UNIVERSITY OF NAIROBI

ENERGY SOLUTION FOR WANANCHI GROUP LTD

ZUKU

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Research project submitted to the department of mechanical engineering, school of engineering in partial fulfilment of the requirements for the award of the masters of Science in energy management of the University of Nairobi

10th MAY 2017

DECLARATION

I hereby declare that this research project is my original work and has not been presented for award of any degree in any other University

Signature: ………………………….……. Date……………………………

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This project has been submitted for examination with our approval as the supervisors of the student and Lecturers at the University of Nairobi.

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ABSTRACT

Power supply is one of the critical challenges confronted by telecommunications operators in deploying their networks. This challenge is readily overcome in developed countries as a result of up-to-date power infrastructure. In the developing world, where a national electricity grid is unreliable, providing dedicated, reliable low-cost power supply for base station sites is very challenging.

This dissertation focuses on the development of a hybrid energy system for the base stations of Wananchi Group (k) Ltd (Zuku) in order to provide uninterrupted power supply to satisfy minimum requirements of Quality of Service (QoS), and reduce the increasing cost of energy per kWh. Various energy sources for telecommunications have been discussed in the report which have been categorised as off grid sites and on grid sites , that includes wind power, solar, fuel cells and a combination of either which the advantages and disadvantages of each source highlighted.

Real historical data was collected that included, monthly kplc meter readings and bills, generator operation and maintenance cost and monthly fuel consumption from the submitted delivery notes and invoices. Currently the problem of poor electricity supply experienced is being resolved by diesel generators. These generators, however, are associated with many problems, which include, among others, noise pollution emanating from the generators and environmental pollution. Diesel generator exhaust contains harmful hydrocarbons in the atmosphere during operations. Operation and maintenance is costly, and typically accounts for 32 percent of the total cost of ownership (TCO)

Hybridizing diesel with renewable energy sources (solar power) is one method of reducing operational cost and improving the service in terms of powering base station sites. This will allow Zuku to circumvent rising energy costs and receive an excellent Return on Investment (ROI), with a payback period of 1.8 years.

It will also make communications more accessible and reduce the environmental impact. A hybrid power system is therefore proposed to solve these aforementioned problems. PVstyt simulation software was used in the design, simulation, technical and financial analysis of the proposed energy solution

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LIST OF ACRONYMS AND ABBREVIATIONS

HFC - "Hybrid Fiber Coaxial

HOMER - Hybrid Optimization Model for Electric Renewables

Head End – Location where all the signals originate from (Data, Video & Voice)

Homes Passed – No. of Homes through which the network traverses

MDU – Multi Dwelling Unit

SDU/SFU – Single Dwelling/Family Unit

RGU – Revenue Generating Unit

Master Node – Device that serves 8 smaller distribution nodes with fiber covering 1,500-2,000 homes

Distribution Node – Device converting fiber to coax serving 150-200 homes

Tap – Device that serves up to 8 homes via coaxial cable

CPE – Customer Premise Equipment

STB – Set Top Box (aka Decoder) connects the coax cable to the TV

Cable Modem – Device that connects the coax cable to the computer

Isolation. The amount of solar radiation reaching a given area

Irradiance is a measurement of solar power and is defined as the rate at which solar energy falls onto a surface

Broadband is a wide bandwidth data transmission with an ability to simultaneously transport multiple signals and traffic types

pay TV television broadcasting in which viewers pay by subscription to watch a particular channel.

High definition. A high degree of detail in an image or screen

CHAPTER ONE

1.0 INTRODUCTION

Unreliable electrical grid supply is one of the biggest challenges faced by the rapidly growing telecommunication industry in Kenya and most of the developing world. Telecom operators currently use grid power, diesel generators and batteries to address the demand-supply gap. The resulting energy costs alone account for a bigger portion of the total network operating costs, affecting the profitability of the operators [1].

This chapter describes the background of the research problem (based on Wananchi Group-Zuku Network), the problem statement, research objectives, research questions and justification for the research.

1.1 Wananchi Group -Zuku

Wananchi Group, formerly Wananchi Online, was established in 2008 and was committed to servicing the emerging African mass consumer market through provision of high quality yet affordable home Internet services as well as the corporate communications market. Wananchi Group which has the brand name Zuku is an East African Brand established with the aim of making quality home entertainment and communication services accessible to a rapidly growing, choice conscious East African middle class.

1.2 Zuku Network Architecture

The Zuku brand currently offers its digital services on two platforms, namely Zuku fiber and Zuku satellite

1.2.1 Zuku Fiber

A cable network currently available only in Nairobi and Mombasa .This platform supports broadband, pay-tv and telephony services through a single cable into customers' homes.

The diagram in Fig. 1.1 represents the Zuku fiber network architecture

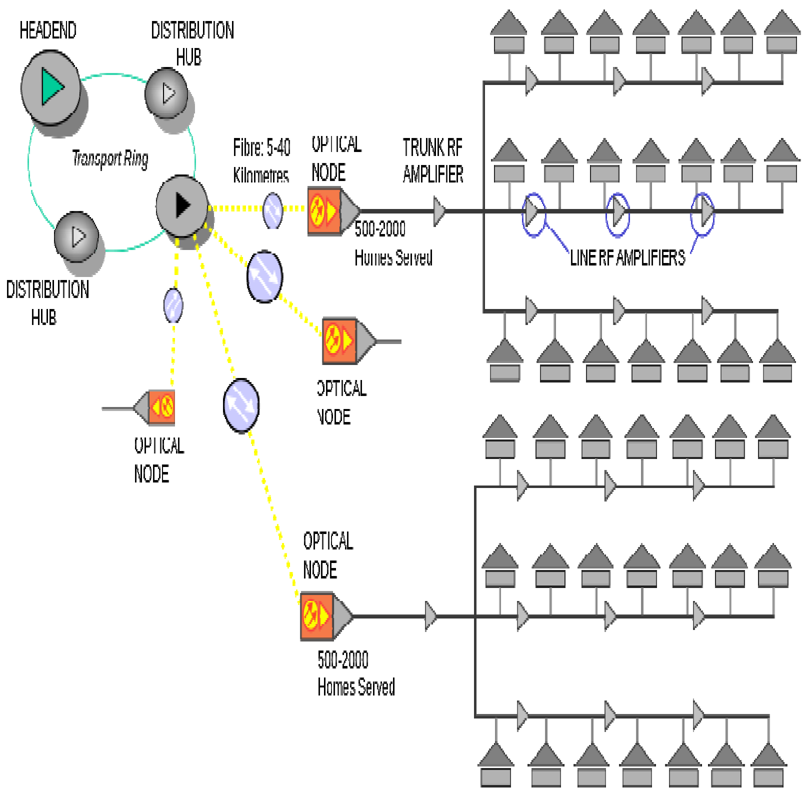

Figure 1.1 Zuku fiber network architecture

1.2.2 Zuku satellite TV

A satellite-based platform and the fastest growing platform gives Zuku's pay-TV service nationwide availability across the region. The platform has High Definition (HD) Channels which have increased the channel capacity and viewer experience for the subscribers. Such channels include Zuku Sports HD and Zuku Max HD. Satellite TV services are currently in Kenya, Uganda, Tanzania, Malawi and Zambia

The diagram below represents the Zuku satellite photo along Mombasa road Nairobi

Figure 1.2 Zuku satellite farm (dish farm)

1.3 Energy Challenges in Deployment of Zuku Services

Power supply is one of the critical challenges confronted by telecommunications operators in deploying their networks. This challenge is readily overcome in developed countries as a result of up-to-date power infrastructure [2]. In the developing world, where a national electricity grid exists, it is always the energy solution of choice for powering Base Transceiver Stations (BTSs). Unfortunately, it is not always reliable and has limited coverage. This is even more complicated in developing countries like Kenya [3]. Providing dedicated, reliable low-cost power supply for base station sites of Zuku is very challenging, as the electricity grid is not reliable. In order to provide uninterrupted power supply to satisfy minimum requirements of Quality of Service (QoS), Wananchi group (Zuku) reports that non-availability of regular grid power supply to sites across the country is responsible for increasing life cycle cost per kWh. The company is now exploring opportunities for hybrid energy solution.

Presently, the problem of poor electricity supply experienced is being resolved by diesel generators. These generators, however, are associated with many problems. These include, among others, noise pollution emanating from the generators and environmental pollution.

Diesel generator exhaust contains harmful hydrocarbons in the atmosphere during operations. Operation and maintenance is costly, and typically accounts for 35 percent of the total cost of ownership (TCO) [4]

Taking into consideration the excess cost of normal operation that the utilization of diesel generating sets brings to the operators, it is inevitable that consumers pay more for service.

Apart from high product cost that is blamed on high operational cost, poor service is also linked with use of diesel generating sets, due to down-times because of maintenance and breakdown thus, it is increasingly evident that diesel-powered stations are becoming a much less viable option for network operators. Hybridizing diesel with renewable energy sources (solar and/or wind power) is one method of reducing operational cost and improving the service in terms of powering base station sites. This will allow telecom companies to circumvent rising energy costs and receive an excellent Return on Investment (ROI) [7]. It will also make communications more accessible and reduce the environmental impact. A hybrid power system is therefore proposed to solve these aforementioned problems.

1.4 Statement of the Problem

Currently, Zuku meets is power requirements via utility supply, diesel generators and uninterruptible power supplies (UPS) as shown in figure 1.3

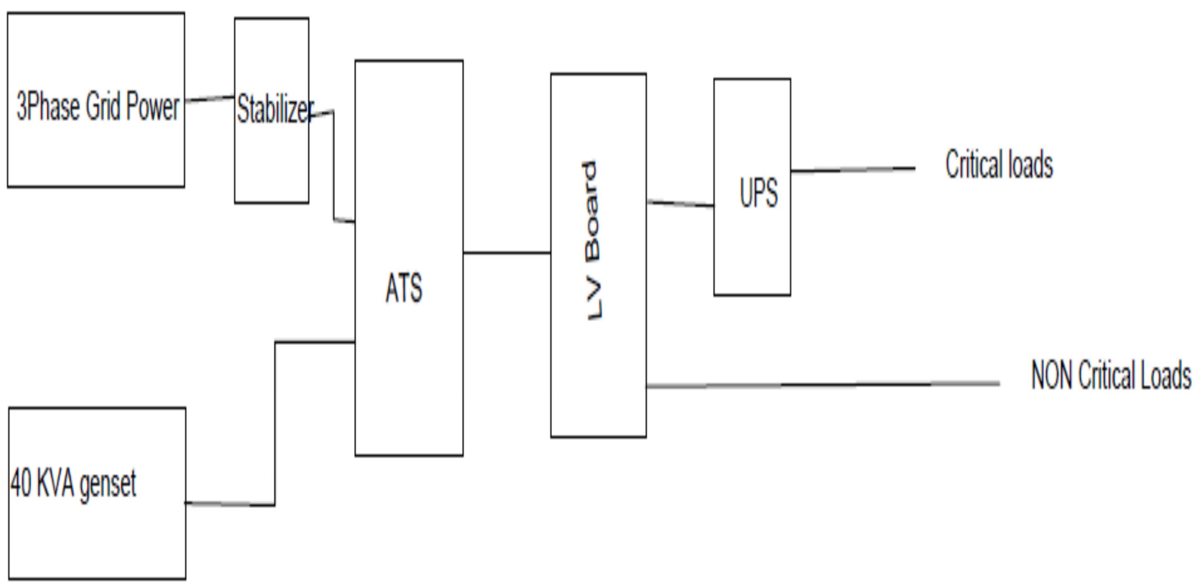

Fig 1.3 power setup for the zuku site

However, whenever there is an outage with utility power, the company depends on expensive diesel generator power. If the generator fails to run, UPSs are used which do not run for long, yet 24/7 power availability is needed for the equipment's to run.

The company spends considerable amounts of money on diesel fuel and maintenance of the diesel generators as shown in the table below

Table 1.1 Energy cost component for the existing solution

Energy cost components		
	Per month	Per year
Investment cost	1,484,500.00	148,450.00
KPLC bills (Ksh)	150,000.00	1,800,000.00
Fuel consumption	40,000.00	480,000.00
O&M (Ksh)		220,000.00
Total cost of ownership		**2,648,450.00**

Thus the need to incorporate a renewable energy source to provide affordable electrical power

The purpose of this research, therefore, is to develop a cost effective hybrid energy solution comprising of Grid power, diesel generator, solar and batteries as power sources for the telecom network of Zuku – that is, developing a cost-effective hybrid electrical power solution.

1.5 Research Objectives

The main research objective was to develop cost-effective hybrid energy solution that incorporates the grid, diesel, and a renewable energy source.

1.5.1 The specific objectives:

i. Determined the load characteristics of Zuku load (load curves)

ii. Designed a cost-effective hybrid power solution.

iii. Calculated the annual cost savings from the hybrid energy solution and scheduling procedure.

1.6 Research Questions

i. What are the load characteristics of Zuku load (load curves)?

ii. What would be the suitable renewable energy source?

iii. What would be a cost-effective hybrid power solution?

iv. What would be the estimated annual cost savings from the hybrid energy solution?

1.7 Justification

The hybrid solution provides all the benefits of renewable energy while securing uninterrupted power for telecommunication services. In addition to a smaller carbon footprint and lower operating costs, renewable energy also provides other advantages. For instance, alternative energy sources ensure reliable telecom services also in areas where AC utility is unreliable or not available at all.

1.8 Scope

The project covers Wananchi group three main hubs (Base stations) within Nairobi region. The hybrid model will be a combination of grid power, diesel generator, solar pv and storage batteries. Model simulation will be done using PVsyst optimization software and results validated using existing actual measured data

Wind power was not considered since the site location is within estates with high buildings that affect wind speed thus the site is not a good candidates for wind.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

A reliable and continuous power supply arrangement is an essential requirement to be considered when powering telecom BTSs to ensure that the customers and operators do not experience any service outages. Over the years, powering BTS sites has been done using typical power supply solutions such as grid power, diesel and petrol generators either alone or together with renewable energy sources (e.g., hybrid PV-diesel power supply systems with or without energy storage). Such power supply solutions are particularly favorable in areas where either extending the grid connection to power the BS site is not economically attractive or the existing grid electricity is not uninterruptedly available to guarantee a continuous power supply [10].

Following the emerging concept of green telecommunication networks, the realization of powering the BTS sites using sustainable solutions has started to receive significant attention. Because of that, various studies and developments have been done in order to help the telecom operators to shift away from using diesel generators as their primary power supply solution for BTSs. It is being realized that by moving away from diesel generators, the unreliability factors and the high O&M costs usually associated with this solution can be avoided. In this section, various power supply and energy storage solutions for are discussed.

2.2 Power Supply Solutions for telecommunication

2.2.1 Diesel Generators & Grid power.

Diesel generators were among the earliest technologies used as backup or primary power supply Solutions for BTSs in areas with poor or no access to the main grid [18]. The sizing of a diesel generator is usually done based on the estimated load. Hence, all sorts of loads such as linear resistive, capacitive, inductive, non-linear, and linear loads are taken into consideration when sizing the diesel generator.

The key advantage of deploying diesel systems is that the system can be tailored according to the load demand. However, the issue of reliability has always been questionable, and the most obvious factor for the diesel generator is its failure probability at power-up, particularly in cold environments. The common failure figure that is often reported is 0.5%, or 5 out of 1000 start attempts fail [19]. This is enough to put an extra set of diesel generators in place to increase reliability, particularly for applications where 100% reliability is needed. Although the reliability increases about 200 times by having extra generators on standby, the additional costs associated with this approach may still render this configuration unfavorable for the telecom operators from an economic point of view [19]. Additionally, the rollout of BTSs using diesel generators can add a significant amount of GHG emissions to the environment. As reported by Webb [2] of *SMART 2020: Enabling the low carbon economy in the information age*, the comparison of projected GHG emissions in the telecommunication sector between 2002 and 2020 shows that an increment from about 150 Mt CO2e in 2002 to 350 Mt CO2e in 2020 is expected. Likewise, from the same report, the mobile network dominates the highest amount of GHG emissions and 103 Mt CO2e is estimated to be released in the environment in 2020 if there is no obligatory action taken in order to achieve green telecommunication networks.

Another major issue associated with deploying the diesel generators for powering BTS sites is that the performance capability of the diesel generators is very low and often inefficient, at about 30% or less, while the rest of the energy is lost as heat [5]. This, in turn, greatly contributes to the high O&M costs of the BSs powered by these generators. In a specific case of BTSs in remote Kenya, it takes more than 100 trucks to supply enough fuel to the BS sites and a lot of full-time technicians are required to overcome the service outages, leading to various economic disadvantages (e.g., additional unnecessary labor, fuel, and transportation costs) [5]. Another example shows that a telecom operator like Vodacom has to spend more than $5 million per year for all of their 157 diesel-powered BS sites (about $32,000 per year per BS) located in the Democratic Republic of Congo (DRC), mainly for O&M purposes [5,20]. Additionally, it is noteworthy that there are also other common issues related to the deployment of diesel generators such as noise emission, oil spillage, theft risk, and limited shelf life [24].

