UNIVERSITY of the WESTERN CAPE

RESPICE PROSPICE

University of the Western Cape

COS 731

Supervisor: Prof B. A. Bagula

Co Supervisor: Dr O. E. Isafiade

The G-HiTech SIMBA Energy Box

Authors:
Thabisani Sibanda

Student Numbers:
3580034

April 23, 2018

Declaration

The proposals and information presented in this thesis was solely compiled by ***Thabisani Sibanda*** at the University of the Western Cape under the supervision of ***Prof A. Bagula*** and ***Dr O. E. Isafiade***. This is my own work and has not been submitted before by anyone for any degree or any other assessments. Any contributions from colleagues and other scholarly journals used in this project such as diagrams or calibrations, statistics and any other resources are explicitly referenced in the text.

Thabisani Sibanda, 3580034

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

Contents

Abstract

According to the International Energy Agency(*Energy Access Outlook* ,2016), about 1.1 billion people worldwide, lack access to electricity and about 95% of these people are in Sub-Saharan Africa and Asia. Moreover the electricity needs of many people who have access to electricity in these regions are not met at all, because of unreliable energy supplies. Access to electricity is very vital in promoting socio economic development and impacts very largely on many different economy sectors, especially in African countries. Thus new smart energy supplying solutions must be explored to combat this challenge. The aim of this project is to address the energy need by harnessing the abundant solar photo voltaic (PV) energy from the sun. We designed a compact solar (PV) energy absorbing unit called the *Simba Energy Box.* The Simba Energy Box is a solar energy based intelligent system that consists of a solar panel, DC/AC inverter, battery and controllers. The main idea is to allow the Simba Energy Box units to be able to communicate and to do electrical energy transactions (sharing) over a blockchain architecture.

Keywords : ***blockchain, solar,***

1 Introduction

1.1 Motivation

The global demand for renewable clean electrical energy is growing and Africa still staggers behind in terms of electricity generation and supply to its citizens. The 2016, World Energy Outlook report considered a simple binary measure of those who have access to electricity and those who do not. Its publication stated that only 45% of Africa's inhabitants had access to electricity in 2014 [1]. Which translates to 55% of the mother continent's inhabitants having no access to electricity at all. Africa's energy crisis is one of world's mega crises and has hindered Africa's general development since energy is the key driver of economic growth, globalization, improved health systems and improved standards of living. In most African developing countries this deficiency is inspired by financial constrains to setup and maintain electricity power stations.

1.1.1 Current Electrification Status

According to the United Nations Industrial Development Organization (2009), access to the electricity grid in many Sub-Saharan countries is less than 1% [2]. It also states that the electrification rates trends indicate that over 60% of Sub-Saharan Africans will still not have access to reliable electricity even by 2020 [2]. Even though the 60% mark was reached in 2016, the electrification rate is still slow and access to electricity is very difficult for people in marginalized areas. Not only is access to electricity grids difficult, but the power supply is very unreliable. This is so because poor maintenance of the grids. Faults and broken lines may go for months without being fixed. This is mainly as a result of lower tariffs they charge in order to promote access to electricity to the the poor majority. As a result, the utilities are not able to mobilize external capital for maintenance and expansion of rural electrification projects.Most countries have addressed this dilemma by leaving the duty to private power companies. Involving the private sector has increased reliability of electricity supply since private companies prioritize profit more and care less about the poor. However this promotes electrification to be centralized in big cities and towns whilst neglecting people in marginal or rural areas and poorer urban neighborhoods.

1.1.2 Abundant Solar Radiation in Africa

Africa has abundant renewable energy sources and many studies underline the great potential of Africa regarding renewable energy production and consumption. According to the United Nations Industrial Development Organization (2009), the most used renewable energy sources for large-scale applications in Africa are hydro-power, modern biomass, geothermal, wind and solar, amongst others [2]. Africa receives the most abundant solar energy radiation throughout the year, compared to any other continent. However, most of this radiation endowment remains largely underutilized. Large-scale solar energy projects are very limited in Africa because of their high cost [3]. Small scale solar energy systems have been setup in a few African countries to provide energy to communities that are not accessible to conventional energy supply systems such as the electricity grid.Unfortunately, poor households have not benefited much from these photovoltaic (PV) systems because of their costs [3].

1.2 Proposed Solution

The energy crisis in Africa shows the need of inexpensive alternatives to generate electricity. Harnessing the abundant solar energy is one of the alternatives that can generate electricity for the poor who are in isolated areas where electricity lines have not yet been erected.

The G-HiTech SIMBA Energy Box
Over the past 20 years, off-grid solar home systems (SHS), comprised of solar panels, batteries, a charge controller and loads, have proved the most popular and immediate solution increasing energy access, mainly through rural electrification, across the Global South. Although deployed in significant numbers, issues remain with SHS cost, reliability, utilization and sustainability. Interconnection of SHS to form a micro-grid of connected prosumers and consumers may offer a solution that, by employing smart management of the power distribution amongst connected households, has the potential to unlock latent generation and storage capacity and so improve reliability and security of supply, reduce the system cost per head, and ultimately the levelized cost of energy supplied [4]. The G-HiTech SIMBA Energy Box (SEB) is an intelligent solar power system which ensures maximization of use of the generated electrical energy by allowing users in a community to do electrical energy sharing transactions using blockchain.Users can import or export their excess or surplus energy. Simba Energy Boxes in a community are connected to each by WiFi. A SEB unit consists of :

- A photovoltaic solar panel
- Battery (power storage)
- DC to AC inverter
- Sensors (voltmeters and ammeters
- Raspberry Pi (single board computer) /arduino (microcontroller) with a WiFi module or chip
- Regulators

