind needed for decision making during wind power investment may be acquired by carrying out wind speed measurements at anticipated wind turbine hub height. Local metrological wind data for a site can be used to make wind power investment to high degrees of success. Where the local measurements are made at a height different from a turbine hub height, the wind shear described by power law or logarithmic law may be used to estimate wind speed and power output at a designated turbine height (Kubik, Coker & Hunt, 2011). The reliability of either laws depends on the quality of data used in determining the input parameters like power law coefficient and the roughness length.

Power law gives the relationship between wind speeds at a given height in a location to wind speed at anemometer height at the same location. The relationship is given by Equation 2.19 (Manwell et al., 2002)

$$\frac{v}{v_0} = \left(\frac{H}{H_0}\right)^{\alpha} \quad \text{.........} 2.19$$

Where; $H_0$ is the reference height, $V_0$ is wind speed at reference height and α is the power law coefficient.

Logarithmic law on the other hand is given by Equation 2.20 (Manwell et al., 2002)

$$\frac{V}{V_0} = \frac{\ln\left(\frac{H}{z}\right)}{\ln\left(\frac{H_0}{z}\right)} \quad \text{.........} 2.20$$

Where *z* is the roughness length of the site.

### 2.4.4.2 Wind regime representation

Wind speed distribution over a given period in a site can be analytically described by two functions;

1) Probability density function (f(v)) which indicates the fraction of time for which the wind speed is at a given velocity V and is given by Equation 2.21 (Twidell & Weir, 2006).

$$f(v) = \frac{k}{c}\left[\frac{v}{c}\right]^{k-1} e^{-\left(\frac{v}{c}\right)^k} \quad \text{.........} 2.21$$

Where; $k$ is the shape factor, $c$ is the scale factor and $v$ is the wind speed.

2) Cumulative distribution function $F(V)$ which indicates the time fraction or the probability that the wind speed is equals to or less than $V$. It is the integral of the probability density function described by Equation 2.22 (Twidell & Weir, 2006).

$$F(v) = \int_0^v f(v)\, dv = 1 - e^{-\left(\frac{v}{c}\right)^k} \quad \text{.........} 2.22$$

Another important parameter for describing wind resource potential of a site is the average wind speed which can be estimated by using the Equation 2.23 (Manwell et al., 2002).

$$v_{av} = \int_0^\infty v f(v) dv \quad \text{2.23}$$

Solving Equation 2.23, it is determined that the average wind speed is given by Equation 2.24.

$$v_{av} = c\Gamma\left(1 + \frac{1}{k}\right) \quad \text{2.24}$$

For a Weibull distribution with a shape factor of 2 (also known as Rayleigh distribution), Equation 2.24 may be simplified and re-written to solve for the scale factor c as shown in Equation 2.25.

$$c = \frac{2v_{av}}{\sqrt{\pi}} \quad \text{2.25}$$

Wind speed characteristics of a site is further described by means of two parameters that give indication on the nature of its availability. The characteristics are Diurnal pattern strength (DPS) and 1hr autocorrelation factor. DPS is a number between 0 and 1 that shows how strongly the wind speed depends on time of day. A low DPS in a site implies that wind speed is not strongly influenced by the time of day and vice versa. On the other hand, the autocorrelation factor is an index for wind speed in a time step (e.g. 1 hour) tends to depend on the wind speed in the preceding time step (Zobaa & Bansal, 2011). A high autocorrelation factor for a site means that the wind speed at a given time step is strongly dependent on the wind speed of the preceding time step. Autocorrelation factor is useful in the creation of synthetic time series data in the absence of measured parameters during design of a wind power system.

#### 2.4.4.3 Wind power density

Wind power density is the available power per unit area of turbine rotor at a given time. Evaluation of available energy in the wind is among the most critical preliminary steps in determining feasibility of a wind power project.

The available power in the wind to a unit area of turbine rotor blade as given by the Equation 2.14 can be used in determining total energy per unit area. Total energy contributed by all possible velocities available for unit rotor area is given by the Equation 2.26 (Twidell & Weir, 2006).

$$E_{d} = \int_0^\infty Pf(v)dv \ldots\ldots 2.26$$

Substituting for P and f (v) using Equations 2.14 and 2.21 respectively, the following Equation 2.27 is obtained.

$$E_d = \frac{\rho_a k}{2c} \int_0^\infty v^{k+2} e^{-\left(\frac{v}{c}\right)^k} dv \ldots\ldots 2.27$$

Solving the integral in Equation 2.27, gives;

$$E_d = \frac{1}{2} c^3 \rho_a \Gamma\left(\frac{3}{k} + 1\right) \ldots\ldots 2.28$$

For k equals to 2, Equation 2.28 becomes;

$$E_d = \frac{c^3 \rho_a 3\sqrt{\pi}}{8} \ldots\ldots 2.29$$

Substituting for c in Equation 2.29 with Equation 2.25 Gives a simplified wind power density Equation 2.30.

$$E_d = \frac{3v_{av}^3}{\pi} \ldots\ldots 2.30$$

**2.4.5 Economic and financial Analysis**

A power project like any other investment needs to be appraised for economic and financial viability while making investment decisions. This is necessitated by the need to mobilize resources for capital, operation and maintenance of a power plant against competing investment opportunities. Funding for a power project can either be raised through equity, debt or a combination of both. The bankability of a power project or its ability to attract funding is determined by design considerations that portray the most profitable outlook (Boccard, 2009). Economic and financial analysis helps in determining the ability of a project to repay investors and/or financiers as well as its net benefit to society. Financial parameters such as Net Present Cost (NPC), Levelized Cost of Energy (COE), Capacity Factor (CF), discount rates and inflation are used in carrying out this analysis. Capacity Factor which is a derivative of energy resource potential and technological maturity of a power system has a bearing on a facility's LCOE and consequently its NPC (Boccard, 2009).

The NPC of a power Project is the current value of all costs of installing and operating a power project minus the present value of all revenue it generates over its lifetime. This considers the time value of money where money at hand now is worth more than in the future. NPC is calculated using Equation 2.31 (Paterson & Fabozi, 2002).

$$NPC = C\left(\frac{1-(1+R)^{-T}}{R}\right) - I \qquad 2.31$$

Where; *T*-time, *R*- Real discount rate, *C*- Cash flow, I- Initial Capital investment

Where cash flow is not uniform over the project's life, NPC is calculated using Equation 2.32 (Paterson & Fabozi, 2002).

$$NPC = \frac{C_1}{(1+R)^1} + \frac{C_2}{(1+R)^2} \ldots.. + \frac{C_t}{(1+R)^t} - I \qquad 2.32$$

Where; $C_1$, $C_2$ and $C_t$ are cash flows for periods 1, 2 and t is the lifespan of the project.

In capital budgeting, it is common to determine an annual cost which if it were to occur equally every year over the lifetime of a project will give the same NPC as the actual cash flows. The annualized cost of a project is calculated by dividing the total NPC by a factor known as the annuity factor *(A)* which is calculated using Equation 2.33.

$$A(t,r) = \frac{1-(1+r)^{-t}}{r} \qquad 2.33$$

Where; *t*= the project lifespan, *r* = the real discount rate

As shown by Equations 2.31 and 2.32, the NPC of a project is dependent on the discount rate. The discount rate on the other hand is influenced by prevailing local financial market environment. In Kenya, it is documented that independent power producers investing in geothermal and wind projects have accessed capital at a discount rate of 10% (Pueyo, Bawakyillenuo & Osiolo, 2016).

Simple payback period (SPP) is a capital budgeting rule that aids in decision making by evaluating the amount of time it will take for business to recoup its initial capital from cash flows gained from an investment. Cash flows in a project are not discounted hence this rule provides a less complex way of appraising a project for during investment decision making (Ardalan, 2012). A short payback period is desirable in order for a project to be considered attractive. Where cash flows are even throughout the project's life, Equation 2.34 is used to calculate SPP.

$$SPP = \frac{IC}{C_A} \qquad 2.34$$

Where: $IC$ is the initial capital and $C_A$ is annual net cash flow.

Several policy instruments exist in Kenya to aid in the development of renewable energy projects in order to enhance renewable energy fraction in the generation mix. Feed In Tariffs (FIT) have been designed for different types of renewable energy sources in order to make them attractive to investors who are interested in developing commercial power projects. Table 2 shows the current FiT as applied to different energy technologies in Kenya.

**Table 2: Feed-in-Tariff structure for Projects up to 10 MW**

| Technology | Installed Capacity (MW) | Standard FIT (USD) | Percentage Escalable Portion of Tariff | Min. Capacity (MW) | Max. Capacity (MW) |
|---|---|---|---|---|---|
| Wind | 0.5-10 | 0.11 | 12 | 0.5 | 10 |
| Hydro | 0.5 | 0.105 | | | |
| | 10 | 0.0825 | 8 | 0.5 | 10 |
| Biomass | 0.5-10 | 0.1 | 15 | 0.2 | 10 |
| Biogas | 0.2-10 | 0.1 | 15 | 0.5 | 10 |
| Solar (Grid) | 0.5-10 | 0.12 | 8 | 0.5 | 10 |
| Solar (Off-Grid) | 0.5-10 | 0.2 | 8 | 0.5 | 10 |

**Source: (MoEP, 2015)**

Net metering is another policy instrument that can be employed to encourage deployment of renewable energy resources by allowing consumers who generate their own power to sell excess generation to the grid. A Net Metering system operates in parallel with electrical distribution facilities of a public utility and measures by one or more meters the amount of electricity supplied (MoEP, 2015). Net metering can be employed to facilitate development of grid connected distributed generation with installed capacity that is less than that which is catered for under FIT. Settlements to consumers who export green energy to the grid can be done through cash payments or credit settlements to offset a customer's bill for energy imported from the utility company (RECP, 2014). Kenya's main electricity distributor (KPLC) can recover its net costs if it gave a 63% credit for every unit of electricity exported to the grid (RECP, 2014). Table 3 shows the proposed credit per unit of electricity exported to the grid for different classes of consumers exporting renewable energy to the grid (RECP, 2014).

**Table 3: Proposed Net Metering credit settlement**

| Consumer Class | DC (<1500) | DC (>1500) | SC | CI1 | CI2 | CI3 | CI4 | CI5 |
|---|---|---|---|---|---|---|---|---|
| USD/kWh | 0.14 | 0.23 | 0.14 | 0.13 | 0.12 | 0.11 | 0.11 | 0.11 |

**Source: (RECP, 2014)**

# CHAPTER THREE

# METHODOLOGY

## 3.1 Site Description

The East African School of Aviation (EASA) located at coordinates 1°18′41″S, 36°54′22″E is a training institution owned and managed by Kenya Civil Aviation Authority (KCAA). The institution's population comprises students, teaching staff, support staff and their families. The institution has the following main sections and facilities; Administration block, lecture buildings, workshops, laboratories, hostels, estate department and sports facilities.

## 3.2 Load Profile Determination

The electric load to be served is a crucial element of energy generation. For proper sizing of a power system, key parameters of the load were defined by carrying out measurements of power usage using a power data logger clamped to the main incoming 3 Phase supply to EASA. A questionnaire (Appendix VIII) was administered to gain more insight into the power consumption at the site. The instantaneous electric load was recorded at a time interval of 5 minutes. Power consumption and quality parameters like voltage, current, harmonics and power factor were also recorded at the same time steps of 5 minutes using the data logger. The collected power consumption data was analyzed in excel to identify trends and cumulative energy usage for the period for which data was collected. The data logger was set and connected in a three phase four wire configuration as shown in Figure 1.

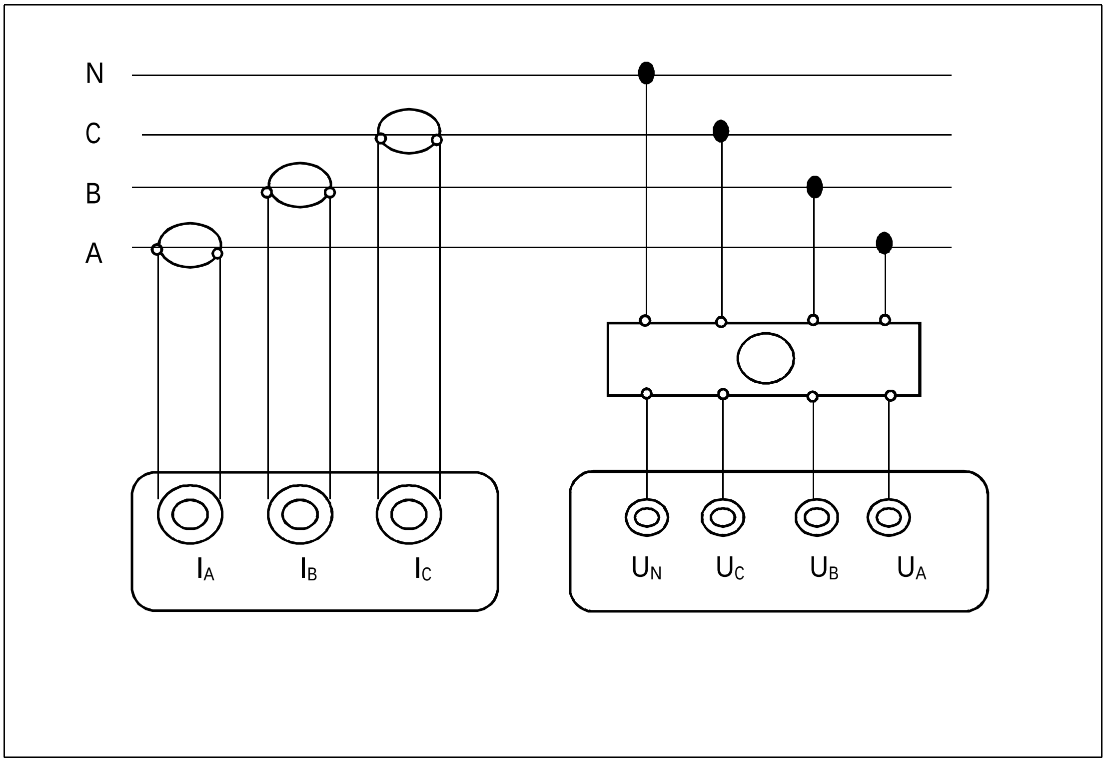


**Figure 1a: Logger with 3 Phase 4 wire connections**

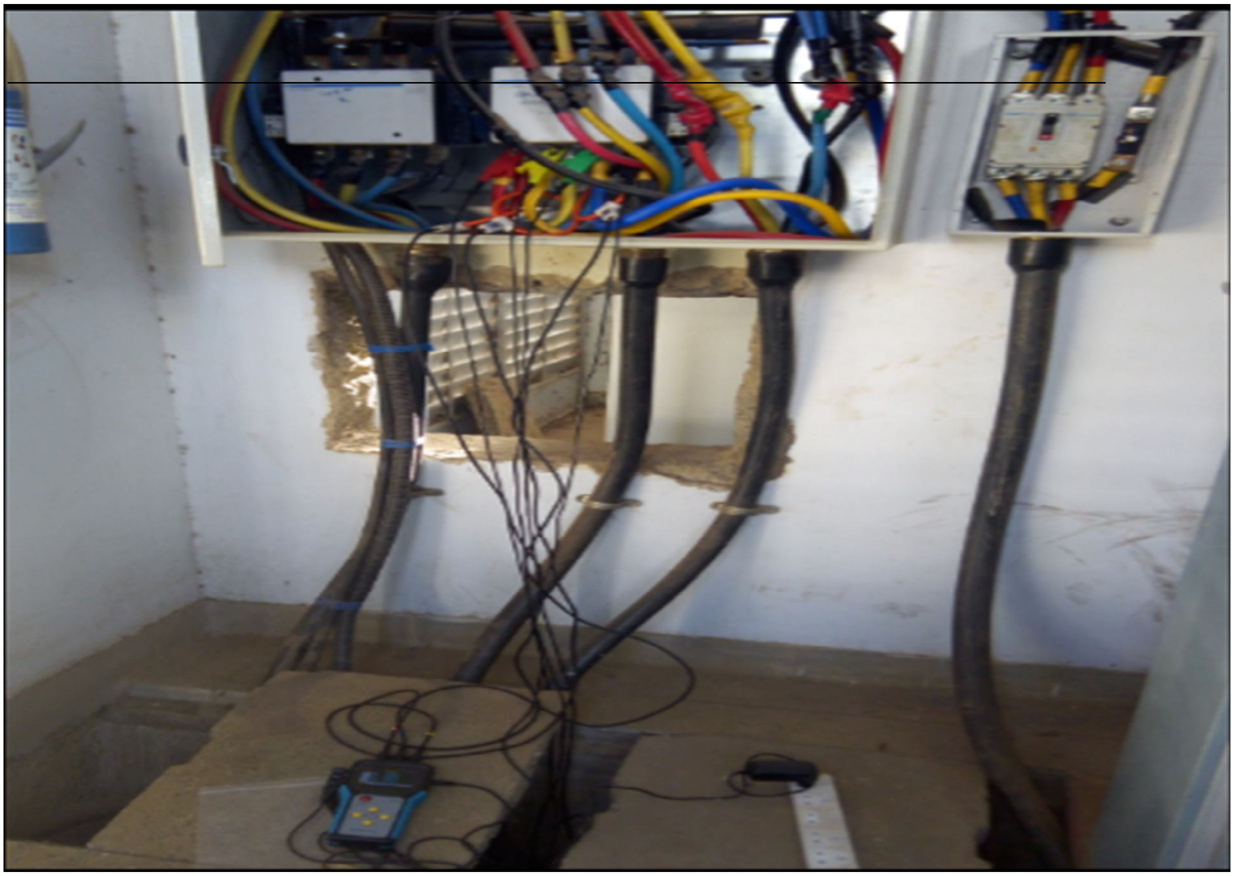

**Figure 1b: ME 435 3-Phase Hand Hold Power Meter in Situ.**

### 3.2.1 Thermal Fraction Assessment

In order to comprehensively describe the load at the site, thermal fraction of the load was determined by estimating the hot water demand of the institution. For purposes of this research, all heating requirements were assumed to be in the form of hot water demand. Hot water demand was systematically estimated by segregating types of hot water demands at the different facilities. There are two main hot water demand centers identified for the institution i.e. the students' hostels and the estate department. Using guidelines developed by ERC for solar water heating, the total energy requirements for water heating was estimated (Appendix V).

The total load to be served by solar water heating system was estimated by calculating the hot water demand for the hostels and the estate departments based on their occupancy.

Both the estate's and the hostel's daily hot water demand was estimated to be 40 liters at 40°C per person where the inlet temperature was assumed to be 20°C. The hostels have a bed capacity of 303 beds and an occupancy factor of 50% hence the energy demand to raise its temperature to 60°C was calculated using Equations 2.3 and 2.4.

There are 84 housing units in the estates with 58 of them being 3-bedroomed and the rest (26) are 2-bedroomed. The housing unit's occupancy is assumed to be 1.5 persons per bedroom and therefore the hot water demand in the estates was similarly calculated as for the hostels. Hot water demands for both the estate's and the hostels were combined in order to estimate total thermal load at the site.

### 3.3 Resource Assessment

The resource potential for Solar and Wind resources for the site (EASA) were obtained from the NASA Langley Research Center Atmospheric Science Data Center Surface meteorological and Solar Energy (SSE) web portal. The weather reports were downloaded for the location coordinates 1°18′41″S, 36°54′22″E corresponding to the site under study. The acquired meteorological data has been compiled over a period of 22 years between the years 1983 and 2005. Typical Meteorological Year (TMY) solar irradiance and wind data as collated by NASA were then used as input energy resource potential data for designing the HPS. Global Horizontal Irradiance and the monthly average wind speed data were obtained and analyzed to determine their viability in developing a power system.

#### 3.3.1 Wind Resource Assessment

Wind power density which is the available power per unit area of turbine rotor at a given time was evaluated in order to determine feasibility of a wind power project. Total energy contributed by all possible velocities available to a unit rotor area was calculated by using Equations 2.17 and 2.30. The calculated air density at altitude of the site (1600 m above sea level) was found to be 1.089 kg/m$^3$. Wind power density values for the site across the year were calculated and tabulated.

Wind power density values obtained for the site were used to score the level of resource endowment at the site. There exists a classification of wind resource potential at a site based on wind speed and wind power density to range from Class 1 to 7. Class 1 represent low resource potential where else Class 7 represents abundant endowment. Table 4 shows standard wind power classes.

**Table 4: Classes of Wind Power Density and Wind Speed.**

| **Height** | **30 m** | | **50 m** | |
|---|---|---|---|---|
| Wind Power Class | Wind Speed (m/s) | Wind Power Density ($W/m^2$) | Wind Speed (m/s) | Wind Power Density ($W/m^2$) |
| 1 | ≤ 5.1 | ≤ 160 | ≤ 5.6 | ≤ 200 |
| 2 | ≤ 5.9 | ≤ 240 | ≤ 6.4 | ≤ 300 |
| 3 | ≤ 6.5 | ≤ 320 | ≤ 7.0 | ≤ 400 |
| 4 | ≤ 7.0 | ≤ 400 | ≤ 7.5 | ≤ 500 |
| 5 | ≤ 7.4 | ≤ 480 | ≤ 8.0 | ≤ 600 |
| 6 | ≤ 8.2 | ≤ 640 | ≤ 8.8 | ≤ 800 |
| 7 | ≤ 11.0 | ≤ 1600 | ≤ 11.9 | ≤2000 |

**Source: (NREL, 1997)**

A Weibull distribution shape factor of 2 is assumed for the site hence the relationship between the scale factor (c) and average wind speed is given by Equation 2.25. Solving for c gives a value of 4.841 m/s at 30 m turbine hub height. This result was used to plot the probability distribution and cumulative distribution curves.

### 3.3.2 Wind Turbine Selection

The available wind power was used as a key parameter to consider in selecting a wind turbine that can meet the hybrid power plant design objective. A turbine that is able to generate power within the prevailing wind regime of low wind speeds was chosen by considering the cut-in wind speed. The operating conditions of the wind turbines obtained from manufacturer's specifications were used to identify their suitability. For the site a wind turbine with low cut-in wind speed was chosen for use because it has a low wind resource potential. Based on the availability of wind at the site having a low diurnal pattern, wind generator is sized to meet entire daily energy demand which was estimated to be 667,877 kWh/yr.

Equation 2.22 was used to calculate time fraction in a year when wind speed is equals or less than 2.5 m/s in order to estimate the productive time fraction per year. The size of wind generator was approximated by dividing annual energy demand by hours of productivity. The ideal size for meeting the load at the site was found to be 101 kW. Accounting for wind generator efficiency (0.4185) as described by Equation 2.18, the wind turbine installed capacity was modified to 241 kW. This rounds up to 3 units of a wind turbine rated 100 kW.

Different wind turbines of ratings close to 100 kW were compared in order to select one that was most suitable for use at the site. Four turbines; Hummer H24.5-100 kW, ZEFIR D21-P100 kW, XANT M-21 (100 kW) and XANT M-24 (95kW). Hummer H24.5-P100 with a power rating of 100 kW was found to be the wind turbine that could ideally serve the power demand at the site. The specifications for this wind turbine are annexed in the Appendix II.

### 3.3.3 Solar Power System Selection

While selecting a solar power system to use, the available insolation in the site was used to determine the projects' viability. The nature of demand (i.e. thermal or electrical) was used to decide on the mode of conversion to be used. As a result, both solar PV and solar thermal systems were found to be viable candidate technologies to meet electric as well as the thermal demands. For both systems, space availability and the cost of installation per unit power of generation were considered in selecting Solar generation components. Based on these criteria, the selected components for both solar PV and solar thermal were Canadian Solar MaxPower CS6X-325P and MEGASUN GREECE-DIRECT respectively. Their specifications are annexed in the Appendices C and D respectively.

Solar PV system sizing was done by choosing to meet the whole of the daytime load through Solar PV. As seen shown in the Time of use chart, daytime energy demand was found to be 58% of daily energy usage which translates to 1080.42 kWh. By using average daily insolation of 5.93 kWh/$m^2$ and the overall PV derating factor of 88%. A Grid Tie Inverter of similar size to the overall PV array installed capacity was selected to convert PV DC input to AC output.

### 3.4 Hybrid System Components

This section gives a brief discussion of the various components used for designing the hybrid system for the site. These include the wind turbines, the Solar PV systems, Converters, Grid, and Solar Water Heating system. Note that, the types, sizes and/quantity of each component is determined after 10,000 simulations. Figure 2 is a schematic diagram of the various components used for the hybrid system.

