DECENTRALISED SOLAR FARM WITH SMART METERING AND BILLING SYSTEM

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A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND INFORMATION ENGINEERING IN PARTIAL FULFILLMENT FOR THE AWARD OF BACHELOR OF ENGINEERING DEGREE IN ELECTRICAL AND ELECTRONICS ENGINEERING.

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DR. VICTOR. O. MATTHEWS

MAY 2019

DECLARATION

I hereby declare that I carried out the work in this thesis in the Department of Electrical and Electronics Engineering, Covenant University under the supervision of Dr. Victor O. Matthews. I also solemnly declare that to the best of my knowledge, this report has not been submitted here or elsewhere in a previous application for the award of a degree. All sources of knowledge has been duly acknowledged.

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CERTIFICATION

This is to certify that the Project titled "**Decentralised Solar Farm with Smart Metering and Billing System**" by Olojede Damilola Rebecca, meets the requirements and regulations governing the award of the Bachelor of Engineering, B.Eng. (Electrical and Electronics Engineering) degree of Covenant University and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This project is first and foremost dedicated the Almighty God, the source through which every other thing subsists, my heavenly Father, guide and strength. Secondly I dedicate it to my wonderful parents Mr. & Mrs. Sola Olojede who have immensely supported in every way all through the project's implementation.

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I pray God blesses you all richly.

ABSTRACT

In using solar renewable energy to supply power to a large community, the method usually adopted is clearing large acres of land to mount solar panels connected to a grid for transmission, whilst in cases where the consumer is a ‘lone ranger’ (i.e. the energy generation is for self-consumption) which is the most common, the panels are mount on the roof top/backyard of the consumer’s apartment with its power output directly connected to the house appliances. Merging the concepts of ‘self’ and ‘large scale community’ solar energy generation can be done by mounting panels on the rooftops/backyard of individual houses (consumers) and connecting all energy generation sources to a power grid, managed by a central dispatch system within the community that monitors energy generation and consumption per house, is what this decentralised solar system design presents.

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CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND OF STUDY

Energy generation through solar as a renewable source is an emerging technology with a growing industry in various parts of the world as it provides a clean and effective alternative source of energy generation dependent on a resource that we have in abundant supply, “The Sun”. Implementing this technology and spreading its market in the nation requires innovation in coming up with a structure to integrate its use in the various sectors of the nation and to all classes of people, in a way that benefits the populace at large. One of such innovations is the decentralisation of solar farms which is what this project seeks to propagate.

In using solar renewable energy to supply power to a large community, the method usually adopted is clearing large acres of land to mount solar panels connected to a grid for transmission, whilst in cases where the consumer is a ‘lone ranger’ (i.e. the energy generation is for self-consumption) which is the most common, the panels are mount on the roof top/backyard of the consumer’s apartment with its power output directly connected to the house appliances.

Merging the concepts of ‘self’ and ‘large scale community’ solar energy generation can be done by mounting panels on the rooftops/backyard of individual houses (consumers) and connecting all energy generation sources to a power grid, managed by a central dispatch system within the community that monitors energy generation and consumption per house. This is the concept of solar energy decentralisation, and it allows for redirection of generated energy not in use to factories or event centres(which usually consume more energy than residential buildings) within the community, and other locations outside the community at a cost determined by the market.

An example can be seen by using an educational institution setting such as Covenant University as a case study that has student residential halls that are considerably vacant during the day between (8-5pm) due to various class engagements. Energy generated by the solar panels mounted on the residential building during these hours, can be redirected to other buildings within the community such as the Hebron water factory or the multipurpose halls which usually consume more energy during the working hours of the day. In the same way, the generated energy could be redirected to other communities around Ota at a cost, thereby serving as an added source of income to the institution and an added energy supply source to the Ota community and more depending on the extent the power grid network reaches. And all of these energy movements can be monitored by a Central Energy Dispatch.

1.2 MOTIVATION FOR THE STUDY

1.2.1 FACILITATING INDEPENDENT SOLAR OFF-GRID SYSTEMS:

The nation is still largely dependent on the power supply provided by PHCN (Power Holding Corporation of Nigeria) which has failed in providing constant/ adequate power for the entire populace. Implementing this concept of solar energy decentralisation would encourage real estate owners and community builders to invest in developing mini grids for energy generation within their local community, thereby providing a relatively stable and sufficient supply which translates to a decline in their dependence on the nation’s main supply.

1.2.2 MAXIMISING LAND USE SPACE:

The concept of centralising solar energy sources before now usually involves clearing large acres of land for panels to be mounted upon, but the concept of energy decentralisation erases the need to waste such amount of land. In a place where the aggregate between human population and available land area is low, such as Lagos Nigeria, this innovation is very essential in propagating the expansion of the renewable energy industry with respect to the ease involved in integration in a community.

1.2.3 RURAL ELECTRIFICATION:

There are many villages that do not yet have access to the power supply provided by TCN. The cost of transporting grid lines to these areas and the losses incurred over these lines due to their distance from the energy generation sources further state the inefficiency of this means of rural electrification. Exploring renewable technologies in this light, with community settings put into consideration, more villages can make use of the natural resource in their disposal to generate electrical energy for use. Villages in the north with high solar irradiance could maximise the opportunity in propagating their local businesses such as cattle rearing, farming with mechanised advancements (which usually involves large masses of land), and their standard of living at large.

1.2.4 REDUCTION OF ELECTRICITY COST:

A study done by Issah Alhamad, a student of U.A.E. (United Arab Emirates) University, on the comparison between a stand-alone, and grid connected roof mounted PV Solar System using HOMER (Hybrid Optimization of Multiple Energy Resources) showed the economic and technical benefits involved in the implementation of grid connected energy generation systems as compared to stand alone systems and 'no PV' energy generation systems. There is a reduction in price associated with power generation covered by utilities, some due to economies of scale attached to bulk purchase of materials etc. which eventually result in lowering electricity prices due to the increase of the flow of electricity over the grid.

Others are to increasing community considerations for implementing renewable energy systems thereby increasing sustainable employment opportunities for residents.

Also, it improves public view on sustainable energy as well as increase consciousness of oneness in a society.

1.3 AIM

This project is aimed at ascertaining the feasibility of operating a decentralised solar power generation system with a smart monitoring system, as well as presenting relevant design considerations that are essential in the physical implementation of similar systems.

1.4 OBJECTIVES

In achieving the above stated, the following objectives have been put in place:

- To analyse the average load usage per consumer unit for a community with an estimated population and then design a decentralised solar energy generation and distribution system.
- Design a visual representation of a mini – solar powered community system with individual housing units connected to a central energy distribution system.
- To design a smart metering system which monitors energy consumption per unit for the connected homes, and transmits this information to the central dispatch system.
- Design a billing system that charges the user based on the energy meter readings.

1.5 METHODOLOGY

In carrying out this project the following will be done:

- Solar System Design: An estimate loa analysis would be done on energy consumption in a community. The result from this would be used to calculate number of solar panels required needed and how they should be connected as well as the rating of the storage devices to be installed.

- Wiring Design Consideration: A load analysis comes next to enable implementation of an efficient wiring system interconnecting the various energy generation sources to the grid and the central dispatch to avoid minimal losses.
- Smart Metering and Billing System Design: This involves design and construction of a meter that effectively evaluates energy consumption per housing unit and transmits this information over the network to a central display for effective monitoring and billing.

1.6 SCOPE

This study involves:

- Design overview for a grid-connected solar energy generation system (roof-mounted solar panels) for an community.
- Building material considerations that would ensure minimal lines loss/voltage drop, from energy generation points to central distribution points.
- Construction of a smart metering system that efficiently measures energy consumption at individual housing units and then transmits information to a central monitoring and control system.

1.7 RELEVANCE

In line with the objectives of REA (Renewable Energy Association), this project would show through practical, the benefits of decentralised solar energy generation and thereby propagate community involvement in energy generation using renewable energy sources. In the long run this project seeks to provide a setting for government involvement in renewable energy technologies so as to encourage them to provide financial incentives to further facilitate its usage. This in the long run would increase energy availability in the nation thereby improving our standard of living.

1.8 REPORT ORGANIZATION

This project report is organized as follows:

Chapter 1 provides a brief background of the project work, the reasons for embarking on the project and a sketch of the methodology which is needed to implement the project.

Chapter 2 focuses on a critical review of the technical and academic literature works on previous efforts. It entails how the project will be carried out in comparison to previous trials by other researchers.

In Chapter 3, information is provided on the system design and methodology used to achieve objectives of the project. Detailed information on the physical implementation of the project will also be provided.

Testing and implementation are carried out in Chapter 4. The results of the implementation and testing for this project are discussed in this chapter. Challenges faced during the implementation of this project including contributions and suggestions on further work that can be done will be discussed.

A quick recap of the entire project including achievements, recommendations and challenges faced are stated in Chapter 5.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter covers a proper description of the concepts building up this work, and a major example is "Decentralised Energy Generation". The history and evolution of the use of Solar in power generation in various nations and economic settings will be analysed. Smart Metering and Billing Systems would also be considered in relation with grid connections and energy flow in grid networks. Finally, a review of previous research and projects relating to the concept of decentralisation of solar energy generation plants and its monitoring and distribution using smart metering and billing systems is considered. The information garnered from this review will be very vital to the situation of this project.

2.2 DEFINITION OF CONCEPTS

2.2.1 ENERGY GENERATION USING SOLAR

Solar energy basically represents the energy gotten from the **Sun.** This is done through the use of setting up photovoltaic cells (solar panels) at angles direct to the sun's rays to capture this radiant light and then convert it to electrical energy suitable for powering appliances and electrical load.

2.2.1.1 SOLAR PHOTOVOLTAIC (PV) TECHNOLOGY

The word photovoltaic is coined up from two words “photo” which means light and “voltaic” that refers to production of electric current by chemical action. It can be simply stated to represent energy generation due to light emissions on silicon cells. According to Mariam Webster Dictionary photovoltaic is used to describe utilizing the generation of a voltage when radiant energy falls on the boundary between dissimilar substances (as two different semiconductors)

The solar PV technology is a semiconductor-based technology used to convert solar radiation into direct electricity via the photo-electric effect, where solar radiation is simply quanta of electromagnetic radiation called *photons*. These *photons* neither have mass nor electric charge but possess energy and momentum, which cause them to displace electrons from semiconductors to generate electricity.

For solar cells, a thin semiconductor wafer is specially treated to form an electric field, positive on one side, negative on the other. When light energy strikes the solar cell, electrons are knocked loose from the atoms in the semiconductor material. If electrical conductors are attached to the positive and negative sides, forming an electrical circuit, the electrons can be captured in the form of an electric current, which is electricity produced. This electricity can then be used to power a load, such as a light or a tool. This is what is known as the photo-electric effect.

2.2.1.2 BASIC COMPONENTS INVOLVED IN SOLAR ENERGY GENERATION

For solar energy generation to occur some processes have to be put in place, it starts with energy moving from point of generation to storage or usage. The components required for this are explained below.

SOLAR PANELS

These are also known as **Photovoltaic (PV) Panels**. The alternative name used for the solar panels is coined from the physical principles guiding their operation known as the photovoltaic effect. This is the conversion of light energy into electrical energy. In the generation of solar energy, the major source of energy is the sun from which solar panels get light to generate into electricity.