The G-HiTech SIMBA Energy Box will be designed to achieve the following:

1. Smart power distribution amongst connected solar home systems enabling P2P energy exchange and business models, with potential to balance supply and demand within the micro-grid, offering consumers more affordable energy, and energy providers a greater return on their investment.
2. Maintain a satisfactory level of power supply reliability, while also providing the flexibility required to manage the affordability of energy provided to customers with different needs, and so making the micro-grid more sustainable [4].
3. Generate small-scale prosumers and consumers with a market platform to trade locally generated energy within their community which promotes the consumption of energy close to its generation and, therefore, foster sustainability and the efficient use of local resources [5].
4. Blockchain [6], as emerging information technology, offer new opportunities for decentralized market designs and provide transparent and user-friendly applications [7] that allow energy consumers to participate in the decision on who produces their energy and by which technology it is generated [5].
5. Micro-grid markets can reduce the need for expensive and inefficient energy transportation with substantial losses [8] by satisfying demand from local energy resources. Furthermore, the latency for managing congestion and distribution faults can be decreased [9].
6. Micro-grid markets strengthen the local community in terms of self-sufficiency and provide the possibility of energy cost reduction. Local transactions keep profits within the community and encourage reinvestments in additional renewable generation [10].
7. To be a primary energy source for small scale businesses and households.

8. Backup energy source in case of grid power outage.
9. Emergency power supply for use in disasters, urgent medical assistance and telecommunication support in remote areas.
10. Power supply for remote non-electrified areas.
11. To create a community energy sharing network for support in cases where the main grid goes down in other parts of the community.

2 Literature Review

2.0.1 Traditional Centralized Energy Systems

One way of utilizing renewable energy sources is to consider the huge energy potential of sunlight, wind, water, geothermal resources, and gravitational forces [11, 2]. Traditional centralized energy systems are characterized by a large number of customers located within a wide area. Energy is supplied by large power plants that operate according to a centralized coordination mechanism [5, 12]. However, it is worthy exploring the decentralized energy systems which may consist of small-scale energy generators that are placed in the same location with an energy consumption point that be can used by a small number of people [5]. One would opt decentralized energy system to avoid a single point of failure among other things. Micro-grid energy systems have been found to provide small-scale prosumers and consumers with a market platform to trade locally generated energy within their community [5]. [5] postulates that micro-grids promote the consumption of energy close to its generation and, therefore, foster sustainability and the efficient use of local resources. A good practical example is the Brooklyn micro-grid developed by LO3 Energy and Siemens.

2.0.2 Modern Decentralized Micro-grid Energy System

LO3 Energy, is a New York based energy company and specialist for the distribution of energy grids.The company is working with Siemens on the Brooklyn micro-grid, a community-powered micro-grid in Brooklyn, New York. In their setup all households in a given community are interconnected and all of these network members are connected to the main electricity grid and some users may have other subsidiary sources of energy such as windmills, photovaltaic and thermal solar energy generating systems.Members with other subsidiary energy sources (producers) in the network can sell the surplus energy generated from their subsidiary power sources to other users who want cheaper and locally produced energy [13]. Energy consumers can note the maximum they are willing to pay for the electricity for a certain time interval [14]. The energy payment transactions are done in a peer-to-peer energy market running on a blockchain. All members of the network can enter directly into energy exchanges with any other member of the network without any restrictions or oversight from the central authority [14].

2.0.3 Our Intended Solution: The G-HiTech SIMBA Energy Box

In our project, we seek to promote the micro-grid decentralized energy system. Blockchain is used for energy export and importing transactions among nodes in our distributed system. However, our nodes are a bit advanced. Firstly, our Simba Energy Box(SEB) is a compact package which comprises of two controllers, a battery and a DC/AC inverter. These components are connected already from the manufacturer.The first controller regulates the out flux of electrical energy from the photo-voltaic solar panel to the battery. Its sensors detect and report environmental and non-environmental parameters [15] such as temperature, aiding to prolong the battery life without a user's interference. The second controller is connected between the battery and the DC/AC inverter to regulate energy transfer from battery to inverter and also to close and open circuits for energy exportation and importation. All the user need to do is to connect the labeled terminals from the solar panels and the electrical adapter to the DC/AC inverter.

Secondly, our micro-grid decentralized energy system is a network of SEB nodes each integrated with network connection capabilities so that SEBs can communicate with each other and to their users if they need any information from them. This make the implementation of the system on top of blockchain technology feasible as information is easily exchanged across nodes with transparency in a common network. More information on how these capabilities of our system benefit the user are described in the sections below. Figure 1 shows a micro-grid energy system of SEB nodes which are WIFI enabled in a community.