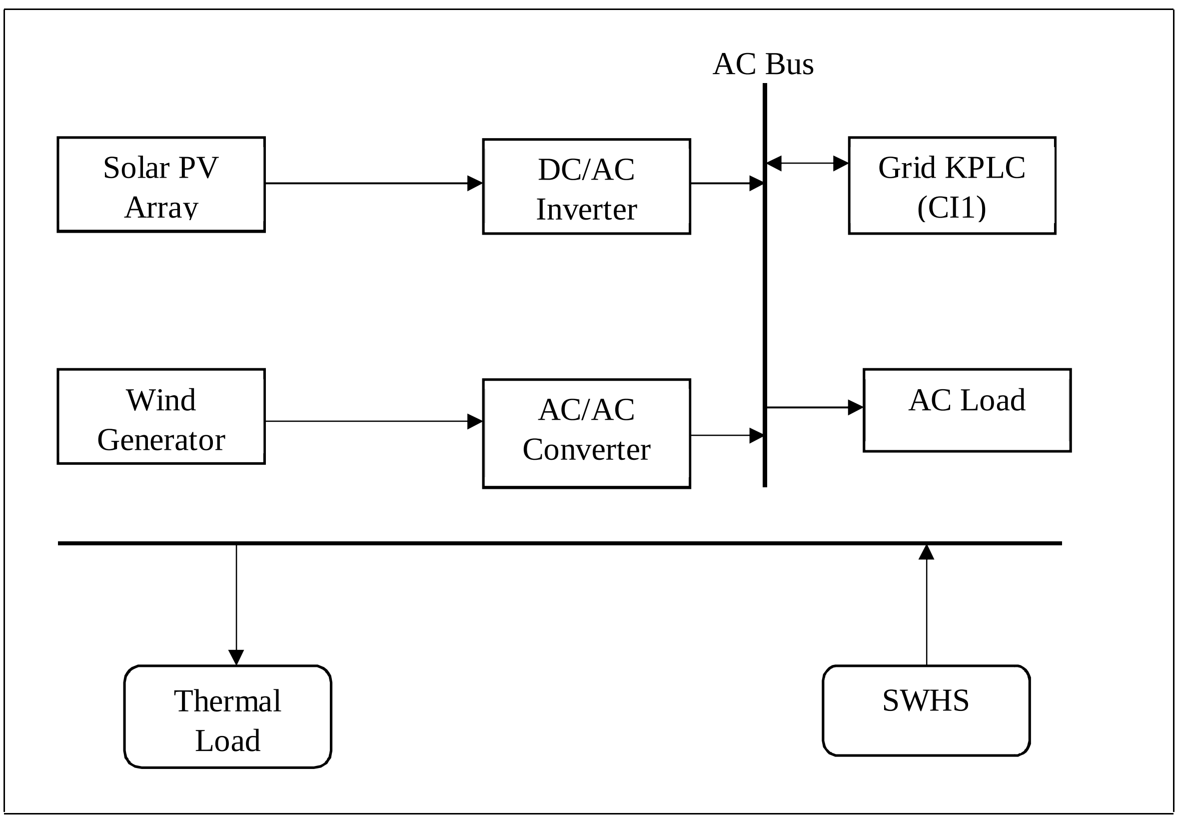


**Figure 2: Hybrid system configuration**

### 3.4.1 The grid

The site under study (EASA) is grid connected under category of Commercial Industrial (CI1). The grid is the baseline system to which all other system configurations are compared to determine feasibility. Local renewable energy generators are connected to the grid through Grid Tie Inverter(s) (GTI) and Converters which have regulation as well controlling functions. When renewable resources are unavailable or inadequate, the grid is connected as a generator to meet the demand shortage. On the other hand, when there is over-generation by the renewable resources, the grid is connected as storage through grid sales (export). The RES is connected to the grid through net metering and for this class of consumer (CI1), the rate per kWh for net sales is proposed to be KSh 12 while grid purchases are priced at KSh 16/kWh.

### 3.4.2 The converters

These are Power electronic devices used to condition DC power generated by the Solar PV system to AC and the AC power generated by the wind generators to AC form that can readily be used to meet the primary load or exported to the grid. The chosen wind turbine (Hummer H24.5-100 kW) has an on-grid converter with grid side circuit breakers and generator side isolation switch and other control components. Simulation of wind turbines performance therefore was done without having to select a converter. A converter was only selected for systems incorporating Solar PV.

### 3.4.3 Wind turbines

Wind turbines are generators that convert wind kinetic energy to electricity. The output power from a wind turbine could either be in AC or DC form. For this study, a wind turbine of AC power output was selected and connected through conditioners in order to deliver power in the required quality. The search space for the wind generators was limited to 3 units of 100 kW wind turbines as calculated in section 3.3.2.

### 3.4.4 Solar PV Modules

Solar PV modules convert solar energy to DC power. Several modules are connected to form an array of desired power output. Solar PV was designed and sized to meet a daytime load of 1080 kWh as discussed in section 3.3.3. For this application, the maximum installed Solar PV installed capacity was estimated to be 207 kW with a similarly sized inverter.

Solar PV system design was carried out by considering hourly electric power production hence it is necessary to estimate hourly global solar radiation striking the PV array at the site from the obtained daily GHI data. For the location being considered, the PV modules are tilted at 15° facing North. The estimated monthly hourly global irradiance striking the PV array surface was estimated using HDKR model in Equation 2.13.

### 3.4.5 Solar Water Heating System

A solar water heating system utilizes the thermal solar energy to heat water that is demanded for use for different applications. For the selected brand of MEGASUN GREECE-DIRECT, the key specifications used in the design process are in Appendix IV.

Assuming an efficiency of 40% and using Equation 2.4, MEGASUN 120 with collector area 2.0705 $m^2$ can supply a water heating load of 4.91 kWh/day. The estimated hot water demand for a 3-bedroom house was found to be 4.2 kWh/day. Since the output for the system was estimated using the average insolation, the oversizing could take care of demand during periods of low insolation like during the month of May, June, July and August. The same model for 2 bedroomed housing units was chosen thus resulting to a larger oversizing. This choice was made because there was no smaller model that could fit much closer to the demand of the 2- bedroomed unit. Similarly, for the hostels, twenty MEGASUN 300 with a collector area of 6.2115 $m^2$ were selected to supply a total water heating load of 282.8 kWh/day.

## 3.5 Hybrid system Selection

The simulation and optimization for the hybrid system to meet the load and the eventual system selection was done using HOMER (Pro) software. Component parameters, Wind and Solar energy resources data input and operation constraints were updated in the system before each simulation run and the outcome analyzed. Constraints considered in system selection were technological, installed capacity, availability of space for installation of wind generators, solar PV modules and financial feasibility. Technological constraints were defined by parameters such as conversion efficiency and permitted generation shortfall. Based on the footprint of selected wind generators, the search space for selecting wind generator capacity was limited by the design capacity to meet the load. The system operating reserve was set at 10% of hourly load while the yearly minimum capacity shortage was not allowed.

HPS simulations were first done by incorporation of solar PV, Wind and Grid. The aim was to determine if it is economically feasible to serve the entire load of 1864.28 kWh/day using a hybrid system that excludes solar thermal. Thereafter, the load was then categorized into two i.e. the primary AC load of 1265.08 kWh and thermal load of 599.2 kWh/day. Solar thermal energy in form of Solar water Heating was used exclusively to meet the thermal load as estimated in section 3.2.1

### 3.5.1 Load data input

Among the most important parameters when designing any power system is the load demand. The load demand for the site was first introduced to the simulation software (HOMER) and this allowed for the selection of equipment necessary for meeting the load. The software requires an input of load data for one year at set time intervals. Load data was collected at five-minute intervals for 4 weeks between 21$^{st}$ November and 21$^{st}$ December 2017. Since data for an entire year is required for simulation, the collected data was used to generate a daily load profile that represents a typical day in a year. The daily load profile was obtained by calculating hourly average load from the collected consumption data which is contained in Appendix I

### 3.5.2 Wind data resource input

Wind speed data for the site at turbine height of 50 m was imported to the simulation software. There are four key parameters needed for HOMER (pro) software to simulate synthetic wind data from monthly averages based on the load time interval. These parameters are; the Weibull factor (k), the hour of peak wind speed, the diurnal pattern and the 1hr autocorrelation factor. For the site, the wind distribution was assumed to take the form of a Raleigh distribution with a shape factor of k equals to 2.

### 3.5.3 Solar input data

Monthly daily averages irradiance downloaded from NASA surface meteorology and Solar Energy database were imported to the Simulation software. The software tool was used to simulate Solar PV array System hourly productivity for a whole year. Selected PV system's technical data; efficiency and derating factor are input in the simulation software so that realistic simulation performance was achieved.

## 3.6 Economic Analysis

The economic analysis of the system was carried out using component costs supplied in the manufacturer's website and by email enquiry. The discount rate chosen for this study was 10% being the discount rate for accessing debt capital by independent power producers investing in geothermal and wind projects in Kenya. Grid connection was designed to be via net metering since the installed capacity of the HPS was less than 0.5 MW.

The HPS was primarily designed to meet onsite demand hence Grid Sales settlement was set to be Ksh 12/kWh which is the recommended settlement rate for consumer of category CI1 (RECP, 2014). Grid purchases energy cost ranges between KSh 15/kWh to KSh 20/kWh but was set constant at KSh 16/kWh for this study.

The Net Present Cost, Cost of Energy and Simple Payback Period were calculated using equations 2.32, 2.33 and 2.34 respectively. Cost of Energy was estimated by dividing the annualized cost obtained using equations 2.32 and 2.33 by the HPS' annual energy generation. The results were used to appraise viability of the HPS over a lifespan of 25 years.

# CHAPTER FOUR

# RESULTS, ANALYSIS AND DISCUSSION

## 4.1 Consumption trends and load profile.

Power consumption data for the site as collected using a power data logger during the study period containing measurements for voltage, current, power factor, power and energy at time intervals of 5 minutes is annexed in Appendix I. From the collected consumption data, the peak load was found to be 177 kW while the base load was found to be 60 kW as shown in Figures 2 to 9. Increased power demand was observed from 0500 hours and peaked between 0900 hours and 1500 hours for all the days of the week.

Daytime power usage was found to be higher than night time use but the night load is still significant. This variation can be explained by increased activities during the day when students come in for classes and laboratory demonstrations. Although the weekends registered reduced total energy consumption the trends of usage remained similar to those of the week days. Figure 2 shows a comparison of the amount of energy used during daytime versus usage at night.

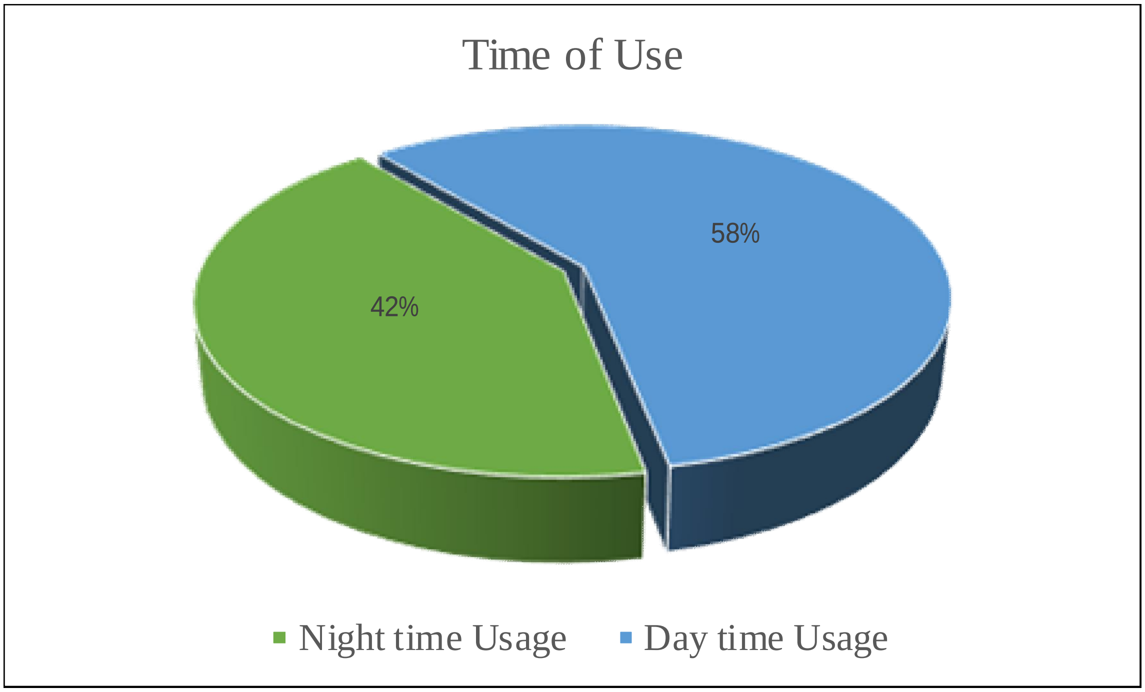


**Figure 3: Energy Time of use at the site**

The daily average energy usage was found to be 1.8531 MWh which translates to 55.5935 MWh per month. This is the expected energy consumption of a Commercial Industrial (CI1) consumer as categorized in the ERC billing schedules of 2013. The core charges for CI1 consumer are; a fixed charge of Ksh 2000, energy charge of Ksh 8.70/kWh and a demand charge of Ksh 800/kVA. Other variable charges and statutory levies include; fuel charge cost, foreign exchange rate, fluctuation adjustment, inflation adjustment, ERC levy, REP levy, power factor surcharge and VAT. The consolidated cost per kWh for this class of consumer can vary from Ksh 15/kWh to Ksh 20/kWh as per the fluctuation of statutory levies.

#### 4.1.1 Sample daily load curves of a typical week in November 2017

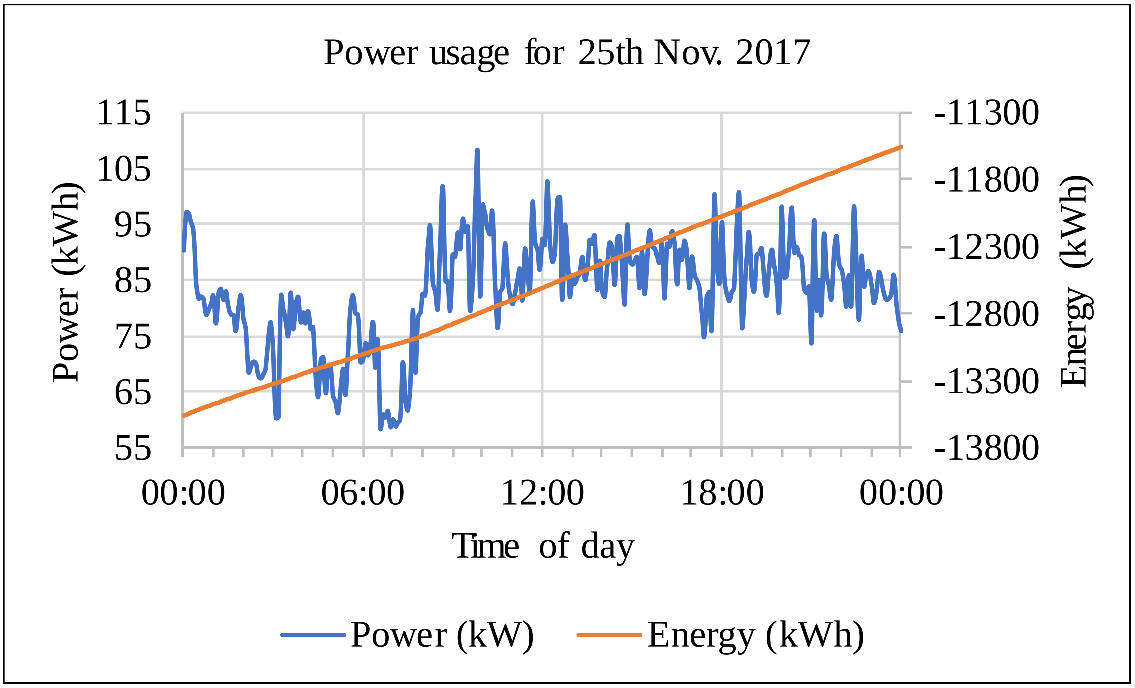


**Figure 4: load profile & energy Usage for Saturday, 25th Nov. 2017**

The total energy used on Saturday 25th was 2.001 MWh. The peak load was 108 kW at 0952 hrs. while the base load was 58.66 kW at 0637 hrs.

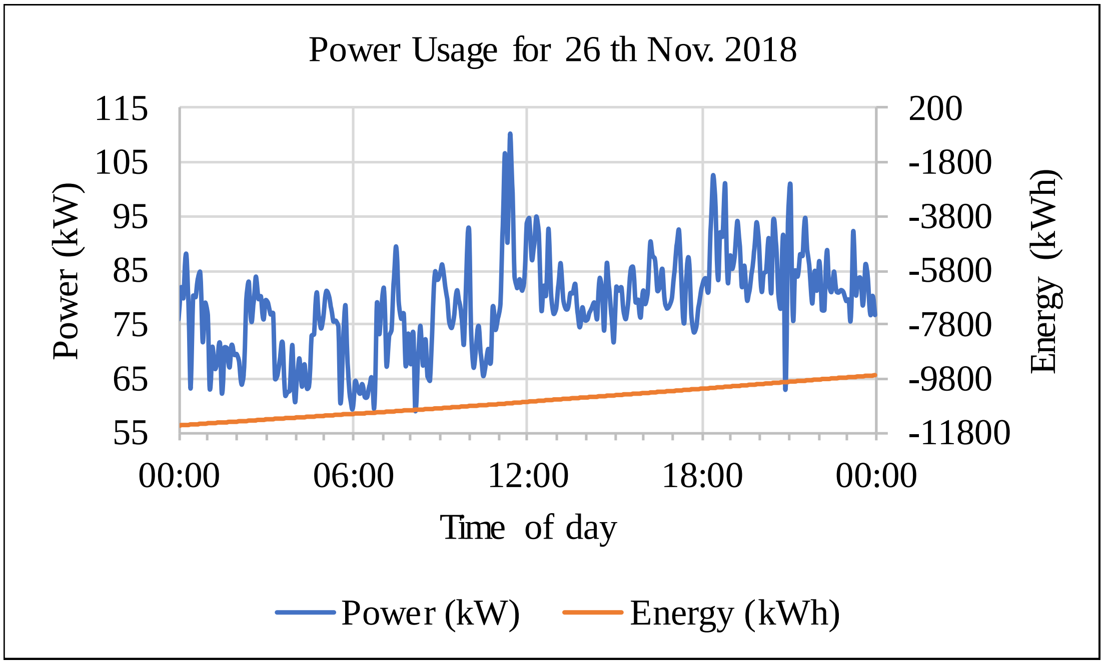


**Figure 5: Load profile & energy Usage for Sunday, 26th Nov. 2017**

Total energy used on Sunday was 1.893 MWh. The peak load was at 110 kW at 1125 hrs. while its base load was 59 kW at 0800 hrs.

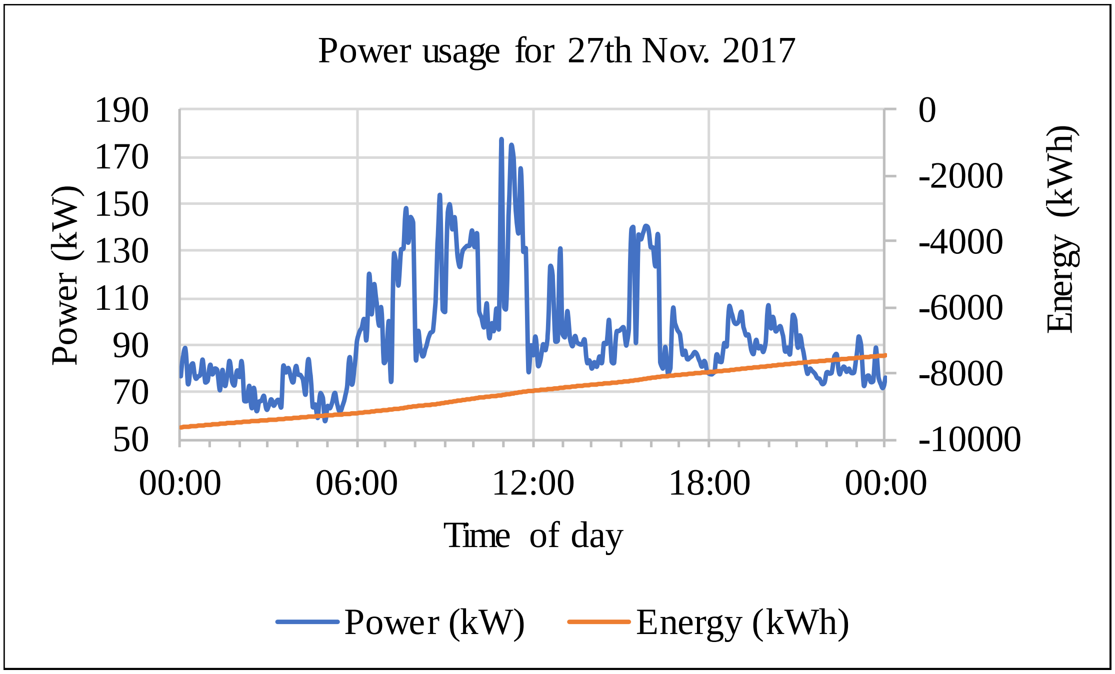


**Figure 6: Load Profile & energy Usage for Monday, 27th Nov. 2017**

Total energy usage for Monday 27th Nov was 2.127162 MWh. The peak load was 177 kW at 1055 hrs. while the base load was 57.6 kW at 0455 hrs.

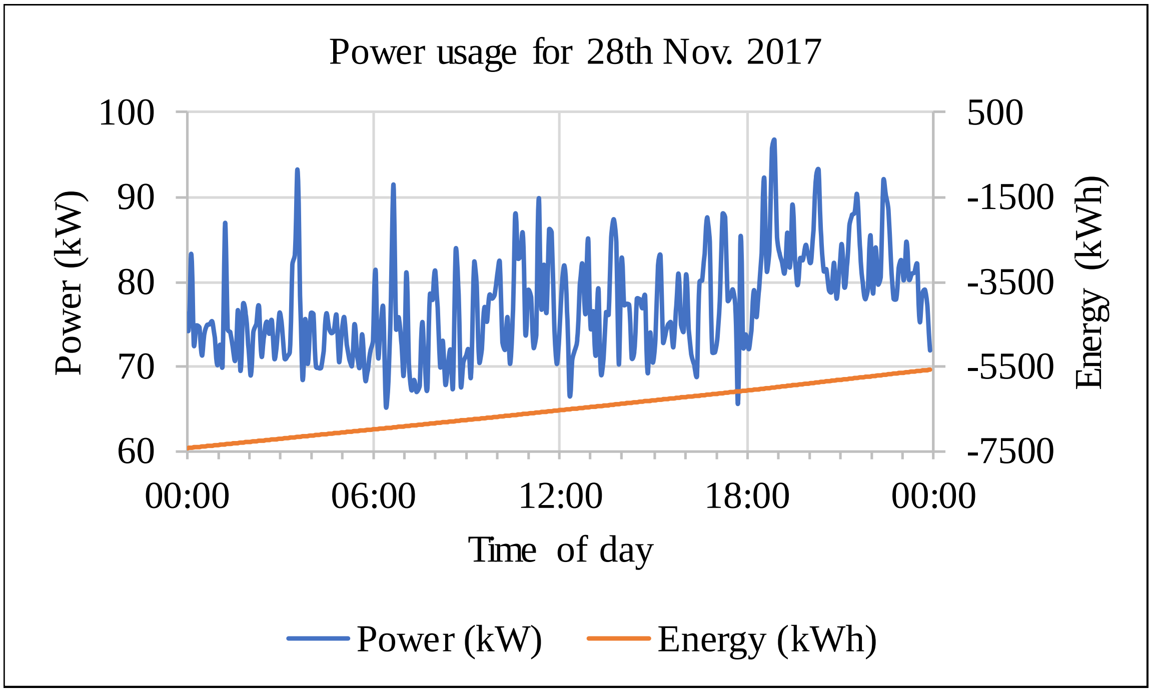


**Figure 7: Load Profile & energy Usage for Tuesday (Public holiday), 28th Nov. 2017**

Total energy usage for Tuesday was 1.845578 MWh. The day recorded a peak load of 96.7 kW at 0655 hrs. and its base load was 65.5 kW at 1745 hrs. Tuesday 28th November was a public holiday and that explains why its trend was similar to that of the weekends.