2.2.2 Renewable Energy Solutions

Harvesting energy from renewable energy sources (*i.e.*, solar and wind, in this case) to generate electricity for powering BTSs is not a new feasible option. These solutions have been strong choices for powering BTSs due to their abundant availability in a wide range of geographical locations around the world. Additionally, the components in solar- and wind-based systems are usually modular, which makes the design, expansion, and installation of these types of systems for the BTS sites very practical and feasible [5]. However, due to the unpredictable and intermittent nature of wind and solar, the systems running on these sources typically need to be integrated with other means of renewable or non-renewable power supply and/or energy storage solutions in order to ensure the continuity of power supply in a BTS site [25].

In a study conducted by the GSMA, which is a mobile trade organization, 320,100 renewable-based off-grid BTS sites have already been rolled out in 2014 in regions like South Asia, Sub-Saharan Africa, Latin America, East Asia, the Pacific, and the Caribbean [26]. This number is expected to increase further in 2020 with about 389,800 sites [27]. Paudel *et al.* [28] highlighted that conducting a feasibility assessment is essential when designing renewable energy systems. This is to mitigate any poorly designed power supply system that is inefficient for powering a BTS site. As is often the case, the renewable energy systems are usually over-sized, and this imposes high capital and O&M costs to the telecom operators. In the same study, Paudel *et al.* [28] also claimed that 99.99% reliability can be achieved if solar and wind are deployed concurrently as a power supply solution and that the calculated, levelized cost of electricity supplied over the lifetime of the system and for an optimum design was reported to be just under $0.90 per kWh.

Another techno-economic study was conducted by Moghavvemi *et al.* [22] based on a HOMER (Hybrid Optimization of Multiple Energy Resources) analysis study for a standalone PV system supported by a battery energy storage system. The result showed that the optimal levelized cost of electricity for the power supply system can be as low as $0.46 per kWh based on a PV contribution of more than 100%, with excess energy after meeting the load demand and a battery autonomy of 2.6 days. Kusakana and Vermaak [5] discussed in their study that a PV system showed the lowest net present cost (NPC) which is $8,336 per year compared to a wind system and a diesel system with costs of $11,420 per year and $29,773 per year, respectively, when used to power a BS site in the Democratic Republic of Congo. These NPC values were based on the total sum of capital, replacement, and O&M costs while considering the salvage value of the power supply components. Furthermore, with the existence of a new generation of small wind turbines that are lightweight and highly efficient, the future of wind-powered BTSs looks more promising than before. This is due to the ability of the wind generators to supply power at lower wind speeds (e.g., 2 m/s) compared to the conventional models of wind generators (e.g., wind speeds at 3–6 m/s) [27,29]. Currently, the existing deployment of the new generation small wind turbines can be found in remote locations like the Middle East and Africa [27]. Based on a trial operation of Zephyr's Airdolphine PRO 48V DC wind turbine (generating 260 W at 6 m/s) at a BS site in Namibia, running a wind-battery system with a typical load of 1.2 kW, the wind turbine produced an average daily energy production of 2.4 kWh [30]. On best day of operation, the energy production went up to 10.1 kWh, making the trial operation a success for the wind turbine to complement the batteries since the application of the PV system is not relevant to that site. Moreover, using the same model of wind turbine, Vodacom tested the wind turbine at a low daily average of wind speeds, from 0.7–6.8 m/s, at a trial site in Tinana, South Africa [30]. The result showed that an average of 0.9 kWh was achieved and, on the best day, 6 kWh was produced.

2.2.3. Hybrid Power Supply Systems

The hybrid power supply system is designed to utilize a combination of two or more power supply solutions (e.g., PVs and diesel generator) in order to achieve a more feasible, reliable, and environmentally friendly power supply arrangement. In particular, in terms of reliability, the deployment of a hybrid power supply system is able to reduce the intermittency of power supply and, accordingly, the need for a larger size of energy storage solution (e.g., batteries or hydrogen storage system) [10,31,32]. The selection of a hybrid power supply solution for a particular BS site is highly dependent on the availability of resources at the location [33]. Presently, the most common arrangements of hybrid power supply systems that are used to power BSs are PV-wind, PV-diesel-battery, PV-wind-diesel, and PV-fuel cell systems.

2.2.3.1 PV-Wind Systems

A hybrid PV-wind system generates energy to meet load demands through the good complementary effect of wind speed and solar radiation [34]. However, due to the stochastic nature of solar and wind energy, the hybrid PV-wind system (as shown in Figure 2.1) might need some form of energy storage (e.g., battery banks) that helps bridge the intermittency of the wind and solar energy sources and thus subsequently supplies power when the renewable energy sources are unable to meet the load demand [35].

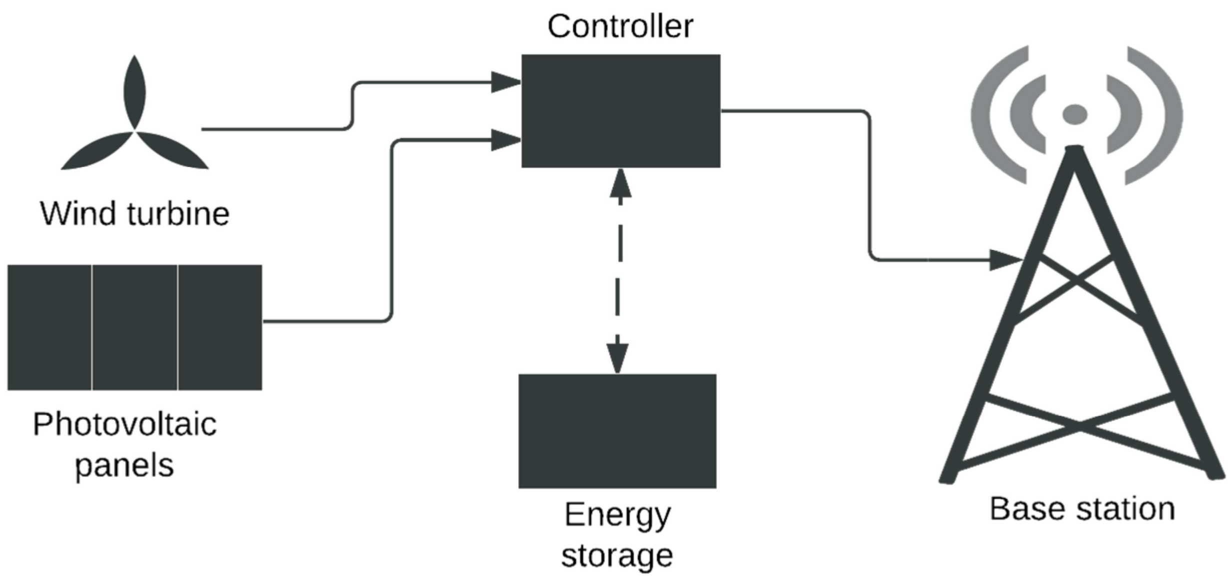

Figure 2.1 Typical configuration of a hybrid PV-wind system in a base station site

Numerous literatures have discussed the application of a hybrid PV-wind system for Btss. Hashimoto Et Al. [36] conducted a research study on a BTS site in Yonaguni Island, Japan, where they proposed an optimal sizing of a hybrid PV-wind system and studied the possibility of service outages in three scenarios of battery capacity. The results showed that the system required a three-day backup battery in order to maintain zero hours of service outages. Furthermore, in a study conducted by Yu and Qian [37], the optimal sizing and control strategy of a hybrid PV-wind system was proposed where the dual-closed loop control method was used to track changes of wind energy in order to eliminate the wind change impacts on the hybrid PV-wind system. Further optimization was made by Ribeiro *et al.* [38] to a hybrid PV-wind system used for powering an off-grid BTS site where multi-input converters (comprised of a Cuk (current-voltage-current) and a buck converter (voltage-current-voltage)) are connected to the PV and wind generator, respectively. Two fault diagnosis techniques for the Cuk and the buck converter were suggested and analyzed using MATLAB/Simulink. As a result, the techniques allow an uninterruptible power supply for the BTS by focusing on maximizing the usage of output power from the PVs and wind generator based on the utilization of the PV maximum power point tracking (MPPT) and port converter properties. Moreover, due to the ability to only use control variables to ensure a continuous power supply to the BS, no additional sensors or equipment (*i.e.*, amplifiers) are needed to do so.

2.2.3.2 PV-Diesel Systems

The hybrid PV-diesel system (typically with battery energy storage) is a comprehensive power supply system that works based on the complementary roles of the key components of the system; for instance, the high capital cost of the PV is compensated by the low capital cost of the diesel generator while the high O&M costs of diesel are compensated by the low O&M costs of PV. In most cases, the energy generated by the diesel generators is fairly available during the absence or shortage of the PV's power output [39]. Additionally, while the existence of diesel as a back-up power supply increases the reliability of the hybrid PV-diesel systems, the overall capital and O&M costs can be further decreased by employing a much smaller size of PVs and batteries [39].

Husain and Sharma [40] conducted a HOMER study for a hybrid PV-diesel system used to power a substation in Nepal and found that based on an NPC economic analysis approach of an optimized hybrid PV-diesel system, the cost of electricity supplied by the system was found to be $0.50/kWh. When compared with a diesel-only system, the cost of electricity supplied by the system was found to be $0.70/kWh. Additionally, by adding an inverter to the hybrid PV-diesel system, there was an improvement in energy delivery from the PV without the need to discharge the battery as long as there is enough solar radiation onsite [40]. This can help prolong the battery's lifetime and prevent the intermittency of the diesel generator, making the combination of the hybrid PV-diesel to be feasible and practical when compared to a diesel-only system [40].

In another HOMER study by Moghavvemi *et al.* [22], an optimized hybrid PV-diesel system proposed to power an off-grid FM (frequency modulation) transmitter located in Kuantan, Malaysia, yielded the lowest cost of electricity, at $0.26/kWh, when compared to a diesel-only system and a PV-only system, at $0.36/kWh and $0.46/kWh, respectively. This optimization was done by considering the two key parameters of autonomy days and PV contribution, suggesting half a day of autonomous operation with a PV contribution of 110% (meaning there was a 100% PV contribution and an additional 10% of excess power from the PV) in order to achieve the lowest electricity cost of $0.26/kWh [22].

It is important to note that factors such as high emissions from diesel usage, possible future increased cost of diesel prices, and unreliability suggested by the service outages (e.g., due to poor supply of fuel or fuel theft) are some of the limitations that prevent the hybrid PV-diesel system to be favorably deployed for powering off-grid BS sites [41–43]. Figure 2.2 shows a typical set-up of the hybrid PV-diesel systems where the power is primarily supplied by the PV system and the diesel generator acts as a complementary power supply system to overcome the intermittency of solar energy. During periods when the PVs are able to generate excess energy, the energy storage is used to store the excess energy as a short-term energy storage option. Nevertheless, due to the non-existence of reliable long-term energy storage, the PV-diesel system is not reliable enough to power the off-grid BS sites with a seasonal type of loading [43].

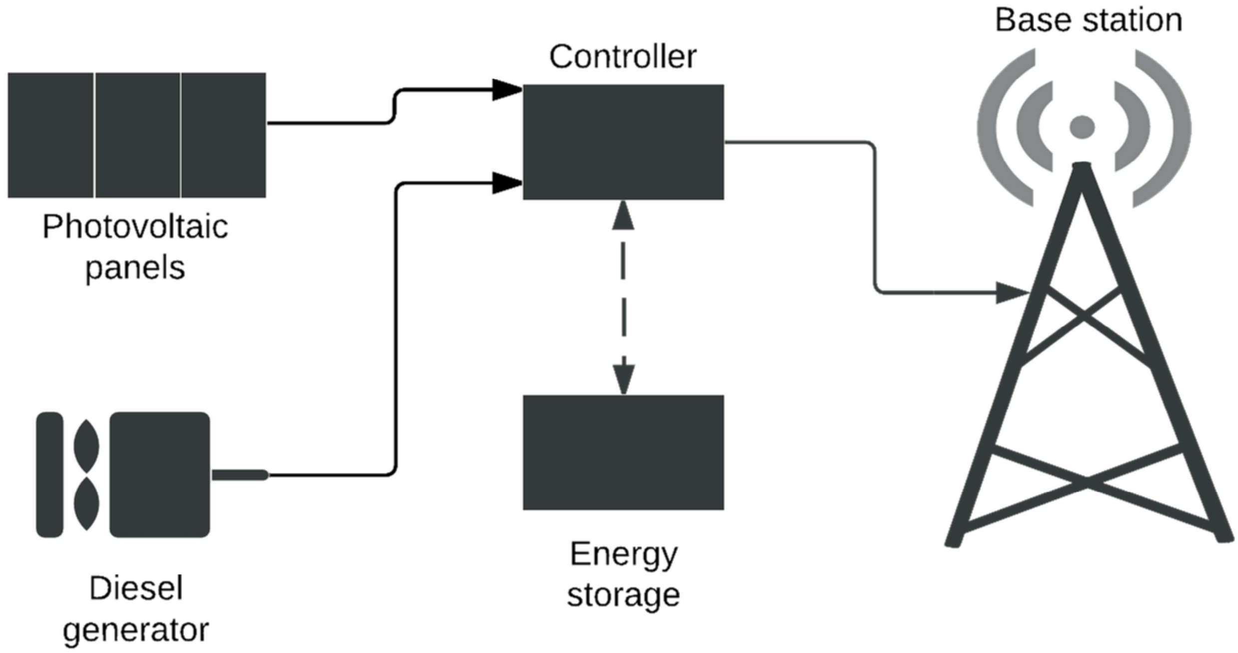

Figure 2.2 Typical configuration of a hybrid PV-diesel system in a base station site

2.2.3.3 PV-Wind-Diesel Systems

In hybrid PV-wind-diesel systems, electrical energy is supplied primarily from solar and wind energy while diesel is used as a secondary or backup power supply when the PVs and wind generators are unable to produce enough power for the BS [21,44]. Figure 4 shows the typical configuration of a hybrid PV-wind-diesel system for powering a BS site. The study conducted by Bitterlin [45] suggests that the hybrid PV-wind-diesel systems are ideal for powering large-sized BSs of 4 kW or more. A similar study has been conducted by Goel and Ali [46] based on a hybrid PV-wind-diesel system that is located at the island village of Barakolikhola in Odisha, India. The study showed that desirable outputs such as low emissions, low operating costs, low net present cost (NPC), and levelized cost can be achieved when deploying a hybrid PV-wind-diesel system to the BS site rather than a diesel-only power supply system. They also showed that the deployment of such a hybrid system is more viable, both technically and economically, when used for larger load demands.