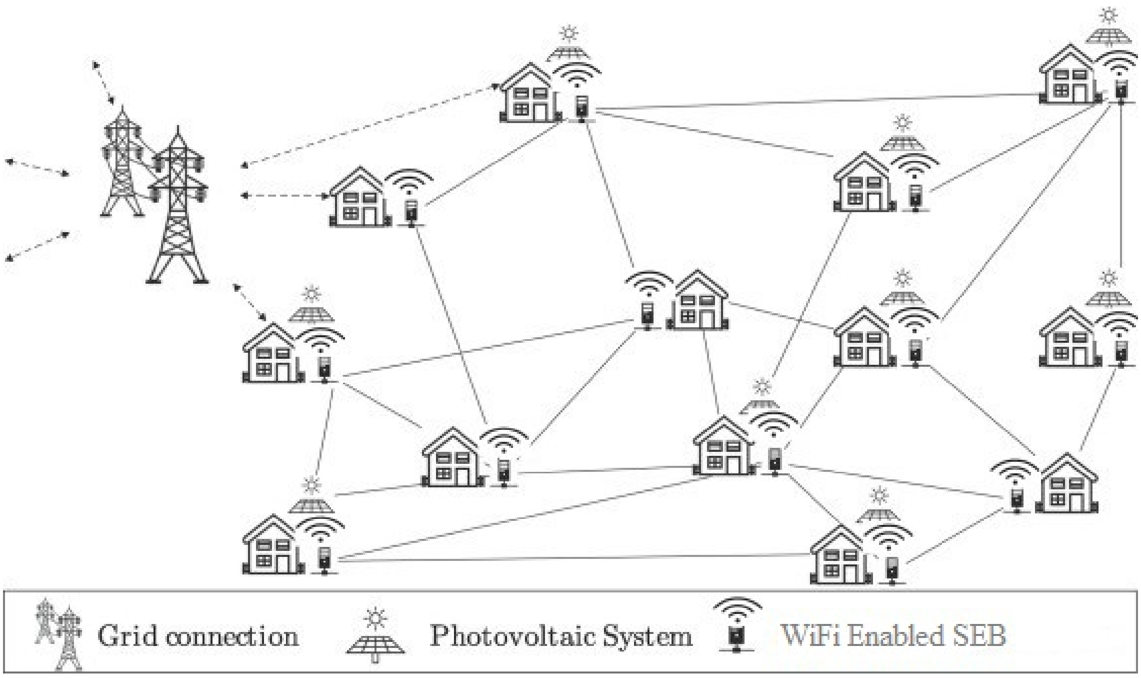

Figure 1: *The Micro-grid Energy System Layout*

3 User Requirement Document

3.0.1 Logging Into System

A registered user must be able to login to the system. If they are not registered, they register into the system first and then login.Unregistered users may sign in using their face book or google accounts.

3.0.2 Notifications

The system must alert and update users about its current state through notifications. The user can then view the notifications by clicking the notifications banner on their home screen.

3.0.3 System Readings

The user must be able to view system status readings on the controller interface or via the platform on their devices where their SEB system is interfaced. System

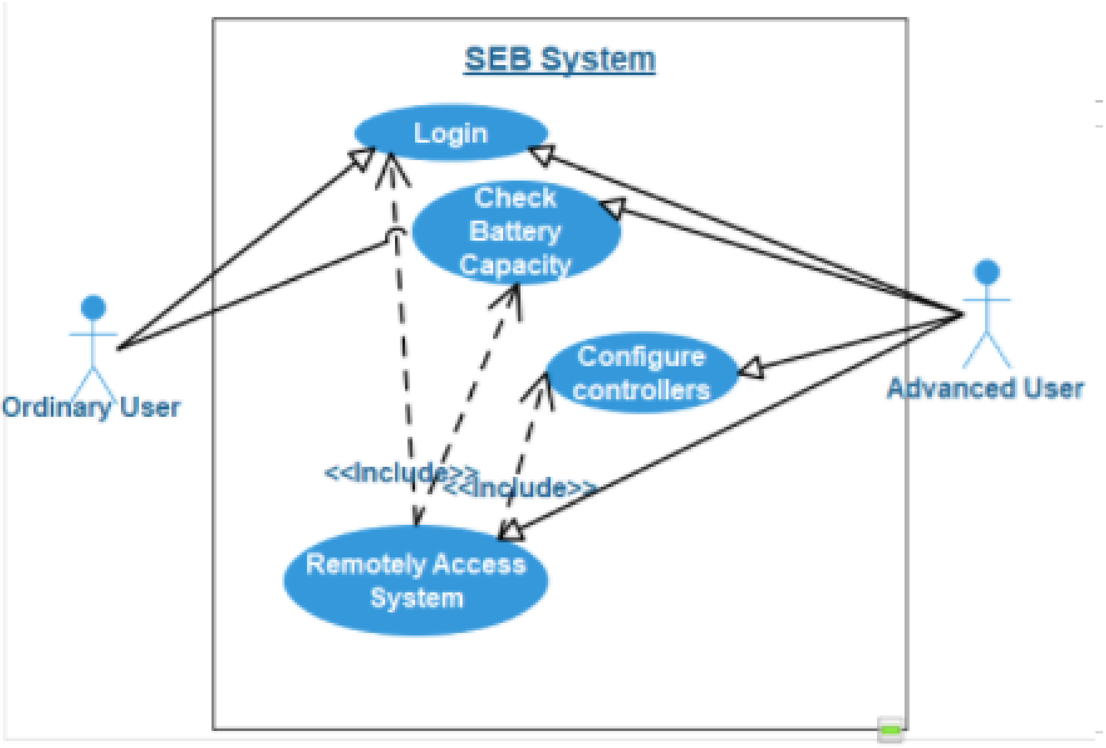

Figure 2: *Use Case Diagram for The G-HiTech SEB Block Chain Technology*

readings include battery electrolyte levels, the capability of a SEB node to trade energy with other nodes and the like.

3.0.4 Automated Energy Sharing

A user must be able to switch the system between manual and automated modes. However the energy trading phase is automated since there might be too many offers and requests at a node to be processed manually.

4 Requirement Analysis Document

4.1 Functional Requirements

4.1.1 Energy Box Compactness

The energy box should be a full package box with both two controllers battery and DC/AC inverter in a box and connected as shown in Figure 3. The goal is to have an easy to use system where a user or SEB installer have to connect the solar panel to CPU1 and to plug in their adapter into the DC/AC inverter to supply energy to the appliances.