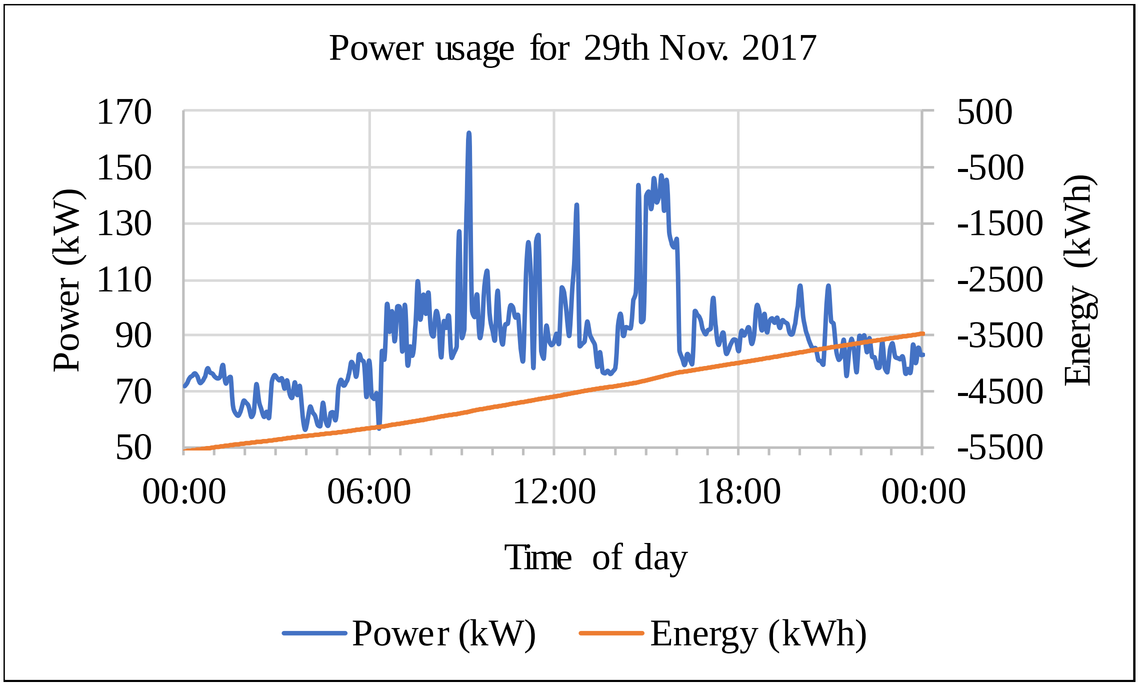


**Figure 8: load Profile & energy Usage for Wednesday, 29th Nov. 2017**

Total energy usage for Wednesday 29th Nov was 2.119571 MWh. The peak load was 161 kW at 0915 hrs. while the base load was 56.9 kW at 0620 hrs. High consumption trends were also recorded between 1445 hrs. and 1555 hrs. ranging between 135 kW and 145 kW.

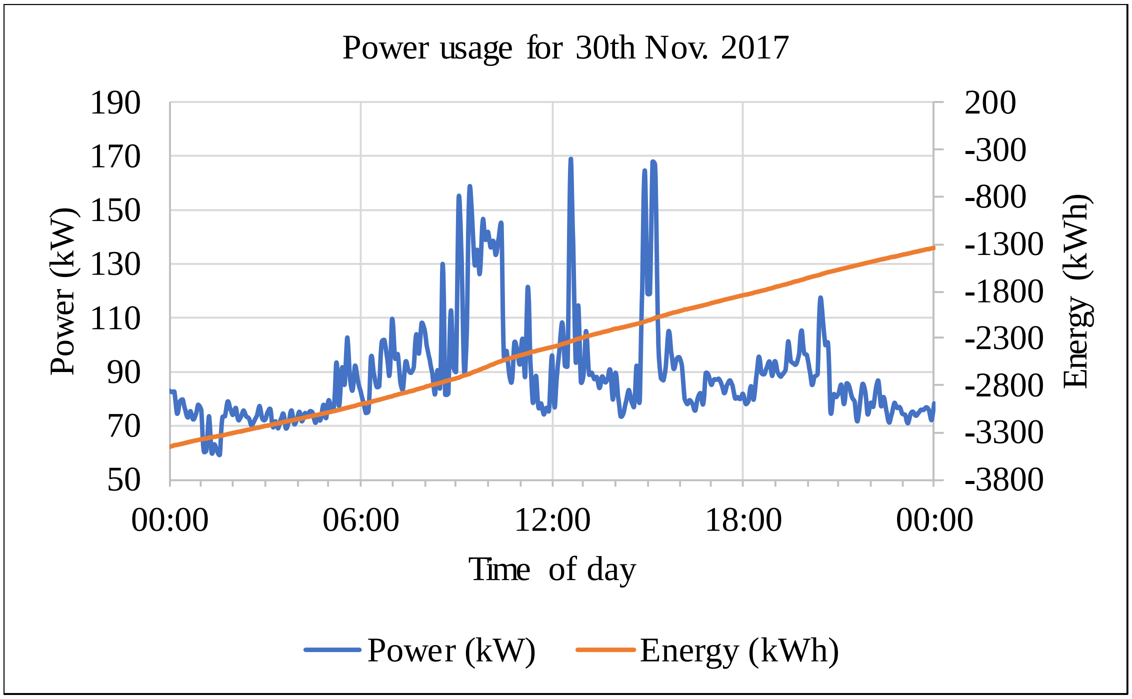


**Figure 9: Load Profile & energy Usage for Thursday 30th Nov. 2017.**

Total energy usage for Thursday, 30th Nov was 2.130059 MWh. The peak load was 167.8 kW at 1235 hrs. while the base load was 59.5 kW at 0135 hrs.

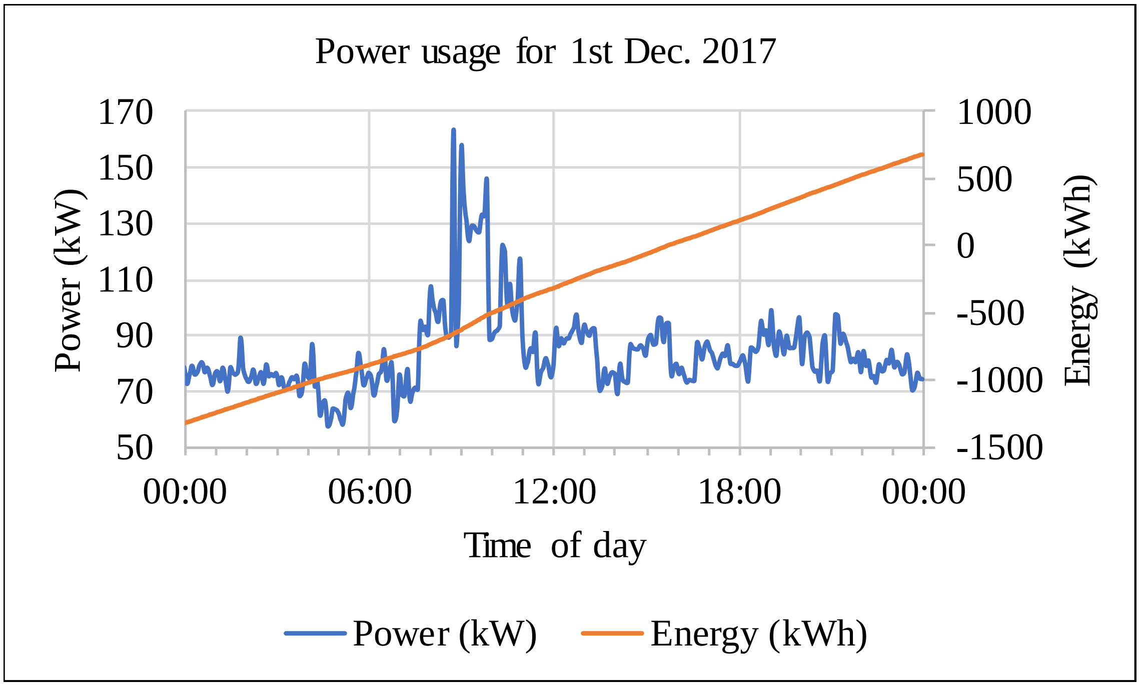


**Figure 10: Load Profile & energy Usage for Friday, 1st Dec 2017**

Total energy usage for Friday, 1st Dec was 2.003594 MWh. The peak load was 163.4 kW at 0845 hrs. while the base load was 57.4 kW at 0440 hrs.

The daily load curves (Fig 4-Fig 10) show that demand for energy during the week is high when compared to the weekends. For most of the weekdays, high consumption is clustered 0600 hrs. and 1700 hrs. after which demand decrease to a minimum at about midnight. As for the weekends and the public holiday, the peak demand and consequently energy usage was not as high as for week days. Further, the hourly average load curve shown in Figure 11 exhibit the overall daily load profile for the site. It is observed that daytime usage is more than nighttime usage while peak load demand is experienced between 0800 hrs. and 1900 hrs.

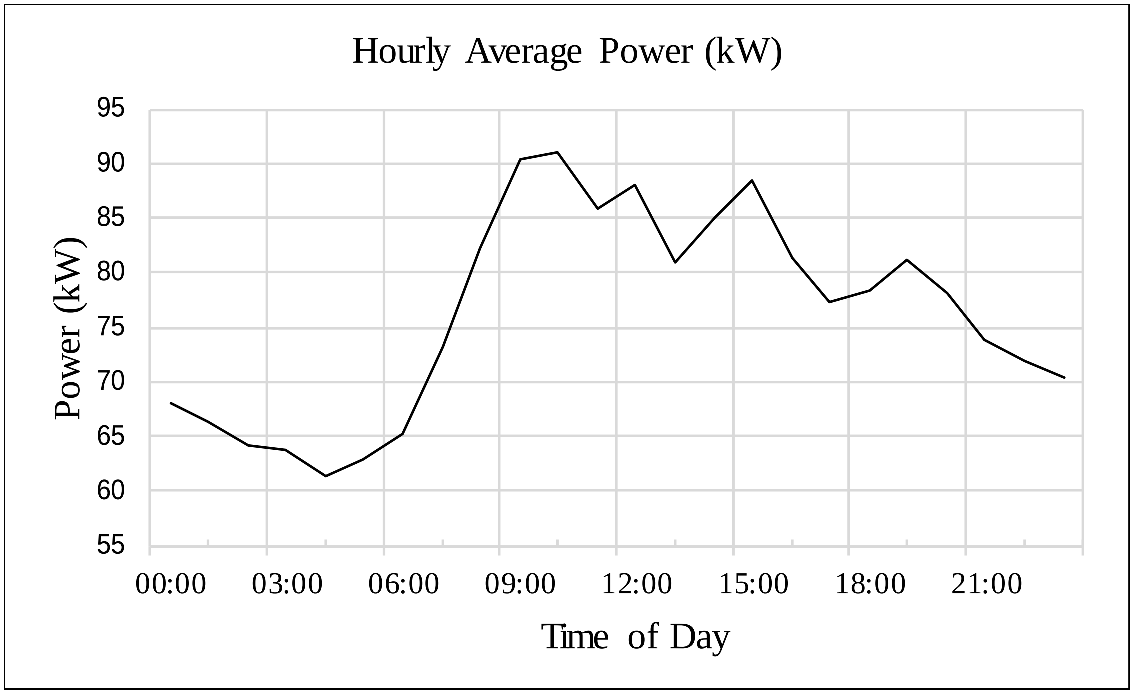


**Figure 11: Typical Daily load profile for EASA.**

### 4.1.2 Thermal fraction of the load

Based on the nature of the institution with residential units and eateries, water heating contributes a significant fraction of the total energy demand. Thermal demands like cooking is primarily met by use of gas or charcoal when gas is not available. Using steps described in section 3.2.1, hostels' hot water in liters and energy demand was found to be 6060 liters and 282.8 kWh/day respectively.

The estate's hot water and energy demands were similarly found to be 6780 liters which is equivalent to 316.4 kWh/day. Total energy requirements for meeting the hot water demand was therefore estimated to be 599.2 kWh/day which translates to 218708 kWh/year.

## 4.2 Wind and Solar Resources

The average monthly wind speed data for EASA located at coordinates 1°18′41″S, 36°54′22″E as obtained from NASA surface meteorological data is shown in the Table 5.

**Table 5: Average monthly wind speed**

| Monthly Averaged Wind Speed (m/s) At 30 m, 50 m and 70 m. | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **EASA** | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | **Annual Average** |
| **30 m** | 4.3 | 4.36 | 4.32 | 4.41 | 4.45 | 4.55 | 4.58 | 4.7 | 4.79 | 4.55 | 4.23 | 4.02 | **4.29** |
| **50 m** | 4.6 | 4.68 | 4.63 | 4.7 | 4.78 | 4.88 | 4.92 | 5.05 | 5.15 | 4.88 | 4.54 | 4.32 | **4.76** |
| **70 m** | 4.8 | 4.91 | 4.86 | 4.97 | 5.01 | 5.13 | 5.16 | 5.3 | 5.4 | 5.13 | 4.75 | 4.53 | **4.83** |

**Source: NASA Surface Meteorological Data**

The Raleigh Probability and Cumulative Distribution Functions for the site at a turbine height of 30 m are shown in figures 12 and 13 respectively.

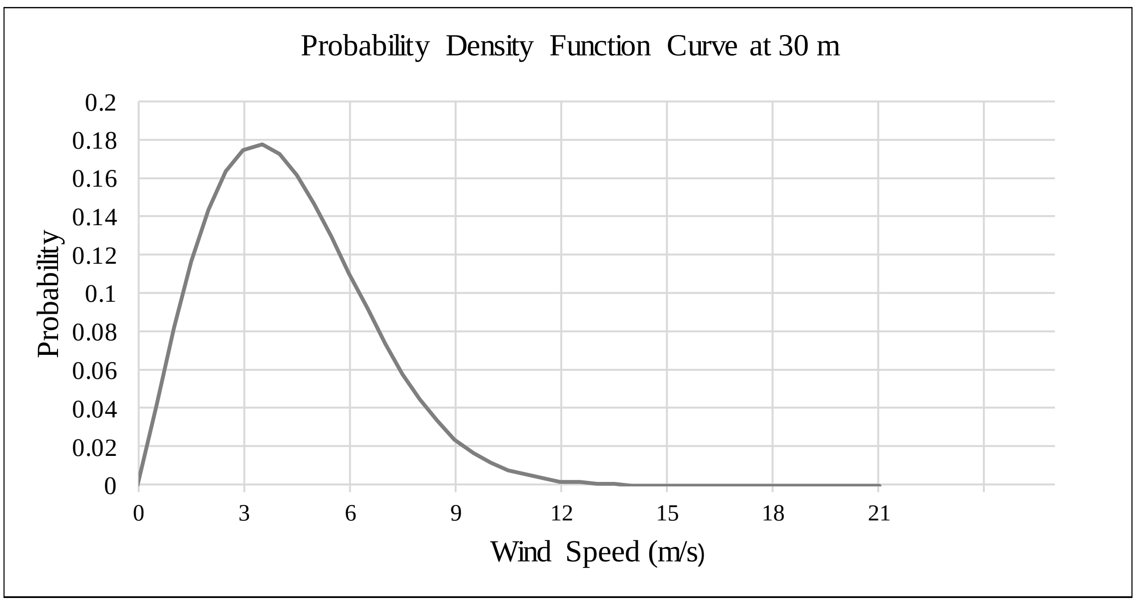


**Figure 12: Probability density function at 30 m height.**

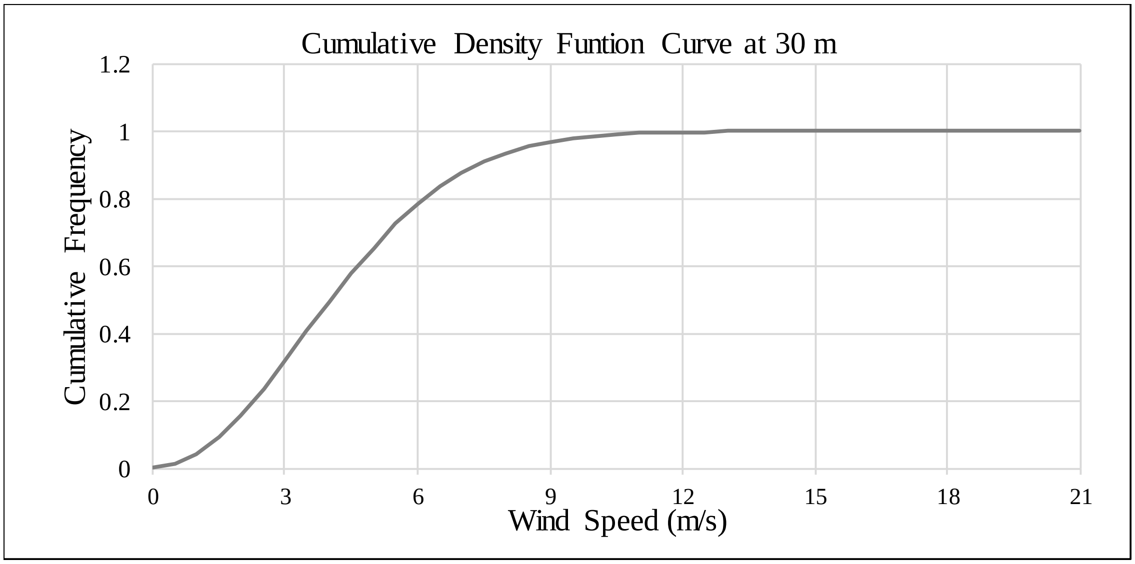


**Figure 13: Cumulative Distribution Function for the site at 30 m height.**

From the distribution curves above, the maximum wind speed at the site was found to be 21 m/s. this information was used in determining the maximum operating condition of a wind turbine that could be installed at the site. A suitable wind turbine for this site must generate power in low wind speed regime.

### 4.2.1 Wind power density for the site

The wind power density at 30 m, 50 m and 70 m calculated using steps outlined in section 3.3.1 are shown in Table 6.

**Table 6: The calculated wind power density values**

| | Height of 30 m | | Height of 50 m | | Height of 70 m | |
|---|---|---|---|---|---|---|
| Month | Average Wind Speed (m/s) | Power density ($W/m^2$) | Average Wind Speed (m/s) | Power density ($W/m^2$) | Average Wind Speed (m/s) | Power density ($W/m^2$) |
| Jan | 4.29 | 75.40 | 4.61 | 93.56 | 4.83 | 107.60 |
| Feb | 4.36 | 79.15 | 4.68 | 97.88 | 4.91 | 113.04 |
| Mar | 4.32 | 76.99 | 4.63 | 94.78 | 4.86 | 109.62 |
| Apr | 4.41 | 81.90 | 4.7 | 99.14 | 4.97 | 117.23 |
| May | 4.45 | 84.15 | 4.78 | 104.29 | 5.01 | 120.08 |
| Jun | 4.55 | 89.95 | 4.88 | 110.98 | 5.13 | 128.92 |
| Jul | 4.58 | 91.74 | 4.92 | 113.73 | 5.16 | 131.20 |
| Aug | 4.7 | 99.14 | 5.05 | 122.98 | 5.3 | 142.17 |
| Sep | 4.79 | 104.95 | 5.15 | 130.43 | 5.4 | 150.37 |
| Oct | 4.55 | 89.95 | 4.88 | 110.98 | 5.13 | 128.92 |
| Nov | 4.23 | 72.28 | 4.54 | 89.36 | 4.75 | 102.34 |
| Dec | 4.02 | 62.04 | 4.32 | 76.99 | 4.53 | 88.77 |

The calculated power density values show that the wind resource potential at the site Class 1 category for the considered turbine heights as shown in Table 4. This implies that wind power deployment is limited to small-scale installations.

### 4.2.2 Wind Turbine Selection

The size of wind generator approximated as outlined in section 3.3.2 was found to be 101 kW. Different wind turbines of ratings close to 100 kW were compared in order to select one that was most suitable for use at the site. Four turbines; Hummer H24.5-100 kW, ZEFIR D21-P100 kW, XANT M-21 (100 kW) and XANT M-24 (95kW). Hummer H24.5-P100 with a power rating of 100 kW was found to be the wind turbine that could ideally serve the power demand at the site. As can be seen in Figure 14, Hummer H24.5-P100 has the lowest cut-in wind speed of 2.5 m/s and the highest power output at low speeds.

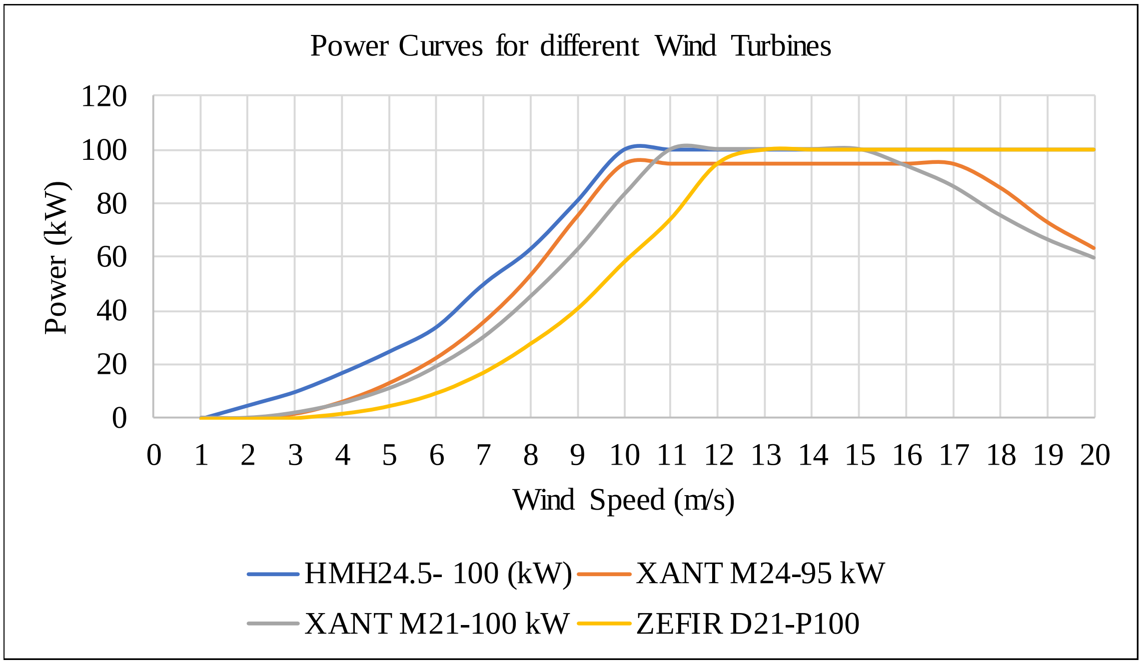


**Figure 14: Power curves for different nominated wind turbines**

In the prevailing wind regime, the wind generators are estimated to supply 849,902.5 kWh/yr. (oversize of 60 kW due to rounding off, accounted for).

### 4.3 Solar Energy for the Site

Solar radiation data of Monthly daily average values for Global Horizontal Irradiance spanning for a period of 22 years (July 1983 to June 2005) are shown in Table 7 curtesy of NASA Surface Meteorology database.

**Table 7: Monthly average values for GHI**

| Monthly Averaged Insolation Incident on a Horizontal Surface (kWh/m$^2$/day) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **22-year Average** | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | **Annual Average** |
| | 6.42 | 6.86 | 6.66 | 5.83 | 5.36 | 5.11 | 5.23 | 5.55 | 6.37 | 6.13 | 5.59 | 6.06 | **5.92** |

**Source: NASA Solar Surface Meteorological Data**

The variation of GHI across the year is shown in Figure 15 with a peak value of 6.86 (kWh/$m^2$/day) in February with a minimum value being recorded for June (5.11 kWh/$m^2$/day). The average value for Global Horizontal Irradiance (GHI) for the site is 5.93 kWh/$m^2$ /day. This represents a good solar resource which is suitable for both solar PV and solar Thermal applications.