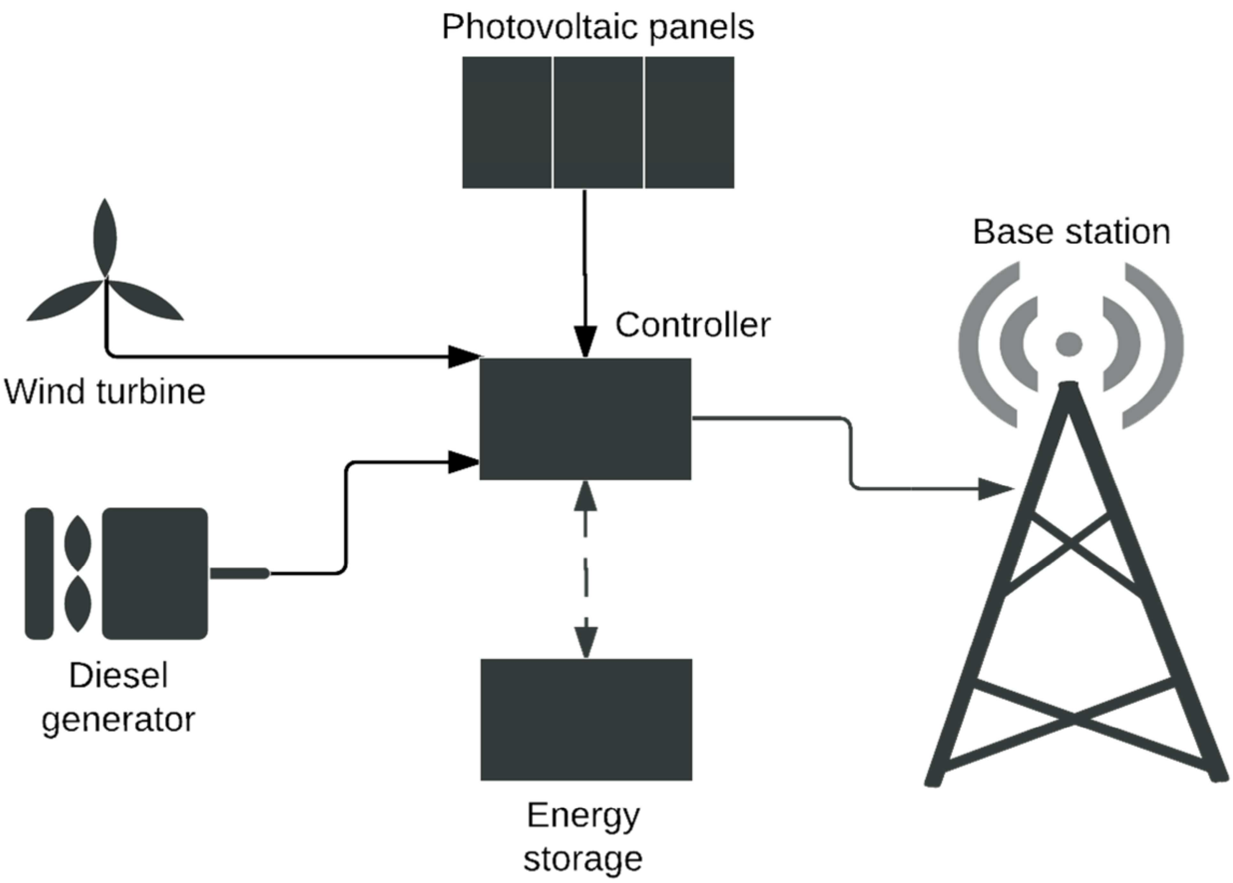

Figure 2.3 Typical configuration of a hybrid PV-wind-diesel system in a base station site

Sharma *et al.* [47] studied the optimization of a hybrid PV-wind-diesel system based on a HOMER analysis of an off-grid BS site located in Imaliya Bhanpur, India. The results showed that the NPC of the hybrid PV-wind-diesel system is 10% and 15% lower than the hybrid PV-diesel and wind-diesel systems, respectively. In addition, the cost of electricity per kWh for the three hybrid systems (*i.e.* PV-wind-diesel, wind-diesel, and PV-diesel systems) was found to be \$0.70/kWh, \$0.77/kWh, and \$0.76/kWh, respectively. Another HOMER study conducted by Olatomiwa *et al.* [48] suggests that the hybrid PV-wind-diesel systems are used to replace diesel generators that were previously deployed for off-grid BS sites in Nigeria. This is because the hybrid PV-wind-diesel system yield a lower cost of electricity at \$0.45/kWh compared to hybrid PV-diesel and diesel-battery systems, where both suggested a unit of electricity of \$0.66/kWh in this case study. Moreover, the renewable fraction of the hybrid PV-wind-diesel system was found to be higher (*i.e.*, above 82%) than just that for the hybrid PV-diesel system (*i.e.*, at 19%), making the proposed hybrid power supply system to be feasible and environmentally friendly compared to other hybrid power supply configurations.

2.2.3.4 PV-Fuel Cell Systems

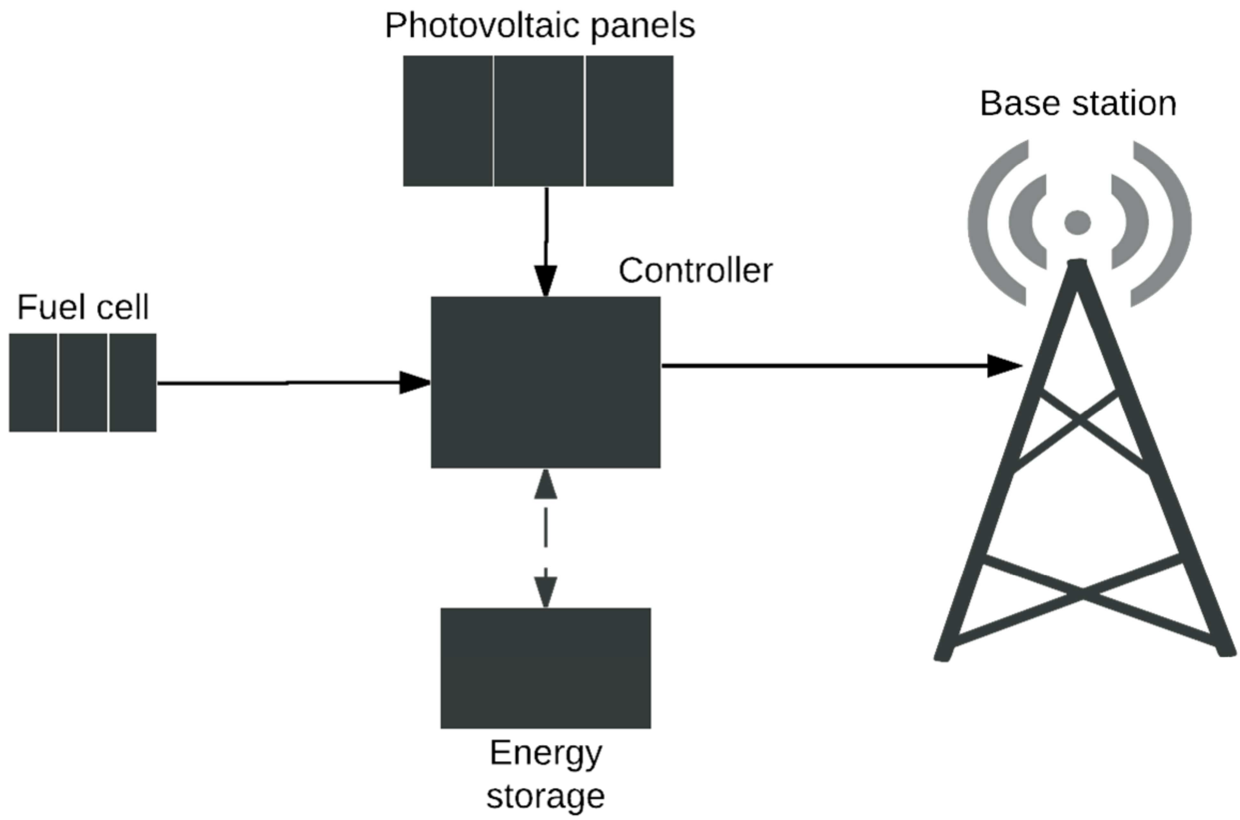

Figure 2.4 Typical configuration of a PV-fuel cell system in a base station site

A hybrid PV-fuel cell system is a sustainable solution (if hydrogen is produced and supplied sustainably) that can be used to power an off-grid BS site based on the attractive features of the PV and fuel cell technologies, such as high efficiency, modularity, and fuel flexibility [49]. Figure 5 shows the typical configuration of a hybrid PV-fuel cell system used for powering a BS site. Generally, the fuel cell system is used to back up the power supply system by covering the intermittency of the PV system, particularly when the energy storage of the system is unable to supply enough electricity to meet the BTS demand. The preferred fuel cell option for this purpose is Proton Exchange Membrane Fuel Cell (PEMFC) due to its low operating temperature (e.g., 60–100 °C), rapid start-up, and rapid response to variable loads [50]. The PEMFCs can run on pure hydrogen that can be supplied to the site or generated onsite, for instance, through water electrolysis or reforming methanol and natural gas [51].

In a study conducted by Jiang [49], an unattended test operation of a hybrid PV-fuel cell system was conducted for a remote radio-telephone repeater station. The results showed that the power supply system operated without any failure for 3239 h (or over 229 days in service) and completed 177 start-stop cycles and kept the batteries at an average of a 76% state of charge (SOC). However, the test operation failed not long after that due to overheating from the fuel cell as the ambient temperature increased and the cooling system was left in an idle state in order to reduce energy consumption of the BS. This highlights the importance of an effective thermal management system for such power supply arrangements; this will be further discussed in section 3.4 of "Thermal Management of Base Stations". Another case study of a remote radio-telephone repeater station was conducted by Lehman *et al.* [52] with the aim of deploying a feasible power supply system for the repeater station. They found that a PV-only system was not feasible as it required a large number of PVs, whereby the diesel-only system required huge amounts of diesel to run the repeater station. Because of that, a hybrid PV-fuel cell system was proposed and the result showed that the PEMFC performed flawlessly as a backup power supply to the hybrid system at 400 to 800 h of operating hours per year. Moreover, a temperature switch was introduced in order to overcome the overheating issue that was previously experienced by the hybrid PV-fuel cell system.

A study by Rekioua *et al.* [33] added that a Power Management Unit (PMU) managed to successfully improve the power coordination between the PVs and the fuel cell. By adding the PMU to the power supply system, the number of PVs needed in addition to the capital cost of the hybrid PV-fuel cell system was further reduced. However, drawbacks like slow dynamics in the fuel cell system and the high capital cost of the fuel cell somewhat inhibited the deployment of the proposed hybrid PV-fuel cell system for the remote telecommunication applications that the system was designed for.

2.3 Components of a Hybrid energy system

2.3.1 Solar PV

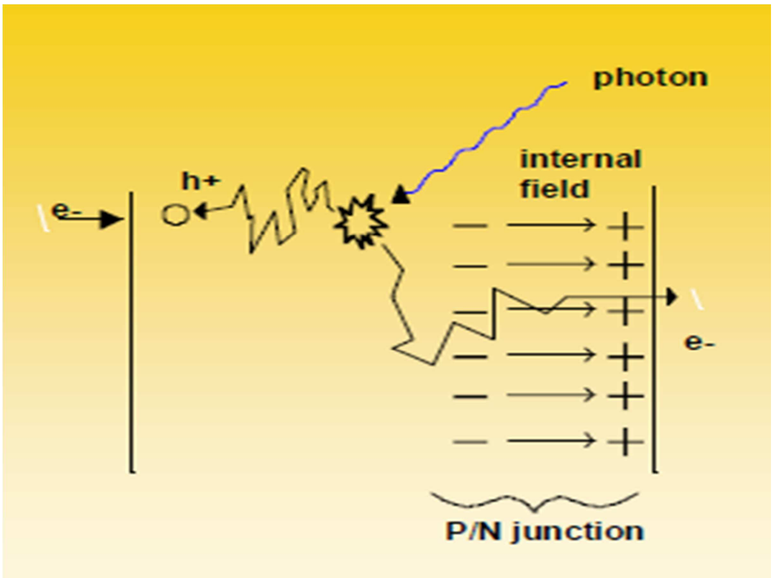

Fig 2.5 solar panel principle of operation

Solar panels generate free power from the sun by converting sunlight to electricity with no moving parts, zero emissions, and no maintenance as shown in figure 2.5. The solar panel, the first component of a electric solar power system, is a collection of individual silicon cells that generate electricity from sunlight. The photons (light particles) produce an electrical current as they strike the surface of the thin silicon wafers as shown in the figure below.

A single solar cell produces only about 1/2 (.5) of a volt. However, a typical 12 volt panel about 25 inches by 54 inches will contain 36 cells wired in series to produce about 17 volts peak output. Multiple solar panels can be wired in parallel to increase current capacity (more power) and wired in series to increase voltage for 24, 48, or even higher voltage systems. The advantage of using a higher voltage output at the solar panels is that smaller wire sizes can be used to transfer the electric power from the solar panel array to the charge controller & batteries.

2.3.1.1 The 3 basic types of Solar Panels

i Mono-crystalline solar panels

The most efficient (15 – 20%) and expensive solar panels are made with Mono-crystalline cells. These solar cells use very pure silicon and involve a complicated crystal growth process. Long silicon rods are produced which are cut into slices of .2 to .4 mm thick discs or wafers which are then processed into individual cells that are wired together in the solar panel.

ii Polycrystalline solar panels

Often called Multi-crystalline, solar panels made with Polycrystalline cells are a little less expensive & slightly less efficient than Mono-crystalline cells because the cells are not grown in single crystals but in a large block of many crystals. This is what gives them that striking shattered glass appearance. Like Mono-crystalline cells, they are also then sliced into wafers to produce12 the individual cells that make up the solar panel.

iii Amorphous solar panels

These are not really crystals, but a thin layer of silicon deposited on a base material such as metal or glass to create the solar panel. These Amorphous solar panels are much cheaper, but their energy efficiency is also much less so more square footage is required to produce the same amount of power as the Mono-crystalline or Polycrystalline type of solar panel.

Amorphous solar panels can even be made into long sheets of roofing material to cover large areas of a south facing roof surface.

Advantages of Mon crystalline solar cells

- Mono crystalline solar panels have the highest efficiency rates since they are made out of the highest-grade silicon. The efficiency rates of mono crystalline solar panels are typically 15-20%.
- Mon crystalline silicon solar panels are space-efficient. Since these solar panels yield the highest power outputs, they also require the least amount of space compared to any other types.
- Mon crystalline solar panels produce up to four times the amount of electricity as thin-film solar panels.
- Mon crystalline solar panels live the longest. Most solar panel manufacturers put a 25-year warranty on their mono crystalline solar panels.
- Tend to perform better than similarly rated polycrystalline solar panels at low-light conditions.

Disadvantages

- Mono crystalline solar panels are the most expensive.
- If the solar panel is partially covered with shade, dirt or snow, the entire circuit can break down.
- Mon crystalline solar panels tend to be more efficient in warm weather. Performance suffers as temperature goes up, but less so than polycrystalline solar panels. For most homeowners temperature is not a concern.

Advantages of Polycrystalline Silicon Solar Cells

- The process used to make polycrystalline silicon is simpler and cost less. The amount of waste silicon is less compared to mono crystalline.
- Polycrystalline solar panels tend to have slightly lower heat tolerance than mono crystalline solar panels. This technically means that they perform slightly worse than mono crystalline solar panels in high temperatures. Heat can affect the performance of solar panels and shorten their lifespans. However, this effect is minor, and most homeowners do not need to take it into account.

Disadvantages

- The efficiency of polycrystalline-based solar panels is typically 13-16%. Because of lower silicon purity, polycrystalline solar panels are not quite as efficient as mono crystalline solar panels.
- Lower space-efficiency. You generally need to cover a larger surface to output the same electrical power as you would with a solar panel made of mono crystalline silicon. However, this does not mean every mono crystalline solar panel performs better than those based on polycrystalline silicon.
- Mono crystalline and thin-film solar panels tend to be more aesthetically pleasing since they have a more uniform look compared to the speckled blue color of polycrystalline silicon.

2.3.2 The Power Inverter

Majority of the load run on 240 volts AC, the Power Inverter will be the heart of the Solar Energy System. It converts the low voltage DC to the 240 volts AC that runs the load. It can also charge the batteries if connected to the utility grid or a AC Generator as in the case of a totally independent stand-alone solar power system. The following are the types of inverters

i. Square Wave power inverters

This is the least expensive and least desirable type. The square wave it produces is inefficient and is hard on many types of equipment. These inverters are usually fairly inexpensive, 500 watts or less.

ii. Modified Sine Wave power inverter

This is probably the most popular and economical type of power inverter. It produces an AC waveform somewhere between a square wave and a pure sine wave. Modified Sine Wave inverters, sometimes called Quasi-Sine Wave inverters are not real expensive and work well in all but the most demanding applications and even most computers work well with a Modified Sine Wave inverter. However, there are exceptions. Some appliances that use motor speed controls or that use timers may not work quite right with a Modified Sine Wave inverter. And since more and more consumer products are using speed controls & timers, I would only recommend this type of inverter for smaller installations such as a camping cabin.

iii. True Sine Wave power inverter

A True Sine Wave power inverter produces the closest to a pure sine wave of all power inverters and in many cases produces cleaner power than the utility company itself. It will run practically any type of AC equipment and is also the most expensive. Many True Sine Wave power inverters are computer controlled and will automatically turn on and off as AC loads ask for service. I believe they are well worth the extra cost.

iv Grid Tie Power Inverter

If you are connected to normal Utility company power and just want to add some Free Sun Power electricity to reduce your electric bill and you do not need a totally independent system, it is possible that a Grid Tie power inverter will suit your needs. With a Grid Tie power inverter, whatever electricity that your solar panels produce will reduce the amount supplied by the utility company, in effect lowering your bill. And, if you are producing more power than you are using, you can actually sell the extra power back to the utility company! For this type of setup a much smaller battery bank can be installed just to cover short term outages from a few minutes to an hour or two. In fact, if you don't have frequent long term power outages and don't need back-up power, then you will not need any batteries at all.

2.4. System Sizing and Optimization

Proper sizing and optimization of the power supply systems used for powering BTSs can have positive impacts toward the systems' reliability, as well as toward the costs associated with their installation, operation, and maintenance [105]. Various studies have been carried out by other researchers to design for the sizing and optimization of the standalone power supply systems, and these the studies mainly focused on suitable hybrid components and configurations of the system at the lowest possible cost while meeting the load demands of the BSs at all conditions [106].

