ENERGY DATA MANAGEMENT SYSTEMS FOR SMART COMMUNITY WITH PV MICROGRID

ระบบจัดการข้อมูลพลังงานสำหรับชุมชนอัจฉริยะ เชื่อมต่อโครงข่ายไฟฟ้าพลังงานแสงอาทิตย์

MANOTE TONSING

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY
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The Title	Energy Data Management Systems for Smart Community with PV Microgrid
The Author	Manote Tonsing
Program	Information Technology for Business and Education
Thesis Advisors	
Advisor	Dr. Worajit Setthapun
Co-Advisor	Dr.-Ing. Jiratkwin Rakwichian
Co-Advisor	Associate Professor Dr.-Ing. Boonyang Plangklang

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…………………………………………………Chairman
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(Dr. Eakkarath Panyathep)

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(Dr. Worajit Setthapun)

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(Dr.-Ing. Jiratkwin Rakwichian)

…………………………………………………Member
(Associate Professor Dr.-Ing. Boonyang Plangklang)

Graduate School at Chiang Mai Rajabhat University approved this thesis as partial fulfillment of requirements for the Degree of Doctor of Philosophy in Information Technology for Business and Education.

………………………………………..Dean of Graduate School
(Assistant Professor Dr. Kamolnut Pholwan)
Date……………………………………

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Thesis Advisors : Dr. Worajit Setthapun Chairman

: Dr.-Ing. Jiratkwin Rakwichian Member

: Associate Professor Dr.-Ing. Boonyang Plangklang Member

ABSTRACT

Energy data such as energy consumption from buildings and energy production from distributed generations are very important to determine the optimal sizing, design and configuration of renewable energy and microgrid systems. The goal for future communities are based on the concept of Smart Community with sustainable energy. The main objective of this research is to develop the energy data management system for the Smart Community with PV AC & DC Microgrid. This work has 3 parts: 1) Analysis of DC & AC Microgrid potential with microgrid simulation; 2) Big energy data collection procedure; and 3) Development of big energy data management system for Smart Community.

Real data for energy consumption was collected from 12 small buildings in the Smart Community of Chiang Mai Rajabhat University. The load profile trend was similar to the simulated full load, however, the real energy consumption was significantly lower than the simulated full load. So, the facility of Smart Community could accommodate more occupant to stay and work. The current DC Microgrid

Hybrid System could provide power to the current load and future full load with full occupancy of the house and buildings. With the modeling of DC Microgrid Hybrid System, it was founded that the current PV system size was properly designed and utilized to the full potential for the current real load and simulated load. Diesel generator component is important and needed as backup power for the Off-grid DC microgrid. However, the diesel generator was over designed. The optimal generator size would be 10 kW based on the future full load scenario. With higher load, the O&M cost would be higher because of the cost for diesel fuel and the replacement of diesel generator. Using only PV and battery for the off-grid Microgrid system was possible. However, the battery and PV system would have a high investment cost than the system with diesel generator. The battery would need to be replaced every 4-5 years, thus, recreating high O&M cost. Therefore, it is necessary to know the load profile and expectation for load increase to properly design the Hybrid Microgrid system to minimize non-essential investment. Energy storage technology is the key to achieve energy security, power quality and power stability. In addition, the results of the Homer simulation DC microgrid and AC microgrid were also compared. The results revealed that currently both systems were over designed for the diesel generator and battery. However, this will be able to accommodate the expansion of the community as full load and more housings. However, if the current load was reduced to about half, only PV could be used as the distributed generation without the use of diesel generator and the operation and maintenance would also reduce significantly. Applying the DC microgrid would also reduce cost more about 14.2% when compared to the AC microgrid from the full load calculations.

For this work, the energy data for the Smart Community is considered as direct energy data and indirect energy data from the community. The data categetories that were chosen were energy consumption, water usage, indoor temperature, humidity and waste generation. The data collected from sensors installed in the buildings were then processed through 3 steps: Capture, Verification and Arrangement. Approximately 1,800 data files per month were processed. Each data file has the maximum of 86,400 data records depending on the data category and collection interval. The sensors installed in real building has several challenges such as lack of data transmission from blackouts, sensor malfunctions from animals, etc. The data verification part is very important to screen for the usable data and reject the bad data.

The processed data were then imported into the energy data management system database. The datasets were systematically grouped and arranged in their category. Responsive Web Design was the concept used for designing the energy data database. Bootstrap was used to frame in user interface with PHP, SQL and JavaScript language. Chart.js was applied for data reporting as graph or to compare the replationship between the data categories. Information can be exported as Excel files. The energy data management system can be used for the real small community data collection with easy to understand reporting format.

Keywords: Community Simulation, Microgrid, Homer, Energy Data Management

หัวข้อวิทยานิพนธ์ : ระบบจัดการข้อมูลพลังงานสำหรับชุมชนอัจฉริยะเชื่อมต่อโครงข่ายไฟฟ้าพลังงานแสงอาทิตย์

ผู้วิจัย : มาโนชญ์ ตนสิงห์

สาขาวิชา : เทคโนโลยีสารสนเทศเพื่อธุรกิจและการศึกษา

อาจารย์ที่ปรึกษาวิทยานิพนธ์

ดร.วรจิตต์ เศรษฐพรรค์	อาจารย์ที่ปรึกษาวิทยานิพนธ์หลัก
ดร.จิรัสกวินท์ รักษ์วิเชียร	อาจารย์ที่ปรึกษาวิทยานิพนธ์ร่วม
รองศาสตราจารย์ ดร.บุญยัง ปลั่งกลาง	อาจารย์ที่ปรึกษาวิทยานิพนธ์ร่วม

บทคัดย่อ

ข้อมูลพลังงาน เช่น การใช้พลังงานจากอาคารและการผลิตพลังงานที่มีรูปแบบที่หลากหลาย มีความสำคัญมากในการกำหนดขนาดที่เหมาะสม การออกแบบและการกำหนดโครงสร้างของระบบการผลิตพลังงานทดแทนและระบบผลิตไฟฟ้าที่มีขนาดเล็ก สำหรับเป้าหมายของชุมชนในอนาคตอยู่บนพื้นฐานของแนวคิดของชุมชนอัจฉริยะ โดยการใช้พลังงานให้ยั่งยืน วัตถุประสงค์หลักของงานวิจัยนี้คือการพัฒนาระบบการจัดการข้อมูลพลังงานสำหรับชุมชนอัจฉริยะด้วย พลังงานแสงอาทิตย์ AC และ DC Microgrid งานวิจัยนี้แบ่งออกเป็น 3 ส่วน คือ 1) การวิเคราะห์ศักยภาพการใช้พลังงานในระบบ AC และ DC Microgrid โดยการจำลองระบบ 2) ขั้นตอนการรวบรวมข้อมูลพลังงานขนาดใหญ่สำหรับชุมชนอัจฉริยะ 3) การพัฒนาระบบการจัดการข้อมูลพลังงานสำหรับชุมชนอัจฉริยะ

ข้อมูลการใช้พลังงานจริงที่จัดเก็บจากอาคารทั้ง 12 อาคาร ในชุมชนอัจฉริยะ ของมหาวิทยาลัยราชภัฏเชียงใหม่ การใช้พลังงานจริงในชุมชุมจะต่ำกว่าการใช้พลังงานที่จำลองจากพฤติกรรมแบบเต็มเวลาอย่างมีนัยสำคัญ ดังนั้นระบบการผลิตไฟฟ้าของชุมชนอัจฉริยะ สามารถรองรับการขยายตัวของชุมชนในอนาคต ในปัจจุบันระบบ DC Microgrid Hybrid ได้รับการออกแบบมาอย่างเหมาะสมและสามารถผลิตพลังงานให้เพียงพอต่อการใช้งานในชุมชนทั้งข้อมูลการใช้พลังงานจริงและข้อมูลการจำลองพฤติกรรมการใช้พลังงานแบบเต็มเวลา ส่วนประกอบของเครื่องกำเนิดไฟฟ้าดีเซลมีความจำเป็นสำหรับใช้เป็นพลังงานสำรองสำหรับระบบ DC Microgrid ซึ่งปัจจุบันพบว่า เครื่องกำเนิดไฟฟ้าดีเซลถูกออกแบบมาเกินความต้องการของชุมชน ซึ่งขนาดที่เหมาะสมสำหรับใช้งานภายในชุมชน คือ 10 kW ขึ้นอยู่กับการขยายตัวของชุมชนและการใช้

พลังงานแบบเต็มรูปแบบในอนาคต ถ้าการใช้พลังงานเพิ่มขึ้นการใช้เครื่องกำเนิดไฟฟ้าดีเซลก็จะสูงขึ้นและทำให้มีค่าใช้จ่ายด้านการดำเนินการ การบำรุงรักษาระบบที่เพิ่มขึ้น อย่างไรก็ตามชุมชนสามารถใช้แต่พลังงานแสงอาทิตย์เพียงอย่างเดียวในการผลิตพลังงานได้ แต่จะมีต้นทุนการดำเนินการและค่าบำรุงรักษาด้านแบตเตอรี่สำหรับจัดเก็บพลังงานแสงอาทิตย์ในระยะ 4 - 5 ปี เพิ่มขึ้นมากกว่าเครื่องกำเนิดไฟฟ้าดีเซล

ดังนั้นข้อมูลการใช้พลังงานจริงและการจำลองพฤติกรรรมการใช้พลังงานแบบเต็มเวลาจึงเป็นสิ่งจำเป็นเพื่อที่จะได้นำมาเป็นข้อมูลในการออกแบบระบบ Hybrid Microgrid ให้เหมาะสมกับชุมชนเพื่อลดต้นทุนในส่วนที่ไม่จำเป็น นอกจากนี้ยังได้เปรียบเทียบผลของการจำลอง AC Microgrid และ Dc Microgrid โดยใช้โปรแกรม HOMER Energy ผลการวิจัยพบว่าในปัจจุบันทั้งสองระบบได้รับการออกแบบเกินความจำเป็นและสามารถรองรับการขยายตัวของชุมชน อย่างไรก็ตามถ้าภาระทางไฟฟ้าของชุมชนลดลงเหลือเพียงครึ่งจะสามารถใช้พลังงานแสงอาทิตย์เพียงอย่างเดียว โดยไม่ใช้เครื่องกำเนิดไฟฟ้าดีเซลช่วยในการผลิต และทำให้ค่าบำรุงรักษาลดลงตามไปด้วย การใช้ DC microgrid จะสามารถลดค่าใช้จ่ายประมาณ 14.2% เมื่อเทียบกับการใช้ AC Microgrid

สำหรับงานวิจัยนี้ข้อมูลพลังงานสำหรับชุมชนอัจฉริยะถือเป็นข้อมูลพลังงานโดยตรง และข้อมูลพลังงานทางอ้อมประเภทของข้อมูลที่เลือกมาวิเคราะห์ เป็นข้อมูลที่มีความสัมพันธ์กับการใช้พลังงาน ได้แก่ ไฟฟ้า น้ำ อุณหภูมิ ความชื้น และขยะ ข้อมูลถูกจัดเก็บจากเซ็นเซอร์ที่ติดตั้งในอาคาร สามารถแบ่งเป็น 3 กระบวนการคือ การรวบรวม การตรวจสอบ และการเรียงลำดับ ซึ่งการประมวลข้อมูลประมาณ 1,800 ไฟล์ต่อเดือน ไฟล์ข้อมูลที่ถูกจัดจัดเก็บมีข้อมูลสูงสุด 86,400 ต่อรายการขึ้นอยู่กับประเภทของข้อมูลและช่วงเวลาในการรวบรวม เซ็นเซอร์ที่ติดตั้งในอาคารจริงมีปัจจัยที่มีผลต่อการจัดเก็บข้อมูลหลายอย่างเช่น เช่น เกิดจากไฟดับเซ็นเซอร์ไม่ทำงาน จากสัตว์ ฯลฯ ส่วนการตรวจสอบข้อมูลมีความสำคัญมากต่อการคัดกรองข้อมูลที่ใช้งานได้และข้อมูลที่ใช้งานไม่ได้

ข้อมูลที่ผ่านการประมวลผลและถูกจัดเก็บในฐานข้อมูลการจัดการข้อมูลอย่างเป็นระเบียบและแยกเป็นหมวดหมู่ที่ชัดเจน และอาศัยหลักการออกแบบ Responsive Web Design ในการออกแบบ โดยใช้ Bootstrap กำหนดกรอบของการทำงานและใช้งานร่วมกับ PHP Language, SQL Language and JavaScript Language ประยุกต์ใช้กับ Chart.js เพื่อสร้างรายงานในรูปแบบกราฟ ระบบสามารถแสดงข้อมูลออกมาได้น่าสนใจและสามารถเปรียบเทียบข้อมูลของปัจจัยที่มีความสัมพันธ์ต่าง ๆ และสามารถ Export เป็นรายงานในรูปแบบไฟล์ Excel ของการใช้พลังงานใน

แต่ละปัจจัย และระบบนี้สามารถนำไปประยุกต์ใช้กับชุมชนที่ต้องการวิเคราะห์จัดเก็บข้อมูลและนำเสนอในรูปแบบที่เข้าใจง่าย

คำสำคัญ: การจำลองระบบชุมชน, โครงข่ายไฟฟ้า, โปรแกรมโฮมเมอร์, การจัดการข้อมูลพลังงาน

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Finally, I wish to thank all of persons who support my work during the study that I could not mention all their names.

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CHAPTER 1

INTRODUCTION

Background

At present, the demand for energy is continuously increasing due to growth in population and the development of technology (Chassin, Fuller, & Djilali, 2014). The main energy sources are mostly from fossil fuel which are decreasing continuously (Jin & Chassin, 2014). There is a need to develop ways to efficiently use the alternative renewable energy sources. Energy from solar, wind, biomass and hydro are being focused as distributed generation. The integration of these renewable energies could be applied to produce stable and sustainable power to the small community. Microgrid system is the network that distribute power from the distributed generations to the loads connected to the network. The loads can also receive power from the main utility if the power sources from the renewables are not sufficient (Barnes et al., 2007). Microgrid systems have been continuously researched and developed especially in Europe, United States of America, Japan and Canada with the goal to achieve the fully efficient distribution system. Many microgrids had been demonstrated through installations and evaluation (Hatziargyriou, Asano, Iravani, & Marnay, 2007). Presently, the microgrid systems are composed of small distributed generations, loads, information and communication technology, energy storage and automatic control system. The components are integrated comparably to the main power grid. In addition, the current technologies are smaller and more affordable than the past which influenced more variety of distributed generations to be installed for power distribution. The present microgrid technologies are more advanced and complex because of more energy data resources to manage and can be called Smart Microgrid.

The electricity generation from renewable energy sources are quite unstable and depend on the weather and nature. The quality and stability of the generated electricity was therefore questioned. Designing the microgrid systems through modeling and simulation program is very important to achieve the optimal system to fully utilize the power from renewable energy within the appropriate parameters of the real power consumption or load. Modeling can provide the best microgrid system configuration to attain the stable and secure power. In addition, microgrid simulation from real load, environmental data and correct assumption can reduce the investment risk in the real system installation (Maria, 1997).