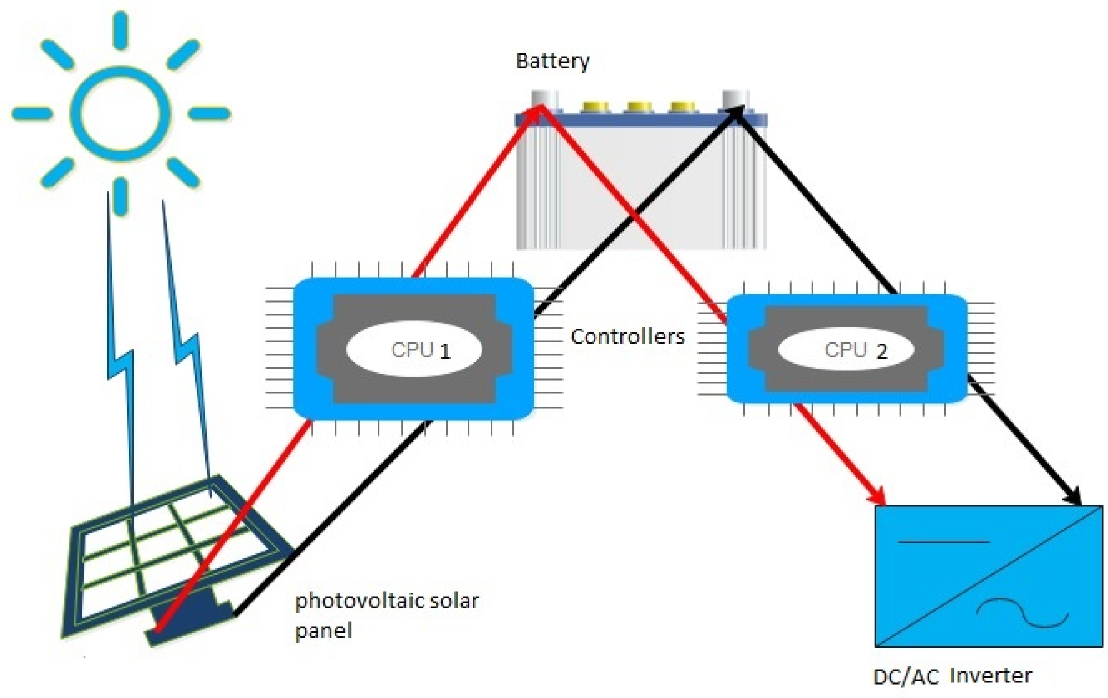

Figure 3: *Components of the G-HiTech SIMBA Energy Box*

4.1.2 Energy Exportation and Importation

SEB nodes must be able to trade energy manually or automatically. By manually we mean the system must be configurable to let a user accept or reject SEB offers and send SEB requests to other nodes. However this process can be too stressful to a user especially during peak hours. The trading of electricity energy to be implemented in the middle-ware layer is via block chain technology. Figure 4 shows the IoT architectural side of our system delineating how information is passed and processed from the Sensing Layer to the Middleware Layer where we implement blockchain.