Generally, the sizing and the design of the power supply systems are dependent on the location and environmental conditions of the site, where the availability of the site’s weather data determines the appropriate sizing method that shall be used to carry out the design and sizing of the systems [107]. Using the existence of weather data, conventional sizing approaches are applied based on the concept of energy balance and the reliability of supply [107]. For instance, to size a PV system, long-term meteorological data is needed. As discussed by Marsan *et al.* [92], sizing of the PV system can be done by looking at the month with the minimum energy production. The value of the nominal peak power of the PV system is then matched with the energy requirement of the BTS on average [92]. Additionally, the daily average load demand together with the daily average available energy from the sun are balanced in order to obtained the number of PV arrays required by the system [107]. Being the simplest technique in sizing the power supply components, the energy balance takes into consideration the path losses and efficiencies of the energy sources (*i.e.*, renewable energy), converters, and controllers, while the reliability of the supply approach estimates the loss of load probability by calculating the ratio of all energy deficits to the load demand at a certain period of time [34,108,109]. Likewise, other similar concepts for the reliability of the supply approach are loss of power probability (LOPP), loss of power supply probability (LPSP), and load coverage rate (LCR) [107].

However, in most cases (*i.e.*, particularly in off-grid BSs), the weather data is often absent and more complex techniques (*i.e.*, Artificial Intelligence (AI)) are needed [107]. This is when the AI generates results based on the prediction or classification of input data (with an appropriate degree of error) and presents it as new sets of data patterns of previous examples and models [107]. The examples of the AI techniques that are commonly used for the design and sizing of the power supply systems are the Artificial Neural Network (ANN) [110,111], Fuzzy Logic [108,112], Genetic Algorithms (GA) [43,66,101,105,113], wavelet transforms [114], and hybrid methods with multi-objectives (combinations of two or more AI techniques) [115,116]. An example of PV system sizing using an AI technique of the ANN is where the longitude and latitude of the BS site location are considered as the inputs to the ANN. The outputs are then estimated based on the ANN model for sizing of the PV system. As a result, the ANN technique is able to determine the number of PV arrays and the size of the batteries with a relative error of less than 6% [117].

Often after the design and sizing of the power supply systems, optimization of the system is needed in order to further minimize the system cost and at the same time increase the reliability of the system [107]. This can be done by assessing appropriate performance indicators in order to measure the level of feasibility and reliability of the power supply components [115]. Some of the key performance indicators used when carrying out the optimization of the power supply systems are: levelized cost of energy (LCE), which is an economic assessment of the energy generated by the power supply system based on the calculated ratio of the total annualized cost of the system to the annual electricity supplied by the system [118,119]; the battery's state of charge (SOC), which measures the energy storage capacity of the power supply system [43,120]; the level of autonomy that assess the reliability of the power supply system by calculating the fraction of time in which the BS demands are met [121–123]; the expected energy not supplied (EENS), which measures the expected energy that cannot be supplied by the power supply system [124]; the net present value (NPV), which measures the economics of the power supply system by calculating the NPV of the system based on the addition of present values of incomes and the subtraction of the discounted present costs throughout the system's lifetime period [125]; and lastly, the annualized cost of system (ACS), which is an economic assessment of the power supply system based on the calculation of the total annualized capital cost, the annualized replacement cost, and the annualized maintenance cost [126].

2.5 Performance Parameters for Grid-Connected PV Systems

The use of appropriate performance parameters facilitates the comparison of grid-connected photovoltaic (PV) systems that may differ with respect to design, technology, or geographic location. Four performance parameters that define the overall system performance with respect to the energy production, solar resource, and overall effect of system losses are the following

1. Final PV system yield (Y_f)
2. Reference yield (Y_r)

3. Performance ratio (PR)
4. PVUSA rating

Accurate and consistent evaluations of photovoltaic (PV) system performance are critical for the continuing development of the PV industry. For component manufacturers, performance evaluations are benchmarks of quality for existing products. For research and development teams, they are a key metric for helping to identify future needs. For systems integrators and end customers, they are vital tools for evaluating products and product quality to guide future decision-making.

As the industry has grown, a clear need has arisen for greater use of and education about appropriate industry-standard performance parameters for PV systems. These performance parameters allow the detection of operational problems; facilitate the comparison of systems that may differ with respect to design, technology, or geographic location; and validate models for system performance estimation during the design phase. Industry-wide use of standard performance parameters and system ratings will assist investors in evaluating different proposals and technologies, giving them greater confidence in their own ability to procure and maintain reliable, high-quality systems. Standard methods of evaluation and rating will also help to set appropriate expectations for performance with educated customers, ultimately leading to increased credibility for the PV industry and positioning it for further growth.

Parameters describing energy quantities for the PV system and its components have been established by the International Energy Agency (IEA) Photovoltaic Power Systems Program and are described in the IEC standard 61724 [23].

Three of the IEC standard 61724 performance parameters may be used to define the overall system performance with respect to the energy production, solar resource, and overall effect of system losses. These parameters are the final PV system yield, reference yield, and performance ratio.

The final PV system yield Y_f is the net energy output E divided by the nameplate d.c. power P_0 of the installed PV array. It represents the number of hours that the PV array would need to operate at its rated power to provide the same energy. The units are hours or kWh/kW, with the latter preferred by the authors because it describes the quantities used to derive the parameter. The Y_f normalizes the energy produced with respect to the system size; consequently, it is a convenient way to compare the energy produced by PV systems of differing size:

Y_f =E/Po in KWh/KW of hours (2.1)

The reference yield Y_r is the total in-plane irradiance H divided by the PV's reference irradiance G. It represents an equivalent number of hours at the reference irradiance. If G equals 1 kW/m^2, then Y_r is the number of peak sun-hours or the solar radiation in units of kWh/m^2. The Y_r defines the solar radiation resource for the PV system. It is a function of the location, orientation of the PV array, and month-to-month and year-to-year weather variability:

Yr= H/G (hours) [24] (2.2)

The performance ratio PR is the Y_f divided by the Y_r. By normalizing with respect to irradiance, it quantifies the overall effect of losses on the rated output due to: inverter inefficiency, and wiring, mismatch, and other losses when converting from d.c. to a.c. power; PV module temperature; incomplete use of irradiance by reflection from the module front surface; soiling or snow; system down-time; and component failures:

$$PR = Y_f / Y_r \text{ dimensionless} \quad (2.3)$$

PR values are typically reported on a monthly or yearly basis. Values calculated for smaller intervals, such as weekly or daily, may be useful for identifying occurrences of component failures. Because of losses due to PV module temperature, PR values are greater in the winter than in the summer and normally fall within the range of 0.6 to 0.8. If PV module soiling is seasonal, it may also impact differences in PR from summer to winter. Decreasing yearly values may indicate a permanent loss in performance.

The PVUSA rating method [25] uses a regression model and system performance and meteorological data to calculate power at PVUSA Test Conditions (PTC), where PTC are defined as 1000 W/m^2 plane-of-array irradiance, 20°C ambient temperature, and 1 m/s wind speed. PTC differs from standard test conditions (STC) in that its test conditions of ambient temperature and wind speed will result in a cell temperature of about 50°C, instead of the 25°C for STC. This is for a rack-mounted PV module with relatively good cooling on both sides of the module. For PV modules mounted close to the roof or integrated into the building with the airflow restricted, PTC will yield greater cell temperatures. Nordmann and Clavadetscher [26] report that PV module temperatures rise above ambient for fielded system ranging from 20°C to 52°C at 1000 W/m^2, with the largest temperature rise for an integrated façade. The difference between the nameplate d.c. power rating and the system PVUSA rating is an indication of the total system losses associated with converting d.c. module energy to a.c. energy. As with decreasing PR values, decreasing PVUSA ratings over time may indicate a permanent loss in performance.

2.6 Economic analysis of a an Energy project

The main objective of conducting a project economic analysis is to help not only assess the sustainability of investment but also to inform the design and select projects that can contribute to a sustainable improvement in the welfare of project beneficiaries, and the country as a whole. Economic analysis is a means to help bring about a better allocation of resources that can lead to enhanced incomes for investment or consumption purposes. Therefore, it is best undertaken at the early stages of the project cycle to enable decision makers to make an informed decision on whether to undertake a particular investment given various alternatives and their corresponding costs.

The tools of economic analysis can help answer various questions about the project's overall effect on society, on various stakeholders/beneficiaries, its fiscal aspects and about the project's risks and sustainability. For example, economic analysis can help determine whether the rationale for public sector intervention is justified. It can help in estimating the project's fiscal impact and inform government/implementing agency accordingly; it can also determine whether there is scope for cost recovery and that arrangements are efficient and equitable. In addition, it can help in assessing the project's potential environmental impact and contribution to poverty reduction.

While each sector has a different set of problems that needs to be addressed, the basic principles of economic analysis can still be applied. The analytical approach and data requirements would have to be adapted or tailored to the specific project. The key here is to select the appropriate level of analysis to inform project decision making.

The following publications are the tools that can be employed for project economic analysis

2.6.1 Payback Period

The payback period of a project is defined as the number of years it takes for the project to recover its original investment.

Let’s take a simple example to understand how payback period is calculated. Assume that a company invests $5,000 in a project, which generates the following cash flow in the next 5 years.

Year	Cash Flow
0	$-5,000.00
1	$2,000.00
2	$2,000.00
3	$2,000.00
4	$1,000.00
5	$1,000.00

The payback period will be equal to the time period when the firm has generated back its $5,000 investment.

In year 1, the firm generates $2000. In year 2, it generates $2,000. By the end of the year 2, the cumulative cash inflow is $4,000. In year 3, it generates $2,000. At the end of year 3, the cumulative cash flow is $6,000, which is more than our initial investment. That means the payback period is somewhere between year 2 and year 3.

By the end of year 2, we have recovered $4,000. The unrecovered amount is $1,000. In year 3, the total cash flow is $2,000.

With this information, the payback period can be calculated as follows.

Payback period = 2 years + $1,000/$2000 = 2.5 years

The payback period is a measure of the firm's liquidity. Generally, the shorter the payback period is, the better it is for the firm. However, the method has some drawbacks. For example, it does not consider time value of money, or the cash flows after the payback period. Because of these drawbacks, the payback period method cannot be used as a measure of profitability.

This method is generally used along with another method such as NPV or IRR while making capital investment decisions.

2.6.2 Discounted Payback Period

One of the drawbacks of payback period is that it does not consider time value of money. An alternative is to use the discounted payback period.

The discounted payback period is the number of years it takes to recover the initial investment in terms of the present value of the cash flows. The present value of each cash flow is calculated and then added to arrive at the discounted payback period.

2.6.3 Internal rate of return

Internal rate of return (IRR) is the interest rate at which the net present value of all the cash flows (both positive and negative) from a project or investment equal zero.

Internal rate of return is used to evaluate the attractiveness of a project or investment. If the IRR of a new project exceeds a company's required rate of return, that project is desirable. If IRR falls below the required rate of return, the project should be rejected.

How it works (Example):

The formula for *IRR* is:

$$0 = P_0 + P_1/(1+IRR) + P_2/(1+IRR)_2 + P_3/(1+IRR)_3 + . . . +P_n/(1+IRR)_n \quad (2.4)$$

where P_0, P_1, . . . P_n equals the cash flows in periods 1, 2, . . . n, respectively; and IRR equals the project's internal rate of return.

Let's look at an example to illustrate how to use IRR.

Assume Company XYZ must decide whether to purchase a piece of factory equipment for $300,000. The equipment would only last three years, but it is expected to generate $150,000 of additional annual profit during those years. Company XYZ also thinks it can sell the equipment for scrap afterward for about $10,000. Using IRR, Company XYZ can determine whether the equipment purchase is a better use of its cash than its other investment options, which should return about 10%.

Here is how the IRR equation looks in this scenario:

$$0 = -\$300,000 + (\$150,000)/(1+.2431) + (\$150,000)/(1+.2431)_2 + (\$150,000)/(1+.2431)^3 + \$10,000/(1+.2431)^4$$

The investment's IRR is 24.31%, which is the rate that makes the present value of the investment's cash flows equal to zero. From a purely financial standpoint, Company XYZ should purchase the equipment since this generates a 24.31% return for the Company --much higher than the 10% return available from other investments.

A general rule of thumb is that the IRR value cannot be derived analytically. Instead, IRR must be found by using mathematical trial-and-error to derive the appropriate rate. However, most business calculators and spreadsheet programs will automatically perform this function.

IRR allows managers to rank projects by their overall rates of return rather than their net present values, and the investment with the highest IRR is usually preferred. Ease of comparison makes IRR attractive, but there are limits to its usefulness. For example, IRR works only for investments that have an initial cash outflow (the purchase of the investment) followed by one or more cash inflows.

Also, IRR does not measure the absolute size of the investment or the return. This means that IRR can favor investments with high rates of return even if the dollar amount of the return is very small. For example, a $1 investment returning $3 will have a higher IRR than a $1 million investment returning $2 million. Another short-coming is that IRR can't be used if the investment generates interim cash flows. Finally, IRR does not consider cost of capital and can't compare projects with different durations.

IRR is best-suited for analyzing venture capital and private equity investments, which typically entail multiple cash investments over the life of the business, and a single cash outflow at the end

2.6.4 Net Present Value - NPV

Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows. NPV is used in capital budgeting to analyze the profitability of a projected investment or project.

The following is the formula for calculating NPV:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o \qquad (2.5)$$

where

C_t = net cash inflow during the period t

C_o = total initial investment costs

r = discount rate, and

t = number of time periods

A positive net present value indicates that the projected earnings generated by a project or investment exceed the anticipated costs. Generally, an investment with a positive NPV will be a profitable one and one with a negative NPV will result in a net loss. This concept is the basis for the Net Present Value Rule, which dictates that the only investments that should be made are those with positive NPV values.

2.6.5 Equivalent annual cost

E**quivalent annual cost** (**EAC**) is the cost per year of owning and operating an asset over its entire lifespan. It is calculated by dividing the NPV of a project by the "present value of annuity factor

Alternatively, EAC can be obtained by multiplying the NPV of the project by the "loan repayment factor".

2.7 Software's used for solar PV system design and analysis

Simulation is the realization of the real world process or system. It is a technique for modeling and investigating the system or process performance. The simulation software's are basically categorized in simulation tool, economic evaluation tools, photovoltaic industry related tools, analysis and planning tools, monitoring and control tools and solar radiation maps

Evaluation parameters of these simulation software's are presented as per the below criteria.

P1 their commercial and educational availability and cost
P2 their working platform
P3 their working capacities
P4 their scope and output
P5 their updatability

2.7.1 Photo voltaic systems (PVsyst)

PVsyst is used to simulate grid connected, stand alone and pumping system. It is a PC based software and can be installed in any version of Window or any operating system.

P1 their commercial and educational availability cost:

PVsyst available in two types one is PRO30 limited to 30kW installation only and PREMIUM all installation. Cost of PRO30 CHF 1000 for one machine additional CHF 700 for second machine and additional CHF 500 for third machine respectively. Cost of PREMIUM CHF1300 additional CHF 1000 for second machine and CHF 700 for third machine respectively.

P2 their working platform: Windows 8, Windows 7, Vista, XP (older versions of Windows NT, 98, 95). 32-bits and 64-bits processors. MAC OSX (see here) and Linux with a virtual machine running Windows 32-bits (e.g., Virtual Box). Windows servers are not supported.

P3 their working capacities: PVsyst provide multiple choices to user for project design like preliminary design, project design, data base and tools. Preliminary design is the pre-sizing step of a project. It is aimed to quickly define the general features of a planned PV system.

P4 their scope and output: PVsyst provide a very good platform for all type of need to analysis project more effectively for this various provision given in PVsyst 6.19. The mainly two function given in PVsyst front window like database and tools, database provide detail regarding Geographical sites, synthetic hourly data generation, meteo tables and graphs, import meteo data, import ASCII meteo data in component database it provide details like PV modules, grid inverter, batteries, regulators for stand-alone, generators, pumps, regulators for pumps, and many more details regarding manufacturers and retailers.

P5 their updatability: latest version (PVsyst6.19) released on February 11, 2014

2.7.2 Renewable Energy Technologies Screen (RETScreen)

Renewable energy technology screen is developed by Canadian Government, industry and academia. It is free of cost tool for all industry, academia and researcher in the field of renewable energy. It has two separate program one is RETScreen 4 and RETScreen plus. RETScreen 4 is excel based renewable energy software tool that can be used to technical as well as financial visibility of renewable potential, energy efficiency and cogeneration projects. RETScreen plus is a window based energy management software tool that provide details regarding energy performance of ongoing project to owners.

P1 their commercial and educational availability and cost: Free of cost

P2 their working platform: The program requires the use of Microsoft Excel 2003 or higher version; Microsoft Windows XP or higher windows platform; and Microsoft .NET Framework 4 or higher (note that the Full Profile version must be installed, not just the Microsoft .NET Framework 4 Client Profile Version.) It can also work on Apple Macintosh computers using Parallels or VirtualBox for Mac. RETScreen Plus is Windows-based and independent of Microsoft Excel.