DC microgrid is another form of microgrid system where the DC power will be distributed through the microgrid network to the load. PV systems can directly produce DC power and distributed to the DC loads. This type of distribution would reduce loss from the inverters during the conversion from DC to AC. Currently, DC microgrid is widely being considered in buildings and data centers. Becker and co-workers proposed the application of DC microgrid in data centers to analyze the efficiency of renewable energy usage and power consumption of the appliances and electrical devices to reduce electric bills (Becker & Sonnenberg, 2011). The DC microgrid power distribution would be controlled to improve the reliability and flexibility of the main utility power system. DC microgrid system with PV, wind turbine and battery storage could be appropriately manage to supply the power when the main utility is down (Yunjie, Xin, Wuhua, & Xiangning, 2014). Integrating various type of renewable energy to the microgrid is very challenging. Therefore, the DC Microgrid systems need to be simulated for the proper design. Homer Energy is an Application Oriented Simulator which can provide the optimal system configuration for small scale electricity generation system. At present, Homer Energy is widely used in the planning stage to increase the performance and efficiency of renewable energy hybrid system while reducing the investment. The simulation can also provide economic analysis and calculate the emission and environmental impact. Homer Energy has been used to design and analyze renewable energy systems for rural area and islands (Hafez & Bhattacharya, 2012). In addition, Homer Energy could be used to model renewable energy hybrid system usage for remote communities to achieve system that was appropriate for the power demand of the community. It can also be used to design to accommodate the expansion of the community and analyze the power usage from agricultural farms (Sen & Bhattacharyya, 2013). Therefore, part one of this work presents the modeling of DC microgrid for the Smart Community in Chiang Mai Rajabhat University (CMRU), Thailand. This work focused on the analysis of the current DC microgrid hybrid system for the Off-grid community of 12 buildings via Homer simulation. The Smart Community is a real living model community that uses 100% renewable energy for electricity and heat. The students and researcher of Asian Development College for Community Economy and Technology, CMRU lived and studied in the Smart Community. Simulation of the DC Microgrid with Homer Energy will provide an understanding on ways to best utilize the current system and planning to accommodate the expansion of the community and more students. In addition, the comparison between DC Microgrid and AC Microgrid for the Smart Community were also analyzed.

For the big picture, the ultimate goal is to develop Smart Community with PV microgrid. Applying smart grid for the efficient energy management in the community will be the basis structure for the smart community. The starting key factor is energy data measurements and collection through electronic devices. Without the correct and usable data, energy management system and Smart Community can not be implemented. The word “Smart” has been widely used such as Smart Device, Smart Grid, Smart Home, Smart Network, Smart Intelligent Transportation and etc. The electronic devices have major roles in all activities of our daily lives and the movement toward the “Smart” society. RFID sensors are being embedded into the devices for identification and act as the brain of the devices. The devices can then connect to world via internet. The concept was created so all devices can communicate together through sensors. Therefore, the smart devices are able to connect to internet and other devices with sensors for data collection. The data from the electronic devices can be collected and devices can communicate with each other via internet through the Internet of Things (IoT). However, the data collected from all the device sensors are large and complex with and without structure. This create the issue during data compiling, data analysis and data usage. One of the aim of this work is to develop the process to manage the large and complex data from various devices and sensors. To achieve the PV Microgrid for Smart Community, the data which directly and indirectly related to energy production and consumption must be collected and analyzed. With proper data analysis, the data can determine ways to manage, control and optimize the energy system and smart community system. The Smart Community is the model community with sustainable living with self-energy production, energy efficient housing, community business, and organic agriculture. There are numerous data that is directly and indirectly related to energy in the community such as water consumption, waste production, community environment, etc. The energy data collected would be large and quite complex. Therefore, the data must be collected and sorted. The data with and without structure will be transformed to the same format to facilitate data analytics. This procedure of data collection and management is the key to determine the relationship between PV microgrid systems and the Smart Community. With the understanding of the community data, the community resources can be efficiently managed to achieve sustainable consumption and production.

Research Objectives

1. To analyze the DC & AC Microgrid potential for Smart Community with microgrid simulation
2. To develop the data collection procedure for the large and complex energy data for the Smart Community
3. To create the energy data management system for managing energy and resources in the Smart Community

Research Scope

1. Study area is DC and AC microgrid and Smart Community (50 rai) in Chiang Mai Rajabhat University Maerim Campus, Thailand.
2. Simulation components include PV, generator and battery.

3. Energy data include from electricity consumption, indoor temperature, indoor humidity, and waste generation from 12 buildings in Smart Community

Benefits of the study

1. Smart Community have the future plans for the microgrid system from the results of the microgrid simulation.

2. Energy data collection procedure and sensors are used to collect and real time datasets which are large and complex. The large and complex energy data can be arranged and managed for easy understand and usage.

3. Energy data management system can be applied to real community for easy understanding regarding their community energy data for future planning.

CHAPTER 2

LITERATURE REVIEW

This work aims to analyze the current Smart Community energy management potential and develop the energy data collection and management system for Smart community with PV microgrid. The literature review focused on the Smart Community/City concept; Microgrid systems and Simulation; and Data collection and Data management procedures.

Smart City/Smart Community

Concept of Smart City

The concept of Smart City arised with Internet of Things (IoT) technology which connected devices or objects to the internet communication network with city wide planning to support the comfortable life of the people. Smart City management could be defined as the creation of a city with sustainable growth with focus on the balance of the environment, energy saving and clean energy usage. Therefore, the environmental problems such as air pollution, waste water, garbage, and drainage problems will be reduced. Smart City is used in a wide range of countries around the world and has various meanings consistent. Smart City referred to a city that has a technology-based communication system which provide a good quality of living, reduce impact on the environment and reduce the energy consumption. There are may definition for the smart city as follows:

Smart City is a city with digital technology embedded in every city function (smart cities information center, 2015).

Smart City is a city that has a network connection of physical infrastructure, IT infrastructure, social infrastructure and business infrastructure resulting in the upgrading of the genius of the city (Harrison et al., 2010).

Smart City is a city that has a combination between information planning, technology and design structures, in order to shape and speed up the process of bureaucracy and convey new innovations in solving complex urban management problems for livelihood and sustainable development (Toppeta, 2010).

Smart City is a form of digital technology application or information and communication technology (ICT), in order to increasing the efficiency and quality of community services to help reduce costs and reduce the consumption of the population which continues to increase the efficiency of people to live in a better quality of life (Smart city, 2006).

Smart City is a city that uses information technology, communication and physical infrastructure that can be very effective with a strong support system and have economic, social, cultural development that can learn, adjust, develop and be able to respond effectively and quickly to changing situations by emphasizing on the participation of people.

From the various meanings of Smart City, the form of the smart city should be a city that applies the benefits of modern and intelligent digital technology or innovative information and communication technology (ICT). The benefit of the start city were to increase efficiency and service quality of city management; reduce costs and resource usage; reduce the impact on the environment; and reduce the energy consumption of the city in a sustainable manner. Overall, Smart City should consist of 3 important factors: 1) Efficient - using of resources as efficiently as possible; 2) Sustainable - sustainable both in terms of environmental impacts and costs; and 3) Liveable - The quality of life of residents must be good.

Smart City System Components

Smart City has a wide range of components, which included the energy management system, traffic, waste management system, public service, security surveillance and environmental in urban, consists of 7 elements in Table 2.1 (Mohanty, 2016). Similary to Mohanty works, Thailand is now focusing on 7 components of Smart City leading by Digital Economy Promotion Agency (DEPA) and Ministry of Energy. The smart city component from DEPA is represented in Table 2.1. There are similarities in Smart Energy, Smart Mobility, Smart Environment, Smart Economy, and Smart Governance components. Only 2 components are different however the different components were also related to each other such as Smart Community relating to Smart Living and Smart People.

Table 2.1 Components of Smart City

Mohanty, 2016	Smart City Thailand, DEPA
1. Smart Energy	1. Smart Energy
2. Smart Mobility	2. Smart Mobility
3. Smart Community	3. Smart Living
4. Smart Environment	4. Smart Environment
5. Smart Economy	5. Smart Economy
6. Smart Building	6. Smart People
7. Smart Governance	7. Smart Governance

Smart Energy

Reducing energy reduction and using energy efficiency is one of the elements of Smart City under good energy management. Therefore, it is a global approach that emphasized the developed cities basic infrastructure to become a smart energy city, which focused on the use of energy that is stable and sustainable. Therefore, "Smart Grid" is the technology of electric power management that can be applied to the Microgrid system to help manage the production, storage and allocation of energy efficiently, save cost and also environmentally friendly.

"Smart Grid" is the integration of the infrastructure of the existing electrical power transmission system with communication infrastructure that can measure production, control, store and allocate electricity. Smart Grid system will increase communication channels for users to participate in their own electricity management both in the form of electricity for own use or for sale. The user can also choose the source of electricity from environmentally friendly production sources or main centralized power station. The communication between the user and the manufacturer of the Smart Grid system could allocate alternative energy to be used in the system during times of high electricity demand efficiently, make manufacturers and users save costs both in the production and use of electricity.

Microgrid Systems and Simulation

Microgrids

The energy freedom reform created changes in the electricity generation patterns toward the renewable energy sources which are of great interest nowadays especially wind energy, solar energy and biomass energy (Prodan & Zio, 2014).

Electricity generation from natural sources in general can be very unpredictable causing concern regarding the negative effects of both the power quality and the reliability of the system when connected to the main power system (Grid Connected Distributed Generation). Therefore, there are guidelines for the production and delivery of electricity within the area for small-scale electricity source at the point of use (Distributed Energy Resource, DER) to improve the reliability of the electrical system. The concept of Microgrid was born under the project CERTS (Consortium for Electric Reliability Technology Solutions) at the United States in 2002. Under this concept, both the small power source and the internal load were combined into one small independent system which gives both power and heat. Most small electricity power sources in this system must be assembled from electronic devices for flexibility and control. In the abnormality condition, the Microgrid can be able to release itself from the main power system automatically and can be connected back to the main power system when the malfunction in the main power system has been fixed. By this concept, the Microgrid will be seen as a control system from the main power system and will not affect the main electrical power system (Center of Excellence for Innovative Energy System, 2010).

Microgrid system is another development of Distributed Control system which simulates the control of the subsystem to be similar to the control of a large system that is Centralized Control. There are 2 types of Microgrid, Autonomous System and Non-autonomous. The Autonomous System is an independent power supply system separately from the main electrical network system and Non-autonomous system is a system that connected to the main electrical network system. The basis of the Microgrid system design is a system that controls and manages the system to produce electricity from various types of fuels to have the appropriate production costs by remains stable, reliability and electrical power quality be in line of standard within the most effective system that also environmentally friendly. The architecture of the Microgrid system has three main forms. There is AC based architecture, DC based architecture and DC & centralized AC based architecture with consideration to the load and type of electricity produced from DG types (Distributed Generation) in the system. If the load in the system is an alternating current and DG produces most of the electricity in an alternating current, the AC based architecture will be used. If in the system is an alternating current and DG that produces most electricity in direct current, using DC and centralized AC based architecture will be used (Magazine, 2013).

The Microgrid system has continued research, development and experimentation, especially in Europe, the United States, Japan and Canada, in order to improve the efficiency of the micro-grid system in both experimental and real system installation and exchange of knowledge in the form of a seminar between countries and resulting in useful research results to develop Microgrid system to sharing or to using replace the current electrical system (Hatziargyriou, Asano, Iravani, & Marnay, 2007). Currently, research and presentation of DC Microgrid articles is widely used, such as using DC Microgrid in the building and using as a central data center (Becker & Sonnenberg, 2011). Inside the building, there is a system for collecting energy distribution data from renewable energy sources and analyzing the efficiency of loading applications in buildings and electrical appliances. To reduce costs, the distribution control for DC Microgrid substitution to increase reliability and flexibility (Yunjie, Xin, Wuhua, & Xiangning, 2014) is a proposed strategy for managing DC Microgrid while the main electricity is not working. The proposed DC Microgrid system consists of photovoltaic systems and wind power systems, batteries and connections to the grid system. For this dissertation, the microgrid system that located within the Smart Community area of the Asian Community Development and Technology College (adiCET), Chiang Mai Rajabhat University was analyzed. The PV hybrid for the Smart Community were simulated with solar energy, biodiesel battery and generator.

Simulation Systems

System simulation is a duplication of real situations or behavior of systems by using a computer program to avoid or reduce mistakes or to reduce costs due to damage that may occur to the actual operation. The simulation and modeling plays an important role nowadays both in education and industry. The use of computer models allows to display or give results that are as close to the real operation as much as possible. In actually operation, it is impossible to perform experiments or modify work processes until they see the benefits received such as problem elimination beyond expectations that caused the production process to slow down. Therefore, the simulation will help to analyze the current condition of the system and help find the appropriate choice before applying to the actual situation or operation. This will help reduce the risk of errors or failure and it helps to save costs and time (Maria, 1997). Generally, there are 11 steps involved in the design, development and analysis model which are: 1) Identifying problems, 2) Determine problems that want to simulate, 3) Collect data and process actual data, 4) Define and develop the format, 5) Form validation, 6) Document format for future use, 7) Select the appropriate experimental design, 8) Determine experimental conditions, 9) Perform a simulation, 10) Display report and 11) Implementation.

Nowadays, software used to create simulation are divided into 2 groups, Simulation languages and Application-Oriented simulator. Simulation languages are more flexible than Application-Oriented simulator but has more difficulty in using (Maria, 1997). There are numerous characteristics of work can be used with computer models such as weather simulation, electronic circuit, chemical reaction, Mechatronics, heat pumps, estimate control systems, atomic reaction and biological processes. At present, there are also many research programs that used computer programs to model solar power generation systems for the quality of life suitable in remote areas. The study focused the area without electricity at Mae Salong, Mae Fah Luang, Chiang Rai. The results revealed the answers with analytical hierarchy processes with target program techniques (PNNL, 2012).

Simulation Softwares

Homer software is a simulation program in a form of Application-Oriented Simulator. Homer is a program that helps find the most suitable system for small power generation systems (Micro power Optimization Model). It will help evaluate the system that has been designed for both connected and not-connected to electrical systems (off-grid and grid-connected power system). Designing a power system must consider the structure of the system such as suitable component, size, amount, type of technology, pricing and availability of power. Therefore, this is very difficult to determine the most suitable system and process. The Homer program can evaluate and analyze the system to determine the structure of the system with many possibilities (NREL, 2011).

Homer software was used in many research articles such as in designing to achieve the efficiency increase of the integrated renewable energy system. Omar and co-workers reported the similuation of the mixed renewable energy production system in remote rural areas and islands with the simulation goal to reduce cost, compare designs, evaluateeconomic results, and analyze emissions to the environment (Hafez & Bhattacharya, 2012). Moreover, Homer software could simulate the use of renewable energy in remote villages as off-grid electrical system. The objective was to use a combine renewable energy systems to produce energy to meet the needs of the villagers and support the expansion of the community. The analysis also included the energy use in small farms. The analysis of economic trends also affected the use of integrated renewable energy systems. The renewable energy sources were water energy, solar energy and wind turbines. Chhattisgarh State of India (Sen & Bhattacharyya, 2013) and Thailand have applied the Homer software to simulate smart grid work in renewable energy power generation systems. The focus of the simulation was on the smart grid energy distribution, payment and control of the renewable energy systems. Their work started from the overall system design of the control center to receive the information from the production area, production control system, transmission system, transmission control system, protection control system, destination delivery system or system for controlling the state of cutting load in the system and the system showing the results of the operation. The system could increase the learning outcomes or revealed the information that affected the systems for decision making (Khosri & Plangklang, 2010). In this work, Homer software was selected to simulate the AC / DC Microgrid of the Smart Community in CMRU.

The GridLab-D software is a situation simulation program in simulation languages. It is a program used to simulate and analyze the suitability of a flexible small electrical structure design. It is able to create additional system models without copyright and can support real-time work. GridLab-D software could simulate the design of wind energy control system in smart grid by applying numerical methods and simulation methods with time series, economic analysis, and price of energy to develop the working plan of the Start-grid in the future (Chassin, Fuller, & Djilali, 2014). GridLab-D software could also simulate the effects of the use of electrical equipment in homes by analyzing the efficiency and features of each device. Surrounding factors such as heat insulation inside the house, temperature, season and size of housing could be simulated to reduce energy consumption and manage energy efficiency (Iamsomboon, Tangtham, Kanchanasunthorn, & Lert, 2013). In addition, GridLab-D could simulate the physical effects of heating and air conditioning and analyze the linear relationship to find variables effectively meet the needs of users in order to manage energy efficiently and store as a master database (Khomfoi, 2011).

Concept of Complex and Big Data Management

Definition of Big Data

In present, modern information technology has played a role to inevitably affect human daily life. Various agencies both large and small, government and private sector, are trying to adapt the organization's operations to keep up with the rapid changes. Bringing technology to help in the organization operation and business will create an advantage and promote various policies related to the use of information. There is an increase in the amount of information that are enormous and contains variety of information, whether images, videos, text and information from various electronic devices, which are constantly changing in time and fast or include as a feature called Big Data (Taylor-Sakyi, 2016).