A complete solar system setup consists of Photovoltaic (PV) modules. Photovoltaic modules are a combined assembly of solar cells connected in an array as shown in Fig. 2.1. It is this array of PV systems in a photovoltaic module that bring about the generation or supply of solar energy especially in commercial or residential applications.

There are basically three classifications of solar panels and they are:

1. MONOCRYSTALLINE SOLAR PANELS:

   The most efficient and equally expensive panels are made with monocrystalline cells. This is because these solar cells are made with very pure silicon and involves a complicated crystal growth process.

2. POLYCRYSTALLINE SOLAR PANELS:

   Otherwise called multi-crystalline are solar panels made with a variety of crystalline cells which are a little less expensive and slightly less efficient than monocrystalline cells. This occurs due to the way the cells are developed. They are grown in single crystals but in a large block of many crystals. Like monocrystalline cell, they are also sliced into wafers to produce the individual cells that make up the solar panel.

3. AMORPHOUS SOLAR PANELS:

   Are solar panels made from thin layers of silicon deposited on a base material such as glass or metal to create the solar panel. They are much cheaper but their energy efficiency is very low when compared to the carbon panels. Amorphous solar panels can be made into long sheets of roofing material to cover large areas of a roof surface.

Fig. 2.1: Solar Photovoltaic Modules

CHARGE CONTROLLERS

A charge controller regulates the rate at which the batteries dissipate or absorb electric current. It prevents overcharging and helps to protect the system from excess voltage. The charge controller can either be a stand-alone device or an integrated charge circuitry within the battery. In solar systems, they are also known as solar regulators. In summary they effectively improve battery life.

The stand-alone charge controller usually comes in two types, it could be a series charge controller or a shunt charge controller. The series charge controller operates in the system by disallowing the continuous flow of current into batteries that are full while the shunt regulator simply diverts the excess charge into an auxiliary load.

BATTERIES

Solar batteries are deep cycle batteries that provide storage for solar and other types of renewable energy. Deep cycle batteries are different from normal batteries, and so they are recommended foe renewable energy systems as they are the best suited batteries for sustaining renewable energy systems because they are capable of surviving repeated long hours of discharging which is the characteristics of intermittent renewable energy systems. Energy stored in them can be used to power DC loads that could be present at the central dispatch unit directly, and can also be converted with an inverter to supply AC power to the residential homes through the grid.[15]

There are three batteries commonly used in solar PVs and they are:

- Lead-Acid Batteries which is of two different types; Absorbent Glass Mat (AGM) lead acid batteries and Gel-cell batteries
- Alkaline Batteries

Comparing all three, the AGM lead batteries are the industry standard, as they are maintenance free and particularly suited for grid-tied systems where batteries are kept at a full state of charge. They are leak proof and do not emit gases when charging, hence they can be used indoors. They have the advantages of the sealed gel types and are of a higher quality, maintain voltage better, self-discharge slower and last longer. The alkaline batteries are more costly, hence they are only recommended where extremely cold temperatures are anticipated or for specific industrial applications requiring their advantages over lead-acid batteries.

In this project setup, in addition to storing energy in batteries excess energy can be redirected to external load points outside the community in need for a fixed tariff rate

INVERTERS

A solar inverter which is also known as photovoltaic inverter is an electrical component that converts direct current into an alternating current. The inverter takes the DC output signal from the PV panel and converts it into frequency AC signal. Most residential and commercial appliances require an alternating current to be powered up, this is why an inverter is needed to first convert DC to AC and then supply the alternating current to an electric grid that can transfer this energy to its point of use.

They are the vital elements in a photovoltaic system that allows AC powered equipment in a solar energy generation system to function. They also help reduce voltage fluctuations in a PV system.

Figure 2.2a and b below show a chart overview of the energy flow of a typical solar energy generation system as well as a pictorial representation of each component that makes up a PV system and their components, for better explanation.

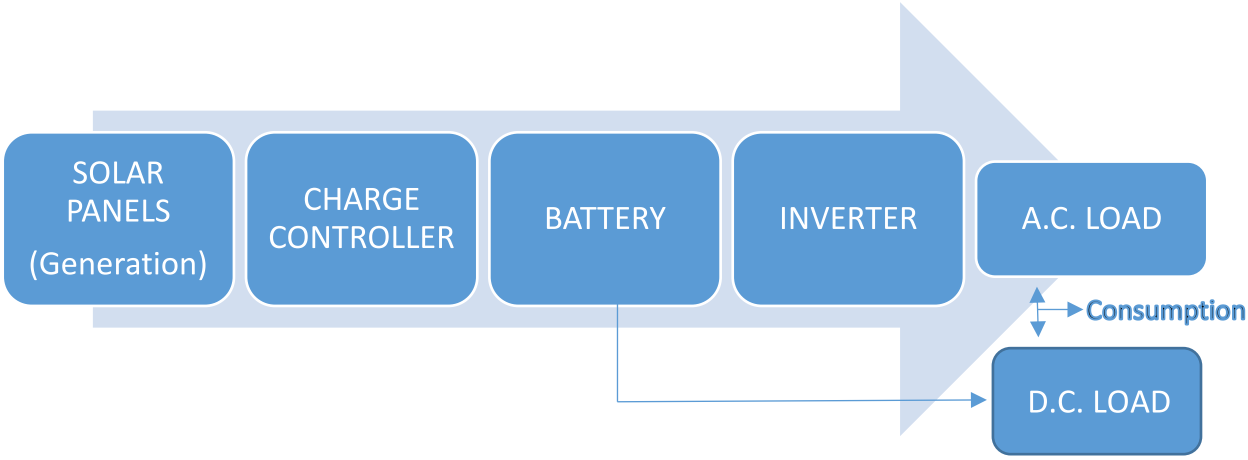


Figure 2.2a Block diagram of a solar energy generation

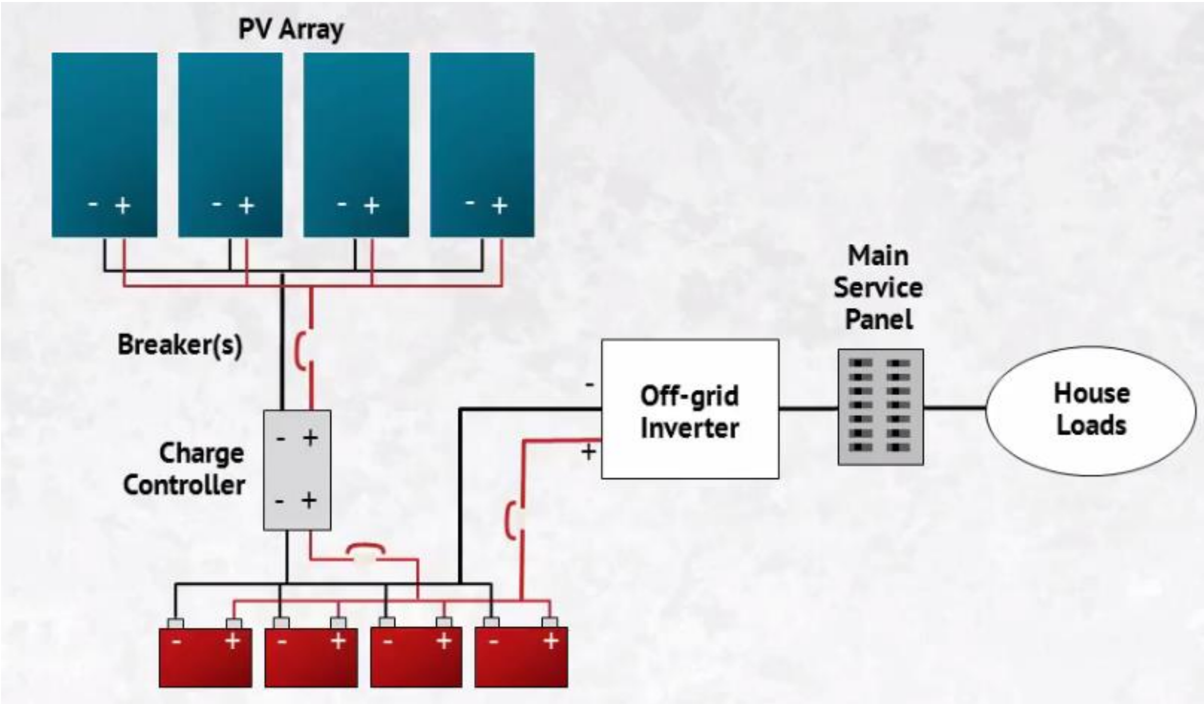


Fig 2.2b Schematic diagram of a solar generation system

Moving further from this we see that the setup for the implementation of this technology (i.e. the location and arrangement of the solar panels for energy generation and consumers) and the wiring pattern is what brings the difference between the centralised and decentralised energy generation system.

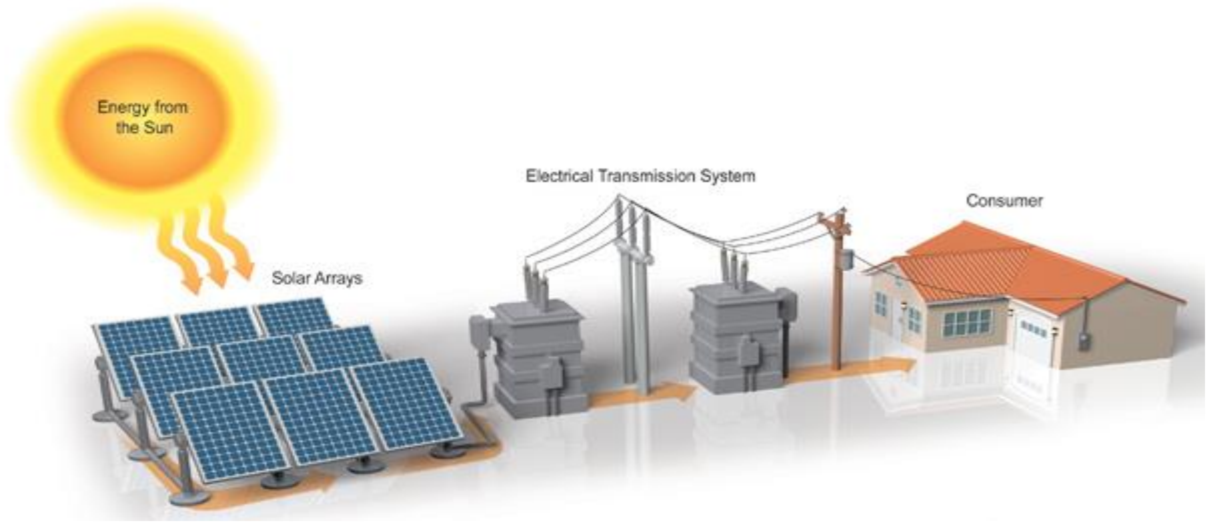


Figure 2.3 Simple diagram showing Solar Energy Generation

2.2.2 CENTRALISED SOLAR ENERGY GENERATION

The concept of solar farms in energy generation is a good example to explain centralised solar power generation. It is a term used to describe a collection of photovoltaic solar panels connected together on a piece of land with the aim of generating surplus energy for a large populace or collection of buildings. A solar farm feeds power into an electrical grid just as fossil-fuel energy plants do, except that they produce no pollution of any kind, and use very little water compared to traditional power plants. [2,3]. Fig. 2.4 best explains a solar farm setup.