P3 their working capacities: This soft is available more than 36 languages that mean its cover almost 2/3rd population of word. This provide various project facility like energy efficiency measure, power, heating, cooling, combined heating & cooling, combined cooling & power many more. Technology can be used are photovoltaic, reciprocating engine, solar thermal power, steam engine, steam turbine, tidal power, wave power.

P4 their scope and output: RETScreen provide detail regarding proposed power generation, emission analysis, and financial analysis. RETScreen plus provide a power full tool it provide option to select climate data from vast meteo database.

P5 their updatability: An updated version of RETScreen 4 and RETScreen plus was released on September 25, 2012.

2.7.3 Hybrid Optimization Model for Electric renewables (HOMER)

HOMER is a computer based simplified model for designing of distributed generation (DG) systems both on and off-grid. HOMER's optimization and sensitivity analysis algorithms allow user interface to evaluate the economic and technical feasibility of a large number of technology options and to account for variations in technology costs and energy resource availability.

P1 their commercial and educational availability and cost: HOMER 2 is $99.99 for as on date and with 6-month license. The 6-month license price will increase to $150 from April 1, 2014.

P2 their working platform: HOMER can be installed on all versions of Microsoft windows and Windows emulators.as parallels for Macintosh.

P3 their working capacities: HOMER basically performs three functions namely Sensitivity analysis, optimization and simulation in distributed generation system. It helps to design micro power systems. It contains a very powerful computation engine as well as a logical unit and true interface between the system and user. That's why it can perform or simulate thousands of system constellations in a trice and optimize for life cycle costs. It provides three functions model for both conventional and renewable energy technologies: power source i.e solar photovoltaic, wind turbine, run of river hydro power electric utility grid micro turbine, fuel cell, and generator: diesel, gasoline, biogas, alternative and custom fuels. Storage: battery bank, hydrogen, flow batteries, flywheels. Loads: daily profiles with seasonal variation, deferrable (water pumping, refrigeration), thermal (space heating, crop drying), efficiency measures

P5 their updatability: Latest version 2.81 of HOMER 2 was released on November 8, 2010 and the first version (original) was released on February 14, 2000.

2.7.4 TRaNsient Systems Simulation (TRNSYS)

TRNSYS is an extremely flexible graphic based software environment that is used to simulate the behavior of the transient system mainly. While the other majority of simulations software is focused on assessing the performance of the thermal and electrical energy system. This was evolved in 1975 by international collaboration of the United States, France and Germany initially. It is available for both commercial as well educational applications.

P1 their commercial and educational availability and cost: Latest version is TRNSYS 17 that is available for $4740 for single user and $ 7700 for five users. For educational purpose it is available for $2370 for ten users and $3850 for 20 users.

P2 their working platform: Only windows operating system (XP/Vista/Window 7) can be used to run TRNSYS. If someone wants to create their own TRNSYS components to use their simulation then FORTRAN compiler required.

P3 their working capacities: TRNSYS is available in different suit like TRANSYS3D allow user to draw multi-zone building and import the geometry including self-shading, TRNBUILD allow user for creating and editing all of the non-geometry information required, TRNEDIT is a full-featured text editor for writing and viewing TRNSYS input and output files and for upcoming parametric and TRNSED allow user to create customized graphic for specific application and then distribute those application to non-TRNSYS users.

P4 their scope and output: The TRNSYS is robust, intuitive, graphical front end for the simulation, making the user's job of assembling of a detailed system in a simple endeavor. The output of one component is graphically connected to the inputs of another. Users can watch the value of ANY system variable on an online plot as the simulation progresses. Output devices also allow the user great flexibility in integrating, and reporting any component output value.

P5 their updatability: Yes. Latest version of TRNSYS is available in market TRNSYS 17.1 was released in June 2012.

2.7.5 INtegarted Simulation Environment Language (INSEL)

INSEL is graphical programming language for common objective in integrated simulation environment by INSEL we can solve any of computer simulation problem for photovoltaic systems.

It provides functional block diagram for the simulation of meteorological data, thermal energy and electrical constituents which is a strong right answer for the simulation problems. It works basically as a modular simulation environment for understand, plan, monitor and visualize energy systems.

P1 their commercial and educational availability and cost: Cost of INSEL for single user is $2023 and $ 6069 for five-user license. Cost for research and education institutes is $ 1011 for single user and 3034 for five-user. Student version is available only for $101.

P2 their working platform: Windows XP, Windows Vista or Windows 7 computers with 32 or 64 bit.

P3 their working capacities: Using the graphical tool of INSEL, we can develop full visualization and monitoring of your energy plant. Simulation model can be made easily with graphic editor with some mouse click. It works with database for photovoltaic modules, inverters, thermal collectors and meteorological condition. INSEL offers a programing interface for the extension of block library.

P4 their scope and output: INSEL contains a variety of application like graphical and numerical output either user defined or built in. It covers solar irradiance simulation, photovoltaic, and solar thermal applications. We can see 1-axis tracking, 2-axis tracking and losses for tilted fixed angles.

P5 their updatability: Yes. Latest version 8.1 is available.

2.7.6 Photovoltaic F-Chart (PV F-Chart)

PV F-chart is a photovoltaic system for design and analysis that include almost all aspect of system analysis. PV F-chart is an implementation method developed at the University of Wisconsin Solar Energy Laboratory to estimate long-term average performance of utility interface systems, battery storage systems and system with no interface or battery storage i.e battery storage system.

P1 their commercial and educational availability and cost: Single user license $400 and academic $600.

P2 their working platform: PV F-chart can be run on all version Windows.

P3 their working capacities: PV F-chart has a good collection of data over 300 location data are stored in PV F-chart and more location can be included at user level. Using this software we can model utility system battery system and stand-alone photovoltaic systems. The main feature of PV F-chart includes fast execution, hourly load profiles for each month, buy/sell coat difference and statistical load variation**.**

P4 their scope and output: PV F-chart shows the energy production and saving, system performance results, solar fraction, efficiency, electricity sold, electricity bought, life cycle saving, life cycle cost, greenhouse gases emission reduction for various energy efficient and renewable technologies and finally financial viability and risk for central-grid, isolated-grid and off-grid.

P5 their updatability: Yes

2.7.7 National Renewable Energy Laboratory Solar Advisor Model (NREL SAM)

It is designed for performance and economic analysis of renewable energy projects; it is best suit to the people involved in renewable energy industries. NREL SAM is best suitable to the project managers and engineers, policy analysis, technology developers and researchers.

SAM predicts the performance and cost of the project is based on installation and operating cost of the project.

P1 their commercial and educational availability and cost: Free of cost

*P2 their working platform***:** Windows 7/8/Vista or Operating system X 10.6 Intel or later.

P3 their working capacities: NREL SAM is a System-Driven Approach and solar energy technologies program technology. System-Driven Approach is very useful for effective resource allocation. Performance model of SAM include the following technologies: Photovoltaic system, parabolic trough concentrating solar power, power tower concentrating solar power, Fresnel concentrating solar power, dish-stirling concentrating solar power, conventional thermal, solar water heating for residential or commercial buildings, large and small wind power, etc.

P4 their scope and output: SAM displays modeling result in tabular form, graphs and metrics that shows levelized cost of electricity, operating cost, capital cost and maintenance costs rather than cost it also shows the peak and annual system efficiency, system energy output and hourly system production.

P5 their updatability: Yes, latest version is SAM 2014.1.14, updated on 14 January, 2014

2.7.8 Solar Design Tool

Solar Design Tool in online tool for designing solar system online, that provide user a comfortable platform to design and configure solar electric power system and panel layout.

It has many features like string configuration for string and distributed MPPT inverter systems, branch configuration for micro inverter system, automatic optimal panel layout generation and an embedded drawing tool to quickly sketch or modifying installation areas.

*P1 their commercial and educational availability and cost***:** Free version is available for trial but further we have to pay for it. It is available in three mode Lite, Professional and smallmedium business, professional is available in $25 per machine for a month validity, $22.67 per machine for quarter and $20 per machine for annual.

P2 their working platform: It is internet based platform can be used on Google Chrome, Firefox 3.5 or above, Internet Explorer 7/8, and Apple Safari. It do not support Internet Explorer 6.

P3 their working capacities: It can be used to generate system designs, string sizing, and system comparison and array layout design

P4 their scope and output: It provides a list of all system output for the supplied inputs and provide output in comparative form is a summary report of the system. The major output in summary report include record of low temperature and average high temperature of installation site, STC DC output, of array, PTC DC output of array, CEC output of array, number, model name sand specification, area of array maximum AC output current and basic schematics of the roof.

P5 their updatability: No, not required

2.7.9 Environmental System Performance-renewable (ESP-r)

ESP-r is an integrated renewable energy modelling tool for simulation of the visual, acoustic and thermal performance of building and the energy use and gaseous emissions along with associated environmental control system.

It equipped to model heat, air, moisture and electrical power flows at user determined resolution. It was developed by the University of Strathclyde; it is primarily used in research or as a teaching tool.

P1 their commercial and educational availability and cost: Free of cost available for all users.

P2 their working platform: Windows NT/2000/XP or newer, Linux.

P3 their working capacities: It has state of art standard simulation features; it has powerful capability to simulate many innovative technologies including daylight utilization, natural ventilation, contaminant distribution, combined heat and electrical power generation and photovoltaic exterior of the building, adaptive 3D computational fluid dynamics, multi-gridding in 2D/3D environment and control systems.

P4 their scope and output: It is an interactive tool that provides different views of simulation results, variety of performance analysis and interaction between session between assessment domains. Many tools provided to enable the construction of an integrated performance analysis over a range of relevant criteria as per user choice. Analysis is essentially unrestricted and data can be exported to another analysis and graphics.

P5 their updatability: Yes, latest version is ESP11.11 released on June 29, 2011

2.7.10 Solar Pro

Solar Pro is sophisticated simulation software for photovoltaic system; it is able to simulate electricity generation under different conditions that is varied by each system, so that it allows system design based on precise data, since the calculated data come out with persuasive and graphical look. It can be utilized for presentation and education related to photovoltaic system generation.

P1 their commercial and educational availability and cost: Free of cost/ open for all purpose

P2 their working platform: It supports Windows XP/Vista/7 with 32 bit processing.

P3 their working capacities: Solar Pro contains many features basically; it has 3D CAD which is used to simulate shadow influence by the surrounding building and objects, so the user can set optimal setting before the installation of panel. IV cure that is calculated based on module electrical characteristics of each manufactures accurately and quickly.

It also calculate the amount of power generated form the system based on the latitude, longitude and the weather conditions of the installation site, this provide precise simulation results.

P4 their scope and output: Solar Pro output in many forms electrical power generation, I-V curve, shadow effect and life cycle analysis.

P5 their updatability: Yes, latest version is Solar Pro Ver. 4.1 and Ver. 4.2 coming soon.

2.7.11 Photovoltaic Design Program-Grid connected system (PV DesignPro-G)

It designed to simulate photovoltaic energy system operation for one year on an hourly basis. The simulation result is based on climate and parameter selected by the user. PV DesignPro is available in three version PV DesignPro-S for standalone systems, PV DesignPro-G for grid connected systems and PV DesignPro-P for water pumping systems.

P1 their commercial and educational availability and cost: Available in package of $249 solar design Studio.

P2 their working platform: It supports window XP / Vista / 7 / 8 / 32&64 bit / Mac OS

*P3 their working capacities***:** PV DesignPro is best suitable to professional as well as for research purpose. The main objective behind the development of this software is that it provide accurate and depth information on likely system power output and load consumption, backup during the system operation as well as financial impact of the installing the proposed system. Six type of panel tracking is incorporated into the program fixed slope and axis, tracking on horizontal north-south axis, tracking on horizontal east-west axis, tracking on north-south axis parallel to the earth axis, tracking on vertical axis with fixed slope and continuous tracking on two axis. Panel shading information also can be entered into the syste.

P4 their scope and output: Output of PV DesignPro is very user friendlily; it shows solar fraction charts by month, storage states of the charge by month, annual performance of energy produced, necessary backup and state-of-charge. It also provide the detail analysis regarding cash flow of purchased and sold energy, systems cost, cost of backup energy, prices of sold energy, maintenance and replacement cost and estimated life of the system.

P5 their updatability: Yes, latest version 6.0 is released on 19 December, 2010

2.7.12 PhotoVoltaic Solar Expert (PV*SOL Expert)

PV*SOL Expert is solar project analysis and planning tools that is used to represent the real word the shading effect from the surrounding objects, so this software is used to takes shading into analytically as much possible.

We can also visualize all roof-integrated or mounted system; even we can calculate shading on the basis of 3D object. It is a multiproduct suite of software for the design, simulation and project financial analysis of the photovoltaic systems ranging from small off-grid to large grid connected system and utility scale.

P1 their commercial and educational availability and cost: Cost for single user Euro 1228.00 PV*SOL Expert Set and Euro 998.00 PV*SOL gridcon.

P2 their working platform: It supports Windows XP/SP3/Vista/7/8 operating system.

P3 their working capacities: The PV*SOL contains two types simulation software PV*SOL expert and PV*SOL gridcon, PV*SOL gridcon contains 3d visualization of PV systems with shade calculation based on 3D shading or object. Optimization can be done by user first select modules and then modules are configured with the inverters. User can optimize the allocation of the module based on the shading position. Then software configures the individual strings.

P4 their scope and output: It provide 3D visualization of yearly radiation reduction for each point of the PV area as well as optimized PV module coverage and the configuration depends on the corresponding to the shading position. It has manual as well as automatic PV module roof coverage and accounts restricted area also. Simulation results intervals 10 minute module yield accounts precise shading ration for each module. Animated 3D visualization can be done of the shade and can be obtained at any time.

P5 their updatability: Yes, PV*SOL 6.0 available for end user.

In conclusion here is an apparent extent of simulation software for simulation, economic evaluation, photovoltaic industry related, analysis and planning, monitoring and control, solar radiation map and online simulation software. All discussed simulation software's are available for commercial and educational purpose; some are free of charge and for some a fee is required is charged to use them. All these simulation software's are updated, user friendly and experimental validation. These software's are designed with different goals in mind, they have some limitation to solve certain problems as summarised in table 2.2

Summary

Most HES designed are mostly for off grid sites, but with the government initiative through Rural Electrification Authority (REA), most of the Kenyan parts will be grid connected, as a result the utilization of renewable energy sources could slow down. Also HES designed for off grid tend to have large battery banks which are costly and have to be replaced every 4- 5 years depending on the operating conditions. Summary of the solar pv software's is as shown in table 2.2

Table 2.2 pv software comparisons.

	Software	Commercial & educational availability	Working platform
1	*Photo Voltaic systems (PVsyst)*	Costly. 102 USD	Any version of Window or any operating system.
2	*Renewable Energy Technologies Screen (RETScreen) by Canadian government*	Free of cost	MS excel and windows
3	*Hybrid Optimization Model for Electric renewables (HOMER)*	99.9 USD	All versions of Microsoft windows and Windows emulators.as parallels for Macintosh.
4	*TRaNsient Systems Simulation (TRNSYS)*	4740 USD	Only windows operating system
5	*INtegarted Simulation Environment Language (INSEL)*	2023 USD	Windows XP, Windows Vista or Windows 7 computers with 32 or 64 bit.
6	*Photovoltaic F-Chart (PV F-Chart)*	400 USD	All version Windows
7	*National Renewable Energy Laboratory Solar Advisor Model (NREL SAM)*	Free	Windows 7/8/Vista or Operating system X 10.6 Intel or later.
8	*Solar Design Tool*	Free	It is internet based platform
9	*Environmental System Performance-renewable (ESP-r)*	Free	Windows NT/2000/XP or newer, Linux.
10	*Solar Pro*	Free	Windows XP/Vista/7 with 32 bit processing.
11		249 USD	window XP / Vista / 7 / 8 / 32&64 bit / Mac OS

CHAPTER THREE

3.0 METHODOLOGY

The following were the research objectives hence the methodology steps

i. Determining the load characteristics of Zuku load (load curves)

ii. Designing a cost-effective hybrid power solution.

iii. Estimating the annual cost savings from the hybrid energy solution and scheduling procedure.

3.1 Load curves and load profile

In determining the load curves and load profile, the following instruments were used.

The Analyzer setup was checked to meet the characteristics of the system under test and the accessories that are used. These included

1. wiring configuration
2. nominal frequency
3. nominal voltage
4. limits used for power quality monitor and event detection
5. properties of voltage leads and current clamps

3.2 Analyzer Input Connections

The Analyzer has 4 BNC inputs for current clamps and 5 banana-inputs for voltages. These clamps have a plastic BNC connector. The use of insulated BNC connectors is necessary for safe measurements.