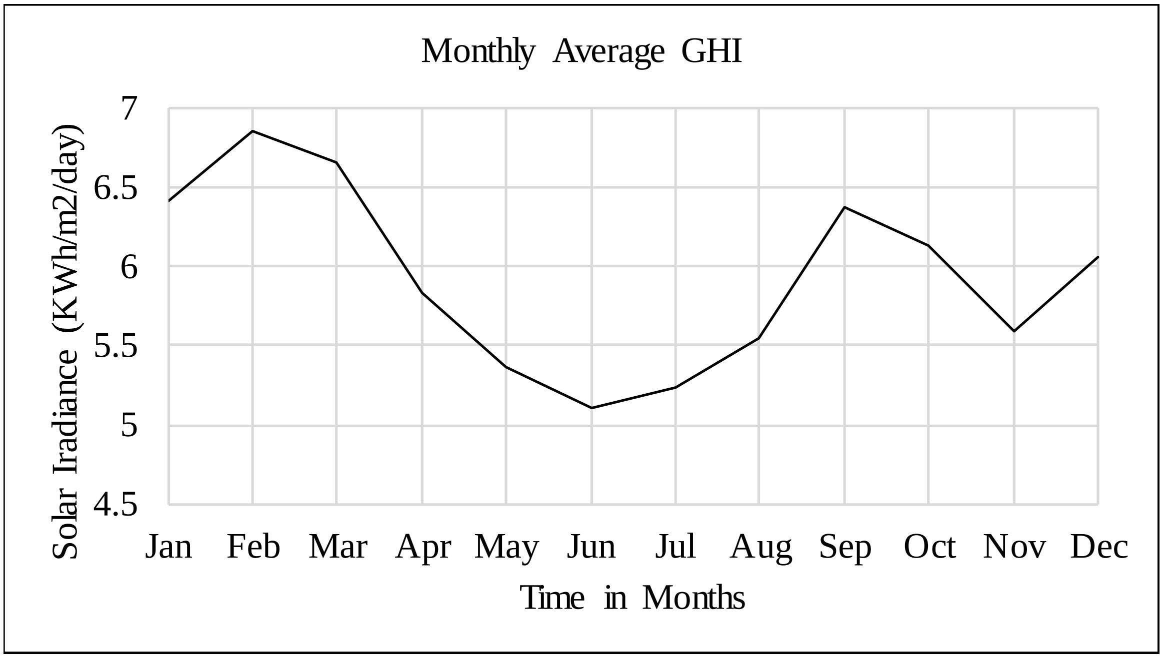


**Figure 15: GHI for the site curtesy of NASA**

Hourly Solar Irradiance data that were generated from monthly daily average GHI data according to steps in section 3.4.4 are shown in Figure 16.

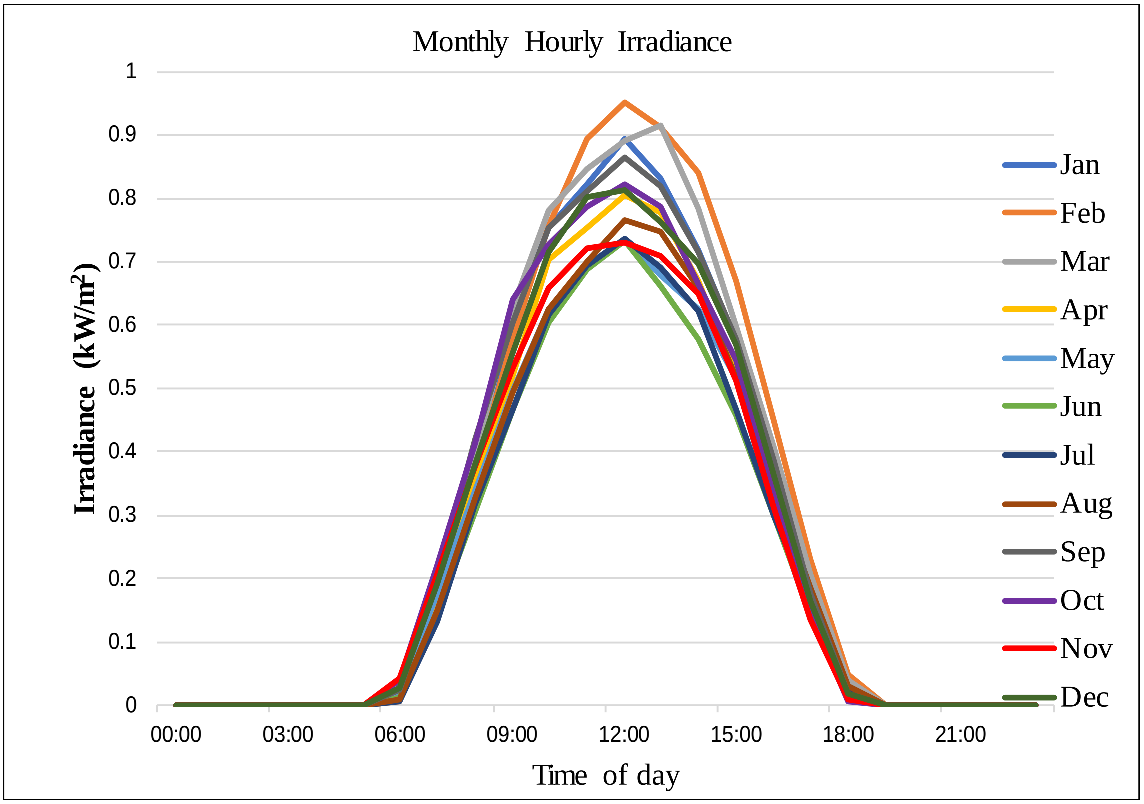


**Figure 16: Monthly Hourly Average Global Irradiance on PV array**

It is clear from Figure 15 that the months of January, February, March, September, October and December have high solar radiation hence Solar outputs from the same months are consequently high.

### 4.3.1 Solar Power System Selection

Based on Solar Power resource assessment results presented in Table 7, it was established that both solar PV and solar thermal systems are viable candidate technologies to meet electric as well as the thermal demands. Considering component and space availability criteria, the selected components for both solar PV and solar thermal were Canadian Solar MaxPower CS6X-325P and MEGASUN GREECE-DIRECT respectively. Their specifications are annexed in the Appendices C and D respectively.

Following Solar PV sizing process outline in section 3.4.4, a PV array of an installed capacity of 207 kW was found to be sufficient to meet the daytime energy demand. This translates to 640 CX6S-325P© modules with an estimated annual generation of 394353 kWh. A Grid Tie Inverter of similar size to the overall PV array installed capacity was selected to convert PV DC input to AC output.

### 4.4 System Simulation

#### 4.4.1 Load data input

The typical daily load profile as determined using power consumption data for between 21st November and 21st December 2017 is shown in Figure 17. The hourly power usage values in the daily load profile is the input load data exported to HOMER (pro) for simulation and optimization.

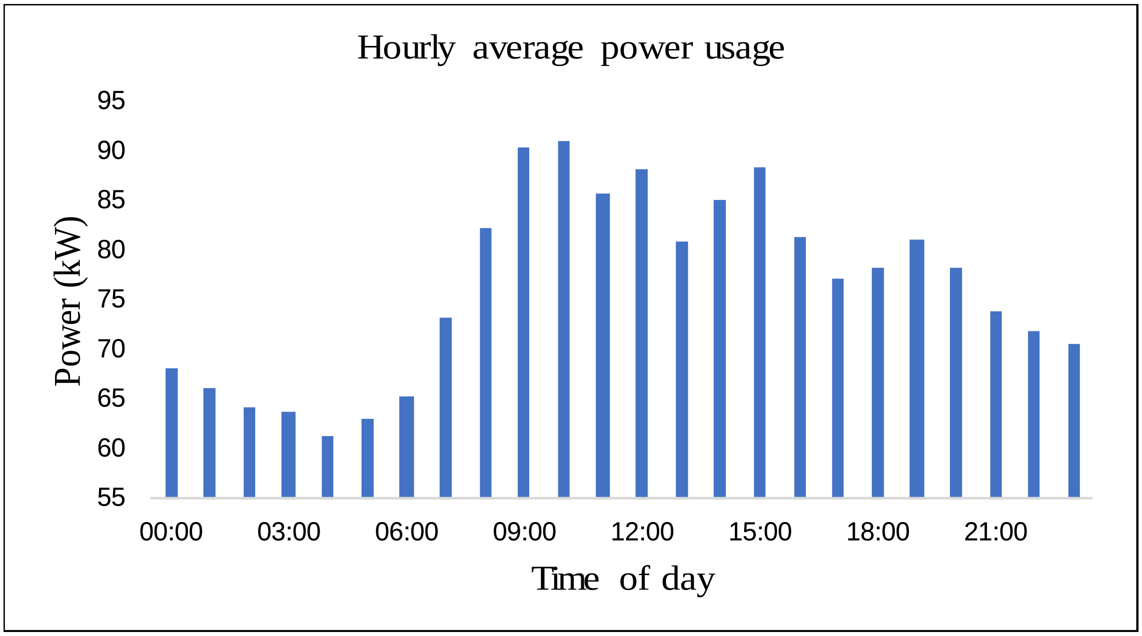


**Figure 17: Input load data for the site**

The daily load profile data was imported to the simulation software (HOMER) which was used to identify time step relationships that were used to synthesize yearly data consumption. Hourly random variability of 20% while day to day variability of 10% of the load were adopted.

### 4.4.2 Wind data resource input

Figure 18 shows average monthly wind speed data as obtained from NASA at a turbine height of 50 m. The wind speed averages were the input data for wind speed energy at the site.

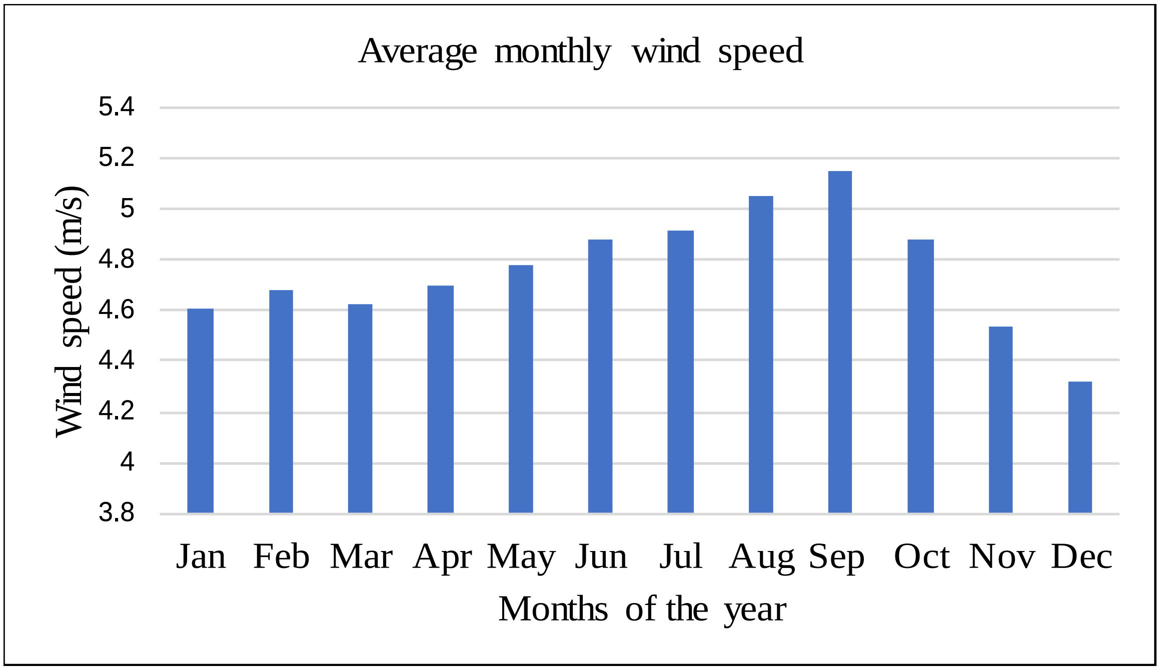


**Figure 18: Input data for the wind resources for the site**

**Source: NASA Surface Meteorological Data.**

### 4.4.3 Solar input data

Table 7 and Figure 19 show the monthly daily average solar irradiance values for site in a Typical Meteorological Year (TMY) which were recorded over a period of 22 years as obtained from NASA and imported to the simulation software (HOMER pro).

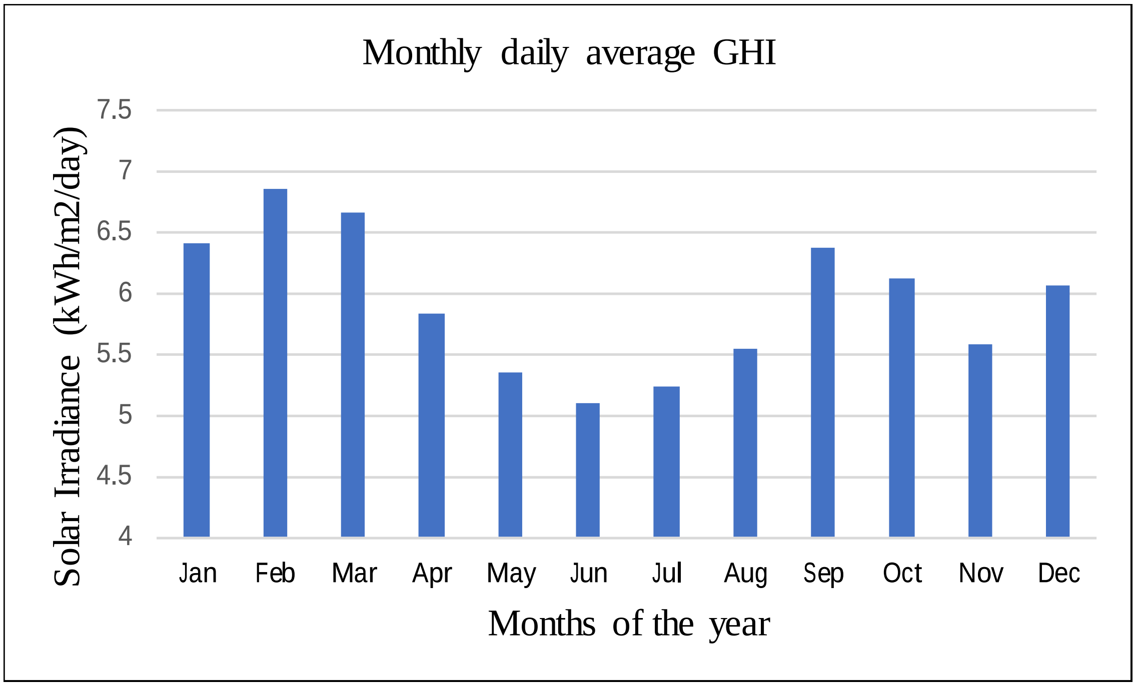


**Figure 19: Input data for the Solar GHI resources for the site**

### 4.5. Simulation Results

This section discusses the simulation and design results of the different HPS configuration scenarios of Wind-Solar PV-grid, wind-grid and wind-grid-solar (PV and Thermal) for the site (EASA).

#### 4.5.1 Solar PV-Wind-Grid Serving Total load of 1864.28 kWh/day

A hybrid system comprising of solar PV, wind and grid was simulated using HOMER and several scenarios were obtained as shown in the Table 8.

**Table 8: Simulation results for 1864.28 kWh/day**

| HPS Architecture | | | | Costs | | |
|---|---|---|---|---|---|---|
| Grid | Solar PV (kW) | Wind (kW) | COE KSh/kWh | NPC (KSh) | O&M Cost (KSh) | Initial Capital (KSh) |
| | 120 | 200 | 8.34 | 77,684,050 | 1,980,904 | 56,251,900 |
| | 100 | 200 | 8.81 | 79,794,140 | 2,430,661 | 53,495,900 |
| | 80 | 200 | 9.29 | 82,101,030 | 2,893,356 | 50,796,720 |
| | 120 | 100 | 11.32 | 89,496,810 | 4,921,254 | 36,251,900 |
| | 100 | 100 | 11.89 | 91,773,840 | 5,386,442 | 33,495,900 |

The simulations results list is long but the above are a sample of the top configurations ranked by their NPC in an ascending order. The top ranked configuration is composed of 2 wind turbines (Hummer H24.5-100 kW) and 120 kW solar PV representing a total capacity of 320 kW and the grid. The system generates a total of 860,486 kWh/yr. where the wind generators contribution is 444,900 kWh/yr., Solar PV is 197,792 kWh/yr. and the grid supplies 217,794 kWh/yr. The total consumption in this system is equal to the total generation hence there is no excess electricity generation, unmet electric load nor capacity shortage. AC primary load of 667,877 kWh/yr. constitutes 77.6% of the total demand and the remainder is grid sales of 192,609 kWh/yr. This system has a COE of Ksh 8.34/kWh and an NPC of Ksh 77,684,049 as shown in Table 9.

**Table 9: Annualized Costs & NPC for the optimal system**

| | | **Net Present costs** | | | |
|---|---|---|---|---|---|
| System Component | Capital (KSh) | Operating (KSh) | Replacement (KSh) | Salvage (KSh) | Total (KSh) |
| CS6X-325 | 14,831,400 | 3,209,460 | - | - | 18,040,860 |
| H24.5-100 | 40,000,000 | 8,655,502 | 8,835,064 | (4,542,641) | 52,947,925 |
| Grid | - | 4,581,385 | - | - | 4,581,385 |
| Converter | 1,420,500 | 307,406 | 457,671 | (71,698) | 2,113,879 |
| HPS | 56,251,900 | 16,753,752 | 9,292,736 | (426,488) | 77,684,049 |
| **Annualized costs** | | | | | |
| CS6X-325 | 1,370,818 | 296,640 | - | | 1,667,458 |
| H24.5-100 | 3,697,070 | 800,00 | 816,596 | (419,862) | 4,893,805 |
| Grid | - | 423,443 | - | - | 423,443 |
| Converter | 131,292 | 28,413 | 42,301 | (6,627) | 195,379 |
| HPS | 5,199,181 | 1,548,495 | 858,897 | (426,488) | 7,180,085 |

### 4.5.2 Wind-Grid Hybrid System for Scaled Load (primary load of 1265.08 kWh/day)

Of the total energy demand of 1864.28 kWh/day, it was estimated that 599.2 kWh/day is needed for meeting the hot water demand and 1265.08 kWh/day of the total load is a primary AC load. For this scenario, a simulation was done with the scaled data (primary AC load) so that the deferrable load demand could specifically be met by solar thermal through Solar Water Heating system.

Among the results obtained incorporated wind-solar PV and grid but the most optimal system consisted of a wind generator (Hummer H24.50-100 kW), 160 kW solar PV and the grid. The total generation of this system is 644,636 kWh/yr. which is equal to the total consumption per year. For this reason, this system has no excess electricity, unmet electric load nor capacity shortage. Wind generator contribute 222,450 kWh/yr. while solar PV contribution is 263,722 kWh/yr. and the grid Purchases is 158,464 kWh/yr. The AC primary load of 461,754 kWh/yr. represents 71.6 % while grid sales is 182,882 kWh/yr.

accounting for 28.4% of the total load. The system's NPC was found to be Ksh50,276,827 and the COE as Ksh 7.21/kWh as shown in Table 11.

**Table 10: Simulation results for scaled load.**

| **HPS Architecture** | | | | **Cost** | | |
|---|---|---|---|---|---|---|
| Grid (kW) | Solar PV (kW) | Wind (kW) | COE (KSh/kWh) | NPC (KSh) | O&M (KSh) | Initial Capital (KSh) |
| | 160 | 100 | 7.21 | 50,276,830 | 802,577 | 41,593,440 |
| | 140 | 100 | 7.76 | 51,628,710 | 1,177,004 | 38,894,260 |
| | 120 | 100 | 8.46 | 53,747,450 | 1,622,309 | 36,195,080 |
| | 120 | 0 | 12.36 | 65,764,730 | 4,581,562 | 16,195,080 |

The NPC and Annualized costs of the most optimal system are shown in Table 12.

**Table 11: NPC & Annualized costs**

| | | | **Net Present costs** | | |
|---|---|---|---|---|---|
| System Component | Capital (KSh) | O&M (KSh) | Replacement (KSh) | Salvage (KSh) | Total (KSh) |
| CS6X-325 | 19,775,200 | 4,279,280 | - | - | 24,054,480 |
| Converter | 1,818,240 | 393,479 | 585,819 | (91,773) | 2,705,765 |
| H24.5-100 | 20,000,000 | 4,327,751 | 4,417,532 | (2,271,321) | 26,473,963 |
| Grid | - | (2,957,381) | - | - | (2,957,381) |
| HPS | 41,593,440 | 6,043,130 | 5,003,351 | (2,363,094) | 50,276,827) |
| | | | Annualized Costs | | |
| CS6X-325 | 1,827,758 | 395,520 | - | - | 2,223,278 |
| Converter | 168,054 | 36,368 | 54,145 | (8,482) | 250,085 |
| H24.5-100 | 1,848,535 | 400,000 | 408,298 | (209,931) | 2,446,903 |
| Grid | - | (273,341) | - | - | (273,341) |
| HPS | 3,844,347 | 558,547 | 462,444 | (218,413) | 4,646,924 |

A simulation of the two optimal systems' operation for a week during the study period clearly outlines the interactions of the different components to meet the objectives of the power system. Figure 20 is a graphical representation of the total production, grid purchases and grid sales for a week (25th Nov to 1st Dec 2017) under unscaled load condition.

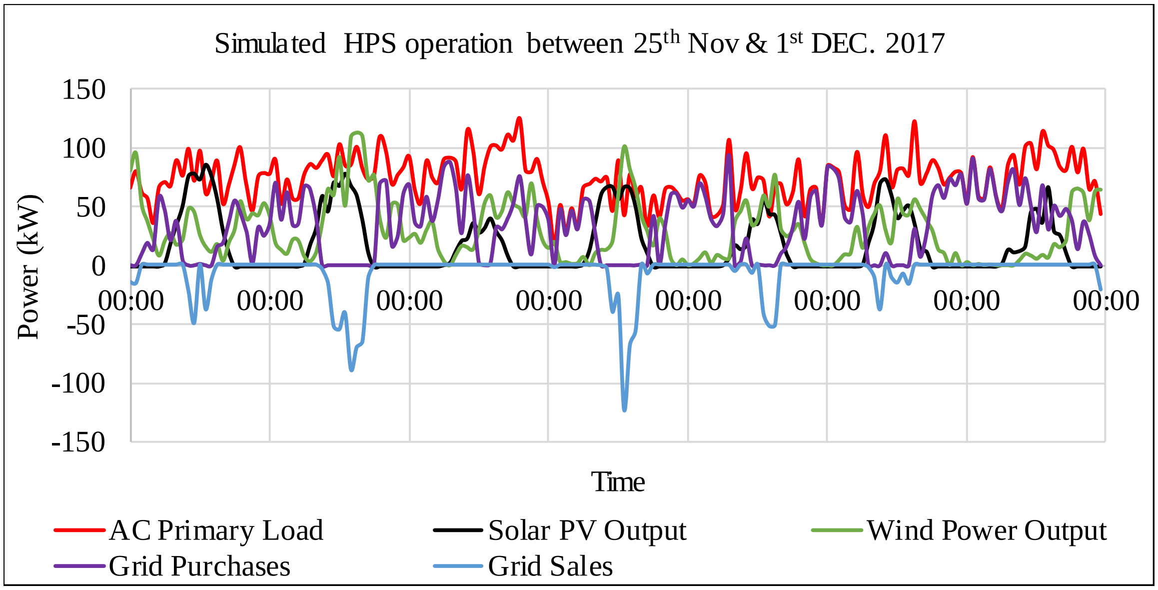


**Figure 20: Unscaled HPS Wind Generation, Grid Purchases, Load & Grid Sales for a week**

During the day when both solar and wind resources are available, the total generation is mostly higher than local demand. For this reason, Grid Sales is significant but the opposite is true for evening and night hours when solar is not available. Supply shortfall from renewable energy generators is met by Grid Purchases.

Similar operation characteristics are observed for the scaled load system as shown in Figure 21.

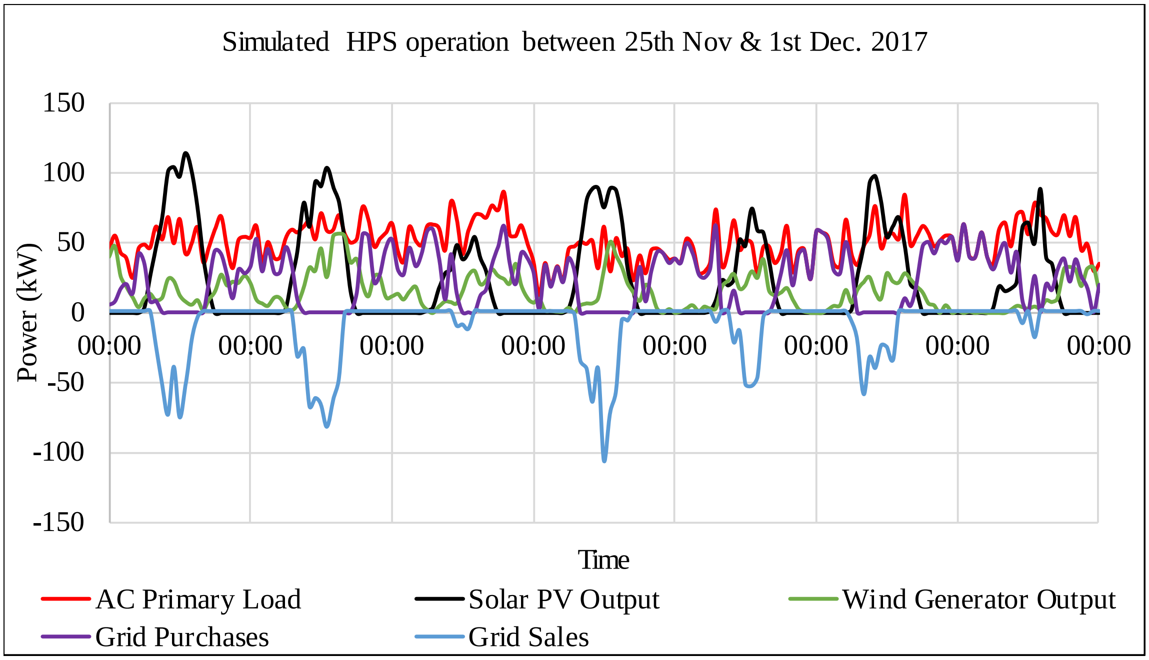


**Figure 21: Scaled HPS Wind Generation, Grid purchases, Load & Grid Sales for a week**

In comparison between the scaled and unscaled loads, Grid Sales constitute a larger fraction of the total load (28.4 %) for the scaled load while it is 22.4 % for the unscaled load. On the other hand, Grid Purchases account for a bigger fraction of generation for the unscaled load condition (25.3%) as compared to 24.5 % for the scaled load. These differences are the reasons for the HPS serving the scaled load having lower COE.