Big Data is a large amount of data on every subject, every aspect, and every form, which may be structured data such as data stored in various data tables, or may be semi-structured such as log files, or even unstructured data such as interaction data via social networks such as Facebook, twitter or media files, etc. It can be the data from within the organization or data from outside which are from the contact with supplier or from all channels of contact with customers. However, this is still only raw data waiting to be processed and analyzed. These raw data may not be in the form that the organization can use immediately. The data must be analyzed to be information useful for the organization and to bring the results to create business value. Big Data has four important features shown in Figure 2.1.

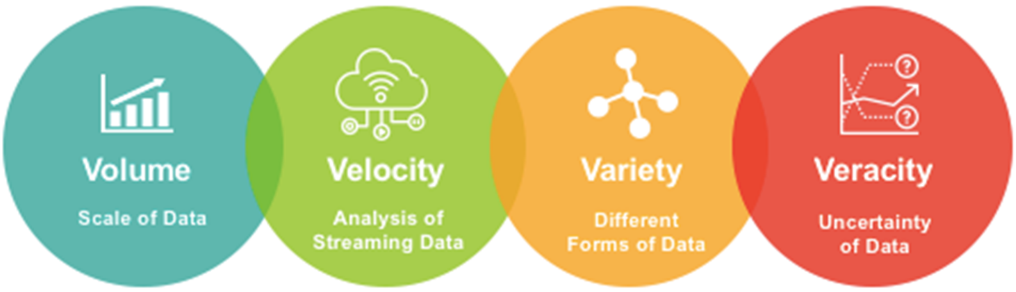


Figure 2.1 4V Framework for Big data

1. Volume: Large amounts of data are obtained from operations, business operations of the organization both online or offline data including to bookmarks URLs that are stored in any type of data. There will be information everyday.

2. Velocity: The data that has a rapid rate of increase such as information of typing conversations, video recording data, order information, various promotion information or sensor information, etc. The data will be transferred throughout the day every hour.

3. Variety: Diverse and complex information data are behavioral data and behavioral data. Behavioral data or Image & sounds are images, videos, recorded audio data, including Languages. Any messages that occur on the website records are data stored in any file type such as: bmp, gif, jpg, png, tif, tiff, svg, doc, docx, odt, pdf, rtf, tex and many others.

4. Veracity: The information are ambiguous and uncertain because information is diverse and comes from sources such as Facebook, Twitter, YouTube, which are difficult to control the quality of information. The quality information must be accurate and reliable. If the data does not have quality, it will affect the analysis. The usable data must be considered and depended on the storage method and the data cleansing process.

Data Cleansing is the process of checking and correcting inaccurate data items from the data set, table or database. This is the key principle of the database because it will eliminate the incomplete and inaccurate data relative to other data. It is necessary to replace, update or delete these incorrect data to provide quality information. Data cleaning is necessary to remove the inconsistency of data which may caused by errors in the recording of data, transmission of data, or storage of data. This process is very important in order for the data to be integrated with many other databases. Therefore, there are high chances that information of resulting in unsafe data or unclean data (Data cleansing, 2012).

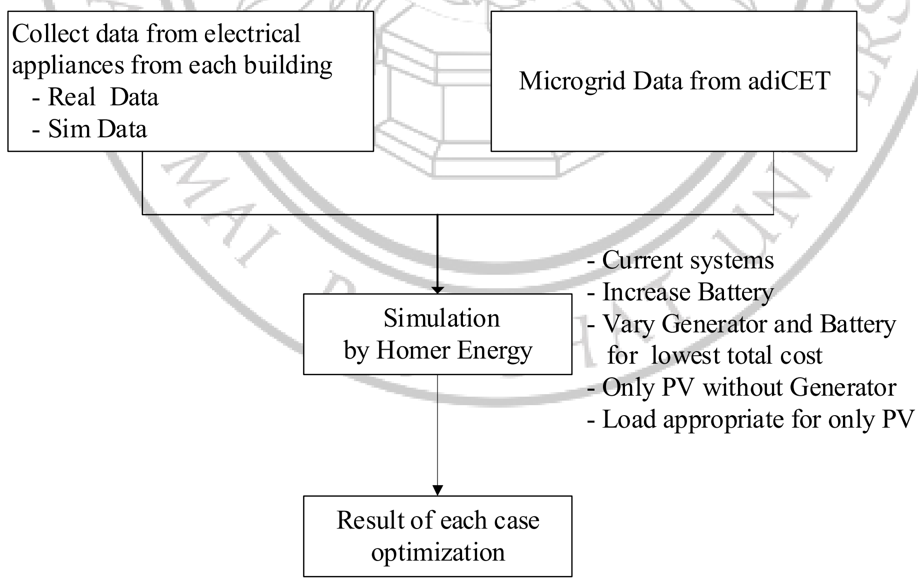
Data warehouse is information that are used for making decision. The accuracy of the information is important in order to avoid false summaries such as redundant or missing information that will result in incorrect or misleading statistics. The data in the data warehouse has a lot of information that large amount of data that is inconsistent. Therefore, Data Cleansing is the biggest problem of data warehouses. During processes such as Extraction, Transformation, Loading, more data errors will be encountered. Cleaning data is therefore more necessary which has the following basic steps. 1) Parsing: data distribution or using the topic of the data set; 2) Correcting: correct the wrong information; 3) Standardizing: make data in the same format; 4) Duplicate Elimination:remove duplicate sets of messages. This may need to write an algorithm to identify duplicate data sets.

Big data can also be used as an efficient energy management service by analyzing and predicting energy demand (Ku, Park, & Choi, 2018). In order to reduce the cost of energy production in the future, Y and co-workers had proposed the concept of how to manage and adjust Big Data circuits in the same format to be more efficient and reducing uncertainty in real time (XU, 2015). In addition, a platform can be offered to help make decisions about managing corporate data for effective planning and implementation. Chen and co-workers also developed the data management framework of big data structures that are structured and unstructured by integrating complex, comprehensive and efficient data storage (Chen, Zhong, Yuan, & Hu, 2016).

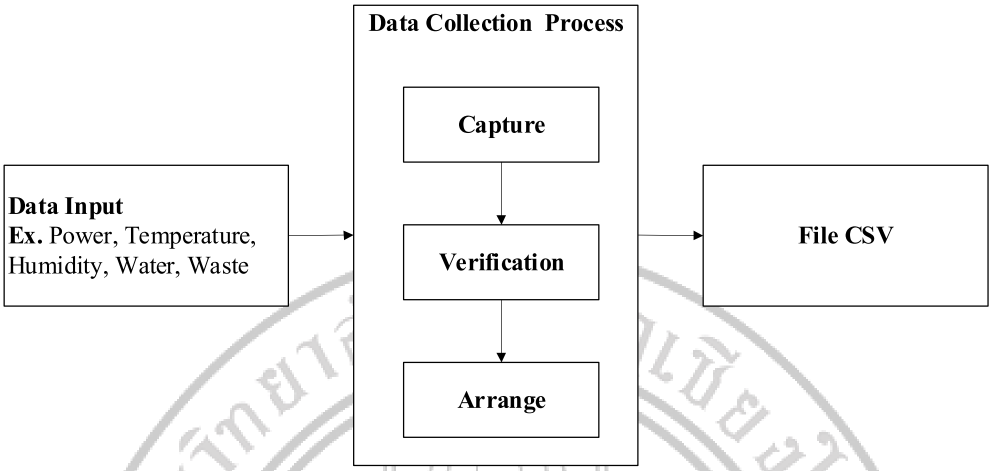
CHAPTER 3

RESEARCH METHODOLOGY

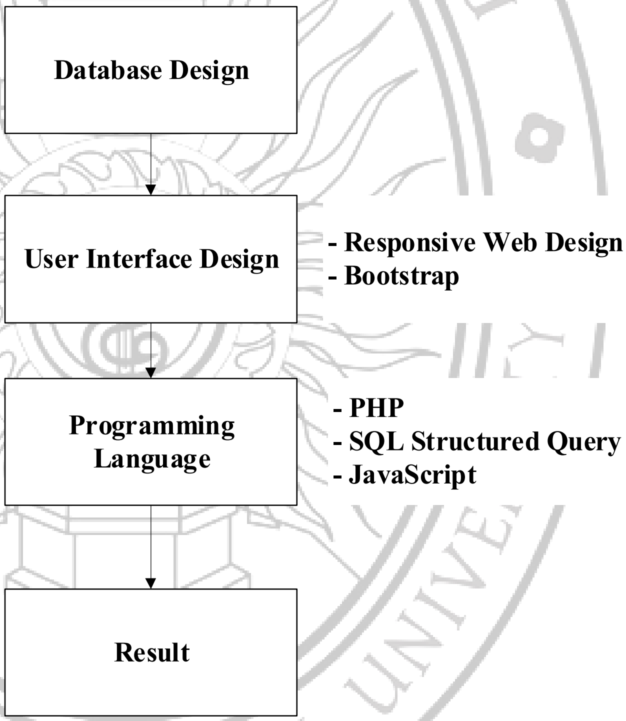
The ultimate goal of this dissertation was to develop the energy data management system for the Smart Community with PV AC & DC Microgrid. The flowchart of the research scope is shown in Fingure 3.1. This research methodology was divided into 3 parts: 1. Analysis of DC & AC Microgrid potential with microgrid simulation (Fingure 3.1(a)); 2. Energy data collection procedure (Fingure 3.1(b)); and 3) Development of energy data management system for Smart Community (Fingure 3.1 (c)). The detail descriptions of the each part of the methodology are explained in the following section.



(a)



(b)



(c)

Figure 3.1 Research methodology flowchart (a) Microgrid and Smart Community Energy Generation and Load Potential Analysis, (b) Energy Data Collection Process and (c) Smart Community Energy Data Management System

Analysis of DC & AC Microgrid Potential for Smart Community with Microgrid Simulation

Comparative microgrid simulation used Homer Energy software. The real data for energy consumption from the building of the Smart Community were used during the simulation. In addition simulated full load data were extrapolated from the real data during various simulation scenarios. The results from the full load would provide a guideline and understanding on ways to best utilize the current systems and planning to accommodate the expansion of the community and more students.

Data Sources

In this work, the DC microgrid and AC microgrid were installed in parallel at the Smart Community. Therefore, the data sources would include the distributed generation and electrical load. Figure 3.2 displayed the layout of both microgrids. The AC microgrid generate DC power from 25 kW PV and then converted to AC by the inverter then distributed to the AC loads. The DC microgrid distributed power from 25.5 kW PV in direct current to the DC loads. There were battery banks at 100 kWh for both the AC and DC microgrids. There was also a Generator 40 kW. In all the buildings, the appliances could use both AC and DC loads. Electrical loads were from the appliances inside the 12 buildings of the Smart Community which included 6 houses, a minimart, a coffee shop, a restaurant, an office, and 2 battery bank buildings. The appliances were grouped into 4 categories: 1) Cooling load such as air conditioner, refrigerator and freezer; 2) Heating load such as microwave, shower water heater, hot water pot, electric plates, and coffee maker; 3) Lighting such as light bulbs and lamp; and 4) Entertainment and Office load such as television, copy machine, printer, projector, computer, and stereo. There were 2 types of loads used in the modeling which were from the combined-measured real load of the buildings and the calculated-simulated load from all the appliances with the assumption of full load utilization.

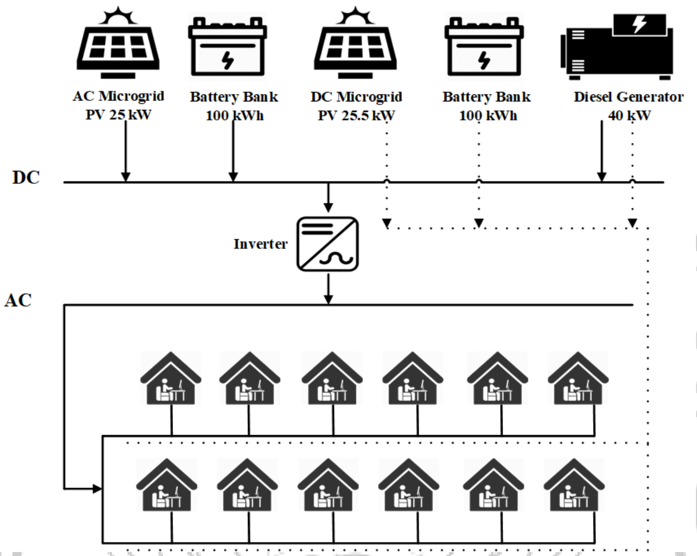


Figure 3.2 AC/DC Microgrid Diagram for the Smart Community

DC & AC Microgrid Simulation

Homer Energy was used in the simulation with 3-steps: Create system diagram, Input data and assumptions, and Processing the conditions to achieve the optimize system. System diagram was created in the Homer program with all the components from the DC and AC microgrid for the distributed generation and loads. Inputting data comprised of RE sources, irradiation data from Homer Energy regional database, diesel price (USD/Liter) from current price in Thailand, generator specifications, and cost estimation for system cost, installation, operation and maintenance. The loads were measured or calculated in kW based on the Smart Community power usage from 0:00 to 24:00 with 1-hour interval.

For the DC Microgrid, the simulation was processed based on the specified criteria which were:

1. Model the current system,
2. Improve the system by increasing the battery size,
3. Determine the optimal DC microgrid system configuration appropriate for the load with the least total cost by varying generator size and battery size,
4. Determine DC Microgrid PV and Battery size without diesel generator as the low carbon system, and
5. Determine the optimal load size for the current system configuration.

For the comparison between DC and AC Microgrid, the simulations were based on the specified scenarios which were:

1. Model the current system,
2. Vary the generator and battery for lowest total cost,
3. Model microgrid with only PV/without generator, and
4. Determine the optimal load size for the current system configuration

Simulation Output

The simulated output provided system configurations (size of PV, size of diesel generator, size of battery), performances (power generated from PV, diesel generator, battery) and economic analysis (cost of system installation, diesel fuel, operation, maintenance, replacement and salvage). The selected results of the system configuration and condition from the modeling were listed from the least to the highest overall cost. The overall cost calculation was based on the system lifetime of 25 years.

Data Collection Process Design for Energy Related Data of the Smart Community

In this work, the direct and indirect energy data were collected from the installed sensors in the 12 buildings at the Smart Community, CMRU. Figure 3.3 showed the data flow diagram. There are 4 types of sensors installed included water, temperature, humidity, electricity and waste sensors. The microcontroller read the data from the sensors and transfer by MQTT Protocol to the server. The data were recorded and saved as CSV files.

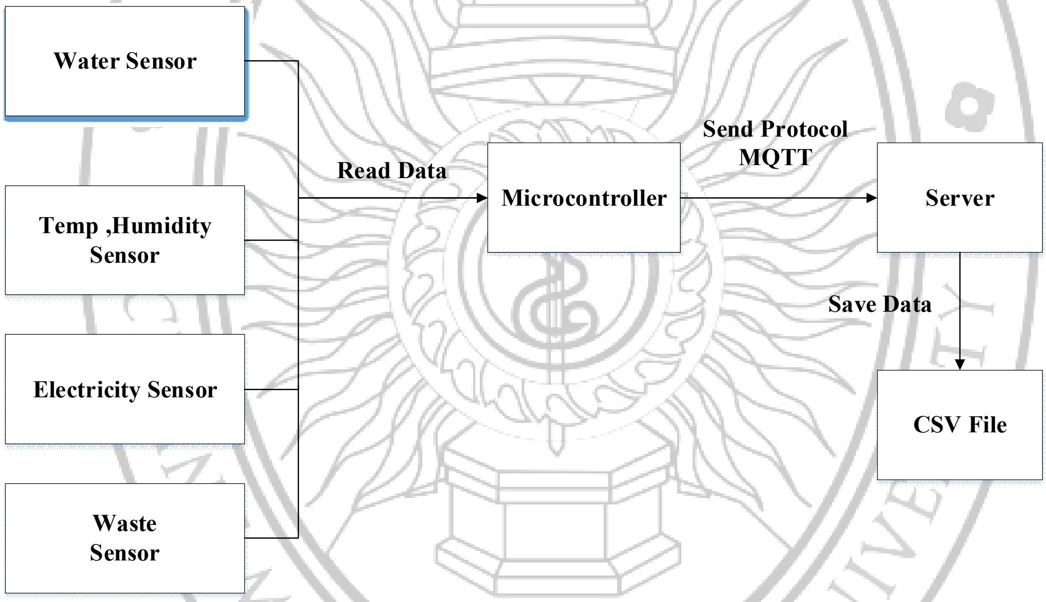


Figure 3.3 Data Flow Diagram for the Smart Community Energy Data

There were numerous data that directly and indirectly related to energy for the Smart Community. In this work, the data categories described in Table 3.1 were selected which were power consumption, temperature, humidity, water usage and waste generation from the building. The category selection criteria were based on the ability for real-time data monitoring with sensors installed in each building of the Smart

Community. The data were constantly changing and increasing. The data were collected in intervals every day and stored as Comma Separated Value (CSV) files. The CSV file is the type of text file where the data are stored in a table form with comma to separate the column. With large and complex datasets, the appropriate data storage format and categories must be defined in order for efficiently utilize and analyze the data.