First put the current clamps around the conductors of phase A (L1), B (L2), C (L3), and neutral. The clamps are marked with an arrow indicating the correct signal polarity.

Next the voltage connections were made: starting with Ground and then in succession N, A (L1), B (L2), and C (L3). The connection was double checked and made sure the current clamps were secured and completely closed around the conductors as shown in the diagram below

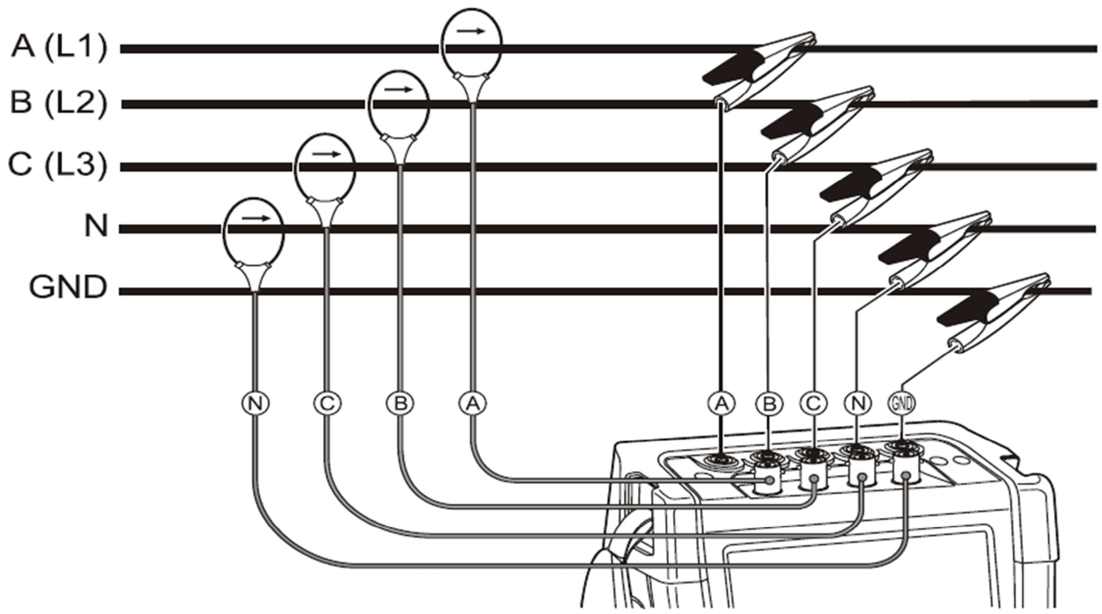

Fig 3.1 diagram showing analyzer connections

3.3 Hybrid energy system design

The system was designed using the PVsyst software. PVsyst is designed to be used by architects, engineer, and researchers. It is also a very useful educative tool. It includes a detailed contextual Help menu that explains the procedures and models that are used, and offers a user-friendly approach with guide to develop a project. PVsyst is able to import meteo data from many different sources, as well as personal data. PVsyst presents results in the form of a full report, specific graphs and tables, and data can be exported for use in other software, whose main page is as show below

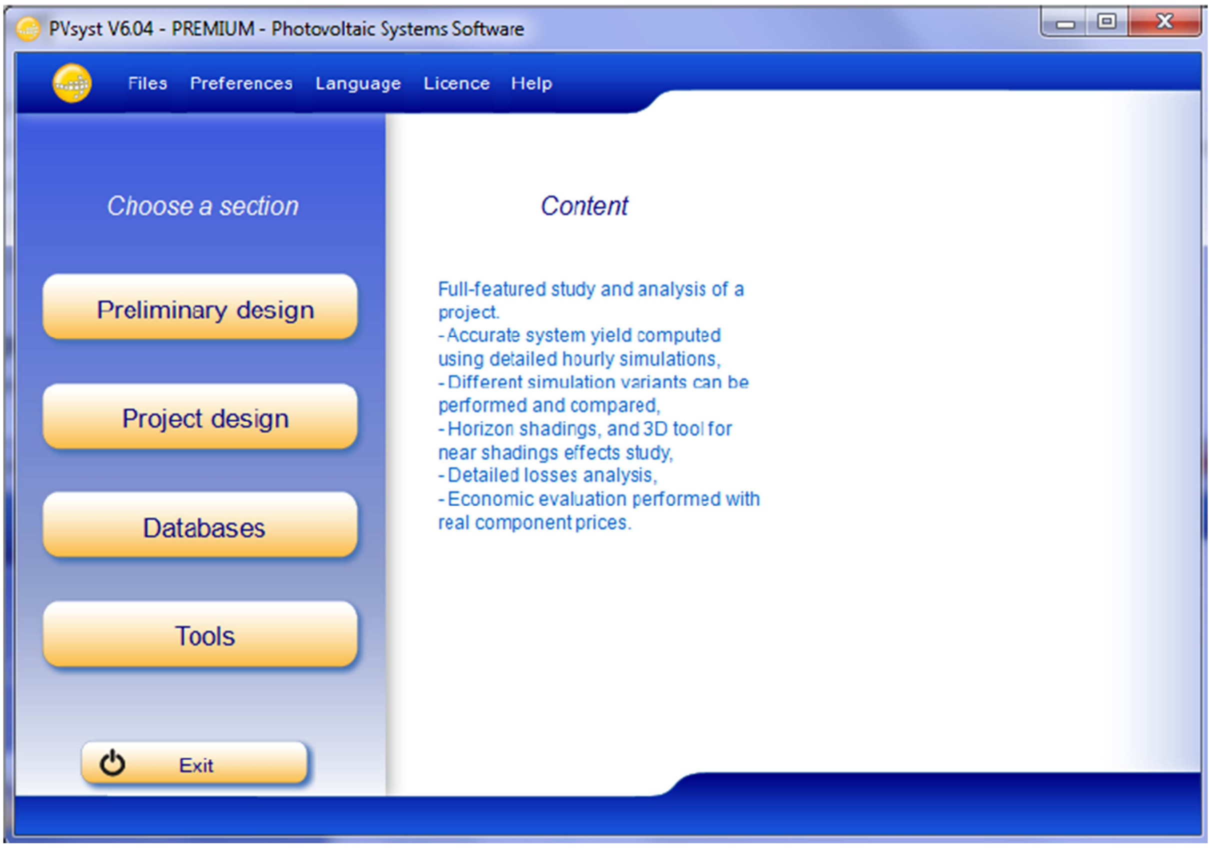

Fig 3.2 diagram showing the main page of the PVsyst software

3.4 General features of the Grid-connected system

Management of the project

For a given project (a defined site and meteo), you can construct several variations for your system ("calculation versions").

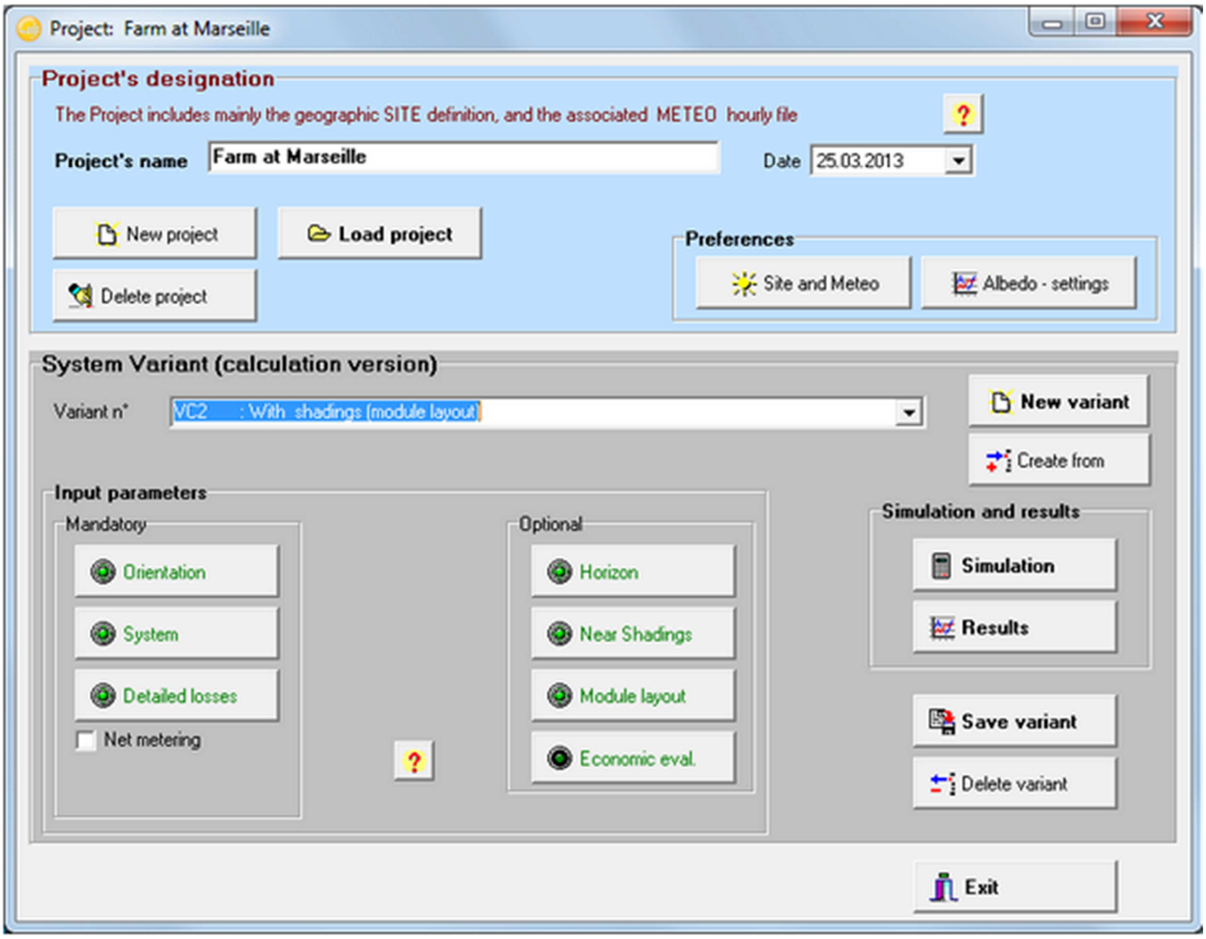

Fig 3.3 diagram showing PVsyst startup of project design

3.5 System design board

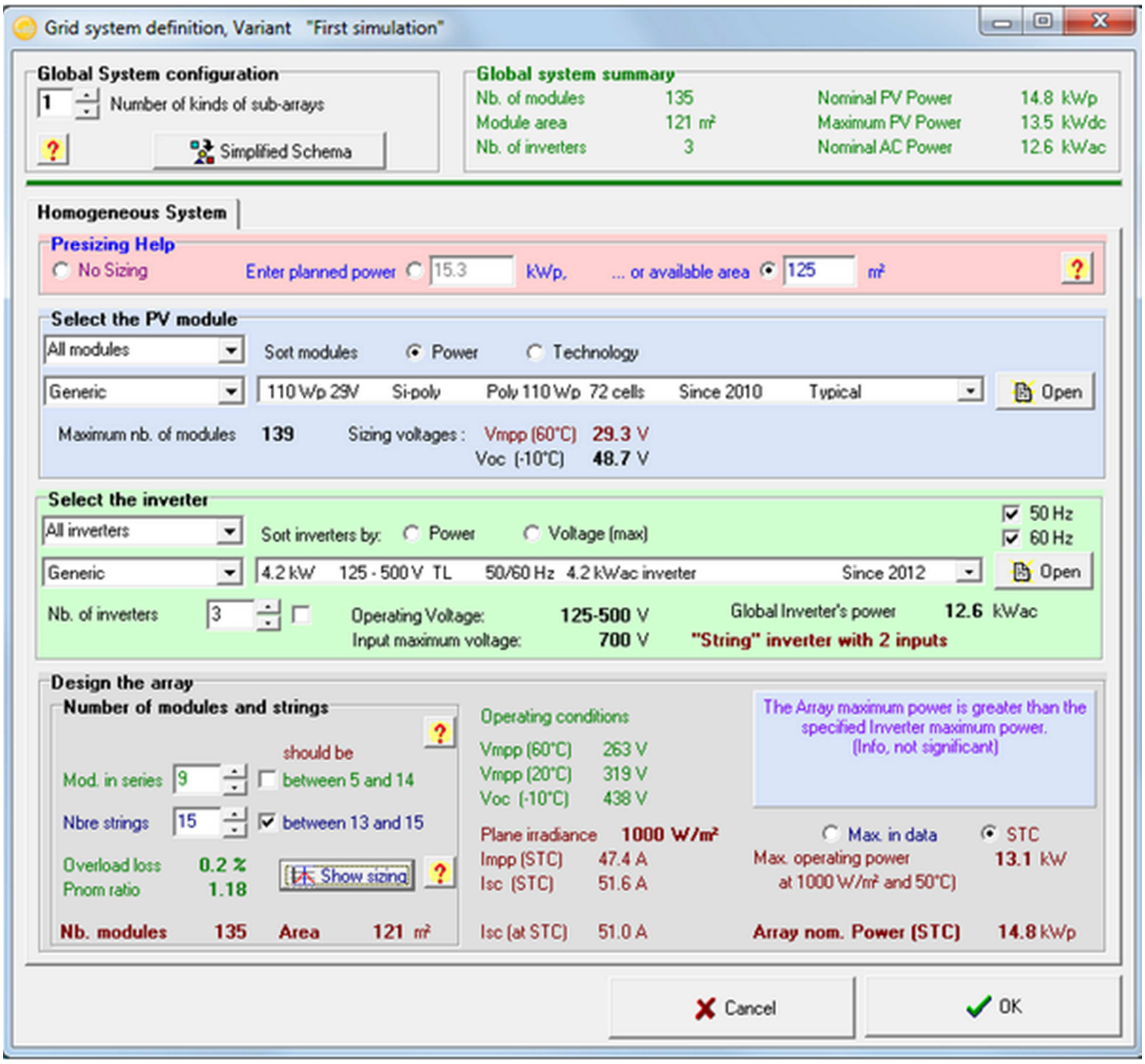

Fig 3.4 Diagram showing how to input solar parameters on PVsyst software

The system design is based on a quick and simple procedure:

1. Specify the desired power or available area
2. Choose the PV module from the internal database
3. Choose the inverter from the internal database

… and PVsyst will propose an array/system configuration, that allows you to conduct a preliminary simulation.

3.6 System sizing: Visual tool

A specific tool gathers all constraints for the sizing of the system:

For the number of modules in a series: the upper diagram shows the I/V curve of the PV array, together with the MPPT range, voltage, power, and current limits of the inverter.

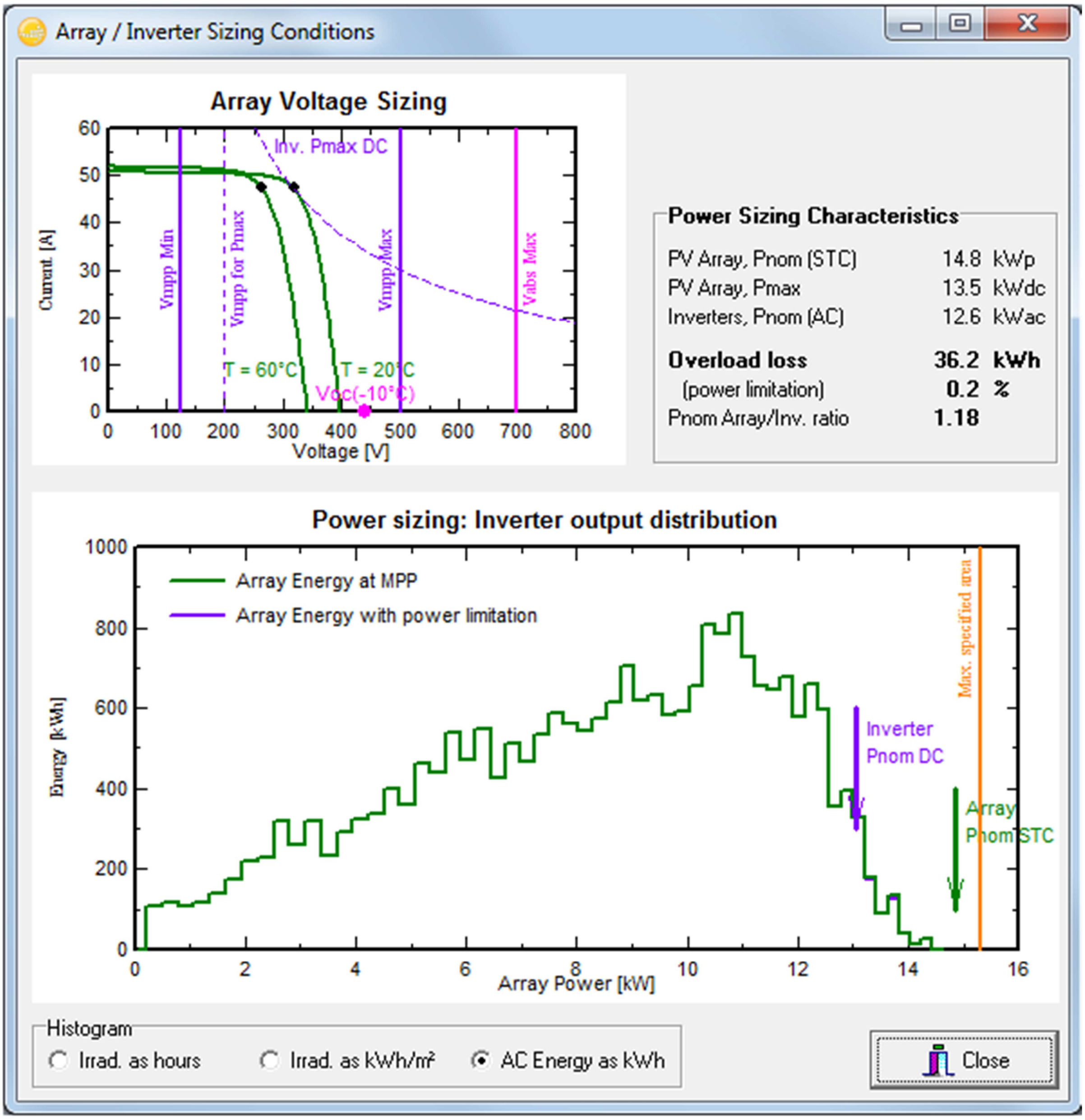

Fig 3.5 Diagram showing inverter design on PVsyst software

For the inverter sizing: the second graph displays the annual distribution of the array power, with the array and inverter nominal power

The optimal sizing of the inverter is based on the acceptable overload loss throughout the year. It usually leads to over-size the power ratio (array nominal power by respect to the inverter nom. AC power), by a factor of 1.25.