### 4.5.3 Wind-Grid-Solar PV-Solar Thermal for the Total Load (1864.2 kWh/day)

Having met all the necessary requirements including a low NPC and COE, the Wind-Solar PV-Grid hybrid system for meeting the primary load (1265.08 kWh/day) was therefore incorporated with solar thermal that met the deferrable thermal load (599.2 kWh/day). The economic analysis for the whole system (incorporating Solar Thermal) shows the feasibility of the overall Power System. Detailed discussion of the SWH and the Wind-Solar PV-Solar Thermal-Grid hybrid system is given in the following sub-section.

#### 4.5.3.1 Solar Water Heating

**Table 12: SWH Annualized costs and NPCs**

| | | | **Net Present Costs** | | |
|---|---|---|---|---|---|
| System | Capital Cost (KSh) | O&M | Replacement (KSh) | Salvage (KSh) | Total NPC (KSh) |
| SWH | 14,022,600 | 1,517,300 | 3,437,600 | (376,800) | 18,600,700 |
| | | | **Annualized Costs** | | |
| SWH | 1,295,700 | 140,200 | 322,800 | (35,400) | 1,723,300 |

The total annualized cost of the SWH system as calculated using the steps outline in section 3.6, the total NPC and COE for the SWH system were found to be KSh 18,600,700 and KSh 7.87/kWh.

#### 4.5.3.2 Cost Analysis for the Wind-Grid-Solar Thermal Hybrid System

The combined NPCs and annualized costs for wind, grid and solar thermal hybrid power system are given in Table 14.

**Table 13: Total NPCs & Annualized costs for Wind-Grid-Solar hybrid system**

| | | | **Net Present Costs** | | |
|---|---|---|---|---|---|
| System Component | Capital (KSh) | O&M (KSh) | Replacement (KSh) | Salvage (KSh) | Total NPC (KSh) |
| H24.5-100 | 20,000,000 | 4,327,751 | 4,417,532 | (2,271,321) | 26,473,963 |
| CS6X-325 | 19,775,200 | 4,279,280 | - | - | 24,054,480 |
| Converter | 1,818,240 | 393,479 | 585,819 | (91,773) | 2,705,765 |
| Grid | - | (2,957,381) | - | - | (2,957,381) |
| SWH | 14,022,600 | 1,517,300 | 3,493,400 | (383,000) | 18,650,300 |
| HPS | 55,616,040 | 7,560,430 | 8,496,751 | (2,746,094) | 68,927,127 |
| | | | **Annualized Costs** | | |
| H24.5-100 | 1,852,941 | 400,953 | 409,271 | (210,431) | 2,452,735 |
| CS6X-325 | 1,832,114 | 396,463 | - | - | 2,228,577 |
| Converter | 168,455 | 36,455 | 54,274 | (8,503) | 250,681 |
| Grid | - | (273,993) | | - | (273,993) |
| SWH | 1,299,153 | 140,573 | 323,653 | (35,484) | 1,727,895 |
| HPS | 5,152,662 | 700,451 | 787,199 | (254,418) | 6,385,895 |

The COE for the entire system therefore was estimated by dividing total system annualized costs by its total yearly production of 863,344 kWh/yr. The calculated COE was found to be Ksh 7.40/kWh. The chart in Figure 22 shows the annual individual generation by the four components of the HPS. Solar PV contribute the largest fraction in the most optimal system while solar thermal and wind each contribute 25 % and 26 % respectively.

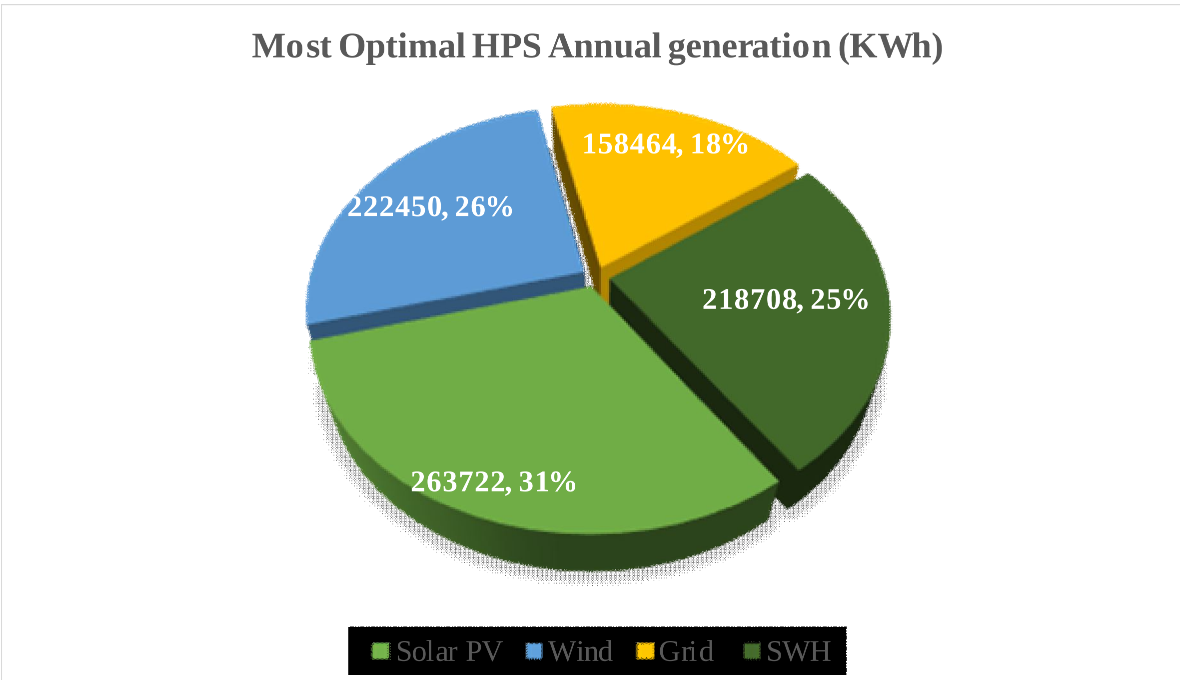


**Figure 22: Hybrid power system annual productions.**

### 4.5.4 Wind-Solar PV-Grid Vs Wind-Solar PV-Grid-Solar Thermal Hybrid Systems

As calculated in the Section 4.5.1, Wind-Grid hybrid system for unscaled load had NPCs and COE of Ksh 77,684,049 and Ksh 8.34/kWh respectively. On the other hand, the total NPC & COE for the Wind-Grid-Solar Thermal hybrid system are Ksh 68,927,127 and Ksh 7.40/kWh respectively. Although the COE for both systems are cheaper than grid prices, the most economical system that can serve the site's total energy requirements (i.e. both the primary load and the deferrable thermal load) is therefore the Wind-Solar PV-Grid-Solar thermal hybrid.

## 4.6 Sensitivity Analysis

Sensitivity analysis was carried out by varying the input parameters of average wind speed, average solar irradiance and cost of solar PV. This analysis was carried out in order to ascertain the impact of the chosen variables on simulation outcomes. Results of this analysis show that the optimal system is influenced by wind speed as shown in Figure 23. The graph represents a surface plot of the optimal system type with COE superimposed. For average speeds below 3.69 m/s, the optimal system is made up of grid power and Solar PV systems. Otherwise for average wind speeds above 3.69 m/s an optimal hybrid system consists of wind, solar PV and grid power sources. For average wind speeds above 4.7 m/s and average daily insolation less than 3.7 kWh/m$^2$, the optimal HPS is made up of Wind and Grid power sources without solar PV. The COE falls with increasing average wind speed and average daily insolation hence sites with better wind and solar resources can have an HPS that performs better than the optimal system for this site.

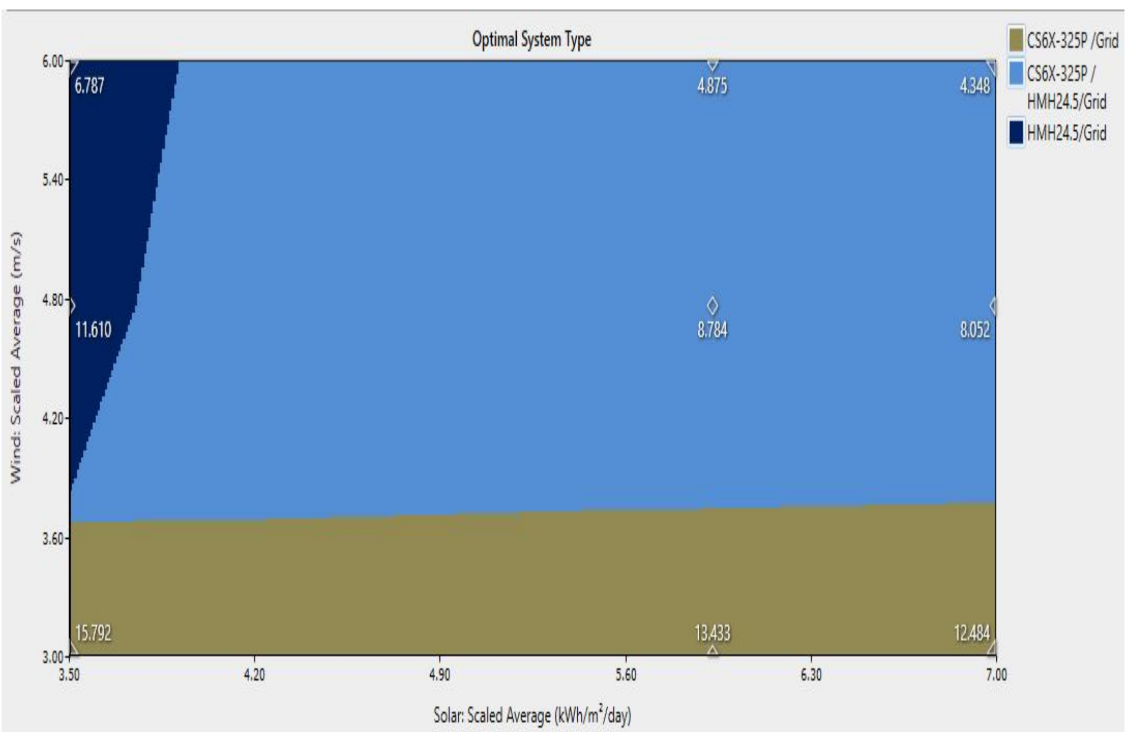


**Figure 23: Sensitivity analysis graph (Optimal System plot with COE Superimposed)**

# CHAPTER FIVE

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusion

The daily load profile of the site showed a higher energy demand during the day and a lower night time demand. Although lower, the nighttime load is still significant and therefore requires that deployed energy resources be available at night. The peak power demand was found to be 177 kW while the average base load was found to be 60 kW. The daily average energy consumption was found to be 1862.28 kWh/day and consequently the monthly usage of 55.86 MWh.

The wind resource potential for the site was found to be a Class 1 wind regime which is a poor endowment. The available wind resource however was found to be sufficient for exploitation to meet a significant portion of the energy demand at the site. Solar resource is abundant in the site and was found to be suitable for both Solar PV and Solar Water Heating (SWH) conversion applications. From comparison of Solar and Wind resource potential at the site, it was observed that there exists some level of seasonal complementarity between them.

Results from the two main scenarios; unscaled and scaled load, Simulation, optimization and sensitivity analysis for HPS showed that the most optimal system consisted of Wind, Solar PV, Solar Water Heating and Grid energy Systems. The total NPC for this system was found to be KSh 68,927,127 while its COE was KSh 7.39/kWh. This cost of energy is the most competitive among the considered options largely because of the low cost of component per unit capacity of renewable energy systems. This system configuration also had a Simple Payback Period of 4.93 years.

This study established that Hybrid Power System of Solar/Wind/Grid can provide lower per unit cost of energy to commercial consumers with trends similar to the site studied. Such a Hybrid system could be implemented by consumers of size comparable to EASA in order to reduce their costs of energy hence making their services more competitive. The findings agree with other researches that have been done in Kenya that adoption of local energy resources to meet onsite demand is favourable. Further, Net-Metering as a policy instrument for promoting deployment of RES is effective for this class of consumer. There is need therefore for development of regulations to streamline implementation of Net-Metering to facilitate exploitation of local energy resources to enhance energy access.

## 5.2 Recommendations

This research presents findings for hybrid power system optimization to meet a commercial load in Kenya. It is the researcher's recommendation that the quality of power consumption data could be enhanced by logging most of the frequently used appliances individually. This can be facilitated by consumers installing smart submeters for onsite energy management while at the same time providing valuable input data for power system design. As a result, demand side management of an energy system by shifting the deferrable loads to periods of high-power generation can be achieved. This will help in enhancing the suitability of local energy resources with variable supply.

Energy resource assessment for the site under study could be carried out by onsite ground measurements for a period of more than two years in order to obtain more accurate local energy resource data. This could improve the quality of input data for simulation and optimization hence a more realistic output could be achieved.