Table 3.1 Data collection categories and interval

Data	Unit	Data collection interval
Power Consumption	kW	1 second
Temperature	Degree Celsius (°C)	2 seconds
Humidity	Percent (%)	2 seconds
Water	Liter (L)	1 second when in use
Waste	kg	5 minutes

The design for data collection process is shown in the flow chart in Figure 3.1(b). The procedure included data capture, verification, and arrange to attain the dataset with the format that can be used in database design.

Data capturing process: Each category of data was captured as one CSV file per day from 00.00 AM to 23.59 PM. Power consumption data were collected from the smart meter in each building at the interval of 1 data per second. The temperature and humidity data were collected from the temperature and humidity sensors installed inside the building at 2 second interval. The waste generation data was collected at the community trash bins. Load cells were installed under each trash bin. There are 4 trash bins for general, recyclable, hazardous and organic wastes. The weight data for the waste were collected every 5 seconds.

Data verifying process: For the data verification for the 5 categories, all CSV files were examined for data completeness. In some case when the sensor malfunctions, the data would not be collected and showed as zero. The data verification process would delete the corrupted data leaving the usable data to be stored in the database.

Data arranging process: The next step was arranged the data files in chronological order. The structure of each data file has to be arranged with the specified column according to the database. Each data category has different sets of specified column ID.

Data Analysis and Database Design

The Smart Community data flow were analyzed to determine the relationship between data input and data output. The data flow is shown in Figure 3.4 as Entity-Relationship Diagram (ER Diagram) which described the structure and relationship in the database. Subsequently, the collected data will be easier to manage through DBMS database management system. The database was developed through MySQL open source software with SQL language.

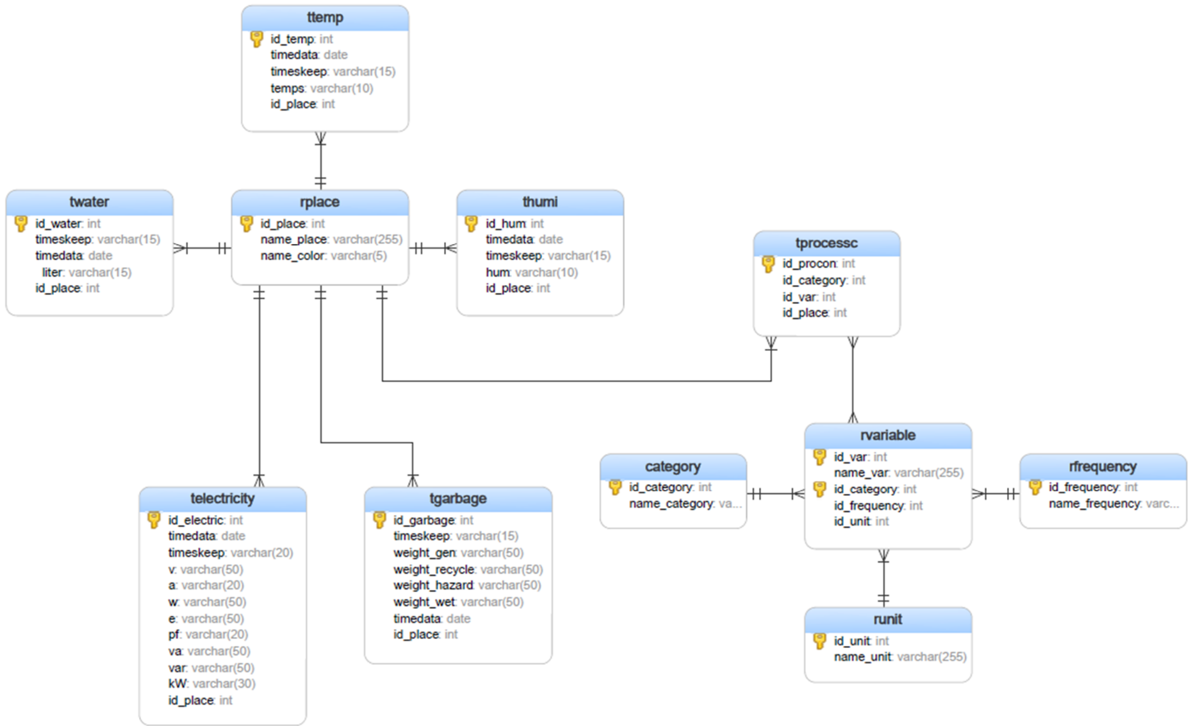


Figure 3.4 ER Diagram for Smart Community Energy Data Database

The database relationship structure design has 11 tables which are 6 Transaction Database tables and 5 Reference Database tables. The Transaction Database is the database with constant changes (Table 3.2). It is used for SQL Insert Statement, SQL Update Statement and SQL Delete Statement. “telectricity”, “ttemp”, “twater”, “thumi”, and “tgarbage” are the Transaction Database Tables used for collecting energy consumption, temperature, water usage, humidity and waste data from each building, respectively. The Transaction Database Tables are linked to the “rplace” which is the Reference Database Table. “tprocess” is the table used for collecting category and variable data which has linkage between “category” Table, Rvariable Table and Rplace Table.

Table 3.2 Transaction Database Table

Table Name	Name	Type	Length	Detail
telectricity	id_electric	Int	11	Used to sequence the data collected
	timedata	Date	0	Use to collect date for the electricity consumption data
	timeskeep	Varchar	20	Use to collect time period during electricity consumption data collection
	v	Varchar	50	Voltage (V)
	a	Varchar	20	Current (A)
	w	Varchar	50	Power (W)
	e	Varchar	50	Energy (kWh)
	pf	Varchar	20	Power Factor
	va	Varchar	50	Apparent power (VA)
	var	Varchar	50	Reactive power (VAr)
	kW	Varchar	30	Use to collect electricity consumption data from each building
	Id_place	int	11	Use as location reference from rplace Table
ttemp	id_temp	Int	11	Used to sequence the data collected
	timeskeep	Varchar	15	Use to collect time period during temperature data collection
	temps	Varchar	10	Use to collect temperature data from each building
	timedata	Date	-	Use to collect date for the temperature data
	Id_place	Int	11	Use as location reference from rplace Table
twater	id_water	Int	11	Used to sequence the data collected
	timeskeep	Varchar	15	Use to collect time period during water usage data collection
	liter	Varchar	15	Use to collect water usage data from each building
	timedata	Date	-	Use to collect date for the water usage data
	Id_place	Int	11	Use as location reference from rplace Table
thumi	id_humi	Int	11	Used to sequence the data collected
	timeskeep	Varchar	15	Use to collect time period during humidity data collection
	hum	Varchar	10	Use to collect humidity data from each building
	timedata	Date	-	Use to collect date for the humidity data
	Id_place	Int	11	Use as location reference from rplace Table
tgarbage	id_garbage	Int	11	Used to sequence the data collected
	timeskeep	Varchar	15	Use to collect time period during waste data collection
	Weight_gen	Varchar	15	Use to collect general waste data
	Weight_recycle	Varchar	15	Use to collect recyclable waste data
	Weight_hazard	Varchar	15	Use to collect hazardous waste data
	Weight_wet	Varchar	15	Use to collect organic waste data
	timedata	Date	-	Use to collect date for the waste data

Table 3.2 (Continue)

Table Name	Name	Type	Length	Detail
	Id_place	Int	11	Use as location reference from Table rplace
tprocessc	id_procon	Int	11	Use to sequence data collection for process data
	Id_category	Int	11	Use to collect reference order from category Table
	Id_var	Int	11	Use to collect reference order from rvariable Table
	Id_place	Int	11	Use as location reference from rplace Table

The Reference Database is the type database that does not change. It is the structure of the fixed database which is used as reference to the other tables in the same database (Table 3.3). “rcategory” is the Table used to collect data, to separate data into groups, and to find statistical analysis accroding to the data category from the community. It is also the Table used as reference to “tprocessc” Table. “rplace is the Table used to collect data of building number and name. It is also the referece to “tprocesc”, “twater”, “tgarbage”, “telectricity”, and “ttemp” Tables. “rfrequency” Table is used for collecting frequency data in data collection and storage. It is also the referece to “rvariable” Table. “runit” Table is responsible for collecting unit data for energy value measurements and collection time period. It is also the reference to “rvariable” Table. “rvariable” Table is fused for collecting variable data for energy data category. It also collect frequency data, energy unit data and act as reference to “tprocessc” Table.

Table 3.3 Reference Database Table

Table Name	Name	Type	Length	Detail
category	id_Category	Int	11	Use to collect sequence order of the category
	name_Category	Varchar	255	Use to collect category name
rplace	id_place	Int	11	Use to collect sequence order of building data
	Name_place	varchar	255	Use to collect building name
rfrequency	id_frequency	Int	11	Use to collect sequence order of frequency
	Name_frequency	varchar	255	Use to collect frequency name
runit	id_unit	Int	11	Use to collect sequence order of measurement unit
	Name_unit	varchar	255	Use to collect unit name
rvariable	id_var	int	11	Use to collect sequence order of variable
	Name_var	varchar	255	Use to collect variable name
	id_category	int	11	Use to collect sequence order of category data with reference from category table
	id_frequency	int	11	Use to collect sequence order of frequency with reference from rfrequency table
	id_unit	int	255	Use to collect sequence order of unit with reference from runit table

Smart Community Energy Data Management System Design

Energy data management system design must consider the analysis of collection process of data flow including relationship between input data, process and data output. The data flow information was used to design the User Interface so the user would be able to understand the data easier and more convenient.

User Interface Design

User Interface is the design of the connector between user and computer for ease of use. The user should be able to easilty understand the system design. In this work, Responsive Web Design concept was used in the design and could display the result appropriately on various devices under the same code and URL. Bootstrap was used to set the operation scope in the same direction. Bootstrap is the Front-end Framework with HTML, CSS and Java Script. The web development supported all Smart Devices and the User Interface display was easily created under less time for the design and layout. The design also included Responsive Layout. This work also included CODE Viewport Mata Tag so the various sizes of display monitor could be supported by specify <Meta> in the part of <head> under HTML language

Figure 3.5. For Bootstrap, layout was divided by using container in 2 formats which were 1) <div class=”container”></div> to show the width of fixed system; 2) <div class=”container-fluid”></div> to adjust the width according to display monitor size (Figure 3.6).

```
<! DOCTYPE HTML>
<HTML>
    <HEAD>
        <META CHARSET="UTF-8">
        <META NAME="VIEWPORT" CONTENT="WIDTH=DEVICE-WIDTH, INITIAL-SCALE=1">
    </HEAD>
</HTML>
```

Figure 3.5 CODE Viewport Mata Tag

```
<BODY>
    <DIV CLASS="CONTAINER" >
    TEXT
    </DIV>
</BODY>
```

(a)

```
<BODY>
    <DIV CLASS="CONTAINER-FLUID" >
    TEXT
    </DIV>
</BODY>
```

(b)

Figure 3.6 CODE Layout Container (a) Container and (b) Container-fluid

The Bootstrap was used for content layout design of the system which included:

1. Saffolding grid system is for 12 columns and both fixed and fluid format.

2. Base CSS style sheets is for usage with HTML elements such as typography, tables, forms and images.

3. Components style sheets is the direction tool for User of the system such as navigation, breadcrumbs and pagination.

4. JavaScript jQury Plugins is used to increase attractiveness of the system such as modal, carousel or tooltip.

Programming language

The selected computer language for this work are PHP for program command, SQL for system development, and JavaScript applied with Chart.js for reporting/graph. PHP language is an open source programming language. In this work, PHP was used for coding on the Server (server-side scripting). PHP also communicate with the database stored by SQL for retrieving information to display. In addition, PHP with SQL could retrieve data from the database and report in Excel format. The syntax for this operation is shown in

Figure 3.7. PHP with Chart.js and JavaScript was also used to create graph reporting.

SQL Structured Query Language was used to access and manage the system database. SQL is the database program with simple language structure, high efficiency, and able to work complexity. In this work, SQL was used in 4 commands.

1. Select query for Select data

2. Update query for Edit data

3. Insert query for Add data

4. Delete query for Delete data

The energy data management system was developed with large and complex database. The data is constantly changing every second and the data is stored everyday which create complexity. SQL language has more functions to assist in problem solving of the system. The fuctions that were selected to manage the database for convenient of usage were SQL SUBSTRING(), SQL COUNT(), AVG() and SUM().

```
<?php
header("Content-Type: application/vnd.ms-excel"); //
header('Content-Disposition: attachment; filename="myexcel.xls"');
header("Content-Type: application/force-download");
header("Content-Type: application/octet-stream");
header("Content-Type: application/download");
header("Content-Transfer-Encoding: binary");
header("Content-Length: ".filesize("myexcel.xls"));
```

Figure 3.7 Excel Report Syntax

Function SQL SUBSTRING() was used to gather and section the time range of the data collection as 1 hour range as shown in Figure 3.8. The fixed time range made generating summary report for 1 data easier and more simple.

```
SUBSTRING_INDEX(string, delimiter, number)
```

Figure 3.8 Function SQL SUBSTRING

Function SQL COUNT(), AVG() and SUM() were used to count, average and sum data, respectively, according to the specified condition. The data were gathered and averaged for all 4 energy data categories as 1 hr interval. The syntax that were used for this command is shown in Figure 3.9

```
SELECT COUNT(column_name)
FROM table_name
WHERE condition;
```

(a)

```
SELECT AVG(column_name)
FROM table_name
WHERE condition;
```

(b)

```
SELECT SUM(column_name)
FROM table_name
WHERE condition;
```

(c)

Figure 3.9 Function SQL (a) COUNT (b) AVG (c) SUM

JavaScript language is an open-source object oriented computer language. It is the most popular computer language and most used in the internet system. In this work, JavaScript was used with Chart.js to produce attractive statistical reports for the energy data within the interval of data collection. Reporting as graph was generated by creating Tag Canvas to determine the size of Chart.js and then import the Chart.js (Figure 3.10(a)). The graph in various format such as bar, line and polar can be generated from the syntax in Figure 3.10(b). The imported data from the database would be shown as graph of Chart.js. The PHP and SQL would ensure the generation of easy to understand graph for the users.

```
<canvas id="myChart" width="400" height="400"></canvas>
```

```
<script src="https://cdnjs.cloudflare.com/ajax/libs/Chart.js/2.4.0/Chart.js"></script>
```

(a)

```
var ctx = document.getElementById("myChart");
        var myChart = new Chart(ctx, {
            type: 'line',
            data: {
                        /*code*/
             },
             options: {
                        /*code*/
             }
```

(b)

Figure 3.10 Script Chart.js (a) Input Script Chart.js CDN Syntax (b) Syntax Call Chart.js

CHAPTER 4

RESULTS AND DISCUSSIONS

The development of energy data management system for the Smart Community with PV AC & DC Microgrid were the main objective of this dissertation. In this chapter, the results and discussion were described in 3 parts:

1. Results of DC & AC Microgrids Simulation with Homer Energy to determine the potential of microgrids for Smart Community
2. Results from energy data collection, verification and format
3. Development of energy data management system for Smart Community

Energy Generation and Consumption Potential of DC & AC Microgrids and Smart Community

The modeling by using Homer Energy Software for Microgrid systems were performed on both the DC Microgrid and AC Microgrid. The results were used as guideline for improving the energy system suitable for existing households and future expansion. Details on the community loads for both simulations were described below.