Fig. 2.4: Centralised energy generation (Solar panels connected in an array to form a solar farm)

2.2.3 DECENTRALISED ENERGY GENERATION

Briefly, it means creating a synergy between different energy sources. Here, energy generated by various sources are obtained through a domestic power network which all consumers are connected to. “Decentralised” can also be referred to as “distributed” or “close to the customer”.

Decentralized generation is in many ways the opposite of the traditional model (i.e. the use of solar farms), in which one large plant provides energy for an entire region. Decentralised energy generation means introducing a very large number of small-capacity units that are all connected to the power grid, natural gas supply network or urban heating/cooling networks to generate energy from renewable sources at local level. Constructed around renewables, this energy generation method is more environmentally friendly and addresses actual local demand for energy. [1]

Before introduction to decentralised solar energy generation, the use of solar farms was the major option explored by owners/ managers of large communities/ industries who sought to generate large amount of energy using solar power, but as technology innovation increased, the concept of decentralised energy generation came into play, and several analysts have studied the benefits gained in investing in decentralised solar as compared to centralised solar energy generation.

Energy matters, a company dealing with solar power (panel installation) generation and distribution best captures a majority of these benefits when it explains, that small and medium scale solar power has the potential to become the "Internet of distributed electricity generation", which means a network resilient to a single point of failure; whether caused by natural disasters (e.g. earthquakes, flooding etc.) or attack by hostile parties.

Decentralised solar power offers a multitude of other benefits over large scale plants; including avoiding “line loss” associated with remote generation, reduction in infrastructure investment while offering major permanent job creation potential and avoiding damage to wildlife habitats. Instead of appropriating undisturbed public lands or utilising productive agricultural land for solar power generation on a massive scale, better use can be made of the very much under-utilised sea of rooftops in our towns and cities."[4]

The Fourth Partner Energy another big solar distribution company also emphasises the benefits involved in investing in decentralised solar. Firstly, they put forward the fact that while power plants which use coals add heavy pollution in the environment, solar does not. Solar is clean and produces zero greenhouse gases, hence zero pollution induced. They then confirmed the proficiency distributed solar over the centralized approach in that the latter becomes inefficient due to the high investment cost and huge transmission loss it takes. Distributed solar on the other hand, will eliminate the need for central solar operated by the large electric utility company. A small solar power plant can be owned by a qualified SME and this will help in local employment. The decentralization approach will first feed the local loads and the excess will be fed into the grid and thereby we will use the full generation capacity of power plant. A distributed approach also produces zero greenhouse gas emission which is the biggest advantage with it as it’s clean and pollution free.

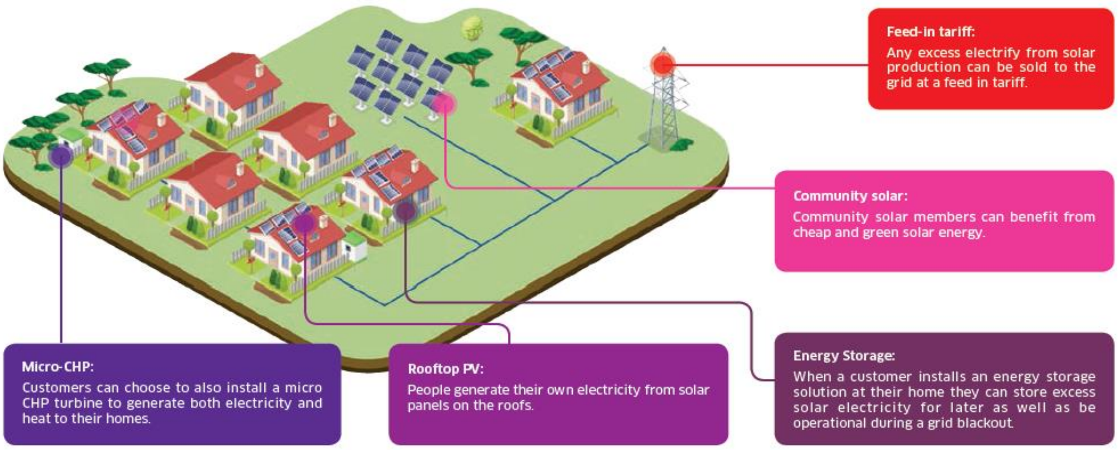


Fig. 2.5: Pictorial representation of solar energy generation with excess energy flowing to the grid.

Fig. 2.5 above shows a small community with a structure for energy generation through solar with a mini solar farm for local clean energy generation for all the consumers in the community. Allowance is also made for the individual installation of solar panels on the roof tops of some of the consumers. All energy generation sources are interconnected supplying energy to every building present and then excess energy generated is sold to the grid at a '*feed in tariff* '. Consumers that install and energy storage solution with their solar energy generating PV panels have excess energy stored and can remain operational even in the case of a blackout.

These benefits are the motivating factors showing the need for the proper implementation of this project, so the perks involved in working with solar can be utilised maximally with cost rates was low as can be.

2.2.3 SMART GRID NETWORK

Building a decentralised energy generation network will require a good monitoring system for energy generated and consumed per time, and this involves good communication between the central dispatch and the meters present in the individual energy generation locations, hence the need for a smart metering system.

Due to the high demand for electricity and the need for energy management, smart meters have been developed to improve energy efficiency both for consumers and the energy providers. A **smart meter** is a digital energy meter that measures the consumption of electrical energy and provides other additional information as compared to the traditional energy meter. The aim is to provide the consumer and supplier an easy way to monitor the energy flow. Smart meters will enable two-way and real-time communication between the consumers and the provider.

The bi-directional communication systems between smart meter and the control centre which is implemented by the utility centres are the basic components that make the smart meters to supersede the conventional meters. Smart metering system is considered as Automatic Metering Infrastructure (AMI). Automatic Metering Infrastructure refers to any system that establishes two-way communication between the energy meter and the utility with an added ability of meter control and monitoring feature by the utility.

Prior to smart metering technology, the Automatic Meter Reading (AMR) system was in use. This technology allowed only for a one-way communication channel between meter and the utility. The major aim of the AMR was to allow remote access of the generated data by the electronic meters installed at the user's end. This was done to eliminate the problem associated with bill estimation and manual meter reading. Usually, this data was transferred to the utility company via radio frequency, telephone, power line which will be discussed further in this review.

According to [5], the evolution of the smart metering infrastructure can be summarized with the aid of the following block diagram:

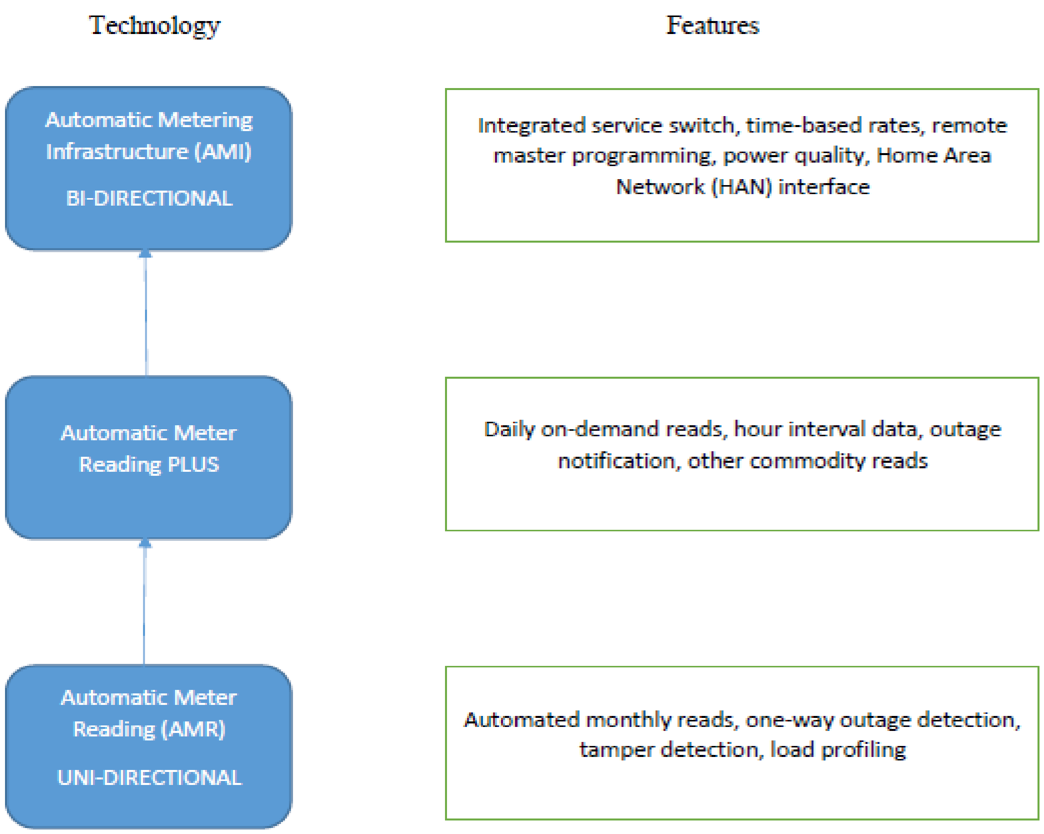


Fig 2.6: Evolution of the Smart Metering Infrastructure

2.2.4 COMMUNICATION MEDIA IN SMART METERING

Communication remains a very important factor which must be considered during the implementation of any smart metering projects. The choice of the communication media to deploy is dependent on factors such as the evaluation of the existing infrastructure, economic impact on the consumer, the distance between the devices and the infrastructure which is already in existence. Over time, numerous media of communication between electronic meters and the central host of the utility have been developed. These communication media can be grouped into the following:

- Wired communication media: Power line communication (PLC), Insteon, KNX, X10, etc.

- Wireless communication media: Wi-Fi, Bluetooth, ZigBee, GSM, Radio Frequency (RF). Selection of the wireless protocols are based on five factors which are good range of transmission, high level of security, good bandwidth , quality data transmission and least latency. In addition, the network coverage radius for wireless communication protocol is dependent on power transmission and frequency. A higher frequency, needs more power to be transmitted and produces a smaller radius when compared to low frequency[8].

- **Bluetooth**: A short ranged open remote protocol for transferring information from mobile gadgets that make personal area networks. Due to its compatibility with different gadgets, the issue of synchronization is eliminated. As a result of radio (broadcast) communication framework, devices need not be in observable pathway to each other. Bluetooth technology makes use of a radio technology known as frequency hopping spread spectrum.
- **ZigBee**: ZigBee is a wireless mesh networking standard. It is best for local coverage like Home Area Networks (HAN). It is preferable as a result of its low sot and low power. ZigBee finds application in home automation in addition to meter-to-meter communication[6].
- **Wi-Fi:** This technology uses radio waves to provide high speed network connections. It is based on IEEE 802.11 standards.
- **GSM:** Global System for Mobile Communication. This technology digitizes data, compresses it before it is sent out. It is the most widely used technology. Its Subscriber Identity Module (SIM) cards allow for sending and receiving of short message service (SMS) messages[6]. It uses a variation of time division multiple access (TDMA).