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# APPENDICES

## Appendix I: Consumption Data for EASA.

| ProductSN:3117099001 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date&Time | | Voltage (V) | Current (A) | Frequency (Hz) | Power Factor (PF) | Active Power (W) | Reactive Power (Var) | Apparent Power (Va) | Active Energy (Wh) | Reactive Energy (Varh) | Apparent Energy (VAh) |
| Date | Time | UAvg | IAvg | FAvg | PFAvg | PSum | QSum | SSum | EPSum | EQSum | ESSum |
| 11/24/2017 | 11:47:51 | 243.51 | 112.93 | 49.89 | 0.981 | 80973.6 | 14173.46 | 82609.9 | -14700732 | -3221950 | 16681192 |
| 11/24/2017 | 11:52:51 | 246.35 | 106.5 | 50 | 0.98 | 77171.4 | 13846.6 | 78830.68 | -14693890 | -3220780 | 16688200 |
| 11/24/2017 | 11:57:52 | 245.69 | 127.92 | 49.99 | 0.986 | 93024.5 | 13731.25 | 94431.78 | -14686519 | -3219658 | 16695714 |
| 11/24/2017 | 12:02:51 | 246.32 | 109.68 | 49.96 | 0.983 | 79681.5 | 12714.35 | 81161.03 | -14679298 | -3218541 | 16703032 |
| 11/24/2017 | 12:07:51 | 247 | 108.18 | 49.99 | 0.981 | 78709.8 | 13667.25 | 80280.83 | -14672398 | -3217370 | 16710047 |
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| 11/24/2017 | 12:32:51 | 249.1 | 133.94 | 50.04 | 0.975 | 97694.1 | 20858.93 | 100199.11 | -14635225 | -3209390 | 16748230 |
| 11/24/2017 | 12:37:51 | 249.19 | 138.13 | 50.04 | 0.972 | 100459 | 22966.15 | 103358.48 | -14626958 | -3207481 | 16756729 |
| 11/24/2017 | 12:42:51 | 249.43 | 124.96 | 50.03 | 0.967 | 90450.4 | 23130.78 | 93628.34 | -14618716 | -3205621 | 16765212 |
| 11/24/2017 | 12:47:51 | 250.83 | 126.52 | 50.11 | 0.962 | 91674.8 | 25061.37 | 95342.05 | -14611192 | -3203699 | 16772990 |
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| 11/24/2017 | 12:57:51 | 248.83 | 135.49 | 50.18 | 0.974 | 98587.1 | 21655.04 | 101234.11 | -14595218 | -3199852 | 16789476 |
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| 11/24/2017 | 16:02:50 | 248.23 | 125.59 | 50.12 | 0.972 | 90976.2 | 20893.01 | 93666.73 | -14306820 | -3145641 | 17084196 |
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| 11/24/2017 | 19:27:50 | 244.07 | 141.21 | 50.05 | 0.974 | 100575 | 22256.92 | 103467.23 | -13975508 | -3064786 | 17426324 |
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| 11/24/2017 | 19:42:50 | 244.46 | 134.47 | 50.05 | 0.967 | 95338.8 | 24389.42 | 98741.3 | -13949797 | -3058795 | 17452816 |
| 11/24/2017 | 19:47:50 | 245.43 | 132.29 | 50.06 | 0.97 | 94623.1 | 22566.66 | 97552.77 | -13942110 | -3056801 | 17460790 |
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| 11/24/2017 | 19:57:50 | 245.18 | 136.53 | 50.08 | 0.968 | 97369.2 | 23053.19 | 100556.05 | -13926058 | -3052925 | 17477394 |
| 11/24/2017 | 20:02:50 | 245.42 | 131.33 | 50.11 | 0.967 | 93591.2 | 23297.33 | 96829.3 | -13918153 | -3051042 | 17485552 |
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| 11/24/2017 | 20:17:50 | 246.78 | 130.39 | 50.18 | 0.967 | 93350.7 | 23185.98 | 96663.62 | -13895206 | -3045436 | 17509254 |
| 11/24/2017 | 20:22:50 | 246.73 | 124.49 | 50.23 | 0.977 | 90019.3 | 19007.86 | 92242.16 | -13887908 | -3043751 | 17516792 |
| 11/24/2017 | 20:27:50 | 247.79 | 124.84 | 50.07 | 0.977 | 90687.1 | 18645.32 | 92887.6 | -13880243 | -3042153 | 17524672 |
| 11/24/2017 | 20:32:50 | 247.76 | 126.11 | 50.1 | 0.974 | 91252 | 20286.01 | 93822.17 | -13872285 | -3040321 | 17532870 |
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| 11/24/2017 | 20:42:50 | 247.62 | 121.47 | 50.15 | 0.962 | 86850.3 | 23373.48 | 90358.95 | -13857476 | -3036625 | 17548190 |
| 11/24/2017 | 20:47:50 | 247.67 | 138.63 | 50.14 | 0.96 | 99067.5 | 27049.24 | 103156.98 | -13850099 | -3034716 | 17555816 |
| 11/24/2017 | 20:52:49 | 248.42 | 140.67 | 50.16 | 0.974 | 101995 | 22453.71 | 104910.34 | -13842271 | -3032719 | 17563910 |
| 11/24/2017 | 20:57:50 | 248.2 | 141.95 | 50.21 | 0.972 | 102773 | 23148.22 | 105798.85 | -13833954 | -3030817 | 17572464 |
| 11/24/2017 | 21:02:50 | 248.64 | 147.98 | 50.11 | 0.969 | 107064 | 25813.16 | 110515.2 | -13825198 | -3028760 | 17581508 |
| 11/24/2017 | 21:07:49 | 249.77 | 122.72 | 50.19 | 0.962 | 88615.8 | 22697.37 | 92084.16 | -13816972 | -3026843 | 17589968 |
| 11/24/2017 | 21:12:50 | 247.24 | 132.21 | 50.21 | 0.972 | 95265.9 | 22137.09 | 98160.47 | -13809516 | -3024990 | 17597704 |
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| 11/24/2017 | 21:32:50 | 243.78 | 114.48 | 50.15 | 0.975 | 81696.4 | 17216.45 | 83845.76 | -13780163 | -3017638 | 17628220 |
| 11/24/2017 | 21:37:49 | 244.23 | 119.99 | 50.21 | 0.974 | 85355.4 | 18266.79 | 88015.17 | -13773264 | -3016113 | 17635318 |
| 11/24/2017 | 21:42:50 | 246.62 | 127.16 | 49.98 | 0.963 | 90689.7 | 24181.27 | 94208.53 | -13766116 | -3014333 | 17642722 |
| 11/24/2017 | 21:47:50 | 246.96 | 129.15 | 50.14 | 0.965 | 92356.7 | 23596.67 | 95814.77 | -13758480 | -3012371 | 17650618 |
| 11/24/2017 | 21:52:49 | 247.21 | 112.15 | 50.19 | 0.971 | 80703 | 18255.11 | 83269.41 | -13750976 | -3010596 | 17658392 |
| 11/24/2017 | 21:57:50 | 247.31 | 131.86 | 50.16 | 0.976 | 95391.3 | 19817.4 | 97923.78 | -13743426 | -3008856 | 17666190 |
| 11/24/2017 | 22:02:49 | 247.24 | 131.17 | 49.94 | 0.962 | 93704.5 | 24930.02 | 97413.95 | -13735178 | -3006971 | 17674692 |
| 11/24/2017 | 22:07:50 | 248.83 | 122.87 | 50.09 | 0.966 | 88693.9 | 21885.11 | 91853.24 | -13727540 | -3005000 | 17682624 |
| 11/24/2017 | 22:12:50 | 249.35 | 152.43 | 50.12 | 0.977 | 110889 | 23596.35 | 114042.38 | -13719218 | -3003102 | 17691164 |
| 11/24/2017 | 22:17:50 | 249.07 | 139.72 | 50.12 | 0.967 | 100867 | 25383.91 | 104472.8 | -13709884 | -3000990 | 17700784 |
| 11/24/2017 | 22:22:50 | 248.18 | 135.81 | 49.82 | 0.971 | 98220 | 23320.05 | 101239.88 | -13701632 | -2999135 | 17709288 |
| 11/24/2017 | 22:27:50 | 248.91 | 139.74 | 49.99 | 0.968 | 100917 | 25486.63 | 104451.7 | -13693470 | -2997101 | 17717712 |
| 11/24/2017 | 22:32:49 | 247.73 | 110.43 | 49.8 | 0.966 | 79221.5 | 19955.47 | 82170.44 | -13686154 | -2995145 | 17725330 |
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| 11/24/2017 | 22:42:50 | 248.78 | 130.51 | 49.99 | 0.96 | 93558.6 | 25767.57 | 97539.98 | -13671633 | -2991220 | 17740420 |
| 11/24/2017 | 22:47:49 | 249.56 | 112.44 | 49.99 | 0.966 | 81034.4 | 20869.65 | 84260.27 | -13664282 | -2989207 | 17748120 |
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| 11/24/2017 | 22:57:50 | 249.58 | 114.61 | 50.03 | 0.968 | 83117.8 | 20199.94 | 85940.06 | -13650273 | -2985574 | 17762704 |
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| 11/24/2017 | 23:12:50 | 250.14 | 127.91 | 49.89 | 0.958 | 92085.5 | 26201.78 | 96121.81 | -13628095 | -2979952 | 17785716 |
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| 11/25/2017 | 1:57:49 | 246.95 | 114.76 | 49.88 | 0.97 | 82474.9 | 19484.46 | 85141.11 | -13396874 | -2923182 | 18024814 |
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|---|---|---|---|---|---|---|---|---|---|---|---|
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| 11/25/2017 | 5:57:48 | 250.04 | 96.6 | 50.27 | 0.972 | 70475.9 | 15558.17 | 72575.91 | -13103988 | -2862453 | 18325812 |
| 11/25/2017 | 6:02:49 | 250.12 | 96.96 | 50.14 | 0.971 | 70789.9 | 16309.79 | 72875.92 | -13097995 | -2861025 | 18331988 |
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| 11/25/2017 | 6:17:49 | 249.51 | 101.96 | 50.07 | 0.969 | 73963.4 | 17943.77 | 76417.17 | -13079291 | -2856524 | 18351240 |
| 11/25/2017 | 6:22:49 | 248.65 | 106.57 | 50.02 | 0.975 | 77558.4 | 17118.7 | 79606.61 | -13072986 | -2855107 | 18357750 |
| 11/25/2017 | 6:27:48 | 248.82 | 95.57 | 49.98 | 0.974 | 69531.1 | 15259.95 | 71449.45 | -13066570 | -2853714 | 18364348 |
| 11/25/2017 | 6:32:49 | 248.64 | 102.31 | 50.02 | 0.969 | 74309.4 | 16609.13 | 76438.29 | -13060338 | -2852272 | 18370752 |
| 11/25/2017 | 6:37:49 | 248.64 | 79.77 | 49.98 | 0.986 | 58668 | 7633.89 | 59575.74 | -13054801 | -2851282 | 18376422 |
| 11/25/2017 | 6:42:48 | 248.09 | 82.97 | 50.03 | 0.988 | 61041.9 | 7403.35 | 61835.73 | -13049656 | -2850660 | 18381658 |
| 11/25/2017 | 6:47:49 | 247.58 | 82.33 | 50 | 0.989 | 60567.2 | 7710.21 | 61244.66 | -13044500 | -2849956 | 18386900 |
| 11/25/2017 | 6:52:48 | 247.29 | 83.95 | 49.98 | 0.989 | 61675.8 | 7813.24 | 62382.65 | -13039488 | -2849352 | 18391956 |
| 11/25/2017 | 6:57:49 | 246.45 | 79.99 | 49.93 | 0.992 | 58768.5 | 5696.1 | 59244.39 | -13034519 | -2848873 | 18396962 |
| 11/25/2017 | 7:02:49 | 245.52 | 82.47 | 49.78 | 0.99 | 60177 | 6106.63 | 60832.71 | -13029496 | -2848298 | 18402044 |
| 11/25/2017 | 7:07:48 | 244.2 | 81 | 49.94 | 0.992 | 58939.9 | 5515.95 | 59430.54 | -13024362 | -2847788 | 18407228 |
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| 11/25/2017 | 7:17:48 | 247.66 | 81.42 | 49.96 | 0.994 | 60223.1 | 4592.97 | 60593.47 | -13013963 | -2846739 | 18417698 |
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| 11/25/2017 | 7:32:48 | 247.72 | 84.01 | 49.78 | 0.989 | 61830 | 7073.29 | 62525.3 | -12998134 | -2845175 | 18433702 |
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| 11/25/2017 | 7:47:48 | 248 | 93.51 | 50.13 | 0.972 | 68552.3 | 17004.15 | 69685.21 | -12980502 | -2842289 | 18451658 |
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| 11/25/2017 | 8:17:48 | 245.69 | 131.06 | 49.84 | 0.981 | 94891.7 | 17339.81 | 96741.66 | -12939216 | -2834029 | 18493954 |
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| 11/25/2017 | 8:27:48 | 251.21 | 114.15 | 49.96 | 0.965 | 83109.5 | 21734.88 | 86154.35 | -12924924 | -2830999 | 18508638 |
| 11/25/2017 | 8:32:48 | 252.54 | 109.52 | 50.03 | 0.965 | 80191.3 | 20928.69 | 83101.81 | -12918095 | -2829177 | 18515728 |
| 11/25/2017 | 8:37:48 | 250.69 | 126.12 | 49.92 | 0.971 | 92312.5 | 21707.84 | 95002.38 | -12911114 | -2827415 | 18522952 |
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| 11/26/2017 | 17:57:44 | 248.56 | 107.41 | 50.18 | 0.975 | 78225.6 | 16603.54 | 80216.86 | -10178502 | -2222243 | 21335294 |
| 11/26/2017 | 18:02:43 | 247.35 | 111.63 | 50.11 | 0.978 | 81155.9 | 16569.78 | 82949.56 | -10171538 | -2220849 | 21342408 |
| 11/26/2017 | 18:07:43 | 247.65 | 114.08 | 50.23 | 0.979 | 83110.1 | 16448.51 | 84880.76 | -10164683 | -2219507 | 21349418 |
| 11/26/2017 | 18:12:44 | 247.14 | 118.41 | 50.16 | 0.982 | 83589.2 | 14363.2 | 87832.86 | -10157902 | -2218208 | 21356344 |
| 11/26/2017 | 18:17:43 | 247.48 | 111.41 | 50.2 | 0.98 | 81244.2 | 14891.49 | 82845.3 | -10150952 | -2216871 | 21363406 |
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|---|---|---|---|---|---|---|---|---|---|---|---|
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| 11/26/2017 | 18:37:43 | 247.6 | 115.23 | 49.96 | 0.972 | 83312.3 | 18799.07 | 85732.8 | -10119902 | -2210744 | 21395068 |
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| 11/26/2017 | 19:47:43 | 247.33 | 118.79 | 49.96 | 0.956 | 84381.2 | 24842.51 | 88276.8 | -10019093 | -2184017 | 21499830 |
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| 11/26/2017 | 19:57:43 | 247.89 | 130.3 | 49.91 | 0.969 | 94014.1 | 22910.48 | 97030.79 | -10004367 | -2180259 | 21515102 |
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| 11/26/2017 | 20:17:43 | 248.79 | 119.02 | 50.06 | 0.956 | 84996.5 | 25144.41 | 88965.09 | -9975376 | -2172357 | 21545312 |
| 11/26/2017 | 20:22:44 | 249.38 | 125.75 | 50.2 | 0.966 | 90968.6 | 23013.03 | 94198.3 | -9968110 | -2170402 | 21552892 |
| 11/26/2017 | 20:27:43 | 249.02 | 112.59 | 50.06 | 0.961 | 80931.4 | 21968.46 | 84234.68 | -9960738 | -2168493 | 21560518 |
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| 11/26/2017 | 20:47:43 | 250.41 | 108.5 | 50.05 | 0.959 | 78292.1 | 22688.25 | 81621.59 | -9931602 | -2160484 | 21590892 |
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| 11/26/2017 | 21:07:44 | 246.68 | 140.39 | 50.09 | 0.969 | 100798 | 24714.04 | 104022.47 | -9902430 | -2152676 | 21621130 |
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| 11/26/2017 | 21:22:43 | 247.55 | 118.33 | 50.06 | 0.955 | 83947.5 | 25132.25 | 88011.98 | -9881772 | -2147124 | 21642600 |
| 11/26/2017 | 21:27:43 | 248 | 122.05 | 50.07 | 0.97 | 88025.4 | 20824.21 | 90924.42 | -9874951 | -2145292 | 21649720 |
| 11/26/2017 | 21:32:43 | 248.32 | 122.08 | 50.15 | 0.962 | 87775.9 | 22748.73 | 91093.95 | -9867704 | -2143362 | 21657252 |
| 11/26/2017 | 21:37:43 | 248.71 | 132.39 | 50.17 | 0.957 | 94774 | 26732.14 | 98937.03 | -9860450 | -2141461 | 21664804 |
| 11/26/2017 | 21:42:43 | 249.33 | 123.19 | 50.08 | 0.963 | 88848.7 | 22751.13 | 92286.3 | -9853027 | -2139507 | 21672470 |
| 11/26/2017 | 21:47:43 | 249.42 | 117.34 | 50.15 | 0.969 | 85057.3 | 21113.48 | 87905.79 | -9845448 | -2137417 | 21680332 |
| 11/26/2017 | 21:52:43 | 250.49 | 109.34 | 50.22 | 0.959 | 78936.2 | 21493.93 | 82288.78 | -9838154 | -2135527 | 21687876 |
| 11/26/2017 | 21:57:43 | 245.84 | 118.7 | 50.17 | 0.968 | 85001.7 | 20002.67 | 87678.06 | -9831458 | -2133873 | 21694822 |
| 11/26/2017 | 22:02:43 | 244.11 | 114.71 | 50.1 | 0.969 | 81379.2 | 20492.24 | 84116.34 | -9824462 | -2132071 | 21702102 |
| 11/26/2017 | 22:07:43 | 245.15 | 121.92 | 50.3 | 0.966 | 86723 | 21464.17 | 89793.48 | -9817724 | -2130404 | 21709068 |
| 11/26/2017 | 22:12:43 | 246.06 | 108.62 | 50.27 | 0.97 | 77834.1 | 18026.32 | 80303.86 | -9810710 | -2128759 | 21716306 |
| 11/26/2017 | 22:17:43 | 245.22 | 109.2 | 50.02 | 0.969 | 77841.7 | 18995.86 | 80459.3 | -9803946 | -2127082 | 21723294 |
| 11/26/2017 | 22:22:43 | 244.98 | 125.06 | 49.86 | 0.965 | 88782.2 | 22971.59 | 92036.83 | -9797374 | -2125437 | 21730080 |
| 11/26/2017 | 22:27:43 | 246.12 | 115.87 | 50.07 | 0.966 | 82600.9 | 21419.54 | 85668.84 | -9790546 | -2123682 | 21737156 |
| 11/26/2017 | 22:32:43 | 247.57 | 113.05 | 50.3 | 0.968 | 81115 | 19745.41 | 84051.09 | -9783750 | -2121902 | 21744224 |
| 11/26/2017 | 22:37:43 | 247.49 | 118.21 | 50.2 | 0.965 | 84833.4 | 21697.6 | 87904.51 | -9776990 | -2120301 | 21751184 |
| 11/26/2017 | 22:42:43 | 248.08 | 112.83 | 50.21 | 0.967 | 81221.2 | 20225.21 | 84094.59 | -9770178 | -2118565 | 21758272 |
| 11/26/2017 | 22:47:43 | 247.61 | 112.84 | 50.16 | 0.969 | 81031.2 | 19886.04 | 83918.04 | -9763272 | -2116772 | 21765494 |
| 11/26/2017 | 22:52:43 | 247.65 | 113.42 | 50.06 | 0.965 | 81475.8 | 21199.55 | 84388.2 | -9756630 | -2115137 | 21772388 |
| 11/26/2017 | 22:57:43 | 247.76 | 113.01 | 50.03 | 0.966 | 81015.2 | 20946.93 | 84095.23 | -9750098 | -2113485 | 21779172 |
| 11/26/2017 | 23:02:43 | 247.97 | 110.13 | 50.23 | 0.968 | 79424.3 | 18598.76 | 82062.33 | -9743384 | -2111780 | 21786152 |
| 11/26/2017 | 23:07:43 | 248.34 | 110.8 | 50.16 | 0.963 | 79678.9 | 21044.52 | 82678.34 | -9736492 | -2110064 | 21793332 |
| 11/26/2017 | 23:12:43 | 247.74 | 105.41 | 50.01 | 0.97 | 76082.6 | 17886.33 | 78439.84 | -9729908 | -2108441 | 21800134 |
| 11/26/2017 | 23:17:43 | 248.8 | 127.32 | 50.06 | 0.972 | 92358 | 27723.76 | 95132.87 | -9722728 | -2106780 | 21807524 |
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| 11/26/2017 | 23:27:43 | 250.23 | 114.41 | 50.16 | 0.971 | 83559.2 | 18793.15 | 86021.3 | -9709110 | -2103288 | 21821690 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/26/2017 | 23:32:43 | 249.7 | 115.32 | 49.95 | 0.967 | 83705.7 | 20336.41 | 86526 | -9701748 | -2101483 | 21829314 |
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| 11/26/2017 | 23:42:42 | 250.96 | 118.65 | 50.17 | 0.963 | 86128.1 | 22941.83 | 89469.8 | -9688032 | -2097814 | 21843632 |
| 11/26/2017 | 23:47:43 | 251.14 | 115.61 | 50.21 | 0.958 | 83511.2 | 23889.77 | 87227.73 | -9681190 | -2095965 | 21850794 |
| 11/26/2017 | 23:52:43 | 251.03 | 106.55 | 50.23 | 0.959 | 76916.8 | 21348.5 | 80343.52 | -9674647 | -2094228 | 21857600 |
| 11/26/2017 | 23:57:43 | 251.03 | 111.23 | 50.26 | 0.959 | 80443.3 | 22323.63 | 83887.34 | -9667666 | -2092302 | 21864860 |
| 11/27/2017 | 0:02:43 | 251.6 | 105.42 | 50.13 | 0.966 | 76817 | 19883.96 | 79685.3 | -9660960 | -2090465 | 21871860 |
| 11/27/2017 | 0:07:43 | 251.86 | 118.5 | 50.1 | 0.957 | 85678.4 | 25158.96 | 89657.23 | -9654474 | -2088671 | 21878682 |
| 11/27/2017 | 0:12:42 | 251.8 | 122.52 | 50.14 | 0.961 | 88251.9 | 21178.43 | 92671.39 | -9647452 | -2086625 | 21886000 |
| 11/27/2017 | 0:17:43 | 253.73 | 100.19 | 50.27 | 0.964 | 73455.5 | 19164 | 76377.52 | -9640791 | -2084765 | 21892962 |
| 11/27/2017 | 0:22:43 | 249.72 | 112 | 50.04 | 0.96 | 80616 | 22885.52 | 84028.7 | -9634312 | -2083059 | 21899710 |
| 11/27/2017 | 0:27:42 | 249.05 | 114.09 | 49.99 | 0.963 | 82008 | 22165.57 | 85361.16 | -9627570 | -2081177 | 21906806 |
| 11/27/2017 | 0:32:43 | 249.95 | 104.39 | 50.12 | 0.965 | 75771.7 | 18863.07 | 78402.1 | -9620839 | -2079329 | 21913762 |
| 11/27/2017 | 0:37:43 | 250.56 | 105.21 | 50.22 | 0.967 | 76660.9 | 18263.43 | 79220.24 | -9614216 | -2077678 | 21920652 |
| 11/27/2017 | 0:42:42 | 246.36 | 107.71 | 50.17 | 0.972 | 77359.4 | 17638.03 | 79718.55 | -9607794 | -2076113 | 21927284 |
| 11/27/2017 | 0:47:43 | 245.78 | 117.45 | 50.11 | 0.969 | 83880.9 | 20552.71 | 86722.39 | -9601295 | -2074534 | 21934002 |
| 11/27/2017 | 0:52:43 | 245.83 | 103.4 | 50.14 | 0.973 | 74258.9 | 16418.43 | 76369.84 | -9594534 | -2072964 | 21940924 |
| 11/27/2017 | 0:57:42 | 246.25 | 104.01 | 50.11 | 0.972 | 74791.1 | 16750.57 | 76958.98 | -9588130 | -2071456 | 21947508 |
| 11/27/2017 | 1:02:43 | 246.07 | 113.78 | 50.12 | 0.97 | 81617.8 | 19183.04 | 84131.05 | -9581720 | -2069983 | 21954104 |
| 11/27/2017 | 1:07:43 | 246.01 | 108.29 | 49.85 | 0.969 | 77439.4 | 19041.61 | 80030.08 | -9575298 | -2068443 | 21960720 |
| 11/27/2017 | 1:12:42 | 246.2 | 111.95 | 49.99 | 0.969 | 80042.9 | 19705.73 | 82774.94 | -9568587 | -2066739 | 21967658 |
| 11/27/2017 | 1:17:43 | 246.32 | 110.98 | 50.02 | 0.964 | 79154.4 | 20775.74 | 82130.14 | -9561818 | -2065113 | 21974662 |
| 11/27/2017 | 1:22:42 | 246.75 | 98.22 | 50 | 0.973 | 70756.7 | 15537.85 | 72808.76 | -9555383 | -2063547 | 21981336 |
| 11/27/2017 | 1:27:43 | 246.31 | 110.74 | 49.97 | 0.97 | 79447.3 | 19185.13 | 81954.87 | -9549122 | -2062095 | 21987784 |
| 11/27/2017 | 1:32:43 | 246.82 | 100.85 | 50.07 | 0.973 | 72690.4 | 16011.73 | 74789.2 | -9542498 | -2060557 | 21994588 |
| 11/27/2017 | 1:37:42 | 246.84 | 106.15 | 50.04 | 0.971 | 76263.7 | 17709.7 | 78699.55 | -9536050 | -2058978 | 22001256 |
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| 11/27/2017 | 1:47:43 | 247.09 | 103 | 50.11 | 0.972 | 74432.3 | 17440.12 | 76476.67 | -9522878 | -2055847 | 22014818 |
| 11/27/2017 | 1:52:42 | 246.99 | 100.99 | 50.01 | 0.974 | 72878.5 | 16059.09 | 74948.48 | -9516512 | -2054335 | 22021320 |
| 11/27/2017 | 1:57:43 | 247.38 | 110.09 | 50.12 | 0.969 | 79159.5 | 19422.39 | 81814.14 | -9509929 | -2052814 | 22028110 |
| 11/27/2017 | 2:02:43 | 247.24 | 106.56 | 49.94 | 0.966 | 76462 | 19321.12 | 79167.16 | -9503443 | -2051189 | 22034808 |
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| 11/27/2017 | 2:22:42 | 247.38 | 99.69 | 50.01 | 0.982 | 72604.1 | 11873.77 | 74080.44 | -9479773 | -2046622 | 22059094 |
| 11/27/2017 | 2:27:43 | 247.54 | 86.59 | 50 | 0.981 | 63134.3 | 10752.88 | 64397.63 | -9474242 | -2045748 | 22064762 |
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| 11/27/2017 | 2:42:43 | 248.37 | 89.75 | 50.05 | 0.983 | 65789.6 | 10584.74 | 66967.86 | -9457719 | -2043109 | 22081616 |
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| 11/27/2017 | 2:57:43 | 249.35 | 85.2 | 50.07 | 0.985 | 62692.3 | 8247.29 | 63806.57 | -9440744 | -2040120 | 22098972 |
| 11/27/2017 | 3:02:42 | 249.69 | 86.87 | 50.11 | 0.979 | 63960.1 | 9542.57 | 65172.92 | -9435340 | -2039270 | 22104484 |
| 11/27/2017 | 3:07:42 | 249.83 | 91.17 | 50.17 | 0.979 | 66866.2 | 12444.93 | 68433.36 | -9429724 | -2038330 | 22110240 |
| 11/27/2017 | 3:12:43 | 249.74 | 87.16 | 50.17 | 0.984 | 64232 | 9356.66 | 65390.41 | -9424056 | -2037331 | 22116046 |
| 11/27/2017 | 3:17:42 | 250.09 | 89.47 | 50.25 | 0.984 | 65993.6 | 10547.62 | 67216.05 | -9418606 | -2036530 | 22121584 |
| 11/27/2017 | 3:22:42 | 249.66 | 90.63 | 50.17 | 0.98 | 66559.7 | 11474.76 | 67979.19 | -9412981 | -2035547 | 22127380 |
| 11/27/2017 | 3:27:43 | 249.75 | 86.35 | 50.04 | 0.985 | 63710 | 8464.56 | 64794.88 | -9407368 | -2034588 | 22133126 |
| 11/27/2017 | 3:32:42 | 247.95 | 113.03 | 49.91 | 0.964 | 81035 | 21897.58 | 84203.98 | -9401128 | -2033136 | 22139550 |
| 11/27/2017 | 3:37:42 | 247.73 | 109.04 | 49.92 | 0.966 | 78284.4 | 20002.67 | 81146.31 | -9394579 | -2031360 | 22146326 |
| 11/27/2017 | 3:42:43 | 247.82 | 111.87 | 49.89 | 0.963 | 80182.3 | 21266.59 | 83303.95 | -9388013 | -2029662 | 22153112 |
| 11/27/2017 | 3:47:42 | 247.47 | 106 | 49.86 | 0.967 | 76235.5 | 19032.17 | 78821.73 | -9381504 | -2028018 | 22159834 |
| 11/27/2017 | 3:52:42 | 248.52 | 103.2 | 50.02 | 0.967 | 74290.3 | 18536.21 | 77041.5 | -9374980 | -2026308 | 22166624 |
| 11/27/2017 | 3:57:42 | 248.45 | 112.47 | 50.02 | 0.965 | 80949.9 | 21500.81 | 83958.34 | -9368543 | -2024744 | 22173336 |
| 11/27/2017 | 4:02:42 | 248.9 | 107.26 | 50.11 | 0.967 | 77461.1 | 19636.29 | 80213.02 | -9362094 | -2023075 | 22180008 |
| 11/27/2017 | 4:07:42 | 248.78 | 107.33 | 50.06 | 0.963 | 77173.3 | 20592.39 | 80219.42 | -9355602 | -2021364 | 22186708 |
| 11/27/2017 | 4:12:42 | 248.86 | 103.71 | 50.07 | 0.967 | 75013.7 | 18612.2 | 77554.52 | -9348766 | -2019567 | 22193812 |
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| 11/27/2017 | 4:32:42 | 249.58 | 86.26 | 50.18 | 0.984 | 63595.5 | 8931.09 | 64668.22 | -9323709 | -2013547 | 22219754 |
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| 11/27/2017 | 8:02:41 | 247.69 | 116.56 | 50.01 | 0.974 | 84552.6 | 17339.65 | 86753.73 | -9004808 | -1968530 | 22543256 |
| 11/27/2017 | 8:07:42 | 245.72 | 133.02 | 49.84 | 0.978 | 96014.3 | 18129.67 | 98214.2 | -8996870 | -1966843 | 22551388 |
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| 11/27/2017 | 12:47:41 | 246.09 | 127.07 | 50.07 | 0.974 | 91525.7 | 19691.65 | 93921.95 | -8453632 | -1876788 | 23104092 |
| 11/27/2017 | 12:52:41 | 246.33 | 127.85 | 50.05 | 0.971 | 91840.5 | 21753.75 | 94601.94 | -8445160 | -1874909 | 23112784 |
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| 11/27/2017 | 13:27:41 | 246.58 | 130.2 | 50.17 | 0.971 | 93721.1 | 21994.86 | 96456.36 | -8388770 | -1861715 | 23170948 |
| 11/27/2017 | 13:32:41 | 245.35 | 127.25 | 49.92 | 0.972 | 91129.8 | 21303.7 | 93790.19 | -8381098 | -1859963 | 23178824 |
| 11/27/2017 | 13:37:41 | 245.31 | 125.46 | 50.06 | 0.977 | 90309.7 | 18714.43 | 92455.17 | -8373515 | -1858248 | 23186616 |
| 11/27/2017 | 13:42:41 | 244.96 | 125.9 | 49.94 | 0.975 | 90241.9 | 19699.33 | 92629.17 | -8365705 | -1856556 | 23194620 |
| 11/27/2017 | 13:47:41 | 245.13 | 128.17 | 50.1 | 0.978 | 92199.3 | 18489.49 | 94378.69 | -8358134 | -1854914 | 23202378 |
| 11/27/2017 | 13:52:41 | 245.67 | 113.11 | 50.1 | 0.987 | 82302.2 | 11951.84 | 83472.83 | -8350672 | -1853363 | 23210034 |
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| 11/27/2017 | 14:07:40 | 244.27 | 114.82 | 49.8 | 0.985 | 82799.2 | 12182.07 | 84237.23 | -8329973 | -1850412 | 23231048 |
| 11/27/2017 | 14:12:41 | 243.95 | 111.42 | 50.11 | 0.989 | 80691.5 | 9742.07 | 81659.98 | -8323095.5 | -1849531 | 23237964 |
| 11/27/2017 | 14:17:41 | 246.7 | 116.32 | 50.03 | 0.976 | 85050.9 | 19016.97 | 86195.93 | -8316165.5 | -1848569 | 23244994 |
| 11/27/2017 | 14:22:40 | 246.66 | 112.65 | 50.24 | 0.987 | 82293.9 | 11937.29 | 83476.66 | -8309253.5 | -1847642 | 23251988 |
| 11/27/2017 | 14:27:41 | 246.07 | 124.91 | 50.09 | 0.984 | 90737 | 15590 | 92327.24 | -8301790 | -1846622 | 23259558 |