Smart Community Load

In the Smart Community, there are 12 buildings consisting of 6 homes, mini-mart, coffee shop, kitchen, office and 2 battery bank house. The loads were categorized as Cooling load, Heating load, Lighting load, and Entertainment/Office load. The cooling loads included air conditioner, cooler, refrigerator and freezer. The heating loads included microwave, shower water heather, electric rice cooker, hot put, and coffee machine. The lighting loads included light bulb, long light bulb and lamp. Lastly, the entertainment loads includes television, cash register, copy machine, projector, computer, air fan, and cooker hood. The type of loads, amount and power rating were shown in Table 4.1 - Table 4.4. Each buildings had different type and amount of electrical appliances. During the data collection, the CMRU students and staff were living and working in the homes and office, respectively. However, not all the buildings were used regularly occupied because the students were internship students and moved in and out every couple of months. Therefore, in this work, both real data and simulated data were used in the simulation with Home software to determine the optimal configuration of the DC and AC microgrid for the Smart Community.

Table 4.1 Cooling Loads in Smart Community

	Air conditioner		Cooler		Refrigerator		Freezer	
Building	No.	Rated Power (W)	No.	Rated Power (W)	No.	Rated Power (W)	No.	Rated Power (W)
1. A Frame 1	1	578 W			1	194 W		
2. Diamond House	1	578 W						
3. Smart Home	1 1	1,417W 578 W			1	194 W		
4. Box-1	1	578 W						
5. Box-2	1	578 W						
6. DC-1	1	578 W						
7. 60 Watt Mini-Mart	1	578 W					1	1,500 W
8. Green Coffee Villa	1	578 W						
9. Green Kitchen	1	578 W	1	599 W	1	194 W		
10. Smart Community Office	2	578 W						
11. Battery House 1	1	578 W						
12. Battery House 2	1	578 W						
Total Electrical Appliances	14		1		3		1	

Table 4.1 showed the Cooling load in each house. The type and size of the appliances were different in each house. The air conditioners were installed for every building with some buildings having more than 1 air conditioner such as Smart Home and Smart Community Office. The air conditioner of Smart Home used different wattage power, which was 578 W and 1,417 W. The cooler was installed at Green Kitchen with size 599 W. The Refrigerators were installed at A Frame 1, Smart Home, Green Kitchen and Freezer installed at 60 Watt Mini-Mart.

Table 4.2 Heating Loads in Smart Community

	Microwave		**Shower Water heater**		**Electric Rice Cooker**		**Hot pot**		**Coffee Machine**	
Building	No.	Rated Power (W)	No.	Rated Power (W)	No.	Rated Power (W)	No.	Rated Power (W)	No.	Rated Power (W)
1. A Frame 1	1	1,150 W	1	6,000 W						
2. Diamond House			1	6,000 W						
3. Smart Home	1	1,150 W	1	6,000 W	1	200 W				
4. Box-1			1	6,000 W						
5. Box-2			1	6,000 W						
6. DC-1			1	6,000 W						
7. 60 Watt Mini-Mart										
8. Green Coffee Villa							1	750 W	1	3,300 W
9. Green Kitchen										
10. Smart Community Office	1	1,150 W			1	200 W	1	750 W		
11. Battery House 1										
12. Battery House 2										
Total Electrical Appliances	3		6		2		2		1	

Table 4.2 showed the Heating Loads in each building of the Smart Community. Each building had different type of heating load. The Microwaves were installed in A Frame 1, Smart Home and Smart Community Office with the same wattage power of 1,150 W. Water heaters for shower were installed in A Frame , Diamond House, Smart Home, Box-1, Box-2 and DC-1 which had the same wattage power at 6,000W. Electric Rice Cookers were installed at Smart Home and Smart Community Office. The Hot Pots were installed at Green Coffee Villa and Smart

Community Office. Coffee Machine was installed at Green Coffee Villa with a size of 3,300 W.

Table 4.3 Lighting Loads in Smart Community

	Light bulb		**Long Light bulb**		**Lamp**	
Building	No.	Rated Power (W)	No.	Rated Power (W)	No.	Rated Power (W)
1. A Frame 1	16	3 W				
2. Diamond House	5	3 W			1	40 W
3. Smart Home	11	3 W				
4. Box-1	4	3 W				
5. Box-2	4	3 W				
6. DC-1	4	3 W				
7. 60 Watt Mini-Mart	3	3 W	4	44 W		
8. Green Coffee Villa	8	3 W				
9. Green Kitchen	7	3 W				
10. Smart Community Office	2	3 W				
11. Battery House 1	8	3 W				
12. Battery House 2	8	3 W				
Total Electrical Appliances	80		4		1	

Table 4.3 showed the Lighting Loads installed at every building. Each unit had a number of different devices depending on the size and usage area. Light bulbs were installed in every building both inside and outside. Most of the light bulbs were 3 W sized installed in every building. However, there were also 44 W bulbs installed in the 60 Watt Mini-Mart, and 40 W Lamp installed in the Diamond house, respectively.

Table 4.4 Entertainment/Office Loads in Smart Community

	TV		**Cash Register**		**Copy Machine**		**Projector**		**Computer**		**Air fan**		**Cooker hood**	
Building	No.	RP	No.	RP	No.	RP	No.	RP	No.	RP	No.	RP	No.	RP
1. A Frame 1	1	320 W												
2. Diamond House	1	320 W												
3. Smart Home	1	320 W									1	22 W	1	300 W
4. Box-1														
5. Box-2														
6. DC-1	1	112 W									1	22 W		
7. 60 Watt Mini-Mart			1	500 W										
8. Green Coffee Villa														
9. Green Kitchen														
10. Smart Community Office					1	200 W	1	200 W	2	500 W				
11. Battery House 1														
12. Battery House 2														
Total Electrical Appliances														

Note: RP = Rated Power (W)

Table 4.4 showed the Entertainment/Office Loads and were installed in some houses and offices. There were only 2 small size TV with 320W and 112W installed in A Frame 1, Diamond House, Smart Home and DC-1. The Cash Register size 500W was installed at 60 Watt Mini-Mart. Machine Projector size 200 W and Computer size 500 W were installed at Smart Community Office. Air fan size 22W was installed at Smart Home and DC-1. Cooker hood size 300W was installed at Smart Home.

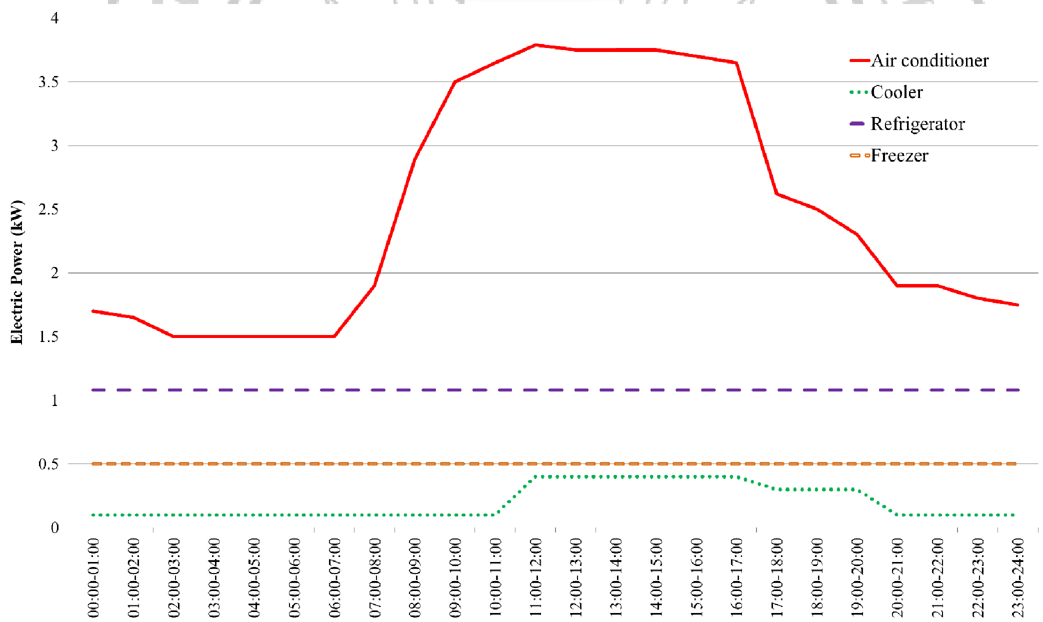
Simulated Full Load

During the experimental period, the real load profile for each buildings in the Smart Community were not fully used because of intermittent occupancy. Therefore, the simulated full load must be developed as the load profile input to the microgrid system simulation of Homer. The simulated full load was based on full occupancy for the entire year. Full occupancy with permanent students was the goal of the adiCET for the Smart Community. In the future planning, more students and staff will be living at the Smart Community, thus, this research will determine the optimal capacity for the microgrid system factoring the expansion of the community and increase occupancies. The simulated full load profile for Cooling load, Heating load, Lighting load, and Entertainment/Office load were represented in Figure 4.1(a), (b), (c), and (d), respectively. The load profiles are the combination loads for all 12 buildings. The loads were divided to 1 hr interval and the time of use for each devices were based on the behavior of the occupants in each building. In Figure 4.1(a) for the cooling load profile, air conditioning consumed the highest energy during the day time because most usage was during the working hours, usually duirng 08.00 - 18.00 hrs. The air conditioning were also used in the evening at the homes during 19.00 - 07.00 hrs. The cooler was installed at the restaurant and used for 24 hours. Therefore, there was electrical load at all times. However, there might be some periods in which the load was not equal and depending on the weather conditions. Such as during 11.00 - 16.00 hrs, there was hot weather and high load usage from cooler and air conditioner an other period. Freezer and Refrigerator were used for 24 hours a day so that there is an electrical load at all times.

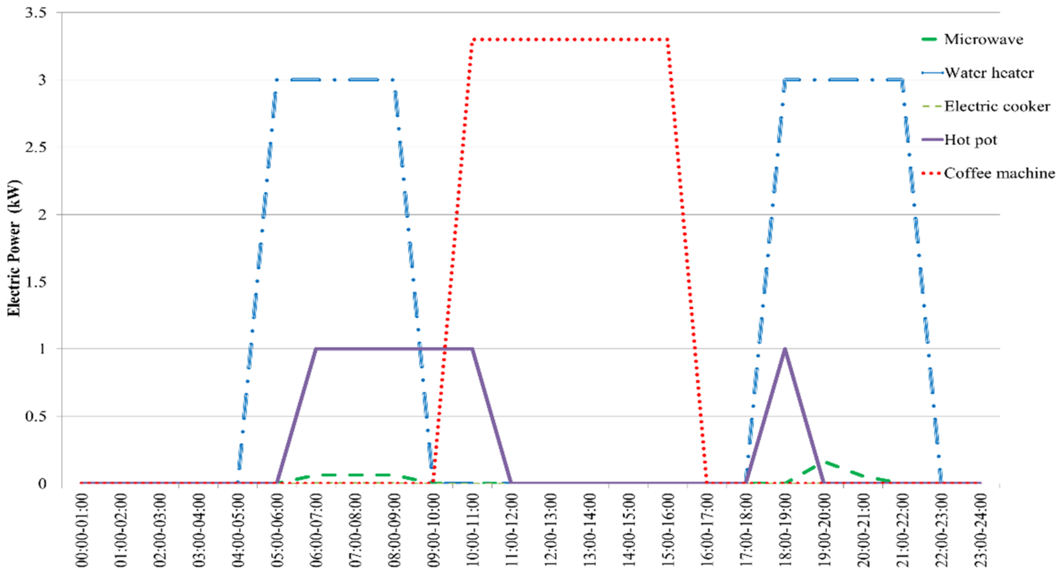
For the heating load profiles, the coffee maker was used during the day time while the hot water for the shower were used fully during the morning and night time (Figure 4.1(b)). The Coffee Machine was used during 09.00 - 17.00 hrs during the opening time of the Green Coffee Villa. The Shower Water heater had high electrical load and used during the hours of 4:00 am - 10:00 am and 5:00 pm - 11:00 pm as well as Microwave, Hot pot, and Electric Rice Cooker. There were occasions that the electrical loads were used at the same time as the Shower Water Heater, because it was the period of similar behavior for home use such as take a bath, cooking, etc.

The lighting load profile were based on the light function of the buildings such as the homes will be used during night time and morning while office and coffee shop used the lightings during the day (Figure 4.1(c)). There were 3 types of which were LED Light bulbs, Long Light bulbs, and Lamp. The LED Light bulb had the most electrical load because they were installed in every building. The period of use of the LEDs were 05.00 hrs. - 12.00 hrs and 17.00 hrs. - 02.00 hrs. The long light bulb usage were between 08.00 - 19.00 hrs. The lightings that were installed in the office building were operated during normal working hours. Thus, the lightings resulted in minimal electrical load in the period of 19.00 hrs. - 24.00 hrs. due to household behavior such as workin and reading.

For the entertainment/office load, the computers were used during the day timewhile the televisions were used at night time at the homes (Figure 4.1(d)). Computers had the greatest electrical load during 08.00 - 20.00 hrs due to being installed at the office. Therefore, there was an electrical burden during high working hours. The cash register installed at 60 Watt Mini-Mart had an electrical load during 08.00 - 19.00 hrs which was the opening hours of the shop. As for other office equipment such as Copy Machine, Projector, and Air fan, there would be less electrical load than other types of equipment because the devices were not always used. The entertainment equipment such as TV would have an electrical load for a period of time from 05.00 - 09.00 and 17.00 - 02.00 hrs, because that was the period before and after work in time. Each house would have activities in the house, such as watching TV or cooking. As the result of the simulated load, the Cooker hood had the least electrical load because usage period was between 06.00 - 09.00 hrs and from 17.00 hrs. - 21.00 hrs.



(a)


Electric Power (kW)
Microwave
Water heater
Electric cooker
Hot pot
Coffee machine

(b)


Electric Power (kW)
Light bulb
Long Light bulb
Lamp

(c)

(d)

Figure 4.1 Simulated Full Load Profiles of (a) Cooling loads, (b) Heating loads (c) Lighing loads, and (d) Entertainment/Office loads

DC Microgrid Simulation

The goal for this research was to analyze the current DC Microgrid system at the Smart Community and determine the optimal configuration for the current load and the future simulated load with the assumption of full utilization of appliances. The results of the real load and simulated full load profiles were shown in Figure 4.2. The total real loads were the measured and combined from 12 buildings. The DC Microgrid systems could only monitor power consumption for each building. The monitoring system could not measure power consumption for each appliance. Therefore, to simulated full load, each appliance was assumed to be used at full capacity based on the behavior of the consumer for each building. The appliances were categorized as heating load, cooling load, entertainment/office load and lighting load.