2.2.5 POWER LINE COMMUNICATION:

Measurements read from smart meters can be transmitted across the utility power lines to a point of collection usually situated at the secondary side of the distribution transformer[7]. Power Line Communication is a convention which requires electrical wiring via a channel to carry both information, and current (AC) in transmission of electricity. Power line communication is also known as power line carrier, power-line networking (PLN) and power-line telecommunications. Power line communication systems work on the principle of impressing a modulated carrier signal on the existing wiring system. There are narrowband and broadband power line communication. Narrowband PLC operates at low frequencies (3-500 kHz). It has lower data rates (up to 100s of kbps); and has a longer range spanning several kilometres. On the other hand, Broadband PLC, works at a higher frequency (1.8-250MHz), has higher data rates (up to 100s of Mbps) but covers a short range. As a result of the already existing power line cables, only higher frequencies or broadband PLC are in use. PLC technology leverages on the use of existing power utility infrastructure such as the poles and the electric wires. The drawback with this technology includes longer data transmit time, less bandwidth and throughput, limited interface with Distribution Automation (DA) devices.

2.3 REVIEW OF RELATED WORKS

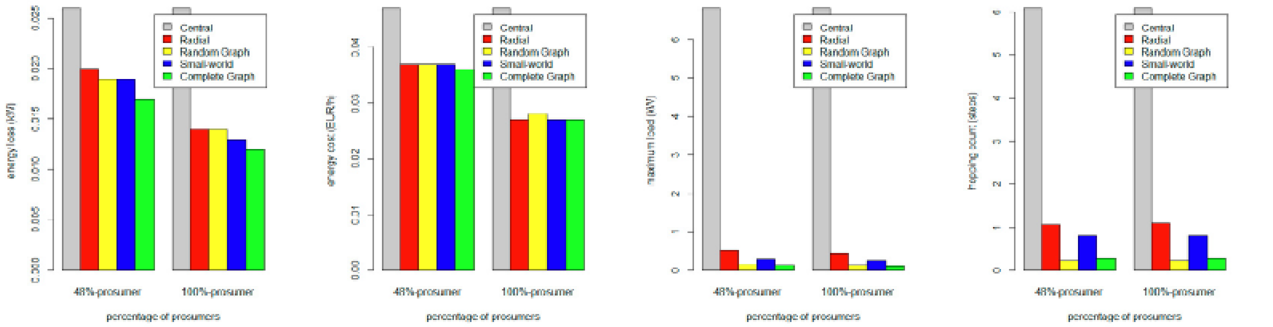
Below is a review of project works related to this course work, the limitations they have and the solution this project proposes.

2.3.1 TOPOLOGICAL CONSIDERATIONS ON DECENTRALISED ENERGY EXCHANGE IN THE SMART GRID

This paper envisioned end-users (basic energy consumers) equipped with renewable energy generators such as solar panels with and the Smart Grid to form ‘prosumers’. The prosumer is one who is engaged in both energy production and consumption. The system allows for energy generated by the prosumer to feed itself as well as bi-directional flow of energy exchange as a commodity between end-users and prosumers in the event of an excess in supply or demand i.e. after fulfilling the needs of the prosumer, the surplus energy can be stored or sold, hence a development on the traditional grid system. The trading of surplus energy among prosumers in the distribution network in this context is described as a form of energy decentralisation, with its contrast centralised energy distribution meaning that end-users buy energy from or send their surplus to a controlling centralised operator. They all combine to form a Prosumer involved Smart-Grid.

The project involved the assessment of different topologies to assess how each influences the performance of decentralised energy exchange for optimisation. The parameter that were the subjects of comparison by the various topologies were energy loss in delivery, energy cost for each end user per day, average hopping count of energy delivery (how many electric lines are needed for energy delivery from one provider to one consumer) etc. Various statistical distributions were used to generate the renewable energy production, energy consumption of users as well as real time energy price, and these were implemented in running a simulation model based on a previously stated model 'Monte Carlo', to assess the different topological scenarios. The result from these assessment cases showed that although the topology that performed the best under the various comparison parameters proved impractical for application due to the cost implications, two other topologies followed closely that can be implemented effectively. This is a large upgrade to the traditional grid as represented by 'central' in the results graph as shown below, thereby encouraging the settings that implement prosumers.[9]

To shed more light on the prosumer technology, we see that energy being generated by each house hold is consumed at the same location except if its surplus being transferred, which helps maximise energy efficiency, as the energy loss that could occur in delivery is eliminated.



(a) Energy loss of delivery. (b) Energy cost per end-user per day. (c) Maximum load in the electric lines of delivery. (d) Average hopping count of delivery in the test feeder.

Fig. 2.7: Evaluation results of topology metrics.

LIMITATION

The limitation of this work is seen in that the prosumer design emphasises majorly on individual energy generation setting, and the cost involved in designing this on an individual basis could pose as discouraging to someone that would be interested in venturing into it. This project proposes a scenario where the total cost is handled by community owners/developers, hence enabling shared cost, large scale construction which attracts economies of scale, as well as an avenue for returns from billing.

2.3.2 ENERGY AUTONOMY IN SUSTAINABLE COMMUNITIES

Energy autonomy refers to the ability of an energy system to function fully without demanding external support in the form of energy import. It can further be expressed as the ability of a system to operate fully and solely on its own, by meeting its energy needs through its local generation, distribution and storage systems. In light of sustainable communities, the topic sought to address and review the role of maximising the use of abundant renewable energy sources available, and optimum implementation methods in developing sustainable energy and the impact of community involvement in this pursuit.

In view of achieving this, the study focused on presenting a detailed review of the current research relating to energy autonomy in sustainable communities by focusing on four central issues as pertaining transitioning towards energy autonomous sustainable communities; the degree and scale of energy autonomy, matching demand with supply, the importance of socio-economic and political factors, and the technicalities behind energy autonomy in remote and island communities. Each section answered questions ranging from the influence of scale on energy autonomy and the varying degrees of energy autonomy that can be realistically achieved. Questions such as whether the system is to be Grid connected or Stand alone, as well as what form of energy storage to be used for the system are also deliberated on.

A major part reviewed was the economies and project finance of the system, which the earlier work [9] only grazed over, and it has a nearly decisive part to play in whether the system would be implemented or not. The major reason this occurs is due to the high initial capital cost required.

Although the above stated is true, in many instances we see that the lifetime cost incurred in venturing into renewable energy technologies, eventually run lower compared to its fossil fuel equivalent. But moving further from this, the paper [10] acknowledges the steps some governments have put in place, such as financial incentives and support systems (grants, Feed in Tariffs(FITs)) and aimed at encouraging the deployment of renewable energy. This is as a result of their understanding of the various socio-economic and environmental benefits venturing into renewable energy technologies (RETs) provides. Detailed review and analysis such as this project is geared towards helping the Nigerian government see these benefits, so as to enable them prioritize RET incentives for the country as a whole.

LIMITATION

This settings this project analyses are renewable energy generation systems that are independent of grid connections which would be perfectly suitable for rural communities which the DISCO haven’t reached in energy distribution. But due to the intermittent nature of renewable energy receiving supply from the nation’s grid would be a good addition, so as to create an alternative source/ support thereby reducing stress from the renewable energy system. This PV/grid system is an extension this project proposes.

CHAPTER THREE: SYSTEM DESIGN AND IMPLEMENTATION

3.1 INTRODUCTION

In the last chapter detailed explanation of the key concepts that build up this project has been done, as well as detailed analysis of related works hence it is believed that basic knowledge of the project's purpose is known. This chapter would provide information on the system design and methodology used to model the objectives of this project in detail, as well as considerations for a real life implementation. The design set-up of a decentralised solar powered community is shown as well as the smart metering system incorporated for monitoring purpose.

3.2 DESIGN OF A DECENTRALISED SOLAR POWERED COMMUNITY

From the review of [10], the definition of energy autonomy highlights three major sections of designing an autonomous energy environment which are: generation, distribution and storage systems. The energy flow is modelled from its point of generation which is the solar panels mounted on the rooftop of the buildings. This energy is then transferred through a proposed wiring arrangement that allows for minimal energy loss in delivery to a central storage system located at the central dispatch where it would be redistributed to the individual homes for consumption.

3.2.1 SOLAR POWER SYSTEM CALCULATIONS

In designing a solar powered community with a battery based system, the following steps are put into place [13] :

1. Perform a Load analysis.
2. Calculate the required PV Array output.
3. Determine the capacity of the Battery bank.
4. Charge Controller specifications.
5. Sizing the inverter.

3.2.1.2 PERFORMING LOAD ANALYSIS: In designing a solar powered community the first thing to put into consideration is the amount of load you want your system to feed. To do a life sized calculation, we would be making some assumption for a virtual estate. Under normal circumstances the load analysis is calculated from the appliances to be used in the various homes, but that'll be a harder estimate to calculate with due to the variety of load combinations that could appear in each home in such a large estate. Hence, we would be working with the average kW consumed by an individual, and then we could multiply that by an average community population.

According to World Data Info , Nigeria has a total consumption of 24.72 billion kWh of electric energy per year, with an average per capita of 130kWh as at 2015 [12]. With an average community population of 900 people. An estimate of 6 people per home, gives us 150 residential homes to power.

Average per capita energy consumption per year = 130kWh

Then, average per-capita energy consumption per day = 0.356kWh

The average estate energy's consumption per day = 0.365kWh * 900 = 320.5kWh

The energy each generation point would be required to produce = $\frac{320.5kWh}{150\ homes} =$ 2.14kWh

Here an assumption is made that every home in said estate has similar building structure and will generate at the same rate. In real-life applications some buildings may have larger rooftops than others based on user's preferences. But from the above calculations every housing unit must be able to generate at least 2.14kWh.

The value above would be very instrumental in designing the PV array arrangement for the generation setup, and this would be discussed a little further down.

For the purpose of visual representation, we scaled down the entire system to a simple model. This design model consists of 3 buildings which represent the community (estate) to be powered. Each building has varying load, to represent the load variation that occurs in a normal home setting. we would be summing up the load consumption of the ‘entire community’ as our load analysis.