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| 11/27/2017 | 14:32:41 | 245.35 | 124.9 | 49.89 | 0.985 | 90571.3 | 14852.61 | 92036.83 | -8294405 | -1845469 | 23267060 |
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| 11/27/2017 | 14:47:41 | 245.37 | 113.46 | 50.02 | 0.988 | 82327.2 | 11604.51 | 83596.28 | -8272719 | -1842276 | 23289028 |
| 11/27/2017 | 14:52:40 | 245.31 | 131.43 | 50 | 0.988 | 95703.5 | 13113.37 | 96865.11 | -8265432.5 | -1841224 | 23296388 |
| 11/27/2017 | 14:57:41 | 244.61 | 134.22 | 49.97 | 0.972 | 95825.6 | 22420.43 | 98633.19 | -8257465 | -1839544 | 23304572 |
| 11/27/2017 | 15:02:41 | 244.46 | 134.91 | 50.08 | 0.976 | 96677.1 | 20738.78 | 99076.48 | -8249389 | -1837777 | 23312862 |
| 11/27/2017 | 15:07:40 | 244.62 | 135.97 | 50.02 | 0.975 | 97406.9 | 21062.92 | 99913.82 | -8240732 | -1835980 | 23321742 |
| 11/27/2017 | 15:12:41 | 245.13 | 124.68 | 50.03 | 0.977 | 89628.4 | 18434.13 | 91815.5 | -8232742 | -1834215 | 23329950 |
| 11/27/2017 | 15:17:41 | 243.74 | 135.67 | 49.89 | 0.974 | 96703.3 | 21814.87 | 99343.86 | -8224308 | -1832551 | 23338554 |
| 11/27/2017 | 15:22:40 | 243.16 | 192.51 | 49.88 | 0.988 | 138891 | 21020.68 | 140645.3 | -8213627.5 | -1830857 | 23349400 |
| 11/27/2017 | 15:27:41 | 244.72 | 192.51 | 49.86 | 0.988 | 139770 | 21147.87 | 141526.13 | -8203137 | -1829134 | 23360058 |
| 11/27/2017 | 15:32:41 | 245.89 | 126.55 | 50.05 | 0.971 | 90796.5 | 21507.85 | 93479.3 | -8194963.5 | -1827337 | 23368440 |
| 11/27/2017 | 15:37:40 | 244.85 | 188.23 | 50.04 | 0.988 | 136674 | 20860.69 | 138458.88 | -8184266.5 | -1825276 | 23379362 |
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| 11/27/2017 | 15:47:40 | 245.12 | 190.07 | 50.07 | 0.986 | 137941 | 22872.88 | 139984.52 | -8160752.5 | -1821572 | 23403176 |
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| 11/27/2017 | 15:57:41 | 245.25 | 191.68 | 50.03 | 0.988 | 139512 | 21040.52 | 141240.83 | -8136990 | -1817605 | 23427324 |
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| 11/27/2017 | 16:07:41 | 244.19 | 180.88 | 49.95 | 0.989 | 131129 | 18578.29 | 132707.53 | -8113773 | -1814249 | 23450808 |
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| 11/27/2017 | 16:17:40 | 245.78 | 184.93 | 50.12 | 0.995 | 135699 | 11013.99 | 136557.13 | -8092865.5 | -1812145 | 23471844 |
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| 11/27/2017 | 19:07:40 | 247.08 | 144.09 | 50.14 | 0.972 | 104003 | 22917.68 | 106964.98 | -7842755 | -1759004 | 23728834 |
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|---|---|---|---|---|---|---|---|---|---|---|---|
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| 11/27/2017 | 21:27:39 | 247.97 | 110.44 | 49.95 | 0.973 | 79980.2 | 17827.45 | 82277.91 | -7626673 | -1710434 | 23951654 |
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| 11/27/2017 | 22:22:40 | 249.53 | 118.37 | 50.13 | 0.971 | 86041.1 | 20541.83 | 88702.19 | -7554956 | -1692780 | 24026026 |
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| 11/27/2017 | 22:47:40 | 250.33 | 109.65 | 50.19 | 0.967 | 79829.9 | 18461.17 | 82481.96 | -7522401.5 | -1684562 | 24059918 |
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| 11/27/2017 | 23:02:40 | 251.41 | 114.61 | 50.26 | 0.972 | 84051.7 | 19234.08 | 86521.52 | -7502531 | -1679881 | 24080466 |
| 11/27/2017 | 23:07:40 | 251.58 | 128.2 | 50.24 | 0.978 | 93497.2 | 17774.82 | 96913.73 | -7495656.5 | -1678392 | 24087550 |
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| 11/27/2017 | 23:17:40 | 252.6 | 99.74 | 50.16 | 0.962 | 72916.9 | 18918.58 | 75694.34 | -7480791.5 | -1675024 | 24102848 |
| 11/27/2017 | 23:22:40 | 251.54 | 104.49 | 49.91 | 0.966 | 76150.4 | 19418.71 | 78956.06 | -7474559.5 | -1673420 | 24109368 |
| 11/27/2017 | 23:27:39 | 252.04 | 105.17 | 50.01 | 0.967 | 76877.1 | 19314.07 | 79616.84 | -7468283 | -1671781 | 24115930 |
| 11/27/2017 | 23:32:39 | 249.32 | 102.34 | 50.17 | 0.968 | 74193.7 | 17890.33 | 76663.45 | -7462054 | -1670243 | 24122438 |
| 11/27/2017 | 23:37:40 | 245.43 | 104.16 | 49.99 | 0.976 | 74827.6 | 15697.84 | 76792.67 | -7455713 | -1668779 | 24128962 |
| 11/27/2017 | 23:42:39 | 243.71 | 126.78 | 49.98 | 0.973 | 88935 | 17869.69 | 92816.59 | -7449493.5 | -1667367 | 24135348 |
| 11/27/2017 | 23:47:39 | 244.44 | 106.52 | 50.03 | 0.976 | 76314.8 | 16141.65 | 78221.06 | -7443408 | -1666128 | 24141570 |
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| 11/28/2017 | 0:27:39 | 246.7 | 103.35 | 50.13 | 0.974 | 74523.7 | 16219.72 | 76591.17 | -7392938 | -1655818 | 24193058 |

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| 11/28/2017 | 0:32:40 | 247.07 | 98.56 | 50.13 | 0.974 | 71236.4 | 15146.83 | 73165.7 | -7386731 | -1654457 | 24199408 |
| 11/28/2017 | 0:37:39 | 246.41 | 102.61 | 50.01 | 0.974 | 73934.6 | 16043.57 | 75950.85 | -7380581.5 | -1653172 | 24205706 |
| 11/28/2017 | 0:42:39 | 246.87 | 103.51 | 50.09 | 0.976 | 74818 | 15528.09 | 76763.25 | -7374331 | -1651853 | 24212084 |
| 11/28/2017 | 0:47:40 | 246.91 | 103.81 | 50.03 | 0.974 | 74927.4 | 16187.4 | 76994.17 | -7368078 | -1650412 | 24218530 |
| 11/28/2017 | 0:52:39 | 246.65 | 104.65 | 49.9 | 0.971 | 75267 | 17599.95 | 77546.85 | -7362031.5 | -1649075 | 24224732 |
| 11/28/2017 | 0:57:39 | 246.14 | 101.89 | 49.87 | 0.975 | 73364.6 | 15734.79 | 75334.84 | -7356066 | -1647774 | 24230822 |
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| 11/28/2017 | 1:07:39 | 247.97 | 99.95 | 50.14 | 0.973 | 72503.6 | 15781.19 | 74470 | -7343940.5 | -1645145 | 24243242 |
| 11/28/2017 | 1:12:39 | 247.71 | 96.34 | 50.09 | 0.977 | 69999.3 | 13887.88 | 71704.03 | -7337940 | -1643871 | 24249366 |
| 11/28/2017 | 1:17:40 | 247.08 | 120.35 | 49.97 | 0.975 | 86982.7 | 19293.6 | 89300.29 | -7331573 | -1642555 | 24255870 |
| 11/28/2017 | 1:22:39 | 246.63 | 102.93 | 49.89 | 0.975 | 74303.7 | 16047.73 | 76260.46 | -7325336.5 | -1641209 | 24262284 |
| 11/28/2017 | 1:27:39 | 247.82 | 102.11 | 50.05 | 0.975 | 73982.6 | 16147.25 | 76018.02 | -7319299 | -1639896 | 24268478 |
| 11/28/2017 | 1:32:39 | 248.05 | 99.76 | 50 | 0.971 | 72189.6 | 16709.45 | 74352.3 | -7313250 | -1638623 | 24274692 |
| 11/28/2017 | 1:37:39 | 249.1 | 96.96 | 50.11 | 0.975 | 70714.5 | 15139.15 | 72573.36 | -7307155 | -1637280 | 24280968 |
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| 11/28/2017 | 1:47:39 | 247.91 | 95.39 | 49.99 | 0.977 | 69352.6 | 13742.77 | 71048.36 | -7294887 | -1634611 | 24293512 |
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| 11/28/2017 | 2:07:39 | 249.16 | 94.52 | 50.03 | 0.974 | 68871.5 | 14899.97 | 70757.31 | -7270394 | -1629033 | 24318632 |
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| 11/28/2017 | 2:17:39 | 249.02 | 103.08 | 50.06 | 0.975 | 75032.9 | 16211.72 | 77108.67 | -7258301 | -1626374 | 24331038 |
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| 11/28/2017 | 2:27:39 | 248.65 | 97.74 | 50.04 | 0.974 | 71097 | 15101.55 | 73020.48 | -7246024 | -1623575 | 24343658 |
| 11/28/2017 | 2:32:39 | 248.15 | 101.46 | 49.94 | 0.973 | 73551.4 | 16414.75 | 75632.3 | -7239916 | -1622167 | 24349926 |
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| 11/28/2017 | 2:47:39 | 249 | 104.07 | 49.91 | 0.97 | 75378.3 | 18239.43 | 77850.05 | -7221920.5 | -1618060 | 24368362 |
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| 11/28/2017 | 2:57:39 | 249.01 | 100.54 | 50.01 | 0.97 | 72823.5 | 17200.62 | 75208.83 | -7209656 | -1615240 | 24380940 |
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| 11/28/2017 | 4:22:39 | 249.76 | 95.31 | 50 | 0.975 | 69720.4 | 14565.59 | 71525.56 | -7103977 | -1591565 | 24489694 |
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| 11/28/2017 | 5:02:39 | 250.82 | 101.05 | 50.17 | 0.971 | 73845.7 | 16986.87 | 76147.23 | -7055229 | -1580399 | 24539744 |
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| 11/28/2017 | 5:12:38 | 250.23 | 99.55 | 50.01 | 0.971 | 72519 | 16840.8 | 74825.02 | -7042990 | -1577509 | 24552308 |
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| 11/28/2017 | 5:27:38 | 250.53 | 103.03 | 49.94 | 0.968 | 74931.2 | 18643.56 | 77543.01 | -7024604.5 | -1573080 | 24571252 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/28/2017 | 5:32:39 | 250.52 | 97.7 | 49.92 | 0.971 | 71203.2 | 16890.55 | 73520.72 | -7018672 | -1571676 | 24577384 |
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| 11/28/2017 | 5:47:39 | 250.03 | 93.59 | 49.96 | 0.973 | 68300.3 | 14872.77 | 70299.94 | -7000383 | -1567184 | 24596304 |
| 11/28/2017 | 5:52:38 | 250.29 | 95.2 | 49.99 | 0.971 | 69424.2 | 16490.1 | 71590.17 | -6994404 | -1565769 | 24602492 |
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| 11/28/2017 | 7:07:38 | 246.89 | 110.55 | 50.04 | 0.988 | 81085.6 | 11270.45 | 82016.91 | -6902136 | -1547968 | 24696530 |
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| 11/28/2017 | 7:27:39 | 246.57 | 91.56 | 50.06 | 0.986 | 66890.5 | 10318.03 | 67835.9 | -6878792 | -1543934 | 24720468 |
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| 11/28/2017 | 8:02:38 | 250.49 | 110.16 | 49.82 | 0.979 | 81284.5 | 15414.01 | 82919.5 | -6834967.5 | -1536624 | 24765062 |
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| 11/28/2017 | 8:57:38 | 249.21 | 95.93 | 50.07 | 0.979 | 70355.6 | 14590.23 | 71818.54 | -6767287 | -1523504 | 24834060 |
| 11/28/2017 | 9:02:38 | 248.55 | 97.26 | 50.02 | 0.979 | 71159 | 14136.98 | 72637.33 | -6761231 | -1522316 | 24840242 |
| 11/28/2017 | 9:07:38 | 247.98 | 98.4 | 50 | 0.981 | 71885.1 | 13673.01 | 73312.18 | -6755352.5 | -1521275 | 24846258 |
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| 11/28/2017 | 9:17:38 | 249.69 | 110.91 | 49.88 | 0.986 | 82092.4 | 12436.29 | 83224.63 | -6743037.5 | -1519190 | 24858748 |
| 11/28/2017 | 9:22:39 | 249.89 | 108.13 | 49.95 | 0.979 | 79496 | 15419.93 | 81184.7 | -6736387 | -1518008 | 24865536 |
| 11/28/2017 | 9:27:38 | 249.14 | 96.08 | 49.86 | 0.98 | 70516.2 | 13588.54 | 71924.72 | -6730437 | -1516873 | 24871620 |
| 11/28/2017 | 9:32:38 | 248.79 | 98.05 | 49.83 | 0.981 | 71941.4 | 13552.7 | 73308.34 | -6724670 | -1515828 | 24877492 |
| 11/28/2017 | 9:37:39 | 248.65 | 104.61 | 49.78 | 0.983 | 76881 | 13272.72 | 78166.05 | -6718522.5 | -1514707 | 24883750 |
| 11/28/2017 | 9:42:38 | 248.54 | 102.76 | 49.77 | 0.98 | 75208.8 | 13662.29 | 76738.94 | -6712299 | -1513642 | 24890052 |
| 11/28/2017 | 9:47:38 | 250.12 | 106.4 | 50.11 | 0.981 | 78408.5 | 14424.32 | 79955.88 | -6706059.5 | -1512460 | 24896430 |
| 11/28/2017 | 9:52:38 | 250.74 | 105.13 | 50.14 | 0.984 | 77948.6 | 13130.81 | 79204.25 | -6699628 | -1511395 | 24902928 |
| 11/28/2017 | 9:57:38 | 249.84 | 105.51 | 50.01 | 0.986 | 78453.3 | 11692.5 | 79222.16 | -6693008.5 | -1510309 | 24909660 |
| 11/28/2017 | 10:02:38 | 249.97 | 109.28 | 50.06 | 0.983 | 80763.2 | 13747.72 | 82081.52 | -6686426 | -1509167 | 24916352 |
| 11/28/2017 | 10:07:38 | 249.52 | 111.62 | 50.06 | 0.983 | 82298.4 | 14696.78 | 83680.72 | -6679360 | -1507878 | 24923504 |
| 11/28/2017 | 10:12:38 | 249.89 | 98.95 | 50.04 | 0.981 | 72929.7 | 13480.06 | 74297.28 | -6673075.5 | -1506731 | 24929904 |
| 11/28/2017 | 10:17:38 | 249.91 | 97.68 | 50.08 | 0.98 | 71915.8 | 13777.32 | 73349.28 | -6667106.5 | -1505604 | 24935976 |
| 11/28/2017 | 10:22:38 | 249.33 | 102.9 | 50.04 | 0.983 | 75778.1 | 13116.41 | 77085.64 | -6661006 | -1504489 | 24942200 |
| 11/28/2017 | 10:27:38 | 249.82 | 95.54 | 50.12 | 0.981 | 70221.9 | 12786.19 | 71705.31 | -6654803 | -1503335 | 24948534 |