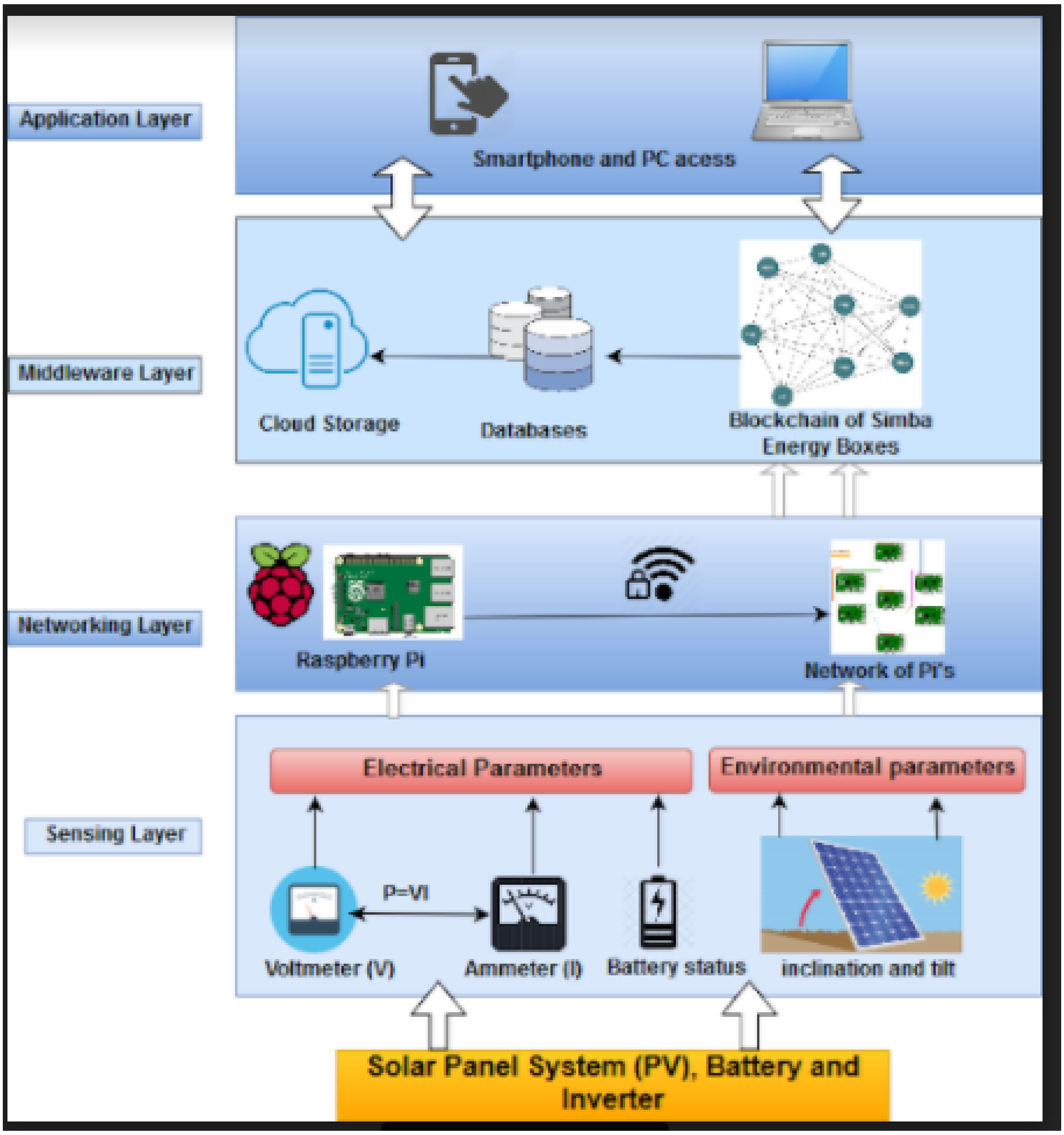

Figure 4: *System Architectural Layers of Connected SEBs*

CPU1 and CPU2 in the SEB outline are the ones in the sensing platform. On receiving a SEB request, the sensors measure the power capacity in our battery and send appropriate signals through the sink node or Gateway on whether to donate energy in a block chain or not. The same gateway is used by the SEB controllers to receive or broadcast a message on a peer to peer block fashion.

4.1.3 The G-HiTech SEB Block Chain Technology

Since its introduction as the underlying technology of Bitcoin [5, 6], blockchain technology emerged from its use as a verification mechanism for cryptocurrencies and heads to a broader field of economic applications. In our system, we use blockchain mainly for security and authentication purposes. All energy importing and exporting transactions are recorded at each SEB node in the block. Also before an energy transfer transaction is commenced, the transaction must be validated across all nodes as there is no intermediaries involved in a block chain system. Thus we ensure that there is no fraud in energy transfers and if there is, a culprit can always be tracked down from previous transactions available at each node. All transactions have unique identification hash codes which are acquired from hashing the current ledger of transactions plus the new transaction. Date and time stamps together with SEB serial numbers may be incorporated to eliminated collisions of transaction id's. Our main goal is to present the concept of a blockchain-based micro-grid energy market without the need for central intermediaries [5].

Intended SEB Block Chain Technology Platform:
The SEB system block chain layer will be built upon the IBM Watson IoT^{TM} Platform. Figure 5 shows how IoT data from SEB nodes is processed and conveyed from Watson Iot Platform to a Business network.

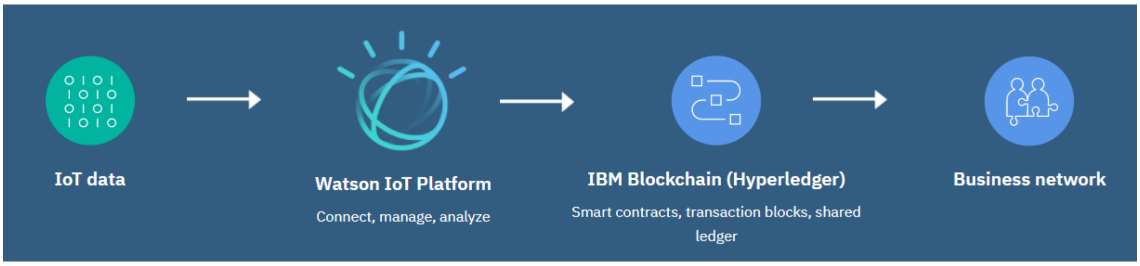

Figure 5: *Data Flow in Integrated Watson IoT Platform with Blockchain [16]*

IBM Watson IoT^{TM} Platform enables IoT devices to send data to private blockchain ledgers for inclusion in shared transactions with tamper-resistant records. The distributed replication of IBM Blockchain enables your business partners to access and supply IoT data without the need for central control and management. All business partners can verify each transaction, preventing disputes and ensuring each partner is held accountable for their individual roles in the overall transaction [16]. Figure 6 shows connected SEB nodes in a micro-grid network.