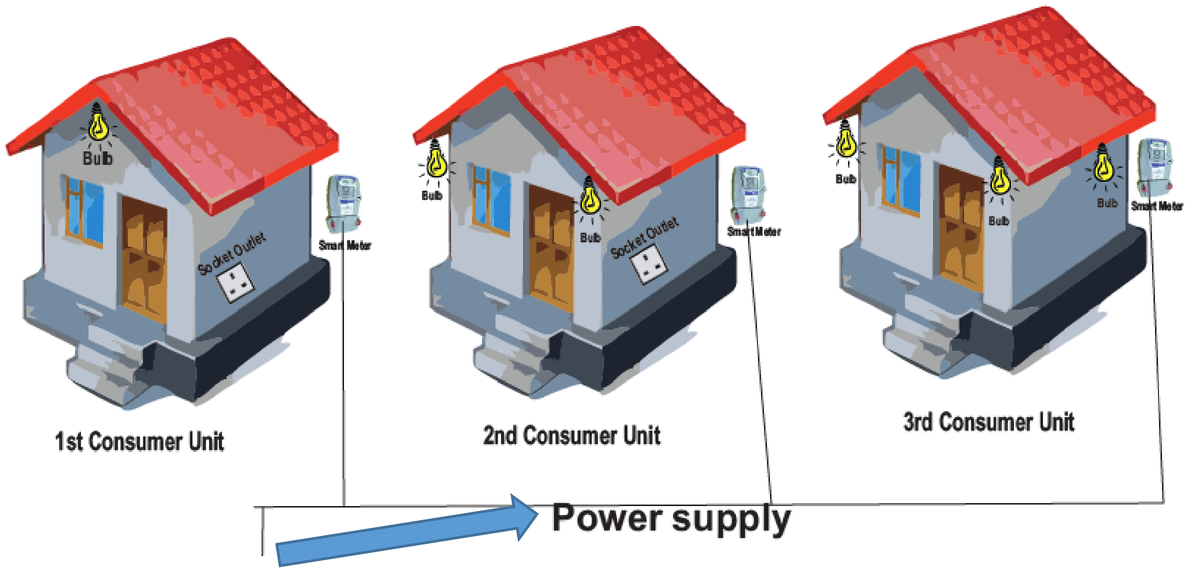


Fig. 3.1 Pictorial view of design model showing the load distribution across 3 housing units

Figure 3.1 above shows a diagram of the load distribution for the visual representation of this project. The first residential home has a single bulb and a socket outlet that would be used to charge a tablet, the second home has 2 light bulbs with a single socket outlet that’ll be used to charge a laptop that could power a smart board, and then the last unit with 3 bulbs only. All of these loads are designed to pass through individual smart meters at each home which would monitor energy consumption to be sent to the central dispatch centre (substation).

The information above has been used to design a table that effectively details the load consumption analysis for the model.

Table 3.1: Model estate load consumption analysis

House	**A.C. Load Description**	**Quantity**	**Power (Watts)**	**Total Power (Watts)**	**Hours/Day**	**Total Energy Whrs/Day**
1.	LED Bulb (indoor)	1	5	5	18	90
	13A Socket (Mobile Device Charger)	1	5	5	10	50
2.	LED Bulb (indoor)	1	5	5	18	90
	LED Bulb (outdoor)	1	5	5	12	60
	13A Socket (Computer - Laptop)	1	50	50	10	500
3.	LED Bulb (indoor)	1	5	5	18	90
	LED Bulb (outdoor)	2	5	10	12	120

From Table 3.1 above we can calculate the total Watt hour each appliance in the home will be used per day. The socket rating is given as such to represent the maximum output/ of the socket. For lack of proper load representation on the simulation software (Proteus) the sockets are represented by motors.

N.B: If there were DC loads in our analysis we would have separated DC and AC loads because they would draw energy directly from the battery and hence are more efficient. However, AC loads would draw from the inverter and as a result of that the inverter efficiency are factored in the calculations for AC loads.

The power consumption can be gotten using the formula:

$$\mathrm{TWh/day_a - AC} = \sum \frac{\mathrm{W_{an}} \cdot Th}{\mathrm{IE}}$$

where, Wan – Total power consumed per day; Th – Total number of hours; IE – Inverter Efficiency.

For this system design, we made use of 5 Watts bulbs, to encourage the advantages of energy saving. Although initial cost implications are high, in the long run they benefit greatly in reducing energy consumed, thereby reducing utility cost, as well as load on the generation supply.

Hence the total load in watts consumed by the 3 homes = 5+5+5+5+50+5+10 = 85 Watts

Total load consumed in kWh per day by the homes = 90+50+90+60+500+90+120 = 1000Wh

Assuming an Inverter Efficiency of 85%

$$\frac{\mathrm{TWh}}{\mathrm{day_a}} - \mathrm{AC} = \frac{1000}{0.85}$$

Total Energy consumed by the household = 1176.47Whrs

= 1.176kWhr

A load calculator designed for renewable energy systems can be used to calculate this information easier. [14]

3.2.1.2 BATTERY SIZING

Making energy storage available is a very essential part of solar system design. The rating of the storage capacity in design is to match that of the total energy consumption of the estate, such that the estate can run fully on battery power in the absence of sunlight.

In our estate design all the batteries are located at the central distribution station, where all the solar panels are connected from the various houses. The reason for this is stated as follows:

- The energy consumption in the estate is effectively monitored at the central dispatch centre. This is done by connecting smart meters as intermediaries between the energy supply from the central dispatch and the distribution boxes at the homes.
- It helps to reduce energy theft at the residential point. A typical situation would be where a consumer decides to draw energy directly from the individual battery unit installed in his home, rather than passing through the installed meter.
- It reduces the overall cost for individual installations as fewer storage capacity batteries can be connected as opposed to multiple smaller rated batteries, as influenced by economies of scale

Hence the storage capacity rating is designed for the entire estate’s energy use, 350.2kWh/day.

To calculate the capacity of the battery to be used for the virtual estate design the following would need to be put into consideration:

- The Days of Autonomy - the number of days you expect the battery bank to last without recharging) – 2 days
- The battery operating temperature i.e. the lowest temperature the battery would be exposed to.

Deep cycle batteries are affected by temperature, as cold temperatures tend to reduce battery life while alternatively high temperatures lead to shorter life spans for the battery life. Table 3.2 shows the multiplying factor for various battery temperatures.

- Depth of discharge (measure of maximum capacity to be withdrawn from the battery) – 50% or 0.5
- Total energy consumed by the estate (Wh_p) - 350.2kWhrs

Table 3.2: Battery Temperature Multiplier for various temperature ranges

Temperature	**Battery Temperature Multiplier**
80°F (26.7°C)	1.00
70°F (21.2°C)	1.04
60°F (15.6°C)	1.11
50°F (10°C)	1.19
40°F (4.4°C)	1.30
30°F (-1.1°C)	1.40
20°F (-6.7°C)	1.59

To calculate the total battery storage capacity;

Total Energy daily use * Days of autonomy = 350.2kWh * 2 = 700.4kWh

Dividing the above value by depth of discharge = $\frac{700.4kWh}{0.50} =$ 1,400.8kWh

Ambient temperature effect for 21.2^{o}C (as shown in table 3.2) – 1,400.8kWh * 1.04 = 1,456.832kWh

Therefore, the total battery capacity in Wh = 1,456.832kWh

Considering the fact that the solar panels are going to be a far distance from the batteries, a high nominal voltage is preferably used, seeing as higher voltage translates to lower current hence reducing line losses (I^2R losses) and also reduce the range of expensive copper wire needed.

Hence the selected nominal voltage for this battery will be 48V

Dividing the above by system voltage of 48V = $\frac{1{,}456.832kWh}{48V}$

Battery Capacity (in Ah) = 30350.67Ah [17]

To battery connection is determined by the number of batteries would be connected either in series or in parallel. Connecting batteries in series would lead to increased voltage, while a parallel connection will provide increased current.

Batteries with lower voltages have higher storage capacity.

Hence, a 2VDC, 2550Ah battery is proposed.

No. of series string = $\frac{Battery\ Bank\ Capacity\ required}{Battery\ Ampere\ Rating} = \frac{30350.67Ah}{2550\ Ah}$ = 11.9 ≈ 12 strings

No. of batteries in each series string = $\frac{DC\ system\ voltage\ battery}{Battery\ Voltage} = \frac{48V}{2V} = 24$

batteries

Total number of batteries needed = Number of series string * No. of batteries in each string.

= 12 * 24 = 288 batteries

For the visual model housing that was designed, the total energy consumption is 1kWh. Assuming inverter efficiency of 0.95 is used, the energy consumed becomes 1.053kWh.

The conditions for its use varies with the virtual estate seeing as its purpose for presentation. It would be on for a much lesser amount of time, and this directly affects the days of autonomy and depth of discharge constraints

To calculate the total battery storage capacity;

Total Energy daily use * Days of autonomy = 1.053kWh * 1 = 1.053kWh

Dividing the above value by depth of discharge = $\frac{1.053kWh}{0.9} =$ 1.17kWh

Assuming an ambient temperature effect for 26.7^{o}C (as shown in table 3.2) –

1.17kWh * 1 = 1.17kWh

The selected nominal voltage for this battery will be 12V due to the small amount of loads it is carrying, hence:

The minimum battery capacity = $\frac{1.17kWh}{12V}$

Battery Capacity (in Ah) = 97.5Ah

A battery of 12V, 100Ah was chosen for this set-up.

3.2.1.3 DETERMINING THE SIZE OF THE PV ARRAY

Insolation also referred to as sun hours refers to the number of hours a day that the sun's intensity is equal to standard test conditions (i.e the brightest parts of the day)

In determining the size of the PV array some fundamental factors are to be considered. We'd be working on the following average values for the real-life estate calculation

- Estimated PV Array efficiency – 67% or 0.67
- Peak Sun hours : In Lagos, we get an average of 4383 hours of sunlight per year with an average of 5.09 hours of sunlight per day. In design we plan with the worst case peak sun hours to factor in cloudy days, and rainy seasons which is about 4.2 hrs
- Total energy consumption for virtual estate – 2.14 kWhrs

The formula for calculation the size of the PV array is given as follows;

$$Size\ of\ the\ PV\ Array = \frac{Total\ energy\ consumption\ in\ Wh}{\text{PV array efficiency} * \text{Peak Sun hours}}$$

$$Size\ of\ the\ PV\ Array = \frac{\text{2136.7 Whrs}}{0.67 * \text{4.2hrs}}$$

= 759.31Watts or 0.76kW

For this design 260 Watt, monocrystalline panels @ 20V Nominal voltage, 38V Voc each

*Open-circuit voltage (Voc) is the voltage at the terminals of the solar panel when it is in full sunlight but not connected up to the load for use.

**Nominal 20 volts panels are usually used for grid-tied systems not battery based and as such their voltage does not easily match up with typical battery bank, but with an MPPT charge controller (this would be discussed in the next section), they can be used with battery based systems. They are more readily available compared to 24V panels.

Total number of modules needed (W) = $\frac{\text{Minimum array size (W)}}{\text{Module Size (W)}} = \frac{759.31\text{ W}}{260\text{ W}} =$

$2.92 \approx 3$

Number of modules in each string = $\frac{\text{System Voltage}}{Nominal\ Module\ Voltage} = \frac{48\text{V}}{20\text{V}} = 2.4 \approx 3$

Using 20V, 200 Watts solar panels arranged in series, so as to increase the voltage with no current additions so as to avoid line losses as stated earlier. An estimate power generation of 780 Watts is gotten from this connection.

In the same way, the PV array design for the model with the same conditions for array efficiency and peak sun hours can be calculated using the following:

For this design 60 Watt, monocrystalline panels @ 5V Nominal voltage are proposed,

$$Size\ of\ the\ PV\ Array = \frac{Total\ energy\ consumption\ in\ Wh}{\text{PV array efficiency} * \text{Peak Sun hours}}$$

$$= \frac{1000Wh}{0.67*4.2} = 355.37\text{Watts}$$

Total number of modules needed (W) = $\frac{\text{Minimum array size (W)}}{\text{Module Size (W)}} = \frac{355.37\text{ W}}{60\text{ W}} =$

$5.92 \approx 6$

Number of modules in each string = $\frac{\text{System Voltage}}{Nominal\ Module\ Voltage} = \frac{12\text{V}}{5\text{V}} = 2.4 \approx 3$

Hence, a PV array of 2 parallel strings with 3 modules of 5V, 60 Watts each is the PV array design will be used.