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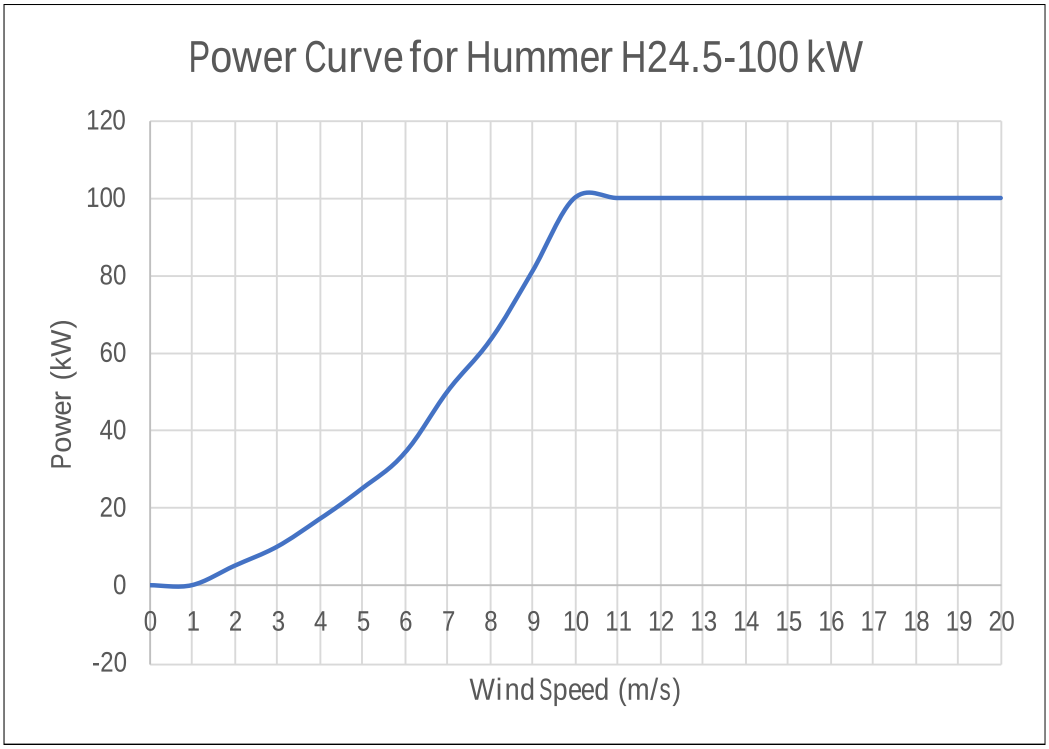
| 11/28/2017 | 10:32:38 | 250.16 | 102.18 | 50.17 | 0.982 | 75416.1 | 13569.82 | 76809.94 | -6648666 | -1502200 | 24954780 |
| 11/28/2017 | 10:37:38 | 249.24 | 121.34 | 50.19 | 0.97 | 87969.8 | 15653.2 | 90825.28 | -6642464 | -1501088 | 24961088 |
| 11/28/2017 | 10:42:38 | 249.55 | 112.06 | 50.18 | 0.984 | 82762.1 | 13585.02 | 84026.78 | -6636236 | -1499992 | 24967388 |
| 11/28/2017 | 10:47:38 | 249.51 | 113.06 | 50.08 | 0.979 | 83016.7 | 15589.84 | 84753.45 | -6629458 | -1498832 | 24974236 |
| 11/28/2017 | 10:52:38 | 249.91 | 115.58 | 50.15 | 0.985 | 85581.2 | 12362.7 | 86786.35 | -6622655 | -1497646 | 24981134 |
| 11/28/2017 | 10:57:38 | 249.52 | 100.03 | 50.09 | 0.983 | 73710.7 | 12266.06 | 74995.17 | -6615983 | -1496594 | 24987928 |
| 11/28/2017 | 11:02:37 | 248.93 | 107.2 | 50 | 0.985 | 78981.7 | 12220.79 | 80175.92 | -6609286 | -1495467 | 24994772 |
| 11/28/2017 | 11:07:38 | 248.79 | 106.87 | 50.06 | 0.978 | 78125.8 | 15800.23 | 79885.52 | -6602905 | -1494317 | 25001272 |
| 11/28/2017 | 11:12:38 | 249.14 | 98.08 | 50.05 | 0.981 | 72101.3 | 13342.79 | 73427.33 | -6596625 | -1493131 | 25007644 |
| 11/28/2017 | 11:17:38 | 248.94 | 100.16 | 50.18 | 0.983 | 73644.2 | 12509.73 | 74915.21 | -6590640 | -1492102 | 25013684 |
| 11/28/2017 | 11:22:38 | 249.16 | 121.4 | 50.12 | 0.99 | 89924.6 | 11627.55 | 90883.48 | -6584235 | -1490991 | 25020170 |
| 11/28/2017 | 11:27:38 | 249.44 | 104.39 | 50.21 | 0.982 | 76814.4 | 12909.7 | 78234.5 | -6576844 | -1489844 | 25027724 |
| 11/28/2017 | 11:32:37 | 248.1 | 111.36 | 49.94 | 0.988 | 81990.1 | 11892.81 | 83001.38 | -6570302.5 | -1488635 | 25034438 |
| 11/28/2017 | 11:37:38 | 249.23 | 103.7 | 50.09 | 0.982 | 76324.4 | 13186 | 77656.88 | -6563810 | -1487566 | 25041020 |
| 11/28/2017 | 11:42:38 | 249.45 | 116.8 | 50.2 | 0.986 | 86213.8 | 14212.18 | 87521.34 | -6557090 | -1486550 | 25047778 |
| 11/28/2017 | 11:47:37 | 249.37 | 118.57 | 50.26 | 0.981 | 85802.5 | 13357.99 | 88819.25 | -6550489 | -1485480 | 25054476 |
| 11/28/2017 | 11:52:38 | 249.39 | 102.67 | 50.11 | 0.977 | 75118.6 | 15566.96 | 76931.48 | -6544287.5 | -1484216 | 25060776 |
| 11/28/2017 | 11:57:38 | 249.27 | 95.64 | 50.02 | 0.981 | 70208.5 | 13071.77 | 71630.47 | -6538312 | -1483048 | 25066850 |
| 11/28/2017 | 12:02:37 | 249.59 | 100.58 | 50 | 0.968 | 73811.8 | 21572.32 | 75434.63 | -6532319 | -1481877 | 25072976 |
| 11/28/2017 | 12:07:38 | 249.28 | 108.87 | 50 | 0.975 | 79495.3 | 17634.83 | 81543.55 | -6525919 | -1480590 | 25079528 |
| 11/28/2017 | 12:12:37 | 248.62 | 111.32 | 50 | 0.984 | 81859.6 | 13512.38 | 83169.61 | -6519420 | -1479391 | 25086158 |
| 11/28/2017 | 12:17:37 | 248.61 | 103.98 | 49.91 | 0.984 | 76443.4 | 12237.11 | 77672.87 | -6512827 | -1478290 | 25092838 |
| 11/28/2017 | 12:22:38 | 249.22 | 90.33 | 49.98 | 0.984 | 66501.5 | 11173.82 | 67635.05 | -6506495.5 | -1477179 | 25099258 |
| 11/28/2017 | 12:27:37 | 248.95 | 96.48 | 49.94 | 0.98 | 70620.4 | 13479.42 | 72153.73 | -6500421 | -1475956 | 25105440 |
| 11/28/2017 | 12:32:37 | 248.44 | 98.33 | 49.94 | 0.976 | 71782.1 | 13289.52 | 73406.22 | -6494402.5 | -1474750 | 25111556 |
| 11/28/2017 | 12:37:38 | 249.64 | 99.76 | 50.07 | 0.979 | 73285.3 | 14665.74 | 74835.26 | -6488453 | -1473634 | 25117648 |
| 11/28/2017 | 12:42:37 | 249.32 | 108.19 | 50.04 | 0.982 | 79669.9 | 14158.74 | 81056.13 | -6482157.5 | -1472537 | 25124040 |
| 11/28/2017 | 12:47:38 | 248.66 | 111.96 | 50.01 | 0.982 | 82113.5 | 14449.12 | 83654.49 | -6475647 | -1471404 | 25130636 |
| 11/28/2017 | 12:52:38 | 249.53 | 103.22 | 50.08 | 0.983 | 76112.1 | 13114.81 | 77388.21 | -6468958 | -1470192 | 25137444 |
| 11/28/2017 | 12:57:37 | 250.05 | 114.82 | 50.07 | 0.987 | 85109.1 | 13269.84 | 86256.7 | -6462261 | -1469126 | 25144200 |
| 11/28/2017 | 13:02:38 | 250 | 101.29 | 50.09 | 0.979 | 74504.6 | 14893.41 | 76091.59 | -6455527 | -1468048 | 25151028 |
| 11/28/2017 | 13:07:38 | 249.78 | 104.41 | 50.07 | 0.976 | 76481.2 | 16338.11 | 78357.31 | -6449453 | -1466855 | 25157222 |
| 11/28/2017 | 13:12:37 | 249.76 | 96.63 | 50.06 | 0.982 | 71191 | 13171.76 | 72514.51 | -6443467 | -1465734 | 25163328 |
| 11/28/2017 | 13:17:38 | 250.07 | 108.2 | 50.17 | 0.982 | 79206.8 | 17176.46 | 81288.33 | -6437639 | -1464703 | 25169254 |
| 11/28/2017 | 13:22:38 | 250.25 | 93.35 | 50.11 | 0.985 | 69108.2 | 10863.76 | 70185.44 | -6431675.5 | -1463637 | 25175304 |
| 11/28/2017 | 13:27:37 | 250.55 | 96.09 | 50.18 | 0.981 | 70854.5 | 13158.96 | 72322.6 | -6425595 | -1462436 | 25181466 |
| 11/28/2017 | 13:32:38 | 249.37 | 103.72 | 49.98 | 0.982 | 76341.1 | 13743.57 | 77718.28 | -6419433 | -1461239 | 25187704 |
| 11/28/2017 | 13:37:38 | 249.34 | 103.25 | 50.04 | 0.982 | 76053.2 | 13392.23 | 77357.5 | -6412787 | -1460116 | 25194446 |
| 11/28/2017 | 13:42:37 | 249.02 | 115.6 | 50.1 | 0.987 | 85290.8 | 13327.27 | 86469.72 | -6406040 | -1459022 | 25201308 |
| 11/28/2017 | 13:47:38 | 248.47 | 119.05 | 49.91 | 0.985 | 87406.2 | 14705.58 | 88836.52 | -6398739 | -1457802 | 25208708 |
| 11/28/2017 | 13:52:38 | 248.4 | 115.21 | 49.95 | 0.984 | 84672.2 | 13604.21 | 85991.23 | -6391269 | -1456502 | 25216252 |
| 11/28/2017 | 13:57:37 | 249.34 | 95.26 | 50.1 | 0.984 | 70106.1 | 12105.27 | 71363.72 | -6384680 | -1455359 | 25222896 |
| 11/28/2017 | 14:02:38 | 249.98 | 112.38 | 50.22 | 0.979 | 82729.5 | 15274.5 | 84412.52 | -6378275 | -1454206 | 25229368 |
| 11/28/2017 | 14:07:37 | 249.59 | 104.81 | 50.07 | 0.982 | 77213.6 | 13581.66 | 78601.67 | -6371735 | -1452997 | 25236038 |
| 11/28/2017 | 14:12:37 | 250.6 | 104.59 | 50.17 | 0.982 | 77370.3 | 13617.81 | 78755.84 | -6365490 | -1451886 | 25242378 |
| 11/28/2017 | 14:17:38 | 249.87 | 104.57 | 50.13 | 0.985 | 77179 | 12661.4 | 78459.67 | -6358945 | -1450779 | 25249030 |
| 11/28/2017 | 14:22:37 | 249.79 | 96.43 | 50.08 | 0.98 | 70862.2 | 13394.95 | 72361.63 | -6352235 | -1449533 | 25255868 |
| 11/28/2017 | 14:27:37 | 249.76 | 97.09 | 50.04 | 0.984 | 71721.3 | 11674.26 | 72865.05 | -6346050 | -1448354 | 25262114 |
| 11/28/2017 | 14:32:38 | 249.45 | 105.81 | 50.09 | 0.982 | 77957.5 | 13823.72 | 79311.08 | -6339528 | -1447218 | 25268676 |
| 11/28/2017 | 14:37:37 | 249.45 | 105.72 | 50.05 | 0.982 | 77882 | 13863.72 | 79241.99 | -6333116 | -1446107 | 25275128 |
| 11/28/2017 | 14:42:37 | 249.93 | 105.01 | 50.07 | 0.978 | 76813.8 | 17135.5 | 78859.47 | -6326476 | -1444898 | 25281828 |
| 11/28/2017 | 14:47:38 | 249.43 | 106.36 | 49.98 | 0.983 | 78309.3 | 14036.51 | 79723.67 | -6319761 | -1443732 | 25288630 |
| 11/28/2017 | 14:52:37 | 250.08 | 93.72 | 50.1 | 0.984 | 69183.7 | 11739.86 | 70418.92 | -6313357.5 | -1442599 | 25295160 |
| 11/28/2017 | 14:57:37 | 249.62 | 100.94 | 50.07 | 0.977 | 73953.8 | 15003.32 | 75698.82 | -6307257 | -1441362 | 25301396 |
| 11/28/2017 | 15:02:38 | 249.15 | 95.91 | 50.05 | 0.98 | 70394.6 | 13553.34 | 71803.83 | -6300918.5 | -1440019 | 25307860 |
| 11/28/2017 | 15:07:37 | 249.18 | 99.82 | 49.99 | 0.978 | 73119 | 14924.77 | 74736.75 | -6294924.5 | -1438879 | 25313964 |
| 11/28/2017 | 15:12:37 | 250.13 | 110.64 | 50.15 | 0.981 | 81607.5 | 15274.66 | 83143.39 | -6288764 | -1437691 | 25320204 |
| 11/28/2017 | 15:17:38 | 249.66 | 112.72 | 50.18 | 0.983 | 83056.4 | 14730.06 | 84525.09 | -6281891 | -1436458 | 25327254 |
| 11/28/2017 | 15:22:37 | 249.44 | 98.94 | 50.02 | 0.982 | 72834.3 | 13201.68 | 74157.2 | -6275429 | -1435246 | 25333860 |
| 11/28/2017 | 15:27:37 | 249.49 | 100.27 | 50.1 | 0.984 | 73901.3 | 12542.85 | 75167.25 | -6269324 | -1434134 | 25340072 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11/28/2017 | 15:32:37 | 248.71 | 102.44 | 50.03 | 0.979 | 74960 | 14646.54 | 76545.75 | -6263271 | -1433048 | 25346216 |
| 11/28/2017 | 15:37:37 | 249.02 | 102.87 | 50 | 0.976 | 75120.6 | 15848.39 | 76962.82 | -6256972.5 | -1431811 | 25352614 |
| 11/28/2017 | 15:42:37 | 249.38 | 98.3 | 49.99 | 0.98 | 72174.8 | 13990.91 | 73659.53 | -6250853 | -1430644 | 25358846 |
| 11/28/2017 | 15:47:37 | 249.19 | 103.87 | 50.05 | 0.984 | 76552.8 | 12679.48 | 77779.69 | -6244662 | -1429502 | 25365156 |
| 11/28/2017 | 15:52:37 | 249.55 | 110.11 | 49.99 | 0.98 | 80918 | 15032.12 | 82563.2 | -6238051 | -1428321 | 25371920 |
| 11/28/2017 | 15:57:37 | 249.88 | 101.97 | 50.09 | 0.978 | 74851.9 | 15018.36 | 76555.98 | -6231361 | -1427024 | 25378744 |
| 11/28/2017 | 16:02:37 | 249.58 | 101.03 | 50.02 | 0.978 | 74101.6 | 15101.08 | 75768.55 | -6225286.5 | -1425843 | 25384944 |
| 11/28/2017 | 16:07:37 | 249.13 | 109.86 | 49.99 | 0.983 | 80839.9 | 14733.58 | 82228.02 | -6218759 | -1424721 | 25391540 |
| 11/28/2017 | 16:12:38 | 249.49 | 101.63 | 49.93 | 0.975 | 74289.6 | 15945.18 | 76180.5 | -6212632.5 | -1423545 | 25397798 |
| 11/28/2017 | 16:17:37 | 248.77 | 97.17 | 49.97 | 0.982 | 71361.2 | 12820.27 | 72633.48 | -6206392 | -1422268 | 25404186 |
| 11/28/2017 | 16:22:37 | 248.69 | 95.59 | 49.87 | 0.981 | 70070.9 | 13170.64 | 71434.73 | -6200397 | -1421083 | 25410312 |
| 11/28/2017 | 16:27:37 | 252.5 | 92.52 | 49.95 | 0.98 | 68785.2 | 13400.39 | 70191.84 | -6194351.5 | -1419840 | 25416474 |
| 11/28/2017 | 16:32:37 | 249.82 | 109.17 | 50.08 | 0.977 | 79981.5 | 17362.37 | 81936.31 | -6188140 | -1418563 | 25422816 |
| 11/28/2017 | 16:37:37 | 249.47 | 108.98 | 50.05 | 0.979 | 80119 | 15457.53 | 81701.55 | -6181771.5 | -1417268 | 25429314 |
| 11/28/2017 | 16:42:37 | 249.75 | 113.1 | 50.06 | 0.981 | 83321.2 | 15556.41 | 84858.37 | -6175144.5 | -1416075 | 25436122 |
| 11/28/2017 | 16:47:37 | 249.29 | 118.57 | 50.03 | 0.986 | 87628.2 | 14051.87 | 88816.05 | -6168586.5 | -1414866 | 25442832 |
| 11/28/2017 | 16:52:37 | 249.95 | 114.91 | 50.06 | 0.983 | 84721.5 | 15459.29 | 86270.77 | -6161363 | -1413567 | 25450242 |
| 11/28/2017 | 16:57:37 | 250.85 | 96.94 | 50.2 | 0.98 | 71568.4 | 13542.62 | 73060.79 | -6154699 | -1412212 | 25457074 |
| 11/28/2017 | 17:02:37 | 251.32 | 96.5 | 50.05 | 0.982 | 71568.4 | 13976.51 | 72862.49 | -6148078.5 | -1410967 | 25463796 |
| 11/28/2017 | 17:07:37 | 252.01 | 99.37 | 50.14 | 0.977 | 73438.2 | 15605.68 | 75245.92 | -6141935.5 | -1409748 | 25470030 |
| 11/28/2017 | 17:12:37 | 252.66 | 106.47 | 50.22 | 0.972 | 78615.8 | 17983.44 | 80828.4 | -6135635 | -1408376 | 25476542 |
| 11/28/2017 | 17:17:37 | 252.28 | 118.35 | 50.16 | 0.981 | 88046.5 | 14655.19 | 89693.05 | -6128994 | -1407052 | 25483336 |
| 11/28/2017 | 17:22:37 | 249.18 | 118.56 | 50.13 | 0.986 | 87586 | 13868.2 | 88754 | -6121766 | -1405796 | 25490642 |
| 11/28/2017 | 17:27:37 | 248.8 | 105.64 | 50.14 | 0.984 | 77718.3 | 12874.34 | 78972.69 | -6115032 | -1404605 | 25497490 |
| 11/28/2017 | 17:32:37 | 248.71 | 106.69 | 50.08 | 0.982 | 78180.1 | 14804.78 | 79721.75 | -6108296 | -1403312 | 25504316 |
| 11/28/2017 | 17:37:37 | 249.35 | 107.3 | 50.26 | 0.982 | 79003.4 | 13723.73 | 80388.3 | -6101852 | -1402207 | 25510858 |
| 11/28/2017 | 17:42:37 | 248.44 | 104.3 | 49.95 | 0.985 | 76670.5 | 12548.93 | 77859.02 | -6095487 | -1401102 | 25517256 |
| 11/28/2017 | 17:50:36 | 250.75 | 87.9 | 49.91 | 0.99 | 65595.8 | 7361.59 | 66216.88 | -6088366 | -1399699 | 25524562 |
| 11/28/2017 | 17:55:36 | 248.74 | 115.83 | 49.83 | 0.987 | 85389.9 | 13266.48 | 86535.59 | -6081544 | -1398743 | 25531468 |
| 11/28/2017 | 18:00:36 | 249.43 | 97.34 | 50.01 | 0.989 | 72179.3 | 8999.24 | 72955.24 | -6074964.5 | -1397800 | 25538194 |
| 11/28/2017 | 18:05:36 | 249.05 | 99.59 | 49.99 | 0.988 | 73685.1 | 9530.89 | 74526.93 | -6069053 | -1396912 | 25544248 |
| 11/28/2017 | 18:10:36 | 248.41 | 98.21 | 50.07 | 0.971 | 71962.5 | 19144.49 | 73293.63 | -6062720 | -1395924 | 25550688 |
| 11/28/2017 | 18:15:36 | 248.48 | 101.24 | 50.15 | 0.982 | 74152.1 | 13613.65 | 75580.48 | -6056593.5 | -1394790 | 25556954 |
| 11/28/2017 | 18:20:36 | 247.8 | 108.74 | 50.12 | 0.976 | 78968.2 | 17008.63 | 80958.25 | -6050262 | -1393562 | 25563430 |
| 11/28/2017 | 18:25:36 | 245.87 | 107.48 | 49.88 | 0.957 | 75801.8 | 20869.17 | 79380.16 | -6044187 | -1392407 | 25569620 |
| 11/28/2017 | 18:30:36 | 246.53 | 109.13 | 49.77 | 0.977 | 79128.1 | 15950.3 | 80852.7 | -6037723 | -1391008 | 25576228 |
| 11/28/2017 | 18:35:36 | 246.09 | 114.76 | 50.19 | 0.983 | 83350 | 13538.46 | 84843.02 | -6031035.5 | -1389657 | 25583096 |
| 11/28/2017 | 18:40:36 | 243.98 | 128.32 | 50.08 | 0.982 | 92359.2 | 15181.87 | 94005.11 | -6023542 | -1388344 | 25590762 |
| 11/28/2017 | 18:45:36 | 246.71 | 113.13 | 49.86 | 0.973 | 81308.2 | 18682.44 | 83843.2 | -6016086.5 | -1386835 | 25598430 |
| 11/28/2017 | 18:50:36 | 250.09 | 115.28 | 49.92 | 0.967 | 83623.8 | 21202.91 | 86605.33 | -6009281.5 | -1385199 | 25605480 |
| 11/28/2017 | 18:55:37 | 249.81 | 130.97 | 49.79 | 0.975 | 95616.5 | 21187.71 | 98266.02 | -6001965 | -1383507 | 25613018 |
| 11/28/2017 | 19:00:36 | 249.95 | 132.37 | 49.9 | 0.975 | 96772.4 | 21362.9 | 99376.49 | -5994027.5 | -1381709 | 25621196 |
| 11/28/2017 | 19:05:36 | 248.7 | 118.55 | 49.94 | 0.966 | 85277.4 | 22163.64 | 88554.42 | -5986745.5 | -1379946 | 25628734 |
| 11/28/2017 | 19:10:36 | 250.49 | 114.91 | 50.13 | 0.965 | 83344.2 | 21593.92 | 86467.8 | -5979681.5 | -1378120 | 25636060 |
| 11/28/2017 | 19:15:36 | 247.19 | 117.95 | 50.13 | 0.971 | 82235.7 | 18637.16 | 87357.59 | -5972899 | -1376493 | 25643056 |
| 11/28/2017 | 19:20:36 | 247.63 | 112.41 | 50.03 | 0.971 | 81093.2 | 18698.28 | 83614.19 | -5966099 | -1374978 | 25650068 |
| 11/28/2017 | 19:25:36 | 248.37 | 117.99 | 50.17 | 0.968 | 85841.6 | 17806.66 | 87974.88 | -5959193 | -1373401 | 25657140 |
| 11/28/2017 | 19:30:36 | 248.3 | 113.48 | 50.13 | 0.969 | 81676.6 | 19579.18 | 84603.13 | -5951902 | -1371766 | 25664656 |
| 11/28/2017 | 19:35:36 | 246.02 | 123.85 | 50.24 | 0.976 | 89167.9 | 19216.48 | 91498.22 | -5944543 | -1370023 | 25672292 |
| 11/28/2017 | 19:40:36 | 245.89 | 115.42 | 50.04 | 0.97 | 82608 | 19497.1 | 85258.8 | -5937697.5 | -1368507 | 25679282 |
| 11/28/2017 | 19:45:36 | 245.63 | 111.05 | 49.93 | 0.973 | 79540.7 | 17307.65 | 81933.13 | -5930957 | -1366973 | 25686178 |
| 11/28/2017 | 19:50:36 | 246.31 | 115.05 | 50.11 | 0.975 | 82768.5 | 17793.06 | 85112.31 | -5924033 | -1365436 | 25693296 |
| 11/28/2017 | 19:55:36 | 245.95 | 115.39 | 49.97 | 0.969 | 82502.4 | 19756.13 | 85250.48 | -5917212.5 | -1363863 | 25700284 |
| 11/28/2017 | 20:00:36 | 246.3 | 117.97 | 50.06 | 0.968 | 84353 | 20613.35 | 87279.55 | -5910301 | -1362221 | 25707432 |
| 11/28/2017 | 20:05:36 | 247.28 | 115.55 | 50.12 | 0.969 | 83149.8 | 19612.3 | 85840.27 | -5903422 | -1360607 | 25714520 |
| 11/28/2017 | 20:10:36 | 247.26 | 114.28 | 50.16 | 0.97 | 82293.9 | 19044.01 | 84885.23 | -5896652 | -1359005 | 25721464 |
| 11/28/2017 | 20:15:36 | 246.17 | 119.36 | 50 | 0.978 | 86139 | 17799.94 | 88231.39 | -5889518 | -1357451 | 25728790 |
| 11/28/2017 | 20:20:36 | 246.49 | 127.61 | 50.04 | 0.977 | 92324.1 | 18732.83 | 94488.71 | -5881950 | -1355917 | 25736580 |
| 11/28/2017 | 20:25:36 | 246.68 | 128.93 | 49.97 | 0.976 | 93269.5 | 19093.93 | 95510.28 | -5874380.5 | -1354378 | 25744366 |
| 11/28/2017 | 20:30:36 | 247.12 | 117.62 | 50.05 | 0.979 | 85323.4 | 16823.84 | 87282.74 | -5866559.5 | -1352749 | 25752412 |

**Appendix II: Hummer H24.5- (100 kW) Data sheet and Power Curve**

| Data sheet for Hummer H24.5-P100 | |
|---|---|
| | |
| Rotor Diameter (m) | 25 |
| Blade Length (m) | 12 |
| Swept Area ($m^2$) | 490.27 |
| Rated Power (kW)@11 m/s | 100 |
| Cut-in Wind Speed (m/s) | 2.5 |
| Rated Rotary Rate (revs/min) | 45 |
| Working Wind Speed (m/s) | (3-25) |
| Survival Wind Speed (m/s) | 60 |
| Hub Height (m) | 30 |
| Generator Efficiency | >0.93 |
| Insulation class | F-class |
| Wind Energy Utilization Ratio | 0.45 |
| Configuration | 3 Blades, Horizontal axis, Upwind |


Power Curve for Hummer H24.5-100 kW
Power (kW)
120
100
80
60
40
20
0
-20
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Wind Speed (m/s)

**Appendix III: Data sheet for Canadian MaxPower**

| Electrical Data \| STC* | |
|---|---|
| Nominal Max. Power (Pmax) | 325 W |
| Operating Voltage (Vmp) | 37.0 V |
| Operating Current (Imp) | 8.78 A |
| Open Circuit Voltage (Voc) | 45.5 V |
| Short Circuit Current (Isc) | 9.34 A |
| Module Efficiency | 16.94 % |
| Operating Temperature | -40 ℃ - +85℃ |
| Max. System Voltage | 1000 V (IEC) |
| Power Tolerance | 0 - +5 W |
| *Under Standard Test Condition (STC) of Irradiance of 1000 W/m$^2$, Spectrum AM 1.5 and cell Temperature of 25 ℃. | |
| Electrical Data\|NOCT* | |
| Nominal Max. Power (Pmax) | 236 W |
| Operating Voltage (Vmp) | 33.7 V |
| Operating Current (Imp) | 6.98 A |
| Open Circuit Voltage (Voc) | 41.8 V |
| Short Circuit Current (Isc) | 7.57 A |
| *Under Nominal Operating Cell Temperature (NOCT), Irradiance of 800 W/m$^2$, spectrum AM 1.5, ambient Temperature 20℃, wind speed 1 m/s | |
| Temperature Characteristics | |
| Temp. Coefficient (Pmax) | -0.41 % / ℃ |
| Temp. Coefficient (Voc) | -0.31 % / ℃ |
| Temp. Coefficient ( Isc) | 0.053 % / ℃ |
| Nominal operating Cell Temperature | 45 ± 2 ℃ |

## Appendix IV: Solar Water Heating System Specifications

| External Dimensions for Megasun SWH models | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Storage Tank | | | Collector | | | | | Support E | Total Weight | |
| Megasun Model | Dimensions (mm) | Weight (kg) | Test Pressure (Bars) | Dimensions (mm) | No of Collectors | Area (m2) | Weight (kg) | Test Pressure (Bars) | Weight (kg) | Empty (kg) | Full (kg) |
| 120 | 530*1100 | 52 | 10 | 2050*1010*90 | 1 | 2.1 | 43 | 10 | 26 | 121 | 231 |
| 160M | 530*1320 | 62 | 10 | 2050*1010*90 | 1 | 2.1 | 43 | 10 | 26 | 131 | 281 |
| 160 | 570*1320 | 62 | 10 | 2050*1275*90 | 1 | 2.6 | 51 | 10 | 27 | 140 | 290 |
| 200 | 570*1320 | 70 | 10 | 2050*1275*90 | 1 | 2.6 | 51 | 10 | 27 | 148 | 338 |
| 200E | 530*1320 | 70 | 10 | 2050*1010*90 | 2 | 4.2 | 43 | 10 | 28 | 184 | 376 |
| 260 | 530*2050 | 103 | 10 | 2050*1010*90 | 2 | 4.2 | 43 | 10 | 30 | 219 | 469 |
| 300 | 570*2050 | 114 | 10 | 2050*1010*90 | 2 | 4.2 | 43 | 10 | 30 | 230 | 520 |
| 300E | 570*2050 | 114 | 10 | 2050*1275*90 | 2 | 5.2 | 51 | 10 | 30 | 246 | 536 |

## Appendix V: ERC Hot water demand guidelines

| ***Type of Building Premises*** | ***Specific Daily Hot Water Demand (DHWD) in litres per day at $60^{o}C$*** |
|---|---|
| Domestic residential houses | 30 per person |
| Educational institutions such as colleges and boarding schools | 5 per student |
| Health institutions such as Hospitals, Health Centres, clinics and similar medical facilities | 50 per bed |
| Hotels, Hostels, Lodges and similar premises providing boarding services | 40 per bed |
| Restaurants, Cafeterias and similar eating places | 5 per meal |
| Laundries | 5 per kilo of clothes |

Further;

i. All premises shall have a minimum annual solar contribution of 60% to the premises' hot water demand. This means that 40 % can come from other sources even if not from renewable sources. Normal practice is however to size for a 100% because of economics of installation and operation

ii. Hot Water Demand calculations at other temperatures (T) shall be adjusted for the $60^{o}C$ reference temperature. For the purposes of making the adjustment, the following equation shall be used:

$$D\,(T) = D\,(T_{60})\ x\ (T-15)/45$$

*The equation assumes that the cold water temperature (inlet water temperature) is $15^{o}C$ and a linear relationship. $45^{o}C$ is the difference between $60^{o}C$ and $15^{o}C$*

iii. For buildings with seasonal variations in hot water demand such as hotels, game lodges and similar premises, the demand may be adjusted by an annual occupancy rate of factor of not less than 70%

iv. In calculating demand, it shall be assumed that the daily hot water demand is constant, throughout the year

v. In calculating demand for domestic residential houses, the number of persons shall be taken to be equal to the number of bedrooms x 1.5

vi. In calculating the heat load of solar water heating system, heat losses in the hot water distribution system shall be taken into account.

## Appendix VI: SWH Calculations Baseline

| | | |
|---|---|---|
| Hot water demand at EASA | | |
| | Parameter | |
| Hostels (No of Beds) | 303 | |
| Estate | | |
| 3-bedroom units (No of bedrooms) | 174 | |
| 2 bedroom units (No of bedrooms) | 52 | |
| Hot water outlet temperature(Degrees Celsius) | 60 | |
| Water inlet temperature(Degrees Celsius) | 20 | |
| Specific heat capacity of water (KJ/KgK) | 4.2 | |
| Unit cost of Energy (USD/kWh) | 0.16 | |
| No of days of operation | 365 | |
| Storage tank replacement cost (USD) | 49,739.66 | |
| | | |
| 1. Hot water demand in the hostels | | |
| No of beds | Hot water demand(L) | Hot water demand(kWh) |
| 303 | 6060 | 282.8 |
| 2. Hot water demand in the Estate | | |
| No of bedrooms | Hot water demand(L) | Hot water demand(kWh) |
| 226 | 6780 | 316.4 |
| Total demand | 12840 | 599.2 |

**Appendix VII: SWH Cash flows & NPC calculations**

| Cash flows, NPC | Amount (USD) |
|---|---|
| Year 0 | (139,993) |
| Year 1 | (1,400) |
| Year 2 | (1,400) |
| Year 3 | (1,400) |
| Year 4 | (1,400) |
| Year 5 | (1,400) |
| Year 6 | (1,400) |
| Year 7 | (1,400) |
| Year 8 | (1,400) |
| Year 9 | (1,400) |
| Year 10 | (51,140) |
| Year 11 | (1,400) |
| Year 12 | (1,400) |
| Year 13 | (1,400) |
| Year 14 | (1,400) |
| Year 15 | (1,400) |
| Year 16 | (1,400) |
| Year 17 | (1,400) |
| Year 18 | (1,400) |
| Year 19 | (1,400) |
| Year 20 | (51,140) |
| Year 21 | (1,400) |
| Year 22 | (1,400) |
| Year 23 | (1,400) |
| Year 24 | (1,400) |
| Year 25 | 23,470 |
| Assumed real discount rate | 7.84% |
| NPC (USD) | -185750.81 |

**Appendix VIII: Power Usage Research Questionnaire for EASA.**

| Research Question | Answer/ Remark |
|---|---|
| What is the institution's total population? (Both staff and students) | |
| What are the identified power intensive devices used within the institution? | |
| What time of day are such devices used? | |
| How many housing units are there in the estate department? | |
| How many bedrooms does each unit have? | |
| What is the average number of persons resident in each estate unit? | |
| What is the bed capacity of the institutions' hostels? | |
| Is each bathroom fitted with an instant water heater shower? | |
| If yes, what is the power rating of the heaters? | |
| What is the main source of fuel for cooking of food? | |
| Are alternative sources of heat energy e.g. firewood, gas and/solar water heating used? | |
| How much electricity does the institution use per month/year in kWh? | |
| How much fuel is spent on running the backup generators during blackouts per month/year? | |