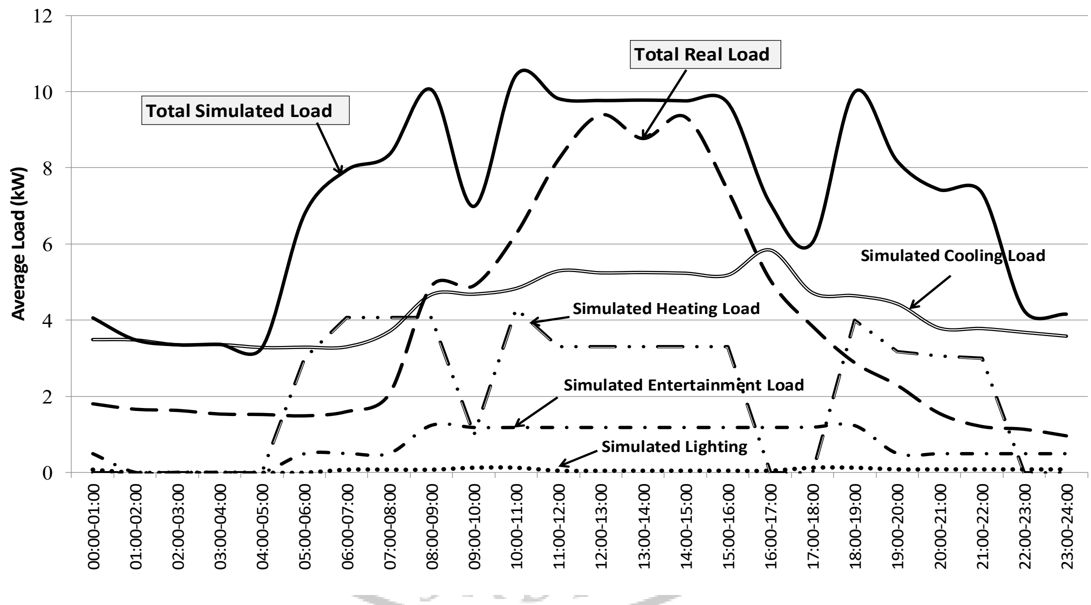


Figure 4.2 Average Total Real Load and Simulated Load Profiles for the Smart Community in 1 day

From Figure 4.2, the measured real loads were 76.1 kWh/d which were overall less than the simulated full load of 170 kWh/d. However, the trend of the total real load and total simulate load were quite similar with the peak power consumption during the day time (9.00 – 17.00 h). There was slight higher load observed in the morning at 8.00 h for real load and simulated load. This was due to the usage of shower water heater. Slight peak was also observed during the night at 19.00 pm which might due to the usage of the shower water heater as well. The main reason that the real load was less than the simulated load was because not all the houses were occupied. So not all the appliances were used at the same time. So, to prepare for more occupancy, simulated full load must be studied. Based on the behavior of power consumption of the student and researcher from the real load, the cooling loads were used mostly during the day and less at night. The air conditioners were installed in all building and houses. If all the air conditioning units in each house and offices were used, the trend would be as the simulated cooling load in Figure 4.2. The cooling appliances required the most power during 9.00 – 19.00 h. and about half at the night time. The office used the most air conditioning during the work hours while the houses would use the air conditioner in the period of 17.00 – 8.00 h. Some building and houses have refrigerator and freezer, therefore, would have power consumption for 24 hrs. The least power consumption appliance was the lighting loads. Lightings were mostly used all the time because lights were used in the office and homes. Low lighting loads were due to the usage of LED lightings which were more energy efficient. The office and entertainment consumed significantly less than the cooling and heating load. The heating loads would be mainly used intermittently with the shower water heater, coffee machine, hot plate and water pots as shown in Figure 4.2. Therefore, per the load profile, to achieve energy efficiency, optimization of heating and cooling load would be the priority more than the office and entertainment load.

DC Microgrid Configuration

For the modeling, the current DC Microgrid configuration was input into the Homer Energy program (Figure 4.3). The diagram consisted of PV system of 25.5 kW with irradiation data at location of Chiang Mai, Thailand; Diesel Generator of 40 kW with diesel price at October 2017 in Thailand; and Battery bank as Lead-Acid Deep Cycle at 12 V & 200 A per battery unit. This system was an off-grid system which means that it did not connect to the utility main grid. Therefore, battery storage was needed to store the PV power during the day time to be used at night time. The battery bank was also used as the buffer and provide stable power to the community at 260-297 VDC. The diesel generator was also needed as the backup power when battery storage was not enough for the power consumption the community. The diesel generator specification was 50 kVA rated voltage 380/220V, Current 72A, and speed 1500 rpm. The operating lifetime was 15,000 hr. The configuration of the DC microgrid system was input into the Homer software according to Figure 4.4. The load profiles were input as overall averaged load per hour according to Figure for the real load and simulated full load in Figure 4.4(a) and (b), respectively.

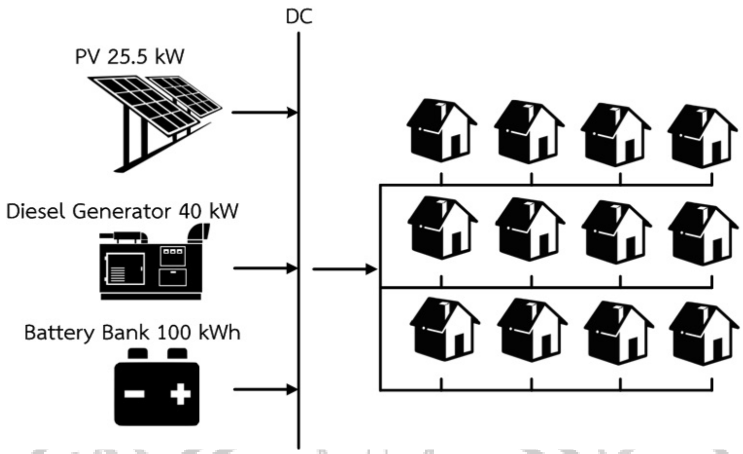
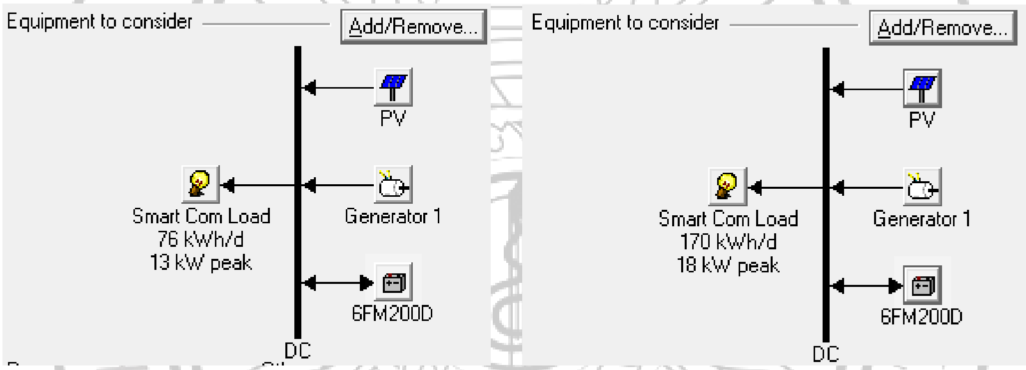


Figure 4.3 DC Microgrid Diagram for the Smart Community



(a) (b)

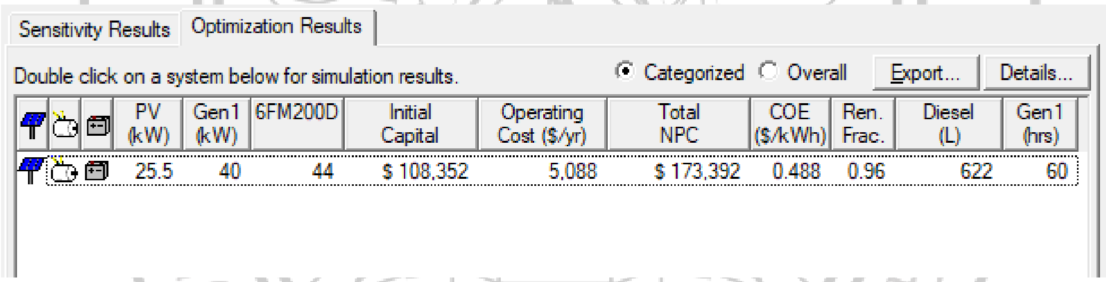
Figure 4.4 DC Microgrid Diagram from Homer (a) Real load profile and (b) Simulated load profile

DC Microgrid Simulation Results

Table 4.5 showed all simulation results of the DC Microgrid based on the average real load of 76.1 kWh/d (5 scenario cases) and simulated full load of 170 kWh/d (4 scenario cases). The details of the simulation results for each Scenario Cases were displayed below:

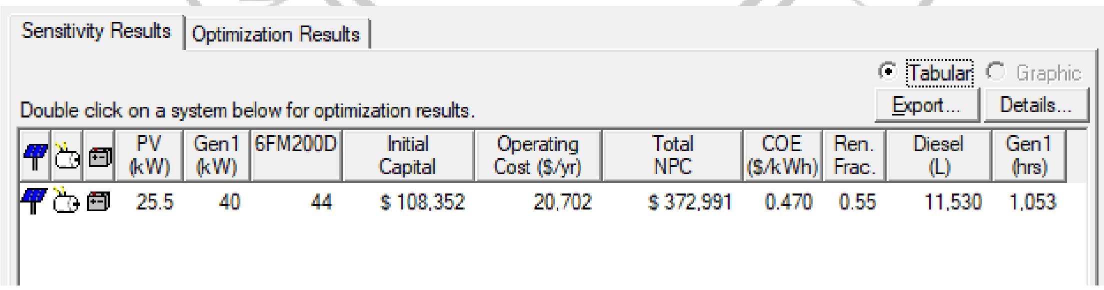
Scenario 1 – Current System:

Figure 4.5 showed the simulation results from the current system scenario. According to the current DC Microgrid configuration, the system could provide sufficient power to both the real load and simulated full load. With higher load at 170 kWh/d, the diesel generator and battery would produce 32,641 and 28,155 kWh/yr, respectively. With higher usage of diesel generator and battery, the total cost of the system over 25 years would approximately double (372,991 USD) (Figure 4.5 (b))when compared to the system cost with real load at 76.1 kWh/d (173,392 USD) (Figure 4.5(a)). This is due to the O&M cost from the replacement of generator, diesel fuel cost, and replacement of battery. On the contrary, the PV power generation was the same irrespective of the load variation, therefore, the PV was operating at full capacity.



PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25.5	40	44	$ 108,352	5,088	$ 173,392	0.488	0.96	622	60

(a)



PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25.5	40	44	$ 108,352	20,702	$ 372,991	0.470	0.55	11,530	1,053

(b)

Figure 4.5 Simulation Results of Scenario 1 - Current System for (a) Real load profile and (b) Simulated load profile

Scenario 2– Increase Battery:

When increasing the battery from 100 to 158.4 kWh, PV generation remained the same, diesel generator only slightly reduces power generation but not significant for both low and high loads. Therefore, increasing battery by one third will not significantly benefit the DC Microgrid performance and cost .

Sensitivity Results | Optimization Results

Double click on a system below for simulation results. ○ Categorized ● Overall Export... Details...

PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25.5	40	22	$ 99,926	5,192	$ 166,297	0.468	0.93	1,297	183
25.5	40	44	$ 108,352	5,088	$ 173,392	0.488	0.96	622	60
25.5	40	66	$ 116,778	5,341	$ 185,058	0.521	0.97	394	30
25.5	40	88	$ 125,204	5,648	$ 197,400	0.556	0.98	234	18

(a)

Sensitivity Results | Optimization Results

Double click on a system below for simulation results. ○ Categorized ● Overall Export... Details...

PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25.5	40	44	$ 108,352	20,702	$ 372,991	0.470	0.55	11,530	1,053
25.5	40	66	$ 116,778	20,253	$ 375,685	0.474	0.57	10,333	806
25.5	40	22	$ 99,926	22,286	$ 384,822	0.485	0.53	14,954	1,895
25.5	40	88	$ 125,204	20,525	$ 387,578	0.489	0.57	10,022	765

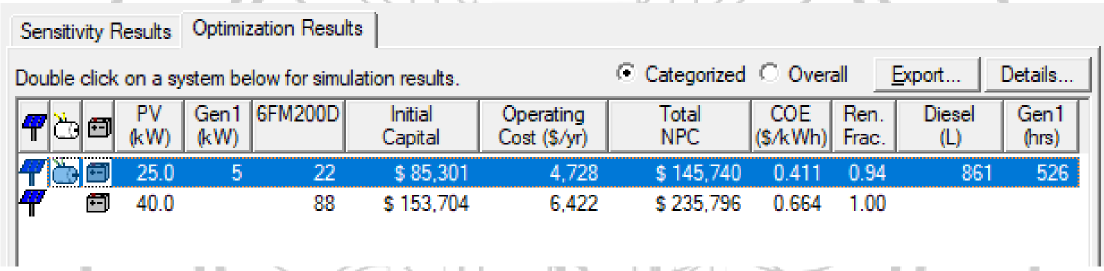
(b)

Figure 4.6 Simulation Results of Scenario 2 - Increase Battery for (a) Real load profile and (b) Simulated load profile

Scenario 3– Vary Generator and Battery for lowest total cost:

To achieve the lowest total cost, the size of diesel generator and battery were varied. The simulation resulted in only 5 kW diesel generator and battery at 52.8 kWh for 76.1 kWh/d load. This system configuration could reduce the total cost down to

145,740 USD. Therefore, the current system configuration was over designed for the real load. With the simulated full load of 170 kWh/d, the best configuration was with generator at 10 kW and battery at 52.8 kWh. With 10 kW generator, it can provide power similar to 40 kW generator, therefore the specification of the generator was also over designed even for full load. With the proper component sizing, the savings of total cost from the current system could be approximately 100,000 USD. The simulation was to minimize the total cost, therefore, the off-grid system must still rely on diesel generator even though high usage would emit high greenhouse gas.

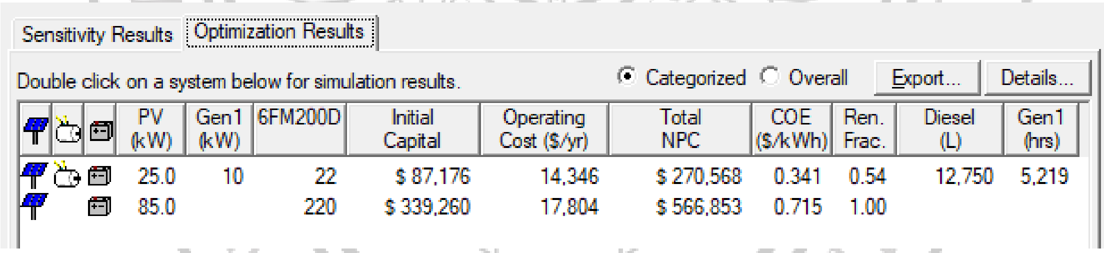


Sensitivity Results | Optimization Results

Double click on a system below for simulation results. Categorized Overall Export... Details...

			PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
			25.0	5	22	$ 85,301	4,728	$ 145,740	0.411	0.94	861	526
			40.0		88	$ 153,704	6,422	$ 235,796	0.664	1.00		

(a)



Sensitivity Results | Optimization Results

Double click on a system below for simulation results. Categorized Overall Export... Details...

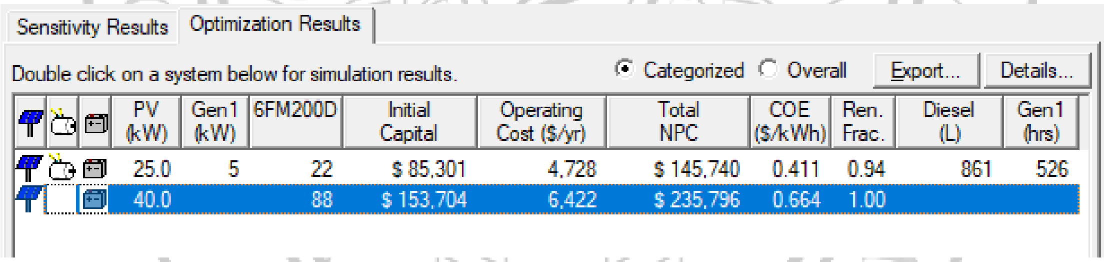
			PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
			25.0	10	22	$ 87,176	14,346	$ 270,568	0.341	0.54	12,750	5,219
			85.0		220	$ 339,260	17,804	$ 566,853	0.715	1.00		

(b)

Figure 4.7 Simulation Results of Scenario 3 - Vary Generator and Battery for (a) Real load profile and (b) Simulated load profile

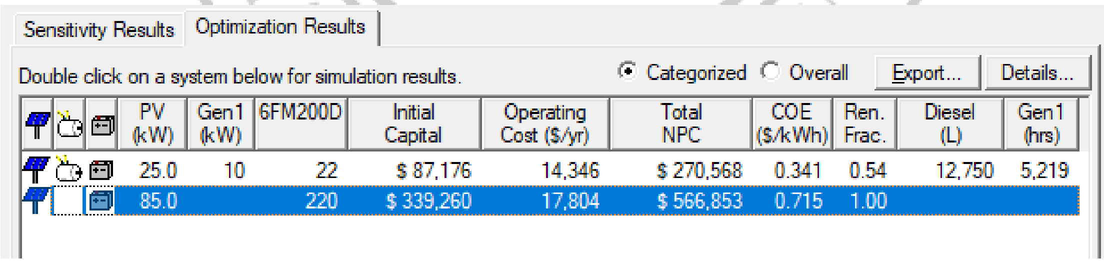
Scenario 4– Only PV without Generator:

The cost of the diesel in this work was based on Chiang Mai price. If we considered off-grid DC Microgrid system on an island, it would be very difficult and costly to transport and ship diesel on to the island to produce power when compared to the mainland. For ease of maintain and environmentally friendly solution, Case 4 focused on determining the size of PV system and battery which were appropriate for the load. For the load of 76.1 kWh/d, 40 kW of PV and 211.2 kWh of battery were needed. The total cost was 235,796 USD which slightly increased from the current system of 173,392 USD. However, with larger load of 170 kWh/d, the configuration significantly increase to 85 kW of PV and 528 kWh of battery. There was almost 200,000 USD increased from the current system. The main cost increase was from the PV installation cost while the Battery O&M cost remain similar to the current system.



PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25.0	5	22	$ 85,301	4,728	$ 145,740	0.411	0.94	861	526
40.0		88	$ 153,704	6,422	$ 235,796	0.664	1.00		

(a)



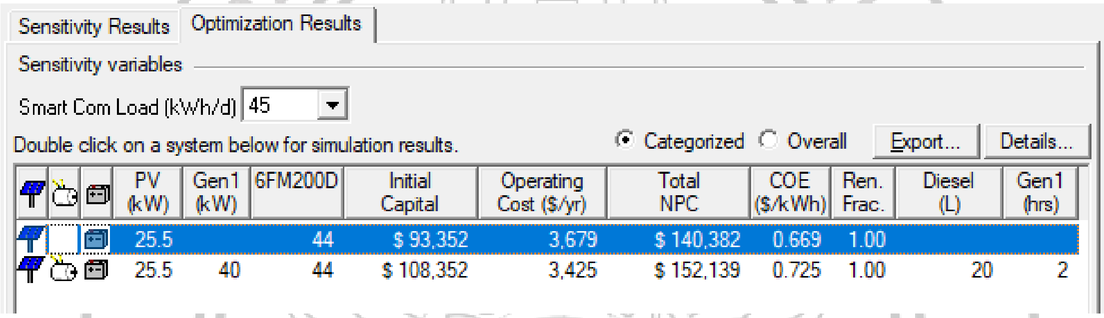
PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25.0	10	22	$ 87,176	14,346	$ 270,568	0.341	0.54	12,750	5,219
85.0		220	$ 339,260	17,804	$ 566,853	0.715	1.00		

(b)

Figure 4.8 Simulation Results of Scenario 4 - Only PV without Generator for (a) Real load profile and (b) Simulated load profile

Scenario 5– Load appropriate for only PV:

The criteria for this simulation was to focus on using power from the existing PV systems of 25.5 kW without using the diesel generator. The appropriate load was then determined from the simulation. The results revealed that if the Smart Community could reduce the load to 45 kWh/d, then this will minimize the O&M cost to 140,382 USD.



PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25.5		44	$ 93,352	3,679	$ 140,382	0.669	1.00		
25.5	40	44	$ 108,352	3,425	$ 152,139	0.725	1.00	20	2

Figure 4.9 Simulation Results of Scenario 5 - Load Appropriate for Only PV

The results from the Homer simulation for DC Microgrid hybrid system were in alignment with Hafez and coworker (Hafez & Bhattacharya, 2012) The off-grid renewable energy hybrid system with mixed diesel-renewable provided the least cost when compared to using a single renewable technology. The work also agreed with Sen and coworker (Sen & Bhattacharyya, 2013) where the hybrid mixing of solar, biodiesel and battery system would be most appropriate for the community and could accommodate the expansion of the community in the future. However, operation and maintenance costs were relatively high.

Table 4.5 Simulated Result from Homer Energy for DC Microgrid Hybrid Systems with Real Load and Simulated Full Load

	Case	System Configuration				Results of Homer Simulation																	
						Electricity Generation (kWh/yr)			Investment (USD)			Operation & Maintenance (USD/year)											
												PV			Generator				Battery			Total O&M	Total Cost for 25 years
		Load (kWh/d)	PV (kW)	Gen (kW)	Batt (kWh)	PV	Generator	Battery	PV	Generator	Battery	Replace ment	O&M	Salvage	Replace ment	O&M	Fuel	Salvage	Replace ment	O&M	Salvage		
Real Measured Load	1. Current System	76.1	25.5	40	100	40,403	1,718	7,837	76,500	15,000	16,852	842	1,224	-472	0	14	479	-246	2,040	1,320	-113	5,088	173,392
									108,352			1,594			247				3,247				
	2. Increase Battery	76.1	25.5	40	158.4	40,403	1,193	7,922	76,500	15,000	25,278	842	1,224	-472	-	7	303	-260	1,818	1,980	-101	5,341	185,058
									116,778			1,594			50				3,697				
	3. Vary Generator and Battery for lowest total cost	76.1	25	5	52.8	39,611	2,601	6,731	75,000	1,875	8,426	825	1,200	-462	-	16	633	-4	1,898	660	-68	4,728	145,740
									85,301			1,563			675				2,490				
	4. Only PV without generator	76.1	40	-	211.2	63,378	-	6,959	120,000	-	33,704	1,320	1,920	-740	-	-	-	-	1,480	2,640	-198	6,422	235,796
									153,704			2,500			-				3,922				
	5. Load appropriate for only PV	45	25.5	40	100	40,403	-	4,038	76,500	-	16,852	842	1,224	-472	-	-	-	-	805	1,320	-40	3,679	140,382
									93,352			1,594			-				2,085				
Simulated Load with Full Usage	1. Current System	170	25.5	40	100	40,403	32,641	28,155	76,500	15,000	16,852	842	1,224	-472	512	253	8,878	-68	8,311	1,320	-98	20,702	372,991
									108,352			1,594			9,575				9,533				
	2. Increase Battery	170	25.5	40	158.4	40,403	31,016	29,300	76,500	15,000	25,278	842	1,224	-472	397	193	7,957	-180	8,452	1,980	-140	20,253	375,685
									116,778			1,594			8,367				10,292				
	3. Vary Generator and Battery for lowest total cost	170	25	10	52.8	39,611	34,298	3,475	75,000	3,750	8,426	825	1,200	-462	1,188	313	9,817	-21	844	660	-18	14,346	270,568
									87,176			1,563			11,297				1,486				
	4. Only PV without generator	170	85	-	528	134,678	-	26,984	255,000	-	84,260	2,805	4,080	-1572	-	-	-	-	6,150	6,600	-259	17,804	566,853
									339,260			5,313			-				12,491				

DC vs AC Microgrid Simulation

DC vs AC Loads

The DC and AC Microgrid Simulations were conducted to compare between the 2 microgrids configurations. Figure 4.10 showed the AC/DC Microgrid Diagram for the Smart Community. The 2 microgrids were set up in parallel to each other. The two power systems distributed electricity to the same buildings. There were power supply box in each building to determine which power were used at one time. The total real loads were the measured and combined from 12 buildings. The power consumption could only be collected for each building. Each appliances could not be measure for the power consumption. Therefore, to simulated full load, each appliance was assumed to be used at full capacity based on the behavior of the consumer for each building. The appliances were categorized as heating load, cooling load, entertainment/office load and lighting load. Overall, the total AC load per day was higher than the total DC load per day. From Table, the current AC load per day was at 90.4 kWh/day and the current DC load per day was at 76.1 kWh/day. This is due to some of the appliances uses DC internally, so energy consumption was less by omitting conversion from AC to DC if DC is used directly from the DC microgrid. For the simulated load of full operation, cooling loads consumed the highest energy and lighting loads consumes the least. The peak loads were observed during 10.00-16.00 hr. The measured loads and the simulated full load were used in the simulations with Homer Energy. The specifications of the components in DC and AC microgrid in addition to the load profiles were input into the Homer program as shown in Figure 4.11.

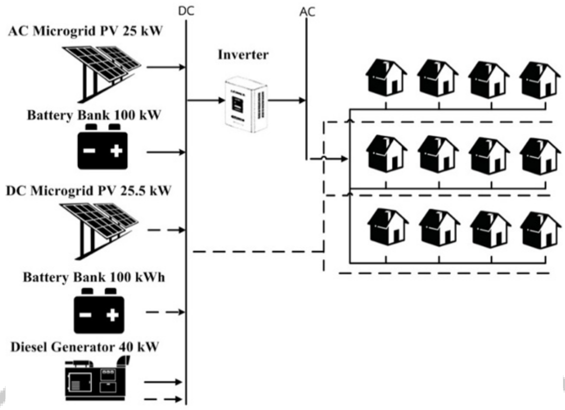


Figure 4.10 AC/DC Microgrid Diagram for the Smart Community

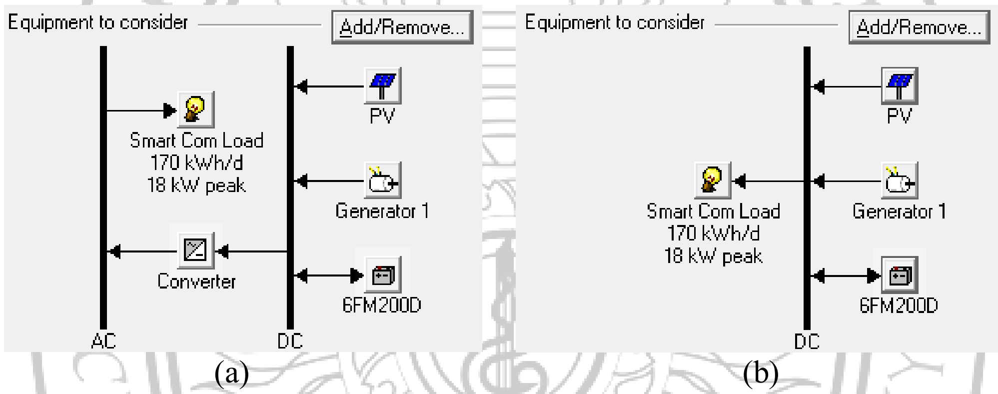


Figure 4.11 AC Microgrid Diagram (a) and DC Microgrid Diagram (b) from Homer

DC vs AC Simulation Results

In this work, 4 scenarios were applied during the simulation. The scenarios were on the basis of the current system configuration, optimize size of generator and battery for lowest cost, determine system configuration with only PV and determine the suitable load for the current system without the usage of diesel generator. The simulations were performed from scenario 1-4. The results from the previous scenarios were taken into consideration. The results are summarized in Table 4.6.

Scenario 1- Current System:

The current AC and DC microgrid configurations were suitable for the current load and simulated load. It could provide sufficient power for the buildings and activities in the community. The DC microgrid had the overall approximately 23.32% lower operation and maintenance costs than the AC microgrid. The higher cost from AC microgrid was due to the cost of inverter for converting DC to AC. With the same simulated load at 170 kWh/d, the DC microgrid overall cost would be 14.22%. less than AC microgrid.

Sensitivity Results | Optimization Results

Tabular Graphic

Double click on a system below for optimization results. Export... Details...

	PV (kW)	Gen1 (kW)	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
	25	40	44	36	$ 98,196	33,980	$ 532,574	0.671	0.46	15,123	1,414

(a)

Sensitivity Results | Optimization Results

Tabular Graphic

Double click on a system below for optimization results. Export... Details...

	PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
	25.5	40	44	$ 108,352	20,702	$ 372,991	0.470	0.55	11,530	1,053

(b)

Figure 4.12 Simulation Results of Scenario 1 – Current System (a) AC Microgrid vs (b) DC Microgrid Simulation

Scenario 2- Vary Diesel Generator and Battery Size:

In the simulation, the size of diesel generator and battery were varied. The results revealed that the current systems were over designed. At the present load, both microgrids should have 25 kW PV, 5 kW diesel generator instead of 40 kW generator and 52.8 kWh battery instead of 100 kWh. With the proper design, the investment cost for the AC microgrid and DC microgrid would be 105,281 USD and 85,301 USD, respectively. In addition, to accommodate the community expansion with full load at 170 kWh/d, the optimal system would be PV 25 kW, diesel generator 10 kW and battery at 52.8 kWh. With the full load configuration, the current microgrids systems were still too extensive for the community. Increasing size of the diesel generator could accommodate the higher load demand. However, increasing the usage of diesel fuel would emit CO_2 and would not be environmentally friendly. So, the next scenario would focus on the usage of renewable energy only as the distributed generation.

Sensitivity Results | Optimization Results

Double click on a system below for simulation results. Categorized Overall Export... Details...

PV (kW)	Gen1 (kW)	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25	5	22	36	$ 105,281	7,225	$ 197,646	0.469	0.78	4,048	3,057
55		110	36	$ 227,110	8,893	$ 340,794	0.808	1.00		

(a)

Sensitivity Results | Optimization Results

Double click on a system below for simulation results. Categorized Overall Export... Details...

PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25.0	5	22	$ 85,301	4,728	$ 145,740	0.411	0.94	861	526
40.0		88	$ 153,704	6,422	$ 235,796	0.664	1.00		

(b)

Figure 4.13 Simulation Results of Scenario 2 – Vary Diesel Generator and Battery Size (a) AC Microgrid vs (b) DC Microgrid Simulation

Scenario 3- Only PV as Distributed Generation:

With the current load of 90.4 kWh/d for AC microgrid, the suitable configuration would be PV 55 kW and battery 264 kWh. The total costs of investment would be 227,110 USD. For the DC microgrid with 76.1 kWh/d load, the optimal configuration would be PV 40 kW and battery 211 kWh. The total investment would be 153,704 USD. With the full load scenario of 170 kWh/d, the PV system would have to increase to 85 -105 kW and battery at 528 kWh. The total cost for 25 years would be around 300,000 USD. However, the maintenance cost would be approximately similar to the current system. So therefore, only usage of PV as distributed generation would not be cost effective when compared to the hybrid system with diesel generator.

Sensitivity Results | Optimization Results

Double click on a system below for simulation results. ● Categorized ○ Overall | Export... | Details...

PV (kW)	Gen1 (kW)	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25	5	22	36	$ 105,281	7,225	$ 197,646	0.469	0.78	4,048	3,057
55		110	36	$ 227,110	8,893	$ 340,794	0.808	1.00		

(a)

Sensitivity Results | Optimization Results

Double click on a system below for simulation results. ● Categorized ○ Overall | Export... | Details...

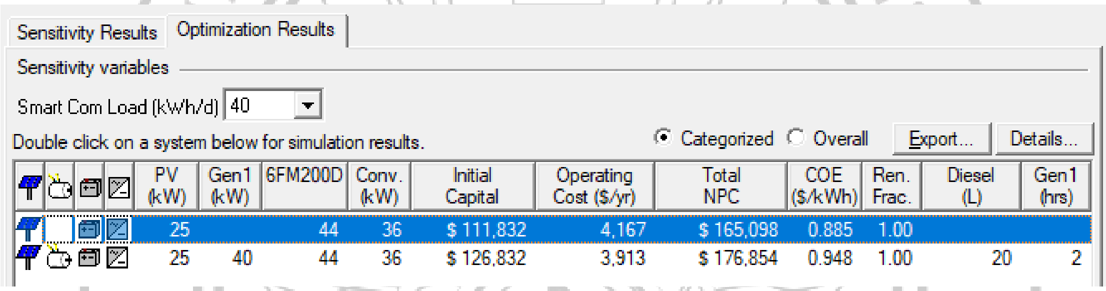
PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25.0	5	22	$ 85,301	4,728	$ 145,740	0.411	0.94	861	526
40.0		88	$ 153,704	6,422	$ 235,796	0.664	1.00		

(b)

Figure 4.14 Simulation Results of Scenario 3 – Only PV (a) AC Microgrid vs (b) DC Microgrid Simulation

Scenario 4- Reduce load for current microgrid configuration:

The current AC system has PV 25 kW and battery 100 kWh. If the community wanted to be totally relying on RE without using diesel fuel. The community have to reduce the load for AC microgrid to 40 kWh/d. For the DC microgrid systems, the load must be reduced to 45 kWh/d for the PV 25.5 kW and battery 100 kWh. With no diesel usage, the operation and maintenance would reduce significantly approximately 100,000 USD per system.