In the housing construction, solar panels were not included due to the extra cost that would be incurred, but a charge controller is connected to the battery to show it's a solar project.

3.2.1.4 DETERMINING THE TYPE OF CHARGE CONTROLLER TO BE USED

Charge controllers are available with 2 different technologies; Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT).

For the former a direct connection is required from the solar panel to the battery where the voltage of the PV array is pulled down to the battery voltage per time. Hence the nominal voltage of the array must match that of the battery. The latter (MPPT) is what suits our project design as it adjusts the voltage and current of the PV array to suit the battery's requirement per time. Hence, the PV array voltage can be higher than the battery voltage (as the charge controller would decrease the voltage and increases the current as needed) helping to get the most current out of any solar installation, as well as leave allowance for new panel additions.

In calculating the rating of the MPPT charge controller to be used, the following ratings of the charge controller need to be put into consideration[19]:

Using 3 260W, 20V panels in series, we have = 780W

With a 780 Watts solar array of 60V, and a battery bank voltage of 48 volts,

The output current of the charge controller = $\frac{Total\ Array\ Wattage}{Battery\ Bank\ Nominal\ Voltage} = \frac{780}{48} =$ 16.25A

Adding an extra 25% in the event of unexpected increase in current would give, 20.3A

Hence, the rating of the charge controller is 48 V, 20 A charge controller.

For the model, housing design,

A PV array of 2 parallel strings with 3 modules of 5V, 60W is selected

Total Array Wattage = 60 W * 6 modules = 360W

Total voltage on a string = 5V * 3 modules = 15V

Battery bank voltage = 12V

Therefore,

The output current of the charge controller = $\frac{Total\ Array\ Wattage}{Battery\ Bank\ Nominal\ Voltage}$

$= \frac{360}{12} =$ 30A

A 12-24V, 30 A charge controller with maximum was chosen for this setup.

3.2.1.5 INVERTER SIZING

The total load being consumed in the housing estate a total load of 350.2kW from our calculation. Adding a 15 % safety margin,

The minimum inverter size = 320.5kW + (350.2kW *15%) = 402.73kW[18]

A 420kW, 48V to 380V 3-Phase inverter is recommended for this design.

For the housing model, the inverter sizing is supposed to feed a total load of 85W. Including the 15% safety margin,

The minimum inverter sizing = 85W + (85W * 15%) = 97.75

Hence an inverter of sizing approximately equal to 12V, 100 Watts will suffice.

3.3 SMART METER BILLING AND MONITORING

The distribution cables are fitted with smart meters at each respective building so the energy consumed in each building is monitored The various specifications needed for the various vital components present in this project are broken down in Table 3.3 below.

Table 3.3 : List of equipment used for smart meter construction, and their specification

S/N	PARAMETER	SPECIFICATIONS
1	Microcontroller	Arduino Uno 5V DC input voltage
2	Wi-Fi Module	NodeMcu V3 3.3V DC input voltage 802.11 b/g/n 115200 Baud Rate
3	Disconnect Feature	1N4007 diodes 3A 5V relays HK4100F
4	Current Sensor	ACS712 30A Maximum Volts per Amp: 0.066V/A
5	Display Feature	LCD 2004A 20x4 display
6	Software Requirement	Arduino IDE, Windows O.S, Visual Studio

3.3.1 HARDWARE REQUIREMENTS

The hardware components required and used in the realization of this project will be discussed in details in this section.

3.3.1.1 METERING SECTION

A major part of the smart metering and billing system proposed in this project is the metering system itself. A metering system is constructed in this project in order to reduce the cost incurred by acquiring an already established meter. It is made up of the following:

- Current Sensor
- Arduino Uno Microcontroller
- LCD 2004A

Current Sensor

The ACS712 30 Amps Max current sensor is used to measure the AC current consumed by the load in this project. It is a current sensor that operates on the hall effect principle. The hall effect is a principle discovered by Edwin Hall in 1879, it is a phenomenon where a potential difference is produced through a conductor due to the application of a magnetic field perpendicular to the flow of current through the said conductor.

Fig 3.2: Current sensor

Description: As stated above the said current sensor uses the hall effect in the measurement of current flowing through a conductor. It is made up of 8 pins as listed below.

- Vcc
- Vout

- Ground
- Filter
- 2 Ip+
- 2 Ip-

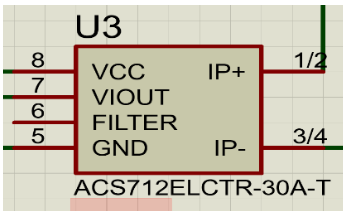


Fig. 3.3 : Schematic diagram of current sensor

It is powered by a 5volts source through the Vcc and properly grounded. The conductor from the AC source goes into the Ip+ and continues through the Ip- to the live terminal of the load. The reading from the Vout is in volts and in order to get the reading of the current a series of calculations are made with the formulas stated below.

$$\text{Vout} = \frac{\sum |\text{Vread} - \text{V0}|}{S} \text{ x } \frac{\text{Vcc}}{1024}$$

$$\text{I} = \frac{\sum |\text{Vread} - \text{V0}|}{mVperAmp}$$

Vread = The voltage reading from the Vout pin of the sensor in millivolts, when current is present

V_0 = The voltage reading from the Vout pin of the sensor in millivolts, when current is absent

V_0 = 512 millivolts

S = Sample size

Vcc = 5000 millivolts

mVperAmp = 66

To get a proper Vout value the mean of a number of Vout samples is taken. This is done to avoid a wide range of variations in the Vout values.

This sensor is chosen for this project because it possesses a number of benefits for the realization of this project which include

- It is cheap to acquire
- It restricts direct current flow from the conductor to the microprocessor in the system
- It possesses a low noise path for the flow of analog signals
- It gives an output voltage proportional to the AC or DC current
- It requires very little voltage to power it up

Table 3.4 below shows the performance characteristics of ACS712, 30A current sensor

Table 3.4: Performance Characteristics of ACS712, 30A Current Sensor

x30A PERFORMANCE CHARACTERISTICS T_A = –40°C to 85°C[1], C_F = 1 nF, and V_{CC} = 5 V, unless otherwise specified

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Optimized Accuracy Range	I_P		–30	–	30	A
Sensitivity	Sens	Over full range of I_P, T_A = 25°C	64	66	68	mV/A
Noise	$V_{NOISE(PP)}$	Peak-to-peak, T_A = 25°C, 66 mV/A programmed Sensitivity, C_F = 47 nF, C_{OUT} = open, 2 kHz bandwidth	–	7	–	mV
Zero Current Output Slope	$\Delta I_{OUT(Q)}$	T_A = –40°C to 25°C	–	–0.35	–	mV/°C
		T_A = 25°C to 150°C	–	–0.08	–	mV/°C
Sensitivity Slope	ΔSens	T_A = –40°C to 25°C	–	0.007	–	mV/A/°C
		T_A = 25°C to 150°C	–	–0.002	–	mV/A/°C
Total Output Error[2]	E_{TOT}	I_P = ±30 A, T_A = 25°C	–	±1.5	–	%

Microcontroller

The Arduino Uno rev 3 serves as the brain of the proposed system as it controls the system and carries out all the processing necessary to make this system work. Arduino Uno is based on ATMEGA328P-PU which serves as an 8-bit microcontroller and possesses a flash memory of up to 32 Kilobytes. It is a high performance AVR that requires low power to function.

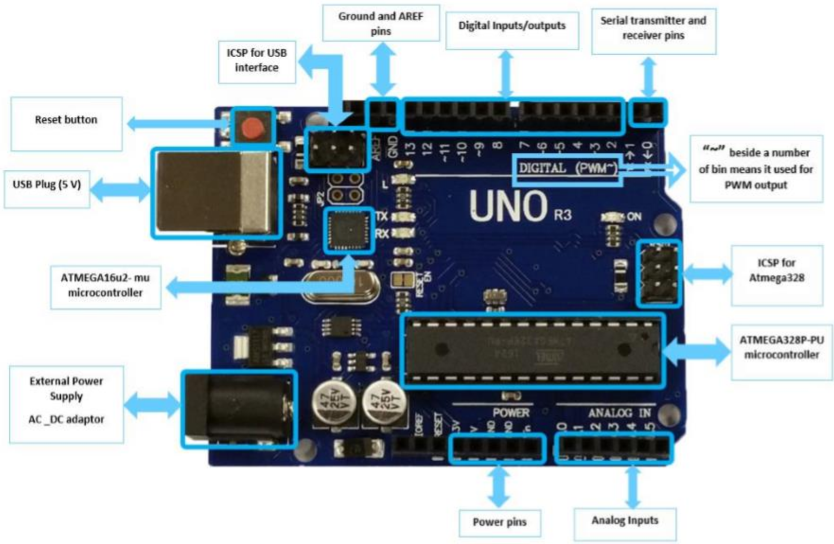


Figure 3.4 Arduino Uno Rev 3

Table 3.5: Specifications of the Arduino Uno

Microcontroller	ATMEGA328P-PU
Logic level of Operating voltage	5V DC
Supply Voltage	7 – 12 V DC
Number of Digital Pins	14
Number of Analog Pins	5
Flash Memory	32 Kilobytes
Current per input/output pin	40mA
Speed of clock	16 MHz

The Arduino is in charge of taking the analog readings from the current sensor via its analog pins A0, A1 and A2, one for each current sensor. It handles the calculation of the current readings, calculates the amount of power consumed by the load and its corresponding KWh value, it also triggers the relays via digital pins 8, 9, and 10 to either connect or cut-off the load. It forwards the readings to the WIFI module to be sent wirelessly to the control center. It also sends this information to be displayed by the LCD

2004A LCD

The modulating characteristics of the liquid crystal is utilized as an electronic visual display. LCD’s are commonly found in most electronic components such as phones, calculators. Their power consumption is very minimal as they can run on 12V or even 5V-DC. The 2004A LCD is 20 x 4 display. It is an I2C component and uses only 4 pins namely;

- Vin
- Ground
- Signal Data
- Signal Clock

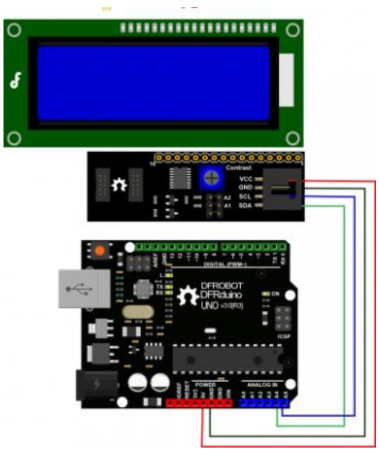


Figure 3.5: Connection between LCD 2004A and Arduino

The Vcc is connected to a 5v power supplied by the Arduino, and the ground is connected properly. The signal data pin SDA and the signal clock SCL pin go to the analog pins 4 and 5 of the Arduino respectively. It is chosen for this this project because it quite easy to interface with an Arduino. There is a potentiometer present at the back of the LCD that can be used to control the brightness and contrast of the LCD. It is also big enough to display the needed information at the user's end.