After a good system sizing, you can define different losses like far and near shadings using a full 3D editor for the definition of the environmental and near shading conditions.

Specialized tools are also provided for the evaluation of the wiring losses (and other losses like the module quality), the mismatch between modules, soiling, thermal behavior according to the mechanical mounting, system unavailability, etc.

3.7 Simulation and results report

The simulation calculates the distribution of energies throughout the year.

Main results:

1. The total energy production [MWh/y] is essential for the evaluation of the PV system's profitability.

2. The Performance Ratio (PR [%]) describes the quality of the system itself.

3. The specific energy [kWh/kWp] is an indicator of production based on the available irradiation (location and orientation).

CHAPTER FOUR

4.0 RESULTS AND ANALYSIS

4.1 Introduction

This chapter presents the results obtained during the data analysis, design and sizing of the solar PV system for the site. The results also include system simulation results using a renewable energy design and sizing software (PVsyst). Using the load data collected and solar insolation data, the hybrid energy system was designed that would adequately supply power to the site. The designed system will power the site using solar power during the day and kplc/ grid power at night; At at any time if solar and kplc power fails, a 8 KVA generator would power the site

4.2 Existing Energy system Layout

The existing energy system serving the network consist of three phase kplc power and a 40 KVA diesel generator as shown in the diagram below

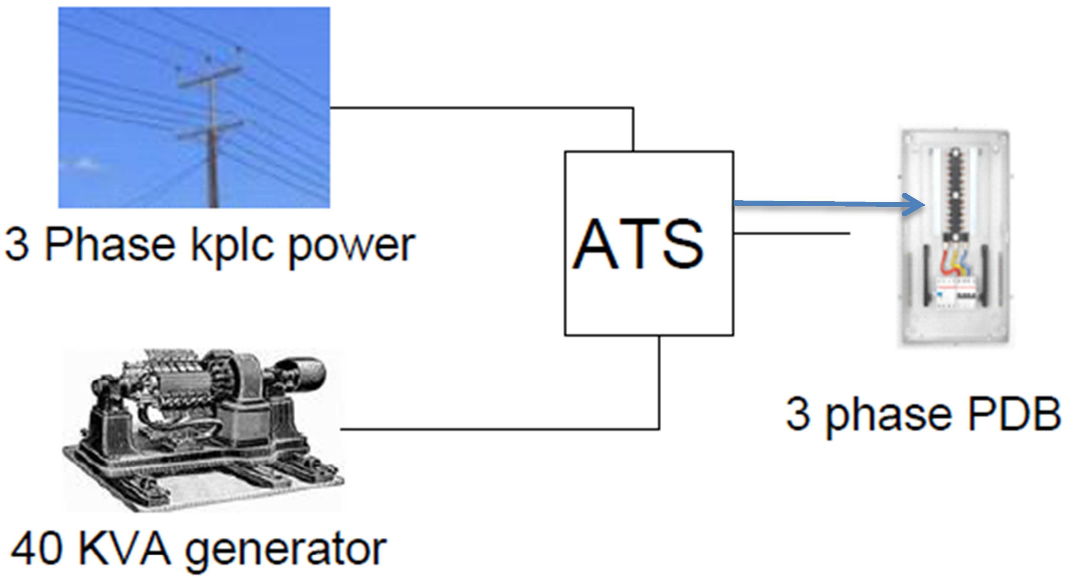

Fig 4.1 diagram showing the existing power layout

4.3 Load Data

The load data was collected and recorded using the power analyzer during weekdays and weekend both day and night and the result recorded in table 4.1

Table 4.1 Load current measured

Day	1	2	3	4	5
L1 (A)	7.1	6.8	6.8	6.5	6.6
L2(A)	5.2	5.3	5	5.2	5.3
L3(A)	6.3	5.8	6	5.8	5.6
Average line current	6.2	5.966667	5.933333	5.833333	5.833333

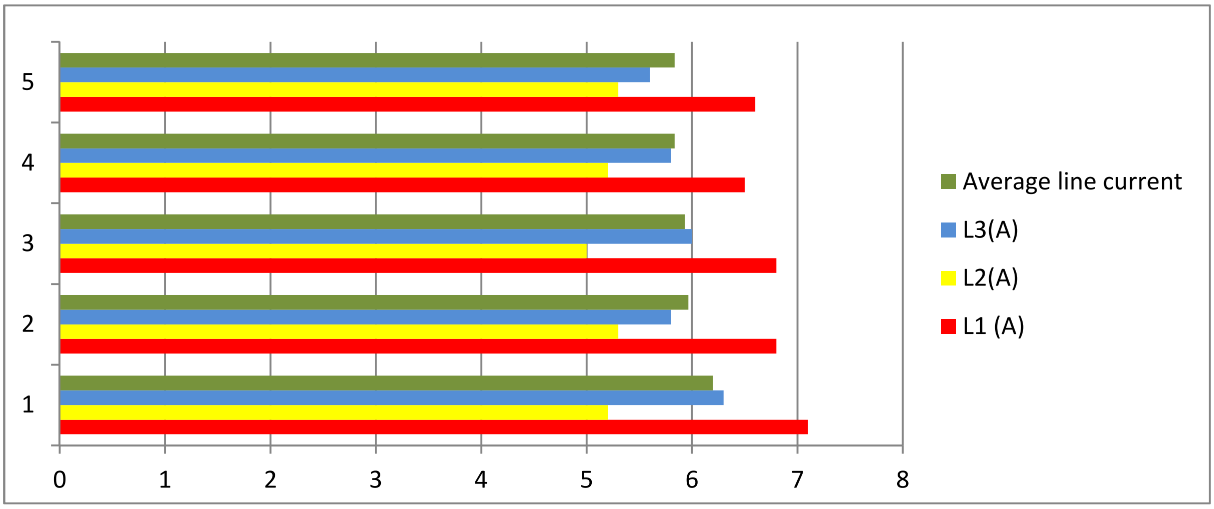

Fig 4.2 Graph showing the current load profile of each phase

4.3.2 Monthly kplc bills and meter readings

From the kplc records, the average kplc bills amounted to KSH 171,757.48 and results for the units consumed and amount charged recorded in table 4.2

Table 4.2 Monthly kplc bills and units consumed

			KPLC monthly bills							
Month	31-Dec	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16
Units (KWh)	9445	1714	9121	2100	8603	4682	5005	4533	5748	5716
Amount (Ksh)	221,236.71	35,316.30	201,242.77	46,566.54	236,101.03	121,820.74	130,180.73	160,514.30	151,679.52	151,284.05

4.3.3 Generator run hours

Table 4.3 generator run hours

Generator operation LOG

Month	Oct-16							
Date	6	13	17	18	26	29	30	31
start	7:10	11:00	16:50	9:10	13:20	6:10	13:35	7:35
stop	9:10	13:50	17:10	17:50	13:50	9:50	23:00	10:55
Duration	2:00	2:50	0:20	8:40	0:30	3:40	9:25	3:20
Total run hour	30:45:00							
Comments	Night power power outages only ocured for 6 hours							

Month	Sep-16								
Date	3	9	13	14	17	24	25	26	28
start	4:13	10:19	16:50	8:45	9:10	9:15	10:17	14:50	22:14
stop	5:16	10:30	17:10	10:14	17:35	18:00	14:52	15:33	23:18
Duration	1:03	0:11	0:20	1:29	8:25	8:45	4:35	0:43	1:04
Total run hour	26:35:00								
Comments	Night power outages only occurred for 1 hour								

Month	Aug-16					
Date	2	4	13	14	15	19
start	7:10	11:00	17:03	0:00	0:00	6:10
stop	9:10	13:50	24:00:00	24:00:00	24:00:00	9:50
Duration (min	2:00	2:50	6:57:00	24:00:00	24:00:00	3:40
Total run hour	63:27:00					
Comments	We had kplc breakdown for 2 days.					

Month	Jul-16					
Date	2	4	7	10	11	23
start	9:20	12:05	7:35	10:02	9:12	13:55
stop	17:40	12:55	9:25	17:15	10:01	16:33
Duration (min	8:20	0:50	1:50	7:13	0:49	2:38
Total run hour	21:40:00					
Comments	Kplc shut down was 1 day					

Month	Jun-16										
Date	5	6	7	12	13	14	17	18	26	27	30
start	9:13	11:00	15:14	9:25	15:20	9:20	19:25	9:35	9:40	8:45	10:20
stop	12:58	11:25	17:05	14:30	16:00	11:01	23:40	11:00	16:20	11:00	17:02
Duration (min	3:45	0:25	1:51	5:05	0:40	1:41	4:15	1:25	6:40	2:15	6:42
Total run hour	34:44:00										
Comments	4 hours black out at night										

Month	May-16									
Date	1	2	7	8	11	15	16	29	30	31
start	6:13	13:13	9:20	10:00	7:10	10:00	16:10	9:33	10:00	9:20
stop	11:30	13:55	16:55	10:30	11:01	14:40	16:35	18:02	10:45	17:52
Duration (min	5:17	0:42	7:35	0:30	3:51	4:40	0:25	8:29	0:45	8:32
Total run hour	40:46:00									
Comments	All power black out occurred during day time									

Month	Apr-16								
Date	1	2	3	13	14	17	18	23	24
start	8:17	11:10	10:09	17:00	8:42	9:20	9:00	1:01	8:45
stop	11:00	15:40	10:42	18:40	9:04	13:00	9:21	5:59	13:06
Duration (min	2:43	4:30	0:33	1:40	0:22	3:40	0:21	4:58	4:21
Total run hour	23:08:00								
Comments	5 hours of blackout at night								

Month	Mar-16											
Date	4	5	11	12	13	20	21	27	28	29	30	31
start	9:12	10:00	9:40	8:50	10:02	8:43	10:00	8:30	9:00	21:02	11:02	0:35
stop	16:55	10:30	16:01	9:24	13:11	17:40	10:30	16:14	9:31	21:42	12:25	3:10
Duration (min	7:43	0:30	6:21	0:34	3:09	8:57	0:30	7:44	0:31	0:40	1:23	2:35
Total run hour	40:37:00											
Comments	3 hours of black out at night											

Month	Feb-16															
Date	1	7	8	10	11	14	15	16	18	18	18	19	20	21	22	23
start	14:05	10:02	8:41	18:00	10:54	9:15	8:30	2:10	8:50	15:15	19:42	9:12	14:55	6:43	9:08	23:02
stop	16:17	17:45	9:27	19:04	11:30	16:52	9:05	3:07	11:35	17:02	20:10	13:24	16:35	8:20	13:07	23:49
Duration (min	2:12	7:43	0:46	1:04	0:36	7:37	0:35	0:57	2:45	1:47	0:28	4:12	1:40	1:37	3:59	0:47
Total run hour	37:58:00															
Comments	2 hours of black out at night															

Month	Jan-16						
Date	18	19	20	26	20	29	31
start	10:10	8:35	13:18	14:01	8:57	9:05	9:20
stop	11:00	8:43	13:22	15:11	15:50	9:20	10:00
Duration (min	0:50	0:08	0:04	1:10	6:53	0:15	0:40
Total run hour	10:00:00						
Comments							

Table 4.3 indicates the time and duration that the generator ran for the year 2016. From The table most power blackouts are experienced during day time thus with the proposed hybrid system, these times the load will be powered with solar thus saving on fuel consumption.

4.3.1 Load Data Analysis

From the data collected the load is fairly constant at 4.2 KW.

4.4 Solar Isolation data for Roysambu Area

This was downloaded from the meteo data

Annual Average: 3.46(KWh/m^2/day

(Source http://www.synergyenviron.com/tools/solar_insolation.asp?loc=nairobi%20kenya)

The table below show monthly insolation data of Roysambu area

Table 4.4 Average monthly insolation data

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3.65	4.37	4.19	3.97	3.36	2.58	2.39	2.56	3.38	3.72	3.76	3.57

The graph below shows the monthly insolation data for Roysambu are

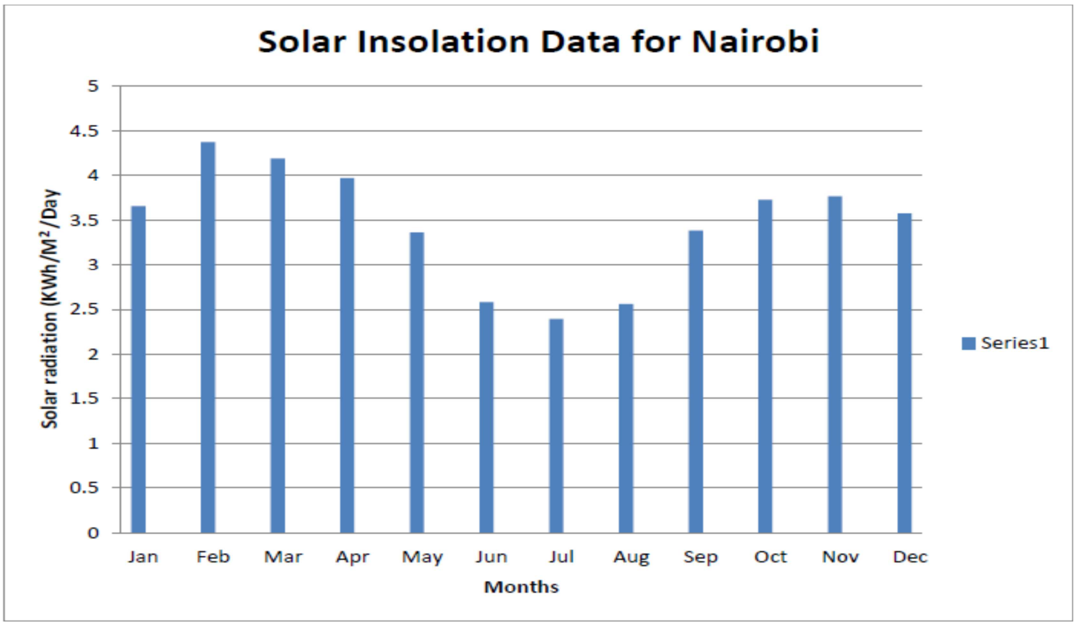

Fig 4.3 solar insolation data for Roysambu area

4.5 Hybrid system sizing and simulation

PVsyst software was used in the design and simulation of the result whose block diagram was as shown in the figure below whose principle of operation and system layout are s show in figure 4.3 and 4.4 respectively. Solar energy provides power to the loads as first priority. If solar energy is not sufficient to power all connected loads, the loads will be powered by utility power. If both solar and utility power is not present then the loads will be powered by a stand by diesel generator as show in the flow chart below