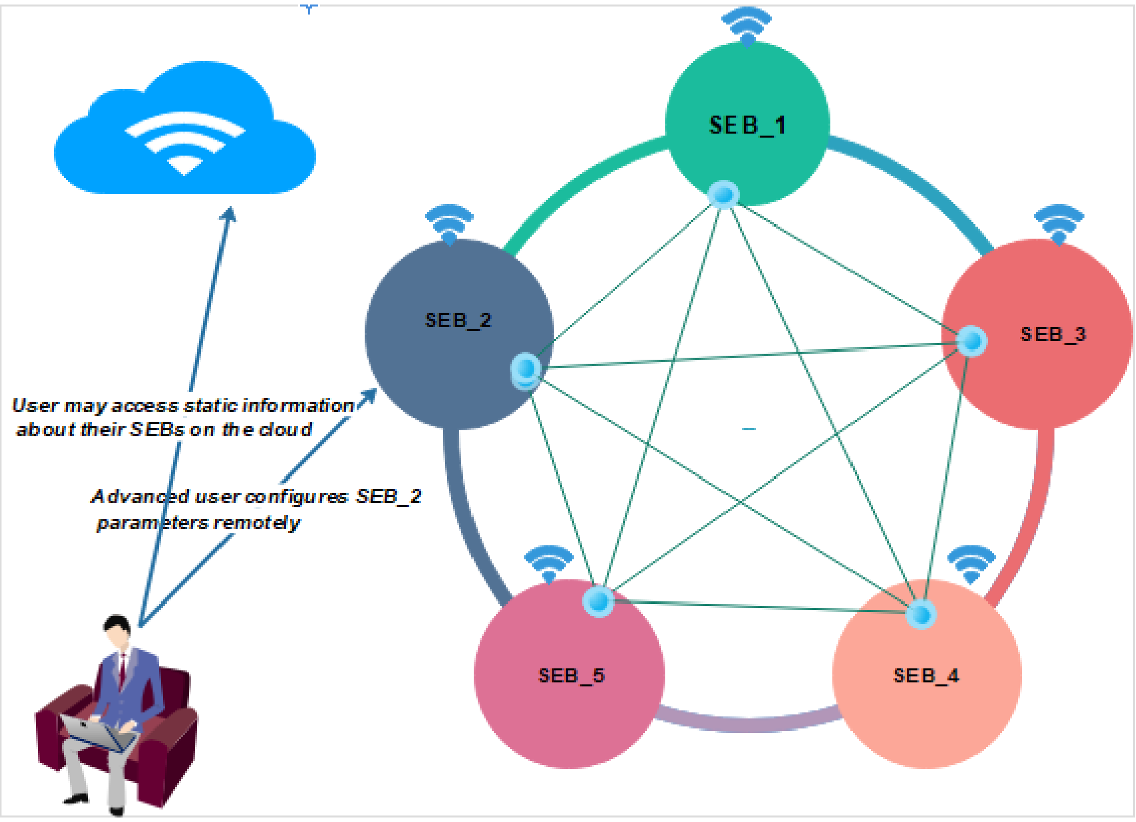

Figure 6: *WiFi Enabled SEBs in a Micro-grid Network*

Case Scenarios of The G-HiTech SEB

- **SEB_1 Wants to Import Power:**
  SEB_1 fires an SEB request across the connected SEBs(note that the SEB have network connection capabilities as shown in Figure 6). If any of the other SEBs has enough to export to SEB_1, it fires a SEB offer back to SEB_1 which is recognizable in the network because it is an IoT device with an IPv6 address. If SEB_1 receives more than one offer, it chooses the one to accept through a selection criteria involving distance between it and the exporting SEB and amount that the exporting SEB is willing to offer among other factors. SEB_1 then fires SEB accept messages to the SEBs it is willing to import energy from. If the total time to live (TTL) of the offer has not elapsed when an exporting SEB receives an SEB accept message, the energy trade transaction

commences between two SEBs. The blockchain technology is implemented to generate and store secure and authorized transactions of energy trade across all nodes. These transactions are stored at each node for transparency and future references.

- **SEB_2 Receives a SEB Request From Another SEB:**
  If it is only one requesting SEB, SEB_2 then checks if he has enough energy to respond with a SEB offer. However, if SEB_2 receives more than one SEB request at the same time, he has to choose which SEB to export power to, should he possess the surplus energy. This decision can be taken after considering factors such as the distance between requesting SEB and SEB_2, the amount of energy requested and previous transactions between the two SEBs. After SEB_2 has chosen which node to export energy to, he fires SEB offer to the requesting SEB with a specific total time to live (TTL). If the node responds before the TTL elapses, the energy trade transactions commence.

4.1.4 Remote Access

SEBs are designed to be connected IoT devices. This enables them to communicate on their own and also to communicate with their users over a network. The users should be able to access their boxes away from their location for configurations and status checking.

4.1.5 System Configurability

The SEB system must be configurable from a block layer level to a user SEB configuration level. Users must be able to configure their home setups anywhere and anytime through interfaces on their phones or PCs. A SEB must also be able to communicate with its user through notifications on issues like need of service, malfunction of a component and any form of defect. Users need to configure system parameters such as threshold values for exporting and importing energy to and from other nodes.

4.2 Data Requirements

4.2.1 Database

- **User**
  Attributes

Name
Surname
Password
Email
User ID

- **Simba Energy Box Attributes**
  User ID
  Serial Number

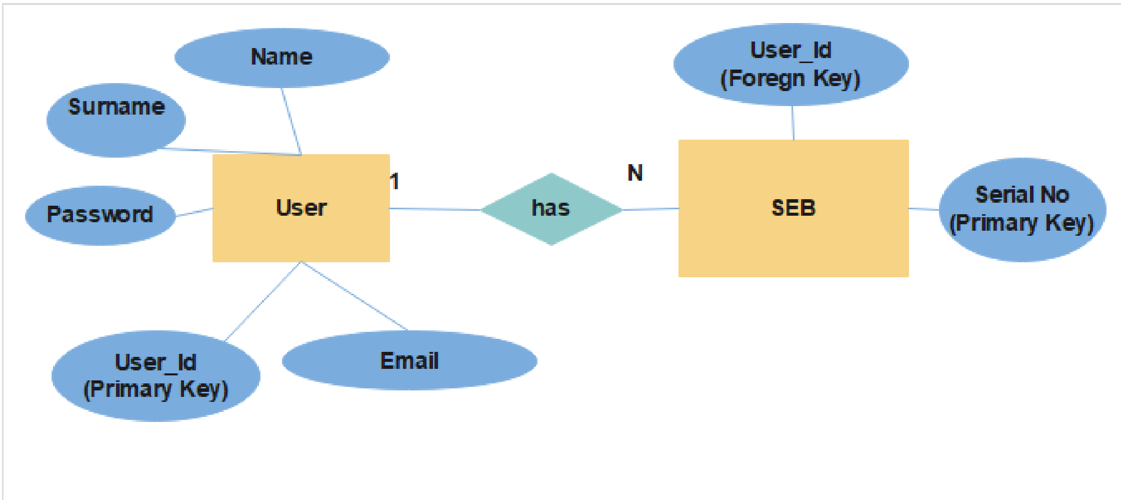

Figure 7: *The Chen Entity Relationship Diagram Model for The G-HiTech SIMBA Energy Box*

4.3 Usability Requirements

4.3.1 Accessibility

The system interface must be simple and clear. Icons must be standard ones and visible for accessibility. We try to avoid nested menus which may hide important functions of the system from the user. The terminology we use to label view components is also be explanatory.