3.3.2 CONNECTION SECTION

The system designed in this project in designed in a way that it can take care of the connection and disconnection of the load from the power supply without supervision. The connection section is responsible for this action, which is carried out by a 5v dc relay incorporated into the system. It is found between the metering section and the load. It cuts-off the load when it uses up the total amount power paid for thereby stopping the meter from calculating the power. It also reconnects when the bills are paid again. As current flows through the coil of the relay, a magnetic field is built up which will attract the lever and close the contacts allowing current to flow to the load. The relay has two switching positions, NC (normally closed) and NO (normally open) which is connected as desired. The figure below shows the physical description and PCB layout of a relay.

Figure 3.6: Pictorial representation of relay

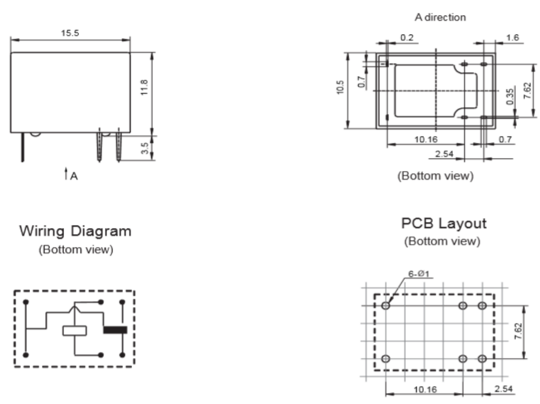


Figure 3.7: PCB Layout of relay

A diode is connected in reverse bias to the relay to protect the Arduino from possible back emf from the relay.

3.3.3 COMMUNICATION SECTION

This section plays an important role as it aids a two-way communication between the metering system and the Monitoring system. A NodeMcu V3 is used as the WIFI module that enables this communication. The NodeMcu uses a microcontroller known as the ESP8266 designed by Espressif Systems. The ESP8266 itself is a self-contained Wi-Fi networking solution offering as a bridge from existing micro controller to Wi-Fi and is also capable of running self-contained applications. It is configured using a USB cable connected to a laptop with the Arduino IDE present on it. It has the following specifications;

- It operates at a voltage of 3.3 volts
- Peer-to-peer and soft-AP capabilities
- Integrated TCP/IP protocol stack.
- +19.5dBm output power in 802.11b mode
- 802.11 support: b/g/n
- It has one analog pin
- 17 digital pins
- Reset button
- Flash button
- Wi-fi range of about 1Km

Figure 3.8 Pictorial representation of NodeMcu

The Wi-Fi module connects to the server at the monitoring end and sends the readings from the meter to the server. It also receives instructions from the utilities and passes this instruction to the meter for execution.

3.3 CIRCUIT DIAGRAM

The complete circuit diagram for the smart metering design, displaying all the components and their connections are shown in Fig. 3.10 below.

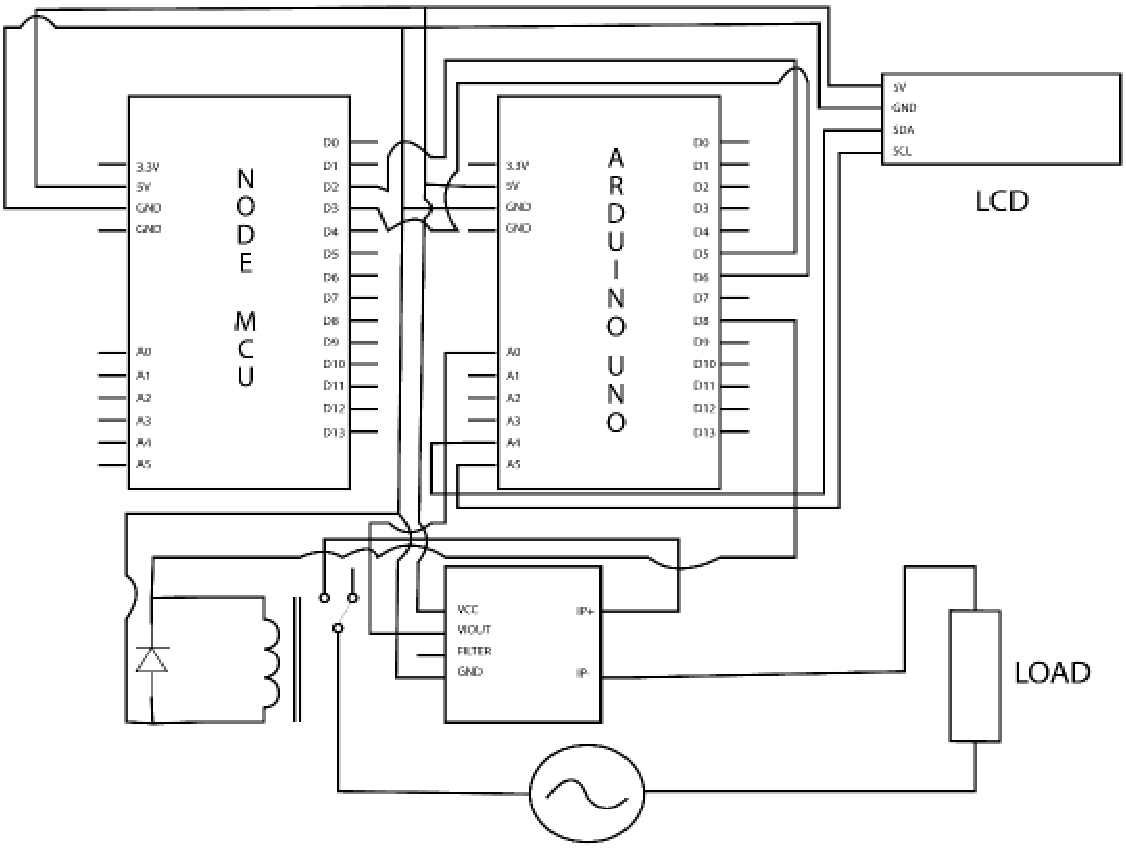


Fig. 3.9 Circuit Diagram of Smart Metering Section

3.3.4 UTILITY BILLING SECTION

The utility section is the final part of this system that takes care of the monitoring, billing and controlling of the overall system. It provides support for monitoring all the information sent to the server via an interface on a computer. This interface and server are designed using Vb.net on Microsoft visual studio. On the monitoring interface, the amount of power paid for, the power being used and the amount of power remaining are displayed in kwh for the various consumers. The billing section converts the money paid to the equivalent amount of power to be used which is sent via the server to the meter. The controlling section sends cut-off and connection commands to meter for the sake of maintenance.

CHAPTER FOUR: TESTING AND IMPLEMENTATION

4.1 INTRODUCTION

In this chapter, the implementation of the system shall be discussed. In addition, the various stages of testing carried out at the different levels to ensure that the project works as desired are also discussed.

4.2 IMPLEMENTATION

The construction of the project work is divided into two parts as follows:

- Power Generation System
- Energy Metering System - Hardware implementation; and

  - Software implementation.

4.2.1 POWER GENERATION SYSTEM

The power supply to this virtual estate/community, can be modified to be PV/grid for communities that have utility grids within close vicinity. Here the PV system is the primary source, and then the grid serves as an alternative source. So that the community is guaranteed full day, stable power supply daily.

In a situation where there are no utility grids (most especially in rural communities), an energy autonomous community design will do well also.

Based on the design done in the previous chapter, below is a table that shows the list of apparatus required for the power generation setup and their individual ratings. Tables 4.1a and 4.1b represent the full system design for the virtual community and model house respectively.

Table 4.1a : Solar System Design for Virtual community of 150 homes, 900 people

APPARATUS	RATING	QUANTITY
Solar Panel	20V, 260W	3 modules * 150 homes
Charge Controller	48V, 20A	1
Battery	2V, 2550Ah	288
Inverter	3-Phase, 48V – 380V, 420kW	1

Table 4.1b Full system design for model housing estate of with total load consumption of 85W

APPARATUS	RATING	QUANTITY
Solar Panel	5V, 60W	6 modules
Charge Controller	12V, 30A	1
Battery	12V, 100Ah	1
Inverter	12V, 100W	1

Fig. 4.1 Model Housing Estate construction showing (3 houses, a charge controller/inverter)

Fig. 4.1 is a picture of the implementation of the model housing construction. The load configuration for the 3 houses is stated in Table 3.1. Also the rated solar charge controller and inverter are also evident in the picture.

MAXIMISING SOLAR ENERGY GENERATION

In addition to the design given, the following are recommendations for construction of a solar powered estate. This is for efficiency to be maximised in energy generation.

The following should to be taken into account when installing the solar PV cells:

BUILDING DESIGN AND ARRANGEMENT

The building arrangement that provides optimal solar energy generation to occur has some specifications such as the roofing type, design materials, building spacing to avoid shading. All of these are discussed in this section.

- Rooftop Structure: The preferable roofing arrangement to be used is the flat roof top, with its orientation angle of the PV modules relative due to south to the nearest 5 degree. Also, firm roofing materials that can hold the large weight of solar panels should be used in the roof construction, so the space is effectively maximised. Such materials are concrete, steel etc.
- Solar Panel Mounting Structure: The suggested mounting structures are the adjustable solar panel mount as its angle of inclination (tilt) of an adjustable solar panel mount can be changed 2 or more times during the year, or the tracking solar panel mounts in which tracking device is installed to follow the sun's intensity during the day. The reason why this is necessary is to enable the panels be positioned in a way where maximum sunlight can be captured.
- Solar Panel Type: The panel type that provides the best efficiency is the one made up of **Monocrystalline Silicon solar cells**. They have an efficiency rate of 15-20% which is the highest rating when compared to their counterparts,

due to the fact that they are designed from the highest grade of silicon. Also they have the longest life span of more than 25 years hence ensuring the durability of the solar system set up.

Also, the buildings would be efficiently spaced with low vegetation areas so as to eliminate the occurrence of shading. Shading is a phenomenon that usually occurs due to the presence of tall trees and buildings that fall on the panel array especially during peak hours (this is the period of the day the sunlight is at its highest) and this would reduce the output of electricity generated and can even cause damage to the panels.

Fig. 4.2 Solar building arrangement with aesthetic design for solar estate

The fig. 4.1 above shows an ideal building arrangement for individual houses in the proposed estate. The roof top design allows for maximum capturing of solar energy, based on the angle to which its tilted, as well as the roofing material used. Also, the vegetation around the house is positioned away from the solar arrays to avoid shading.

4.2.2 ENERGY METERING SYSTEM

This is divided into two; hardware and software and they are explained below:

4.2.2.1 HARDWARE IMPLEMENTATION

The hardware implementation of this energy metering project was in stages. The stages are as follows:

- Circuit Simulation;
- Bread-boarding of the components;
- Mounting and Soldering of the components on Vero board; and
- Packing of entire system.

Circuit Simulation

The circuits were simulated using Proteus software. The various components that could be found on the Proteus software were simulated. Which includes the Arduino micro controller, the relays, the diodes and the current sensor. However, the NodeMcu was not found and Zigbee module was used instead during the simulation.