Flow chart showing the principle and sequence of operation of the system

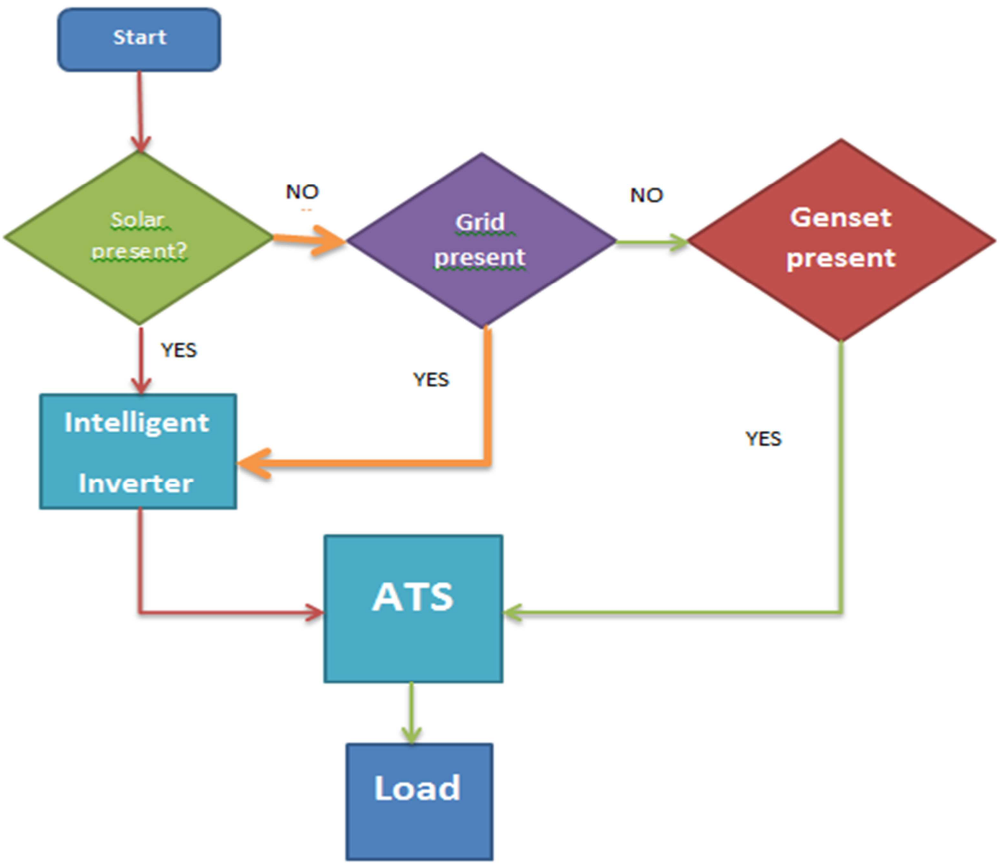

Fig 4.4 System operation flow chart

Design parameters included

Load type. AC power 6 KW

Solar system to power the load for 8 hours daily

Geographical Site Latitude1.2°S and Longitude36.9°E

Legal time zone GMT+3

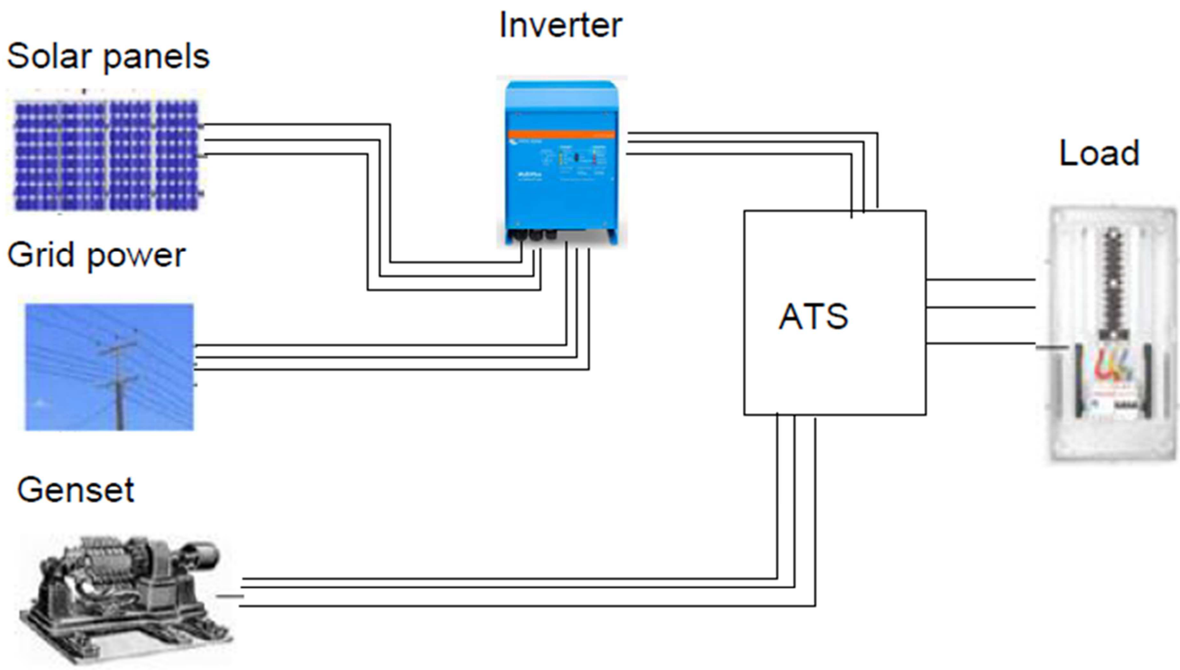

Fig 4.5 diagram showing the hybrid energy solution

Results

PV Array Characteristics

The table below indicates the solar panel specification

Table 4.5 solar panel specification

PV Array Characteristics		
PV module		
make	Si-mono	
Model	SAM66/6 300	
manufacturer	Sunage SA	
Number of PV modules	20 in series	2 in parallel
Total number of PV modules	40	
Unit nominal power	300Wp	
Array global power	12KWp	
Array rating	625V 17 A	
Total Area	72.1M square	

Inverter characteristics
The table below indicates the inverter specifications

Table 4.6 inverter specifications

Inverter Characteristics	
PV module	
Model	IPG 11T
manufacturer	Conergy
Operating Voltage	400-800V
Unit nominal power	11KW

This is three-phase inverter for feeding grid-connected photovoltaic systems and available in performance classes of 8, 11 and 15 kW. Have outstanding peak efficiency factors, patented technology and high-quality workmanship make them a reliable choice for permanently high system yields. The inverter supplies the same output in all three phases and therefore avoid unbalanced loads on the grid. This allows for flexible and simple planning and installation.

4.8 Result simulation

System Overall performance
The table below indicates the total energy produced by the system per hour in a day. The system is able to meet the load demand of 48KWh per hour for 8 hours each day

Table 4.7 Energy produced by the system per hour

Roysambu2
Monthly Hourly sums for E_Grid [kWh]

	0H	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H
January	0	0	0	0	0	0	0	34	105	168	214	222	229	218	192	154	110	55	3	0	0	0	0	0
February	0	0	0	0	0	0	0	26	92	154	193	207	211	210	189	162	120	61	3	0	0	0	0	0
March	0	0	0	0	0	0	0	39	113	169	209	225	227	218	206	179	132	67	3	0	0	0	0	0
April	0	0	0	0	0	0	0	43	105	148	183	198	202	202	178	147	101	46	0	0	0	0	0	0
May	0	0	0	0	0	0	0	50	110	157	188	184	189	182	170	137	94	42	0	0	0	0	0	0
June	0	0	0	0	0	0	0	39	93	132	167	169	174	164	150	128	95	41	0	0	0	0	0	0
July	0	0	0	0	0	0	0	31	78	119	151	159	166	160	148	121	88	42	0	0	0	0	0	0
August	0	0	0	0	0	0	0	34	86	127	154	161	169	161	147	123	86	42	0	0	0	0	0	0
September	0	0	0	0	0	0	0	51	111	158	192	200	195	186	165	131	89	39	0	0	0	0	0	0
October	0	0	0	0	0	0	2	58	114	154	196	204	213	204	183	152	94	35	0	0	0	0	0	0
November	0	0	0	0	0	0	2	53	107	150	178	189	194	183	168	133	85	29	0	0	0	0	0	0
December	0	0	0	0	0	0	0	46	107	161	192	207	210	209	188	146	95	37	0	0	0	0	0	0
Year	0	0	0	0	0	0	4	505	1222	1798	2216	2325	2380	2297	2085	1712	1188	537	10	0	0	0	0	0

The system produces 18279 KWh per year at a performance ratio of 83.9%

The performance ratio is a measure of the quality of a PV plant that is independent of location and it therefore often described as a a quality factor. The performance ratio (PR) is stated as percent and describes the relationship between the actual and theoretical energy outputs of the PV plant. It thus shows the proportion of the energy that is actually available for export to the grid after deduction of energy loss (e.g. due to thermal losses and conduction losses) and of energy consumption for operation.

The closer the PR value determined for a PV plant approaches 100 %, the more efficiently the respective PV plant is operating. In real life, a value of 100 % cannot be achieved, as unavoidable losses always arise with the operation of the PV plant (e.g. thermal loss due to heating of the PV modules). High-performance PV plants can however reach a performance ratio of up to 80 % [14]

The graph below indicates the performance ration of the system per month, indicating that the systems monthly PR is above 80%

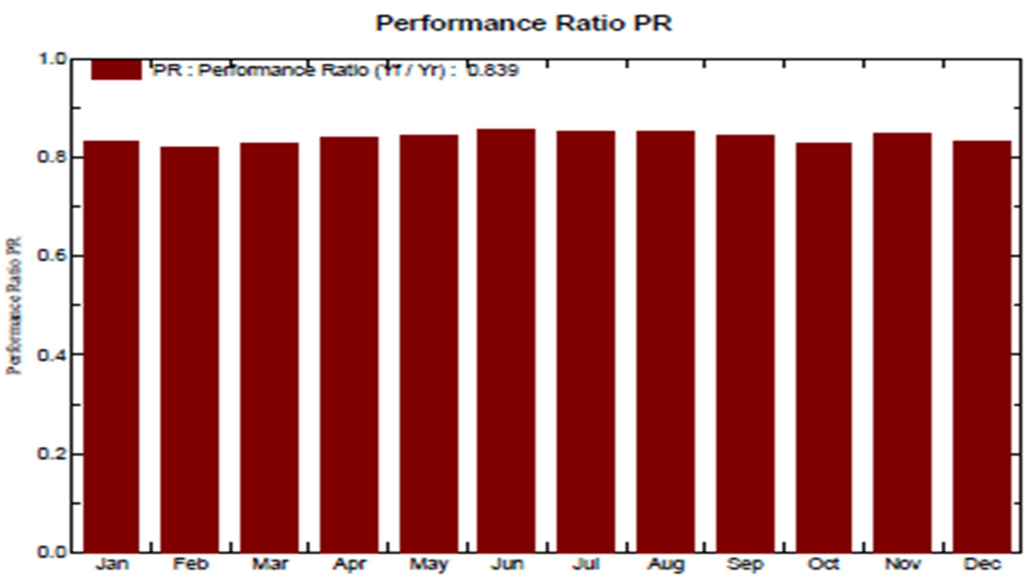

Fig 4.6 system performance ratio

The generator will provide power when both solar and grid are not available. With an average fuel consumption of 2.2 liters per hour

The 8 KVA is able to support the inrush current caused by Aircons due to soft starting enhanced by delayed start up with the help of automatic voltage switchers that are timed differently

4.10 Financial Analysis

Existing Solution

The energy cost components consist of;

1. Monthly kplc bills,
2. Generator cost (KSH 1,484,500.00 as buying price) which is discounted annually at the rate of 14% for 10 years
3. Annual generator operation and maintenance
4. Generator fuel which is delivered at KSH 80 per liter, 500 liters per month

Table 4.8 energy cost component of existing solution

Energy cost component	
	Annual amount
kplc bills,	1,688,558.13
40KVA Generator cost	276,591.63
Annual generator operation and maintenance	220,000.00
Generator fuel delivered (500L*80*12)	480,000.00
TCO	2,665,149.76

The energy cost ratio is as shown in figure 4.5, with kplc bills being highest with 63 % while generator operation and maintenance is least with 8%

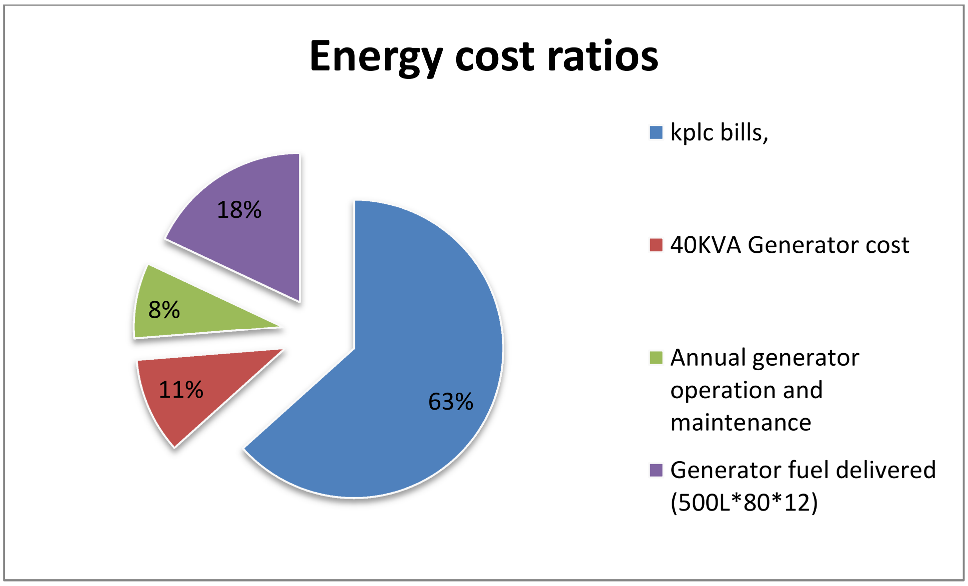

Fig 4.7 Annual cost components

Proposed Hybrid solution

The site to be powered by solar power for 8 hours 365 days a year, thus for the remaining time of the day, the site will be powered by grid power unless an outage occurs where the site will run on a 8KVA generator with a rated fuel consumption of 2.5 liters per hour and Ksh 40,000.00 annually for operation and maintenance. Table 4.8 indicates the investment cost for the proposed hybrid solution

Table 4.9 Investment cost for the proposed hybrid solution

	Investment cost		
		Amount	Annually (Discounted)
1	Solar (25 years discounted	2,242,000.00	334,191.00
2	8 KVA generator (10 years discounted)	240,000.00	45,586.60
	Total investment cost	2,482,000.00	379,777.60

The site is supplied at Domestic consumer (DC) tariff which kplc charges an average of Ksh 26 per Kwh.

The energy cost components comprises of the following

1. Solar solution capital cost with a life cycle of 25 years as provided by the manufacturer. This is to be discounted at the rate of 14.4% for 25 years.
2. 8 KVA diesel generator cost with life cycle of 10 years that consumes 2.5 liters per hour. This is to be discounted at the rate of 14.4% for 10 years.
3. Generator operation and maintenance
4. Fuel cost

Table 4.10 Energy source system usage and produced energy

System	Units generated
Required (6KW*365days*24 hours)	52,560.00 KWh
Solar	18,279.00 KWh
Generator (Approx. 93 run hours*6 KW)	558.00 KWh
kplc	33,723.00 KWh

Table 4.11 Annual Savings realized

Annual Savings on energy cost components				
		Before	After	Savings
1	Investment	276,591.63	379,777.60	(103,185.97)
2	Kplc bill reduction	1,688,558.13	876,798.00	811,760.13
3	Generator operation and maintenance	220,000.00	40,000.00	180,000.00
4	Generator fuel consumption	480,000.00	18,600.00	461,400.00
	Total savings			1,349,974.16

Thus the payback period= investment / annual savings

2,482,000.00 / 1,349,974.16 = 1.8 years

CHAPTER FIVE

5.0. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The simulation results of the solar / grid powered telecom base station suggests that it is more cost efficient to deploy solar grid tie solution for the given load of 6 KW.

Results show that the estimate cost of production was found to be 50.39Ksh/KWh for the grid system and diesel generator as primary back in the event of power blackout.

The new hybrid solution gives the cost of production as KSh15.83/KWh with a payback period of 2 years.

Also the hybrid system gives reduced diesel fuel consumption, reduced operation and maintenance cost hence reducing the carbon footprint.

5.2 Recommendations

I highly recommend the government of Kenya to implement the net metering policy which should include

A. Policy aspects

1 With further price drops being a certainty, GoK should pave the way for net metering to prepare the market within the very near future.

2 Currently PV is exempted from VAT (16%). We recommend maintaining the current situation for at least 2 years until a net metering market is established.

B. General regulatory aspects

1 Allow all customer classes to do net metering

2 Allow all renewable energy sources to be tapped through net metering

3 Do not arbitrarily limit net metering as a percent of the utility’s peak demand.

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