4.3.2 Consistency

The system is design with careful consideration of different cases. Frequencies of the the system crushing are strictly dealt with by thorough testing before deployment. By making use of technologies such as cloud computing, we ensure system scalability and elasticity to cater for peak hours.

4.3.3 Customization

The system is designed to be configurable to a user's preferences. This involves customizing SEB parameter values in the SEB configuration page. Users have privileges to change their view components color and other attributes e.g a user may choose some color background for a page.

4.3.4 Feedback

We intend to build the SEB system with frame works that allow instant responses to the users when they are interacting with the system. Every clickable or responsive component must give a feedback to the user when interacted with, to update the user on the processing of their requests or data. These feedbacks are in the form of sounds, change of state or color of the component and also progress bars.

5 Non-functional Requirements

5.1 Environmental Requirements

The photo voltaic solar panels' surfaces need to be exposed to the sun rays at optimizing absorption angles. Battery life is another issue of concern. Only 30 percent of batteries sold today reach the 48-month mark [15]. In fact 80 percent of all battery failure is related to sulphating [15]. This build up occurs when the sulphur molecules in the electrolyte (battery acid) become so deeply discharged that they begin to coat the lead plates of the batteries. Before long the plates become so coated that a barrier is built up that will result in high internal impedance; the battery loses the capability to transfer power or take any charge [15]. Thus it is important to be aware of environmental requirement issues for a battery powered system to ensure the battery long life. Batteries should be stored in cool places. Batteries need energy loss compensations. Heat of 35°C or more increases internal discharge. As temperatures increase, so does internal discharge [17, 18]. SEBs need to be connected in a mesh for energy import and export to take place in the block chain. Thus SEB physical connections is another concern in our system [4]. Electrical conductors will need to be protected from rusting.

5.2 Data Integrity

Data Integrity is ensured by the blockchain part of our system where all transactions are stored at each SEB node. Thus no one can temper with energy trade data. We host data about SEBs and users on cloud. We chose Amazon Web Services(AWS) as our cloud service provider due to their reliability in maintaining data integrity for their customers [19].

5.3 Scalability

Scalability is a requirement of concern as our network of SEBs enlarges in a micro-grid. Thus we make use of AWS's elastic storage and computing services to cater for scalability needs in storage and computations [19].

6 User Interface Specification

We show the User Interface flow diagram in Figure 8.

6.1 Log in Page

This is an index page which has a form for login and a button which directs the user to the sign up form when clicked. Users also have options to sign in with their Google, Twitter or Facebook accounts. After log in, the user is taken to the home page.

6.2 Sign up Form

When a user is not registered with the system, he has to sign up first by clicking the sign up button in the Log in page. This sign up form has text fields that a user

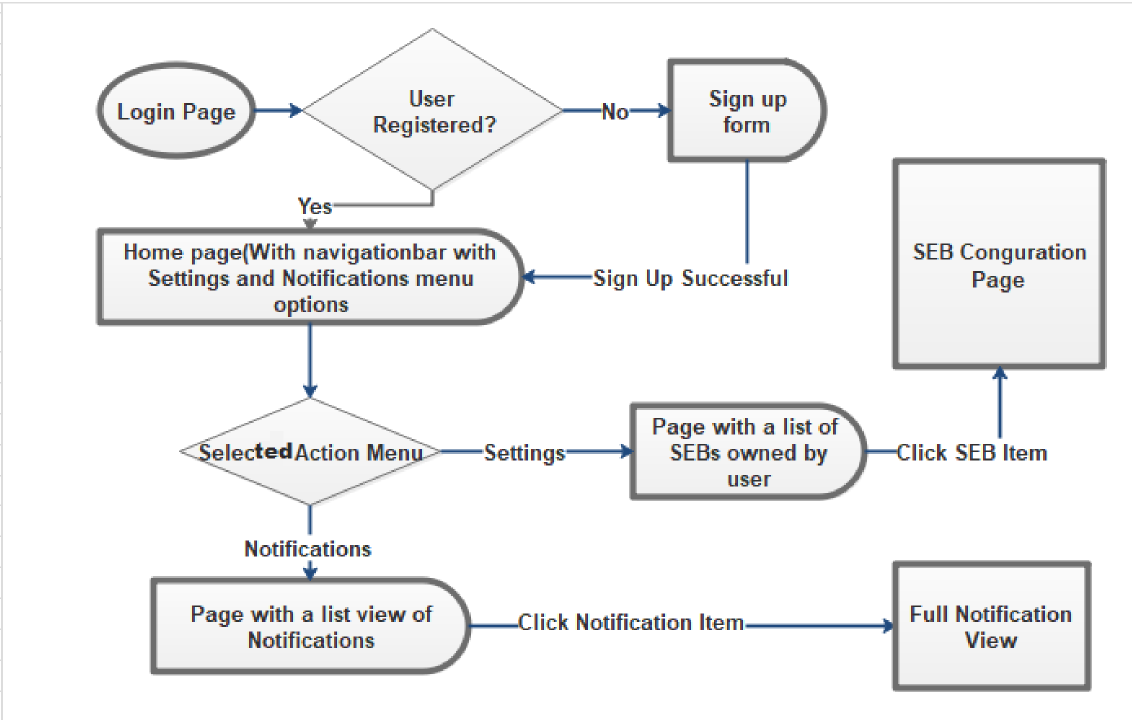

Figure 8: *User Interface Flow Diagram for The G-HiTech SIMBA Energy Box*

has to enter data to be submitted once they hit a submit button. After successfully submitting the user is directed to the home page.