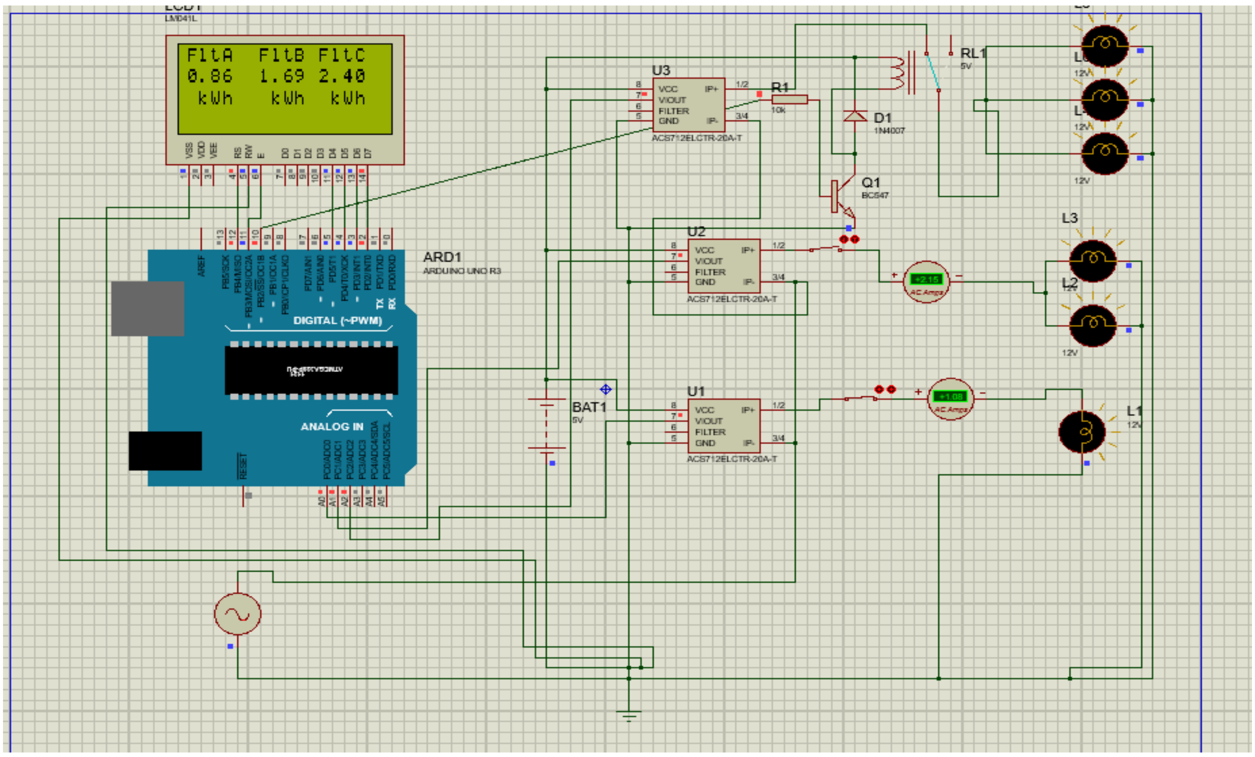


Figure 4.3: Simulation of the meter as shown on Proteus

Compilation of Components on Breadboard

Before the components were permanently soldered, a bread board was used in order to ensure the proper workability of the various components and their connections.

4.2.2.2 SOFTWARE IMPLEMENTATION

This entails the coding of the Arduino Uno microcontroller and the NodeMcu using the Arduino Integrated Development Environment (IDE) installed on a personal computer. The Arduino codes are written in C language. The codes were compiled and uploaded to the Arduino Uno board via its serial port. It also entails the use of Visual studio to implement a server for communication between NodeMcu and the computer wirelessly. This code is written in Microsoft's VB.Net. The codes used for the implementation have been attached to the Appendix section of this project report.

4.3 TESTING

In this section, the various components were tested. The tests carried out were organized into different sections as follows:

4.3.1 SOLAR PANEL SET-UP TESTING

Due to the limitations expressed by virtual design, proper solar system testing wasn't achievable. Although, the model housing estate, was connected with all its appliances connected and they were fully operational.

4.3.2. SMART METER TESTING

The metering section was tested to ensure that it gives accurate readings of energy consumed. Load of known rated value was connected across the meter and its value was compared with that which was read by the meter displayed on the LCD. It was seen that the meter had an 92% accuracy in taken the readings which is acceptable.

4.3.2.1 METERING SECTION TESTING

The energy metering system consists of different units which are integrated to form the whole system. Tests were carried out on the individual units. Such units' testing includes testing the LCD to ensure that it displays correctly, testing the Wi-Fi module to be sure of its connectivity, and testing the relay unit to ensure its workability.

4.3.2.2 CONTROL AND BILLING INTERFACE SECTION TESTING

This section was tested to ensure that it could receive information from the meter and send commands to the meter as well as update the payment status of the meter. Fig. 4.3 below is a snapshot of the LCD display that is to serve as a central monitoring station for the model housing estate.

The interface displays the total energy units that the consumer has paid for (pre-paid metering system), the energy consumption per time, and then automatically subtracts these values to give the remaining units available. Control functions are also included so as to enable the energy manager cut off a flat that has used up his/her energy quota.

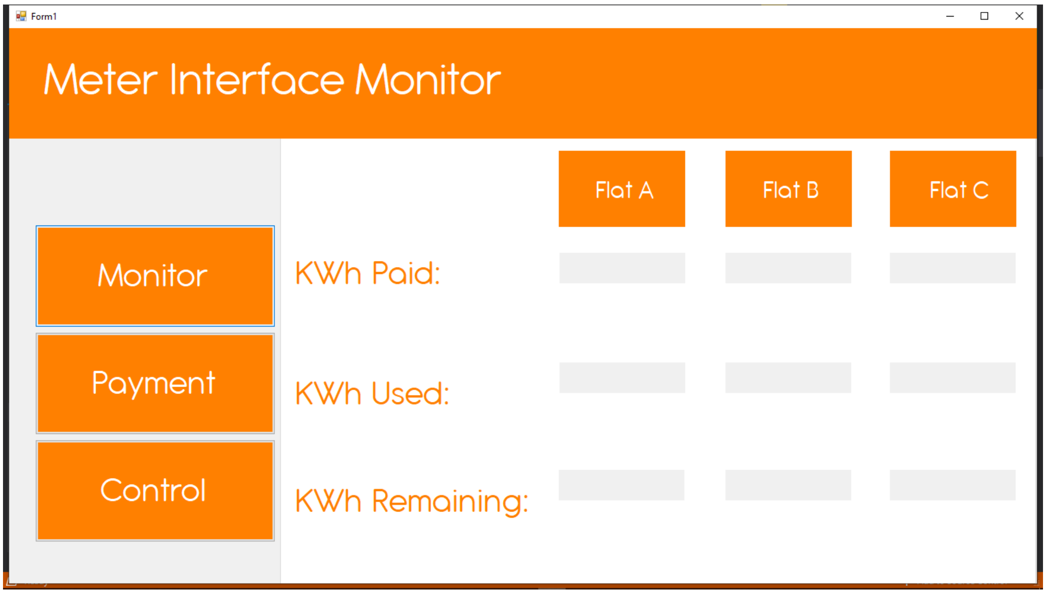


Figure 4.4: Energy Consumption Monitoring and Billing Interface

4.4 COST ANALYSIS

The total cost incurred in the design and physical construction of the model housing project is stated in the BEME report below:

Table 4.2: Bill of Engineering Measurement and Evaluation

S/N	COMPONENT	QUANTITY	UNIT PRICE (NGN)	PRICE (NGN)
1	13A Socket Outlet	2	300	600
2	5 Watts LED Light Bulb	6	500	3,000
3	Lamp holders	6	150	900
4	Switches	3	300	900
5	2.5mm cable	20 meters	150	3,000
6	Screws	50	10	500
7	12V, 100A Battery	1	45,000	45,000
8	Charge Controller	1	11,000	11,000
9	Inverter	1	15,000	15,000
10	Arduino Uno Microcontroller	1	2900	2,900
11	NodeMcu V3	1	3000	3,000
12	2004A LCD	1	2900	2,900
13	Male to Male Jumper wires	1 set	350	350
14	Male to Female Jumper wires	1 set	350	350
15	5v Relays	3	130	390
16	1N4007 diode 1A	5	10	50
17	Bread board MB102	2	300	600
18	ACS712 current sensor 30A	3	1000	3,000
19	Vero Board	1	200	200
20	Carpentry			15,000
	TOTAL			**108,640**

CHAPTER 5: CONCLUSION

5.1 SUMMARY

At the end of this project work, it is established that the decentralization of solar farms is a welcomed idea as it saves land use for other infrastructural development. It can be implemented first in the achievement of a smart estate and later incorporated into a smart grid with little enhancements to the proposed system. It is also established that the introduction of smart meters with enhanced capabilities and features provides a revolutionary advancement in the innovation of energy metering systems. In addition, it offers a transparent energy monitoring system solution.

The major objectives of this project work were achieved as the energy meter measured accurately the power consumed by the test load, sending the readings to a central system for monitoring. A remote access to the energy meter was provided to the utility using wireless networks.

5.2 ACHIEVEMENTS

With the implementation of this project, the following objectives were accomplished:

- Successful design of a virtual decentralised solar energy powered community
- Successful design and construction of a decentralised solar powered model housing estate.
- Successful integration of decentralised solar powered system with a central monitoring system.
- Successful design and construction of a metering system using voltage current sensors that can accurately measure the power consumption of loads connected to it;
- Successful development of a two-way communication infrastructure between the energy meter and the utility using wireless technology;

- Successful development of a remote access feature that offers the user the ability to manage energy better by being able to cut off supply to the load in wirelessly and by the meter itself when power used is equal to the amount paid for
- Successful development of a user-friendly interface for the utility to monitor, control and bill the consumers.

5.3 CHALLENGES ENCOUNTERED

During the course of the implementation of this project, the following challenges were encountered:

- Although steps were taken to minimise losses on the line, in transferring power over long distances, energy was still lost.
- The maximum number of 3 parallel strings is usually recommended in battery design, this is because a higher number increases the rate of uneven charging and discharging, which shortens the lifespan of the batteries. But in this design the amperage rating for storage from calculation exceeds the batteries that are manufactured now, hence the need to increase the number of parallel strings. [16]
- The unavailability of the libraries of some of the components required for simulation of the project posed a major challenge as it slowed down the progress during the simulation stage;
- Damage to some of the electronic components during testing which led to their replacement and as a result, more expenses;
- Balancing the cost and functionality during project implementation was a challenge.
- Getting the right ESP8266 Wi-Fi module to work with.

5.4 RECOMMENDATION

Though the project has achieved its main objective, there is the need for more research and improvements. For further works towards a master's degree certification or doctorate, I would recommend more extensive study on:

- A technology that allows for effective monitoring of energy generated and consumed on the spot i.e. integrating the prosumer model in the decentralised setting.
- Effective techniques/ materials that allow for minimal line loss in transmission over long distances.
- More efficient, and cost effective bulk energy storage devices (batteries).
- A communication between the meter and the user to give the user control over the power usage in his home

5.5 CONCLUSION

In conclusion, the implementation of a decentralised solar energy systems provides obvious economic and social benefits that macro renewable energy projects are lacking in, thereby making it recommended venture in the advancement of solar technology. Although the cost of implementation of such systems is relatively high, it would be the real estate developers decision to venture in it, after properly weighing the benefits.

Also the integration of the smart prepaid energy meter with enhanced capabilities of sending to and receiving information and instruction from a central system, cut-off and reconnect users automatically will provide the utility and users at large with a solution to the distrust in the Nigeria power sector.

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