6.3 Home Page

After successfully log in or sign up, the user is taken to the home page. The home page has a navigation bar which shows number of notifications if any and has a menu for settings. To view notifications, the user clicks the notification option. To configure SEBs remotely, the user clicks the settings options menu.

6.4 Notifications

In this page, the user may view all their notifications in detail. Notifications text can be expanded or constricted to enhance the view.

6.5 Settings

The settings page has a list of responsive card views of each SEB a user owns. When clicked, the card view takes the user to its SEB configuration Page for configurations.

6.6 SEB Configuration Page

A SEB's configuration page shows all the attributes of the SEB and their values. It also shows the previous history of energy sharing transactions involving the SEB. If there is any updates to be done on the SEB they will also be notifications for that. The user can change specific parameter values of the SEB here.

7 Project Plan

- We will be doing pairs programming for building our system softwares.
- We break down our project into modules that can be completed in weekly time intervals. If we cannot finish a task in a week, we may extended its period or switch to another task depending on the cause of the task not being finished.
- We will be meeting with our supervisors for consultations on weekly bases to get feedback on the relevance of our work. This let us avoid working for long periods in the wrong direction which saves time and other resources.
- We will also be presenting on ISAT labs Friday meetings to get constant feedback from other students and our stakeholders.
- Each weekly module will be thoroughly tested before starting to work on another one to avoid having to track the origins of a fault at later stages which may result in redoing tasks thereby wasting time and resources.

References

[1] J. Conti, P. Holtberg, J. Diefenderfer, A. LaRose, J. T. Turnure, and L. Westfall, "International energy outlook 2016 with projections to 2040," USDOE Energy Information Administration (EIA), Washington, DC (United States). Office of Energy Analysis, Tech. Rep., 2016.

[2] United Nations Industrial Development Organization, "Breaking in and moving up: New industrial challenges for the bottom billion and the middle-income countries," *Industrial Development Report*, 2009.

[3] M. S. B. Aissa, M. B. Jebli, and S. B. Youssef, "Output, renewable energy consumption and trade in africa," *Energy Policy*, vol. 66, pp. 11–18, 2014.

[4] B. Soltowski, S. Strachan, O. Anaya-Lara, D. Frame, and M. Dolan, "Using smart power management control to maximize energy utilization and reliability within a microgrid of interconnected solar home systems," in *7th Annual IEEE Global Humanitarian Technologies Conference, GHTC 2017*, 2017, pp. 1–7.

[5] E. Mengelkamp, J. Gärttner, K. Rock, S. Kessler, L. Orsini, and C. Weinhardt, "Designing microgrid energy markets: A case study: The brooklyn microgrid," *Applied Energy*, vol. 210, pp. 870–880, 2018.

[6] S. Nakamoto, "Bitcoin: A peer-to-peer electronic cash system," 2008.

[7] M. T. Alam, H. Li, and A. Patidar, "Bitcoin for smart trading in smart grid," in *The 21st IEEE International Workshop on Local and Metropolitan Area Networks*, 2015.

[8] J. Jimeno, J. Anduaga, J. Oyarzabal, and A. G. de Muro, "Architecture of a microgrid energy management system," *International Transactions on Electrical Energy Systems*, vol. 21, no. 2, pp. 1142–1158, 2011.

[9] E. Kuznetsova, Y.-F. Li, C. Ruiz, and E. Zio, "An integrated framework of agent-based modelling and robust optimization for microgrid energy management," *Applied Energy*, vol. 129, pp. 70–88, 2014.

[10] B. P. Koirala, J. P. Chaves Ávila, T. Gómez, R. A. Hakvoort, and P. M. Herder, "Local alternative for energy supply: Performance assessment of integrated community energy systems," *Energies*, vol. 9, no. 12, p. 981, 2016.

[11] I. Dincer, "Environmental impacts of energy," *Energy policy*, vol. 27, no. 14, pp. 845–854, 1999.

[12] K. Alanne, A. Saari, and A. Salo, "Comparative analysis of the life-cycle costs of residential energy supply technologies," *Energy and Buildings.[Manuscript]*, 2006.

[13] "The future of energy, blockchain and transactive grids," 2018. [Online]. Available: http://lo3energy.com/

[14] A. Thakkar, "How blockchain and peer-to-peer energy markets could make distributed energy resources more attractive," 2017.

[15] “SINETECH, The Power of Choice secrets of battery life and performance,” http://www.sinetech.co.za/battery-care.html.

[16] “Watson Internet of Things implement iot and blockchain for accountability and security,” https://www.ibm.com/internet-of-things/be-en/platform/private-blockchain/, accessed: 2018-04-18.

[17] Y. Y. Chia, L. H. Lee, N. Shafiabady, and D. Isa, “A load predictive energy management system for supercapacitor-battery hybrid energy storage system in solar application using the support vector machine,” *Applied Energy*, vol. 137, pp. 588–602, 2015.

[18] X. Zheng, W. Gao, X. Zhang, M. He, X. Lin, H. Cao, Y. Zhang, and Z. Sun, “Spent lithium-ion battery recycling–reductive ammonia leaching of metals from cathode scrap by sodium sulphite,” *Waste management*, vol. 60, pp. 680–688, 2017.

[19] M. Wittig and A. Wittig, *Amazon web services in action.* Manning, 2016.