Sensitivity Results | Optimization Results

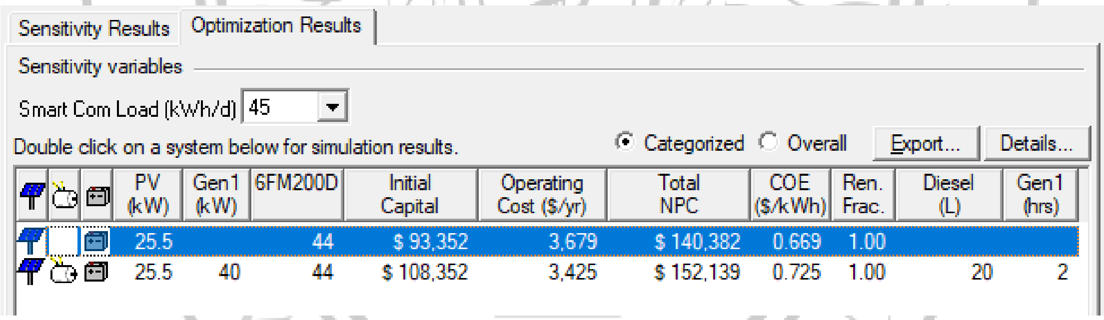
Sensitivity variables

Smart Com Load (kWh/d) 40

Double click on a system below for simulation results. Categorized Overall Export... Details...

PV (kW)	Gen1 (kW)	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25		44	36	$ 111,832	4,167	$ 165,098	0.885	1.00		
25	40	44	36	$ 126,832	3,913	$ 176,854	0.948	1.00	20	2

(a)


Sensitivity Results | Optimization Results

Sensitivity variables

Smart Com Load (kWh/d) 45

Double click on a system below for simulation results. Categorized Overall Export... Details...

PV (kW)	Gen1 (kW)	6FM200D	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
25.5		44	$ 93,352	3,679	$ 140,382	0.669	1.00		
25.5	40	44	$ 108,352	3,425	$ 152,139	0.725	1.00	20	2

(b)

Figure 4.15 Simulation Results of Scenario 4 – Reduce Load (a) AC Microgrid vs (b) DC Microgrid Simulation

Table 4.6 Simulated Result from Homer energy for AC/DC Microgrid Hybrid Systems with Real Load and Simulated Full Load

		AC												DC									
	Case	System Configuration					Results of Homer Simulation							System Configuration				Results of Homer Simulation					
							Electricity Generation (kWh/yr)				Operation & Maintenance (USD/year)							Electricity Generation (kWh/yr)			Operation & Maintenance (USD/year)		
		Load (kWh/d)	PV (kW)	Gen (kW)	InV. (kW)	Batt (kWh)	Pv	Gen.	InV.	Batt	Investment (USD)	Total O&M	Total Cost for 25 years	Load (kWh/d)	PV (kW)	Gen (kW)	Batt (kWh)	Pv	Gen.	Batt	Investment (USD)	Total O&M	Total Cost for 25 years
Real Measured Load	1.Current System	90.4	25	40	36	100	39,611	5,498	32,996	11,264	126,832	7,768	226,132	76.1	25.5	40	100	40,403	1,718	7,837	108,352	5,088	173,392
	2.Vary Generator and Battery for lowest total cost	90.4	25	5	36	52.8	39,611	11,302	32,986	3,897	105,281	7,225	197,646	76.1	25	5	52.8	39,611	2,601	6,731	85,301	4,728	145,740
	3.Only PV without generator	90.4	55	-	36	264	87,144	-	32,980	9,098	227,110	8,893	340,794	76.1	40	-	211.2	63,378	-	6,959	153,704	6,422	235,796
	4. Load appropriate for only PV	40	25	40	36	100	39,611	-	14,600	4,006	126,832	3,913	176,854	45	25.5	40	100	40,403	-	4,038	93,352	3,679	140,382
Simulated Load with Full Usage	1. Current System	170	25	40	36	100	39,611	39,436	62,050	30,905	126,832	24,095	434,845	170	25.5	40	100	40,403	32,641	28,155	108,352	20,702	372,991
	2. Vary Generator and Battery for lowest total cost	170	25	10	36	52.8	39,611	39,445	62,050	3,339	107,156	16,334	315,954	170	25	10	52.8	39,611	34,298	3,475	87,176	14,346	270,568
	3.Only PV without generator	170	105	-	36	528	166,366	-	61,996	29,639	419,240	20,376	679,720	170	85	-	528	134,678	-	26,984	339,260	17,804	566,853

The results from the Homer simulation of the AC and DC microgrid hybrid systems revealed that the present Microgrid used in Smart Community could be able to support the expansion of the community and higher usage of power consumption. The results from the Homer simulation of the AC and DC microgrid hybrid systems revealed similar trend as the results from Off-grid hybrid diesel-renewable mixed (Hafez & Bhattacharya, 2012) and (Mahmud, Hassan, & Rahman, 2013). The cost for the hybrid system would be less than only usage of PV as distributed generations. Integrating PV, biodiesel generator and battery would be a suitable configuration appropriate for the rural area without main utility grid (Sen & Bhattacharyya, 2013). This configuration could be suitable for the expansion of the community, however, there will be higher operation and maintenance cost.

Energy Data Collection Process for Smart Community

In this work, the 5 types of sensors were installed in 11 buildings/areas according to Table 4.7. The picture of the location of the installed sensors are shown in Figure 4.16. Not all sensors could be installed in every building/areas. This was due to installation difficulties and sensors malfuctions.

Data Capturing

The 5 energy data categories that directly related and indirectly related to energy consumption in the smart community were collected via the installations of sensors. The pictures of the installed sensors to collect data for electricity consumption, indoor temperature, indoor humidity, water usage and waste generation from the buildings are displayed in Figure 4.17. In this work, the sensors were not deploy to all 12 buildings in the Smart Community. As this is part of the pilot project, selected buildings were chosen to deploy specific energy data sensors. Electricity consumption sensors were installed in 4 buildings which are houses with occupancy. The temperature and humidity sensors were installed in 10 buildings for comparison however one sensor setup malfunction. Thus, only 9 buildings generated indoor temperature and humidity data. The water sensors were installed in 5 buildings. However, there were difficulty with real-time data recording. Water usage from only 2 buildings were recorded. The Smart Community have one central location for waste disposal. So, the waste generation data were recorded at this site.

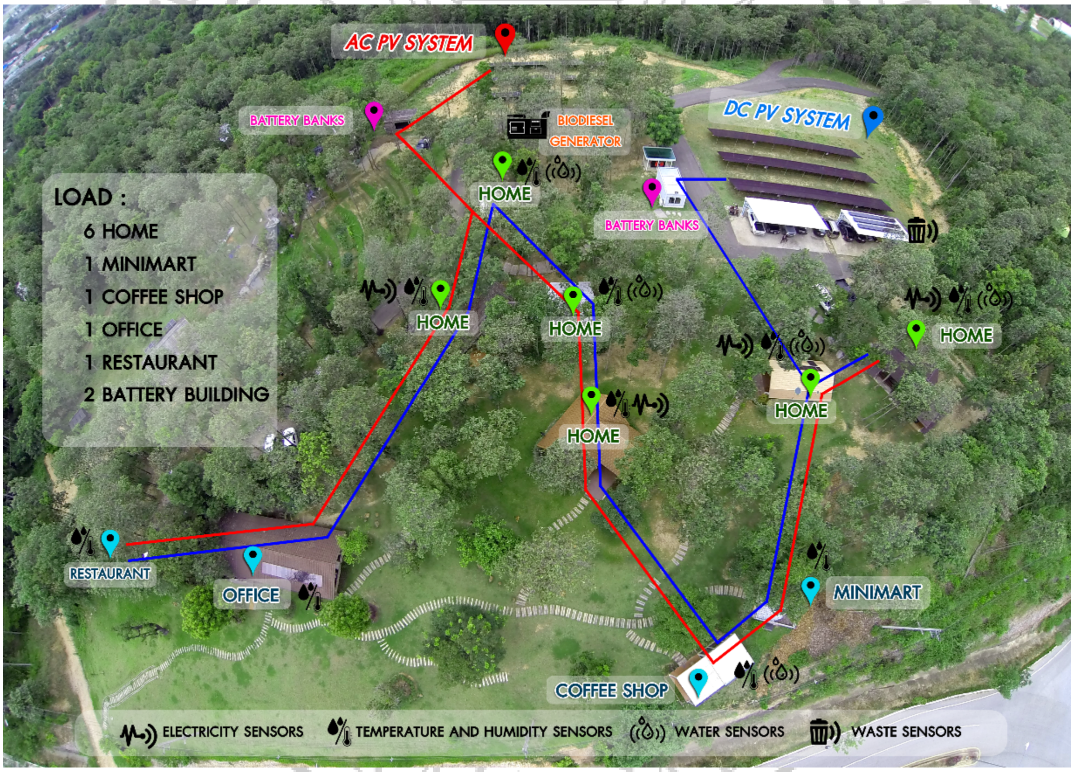


Figure 4.16 Sensor installed in Community

Table 4.7 List of Sensors Installed in Each Building

Building	Water Sensor	Temp Sensor	Humidity Sensor	Electricity Sensor	Waste Sensor
Smart Community office		✓	✓		
Green Coffee Villa	✓	✓	✓		
60 Watt Mini-Mart		✓	✓		
Green Kitchen		✓	✓		
Smart Home		✓	✓	✓	
DC-1	✓	✓	✓	✓	
A-Frame	✓	✓	✓		
Diamond House	✓	✓	✓	✓	
Box 1		✓	✓	✓	
Box 2	✓	✓	✓		
Smart Com Parking Lot					✓

In Chapter 3, the process for data collection was described. The data will be collected as 1 CSV file per day per energy data category. The picture of CSV file are shown in Figure 4.18 which has different file name format depending on the data category and type of sensor. The variety of data format posed complexity during data verification and arrangement. For electrical data, an example CSV file is stored as LOGGER01.CSV as 1 file per day (). Each file is composed of data for DATE, TIME, Voltage (V), Current (A), Power (W), Energy (kWh), Power Factor, Apparent power (VA), Reactive Power (VAr), and Total kWh (kWh). The data is recorded every 1 seconds for 86,400 data records per day (Table 4.8). The actual data were collected from the installed sensors. However in this work, the real data storage had less number of records in each file than the calculated records. This was caused by the unstable power system and natural factors such as power outages, rain, wind, which resulted in sensor variability and time errors during the data collection characteristics. Each data category had different collection frequency. The number of records obtained from the CSV file were consistent with the size of the data storage. If a record number for storing was large, the size of the file would increase according to the number of records (Table 4.9). For example, Power Consumption and Water data were recorded every 1 second per 1 building which would have the highest record per day as 86,400 records and Size 3.60 MB, per month as 108 MB, and per year as 1.27 GB. The Temperature and Humidity data were collected every 2 seconds per building. Therefore, the maximum number of records per day was 43,200 records and the size would be 1.09 MB, per month as 32.7 MB, and per year as 392.4 MB. The waste data were recorded every 5 minutes per 1 bin. The maximum number of record was 17,280 with size 872 KB per day, 25.55 MB per month, and 306.6 MB per year. For all 5 data categories, the total number of record stored from 1 building would be about 3.10 GB per year. Therefore, for the whole community of 12 buildings, the data storage size would be about 34.32 GB per year. From the size of data storaged mentioned previously, the size of data would be increased with realtime monitoring. Therefore, there is a need to have an efficient clean data management and analyze process optimize the data recording time period to only record the usable data. This would help reduce the size of data file and stored only the quality data in the database. The file name for energy data showed only LOGGER and a number. It does not contain information for date or type of energy data category. For the temperature and humidity data, the sensors are bundled and installed together. The examples of CSV files for temperature and humidity are shown as 7-18-4-2018-temp.csv and 7-18-5-2018-hum.csv, respectively. The file name for water usage sensors is the same format as the temperature and humidity data file names such as 5-18-4-2018-water.csv. The file name format indicated the date and data category. However, the file name formats for temperature, humidity and water were different from the electrical data file name. For the waste generation data, the sensors are installed in 4 waste bins at a central location of the Smart Community. The 4 waste bins are for general, recyclable, hazardous and organic wastes. The data from the 4 sensors are grouped together into one file per day. The example of the CSV file name was all4-1-7-2018-kg.csv which indicate the date and type of data.

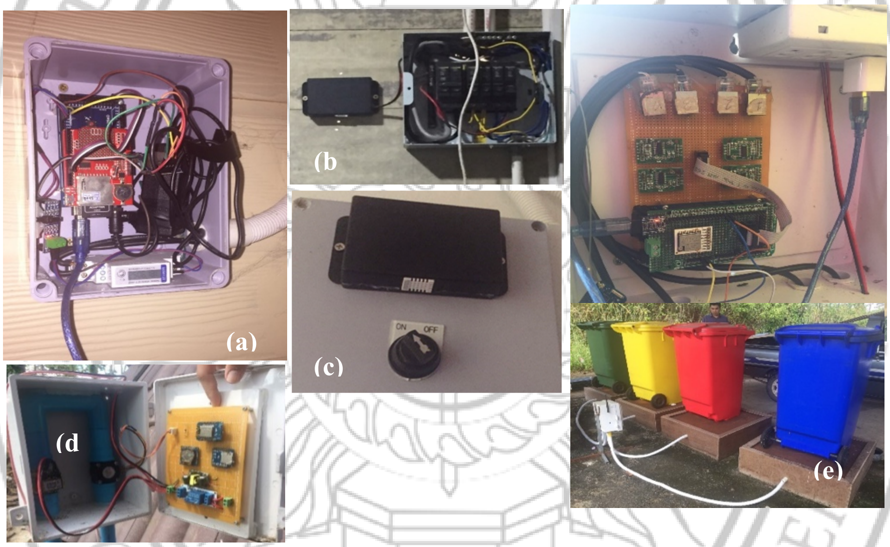


Figure 4.17 Example of sensors installation to collect data for (a) electricity, (b) temperature, (c) humidity, (d) water usage and (e) waste

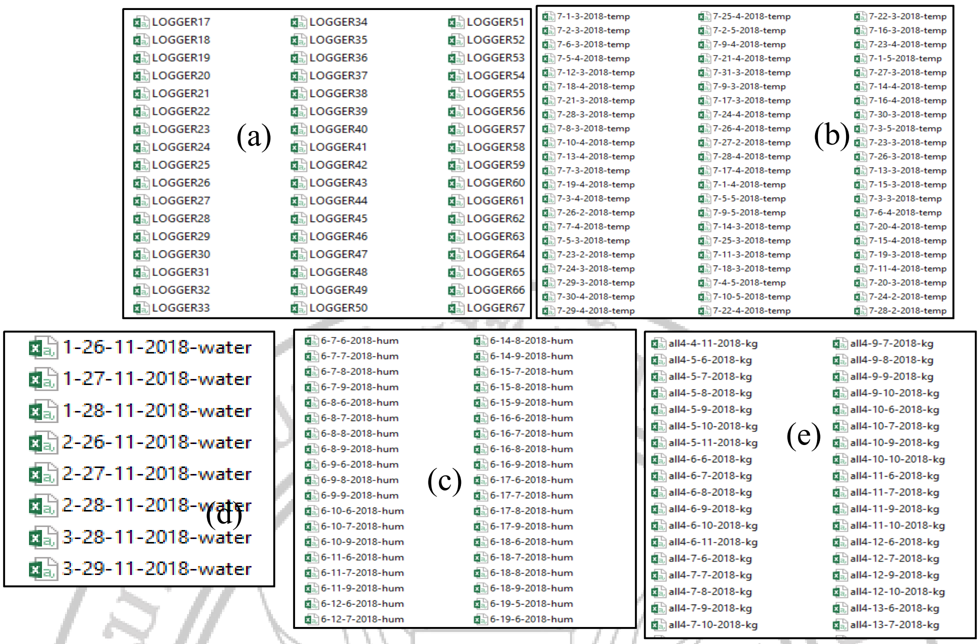


Figure 4.18 CSV files from installed senstors for (a) electricity, (b) temperature, (c) humidity (d) water usage and (e) waste

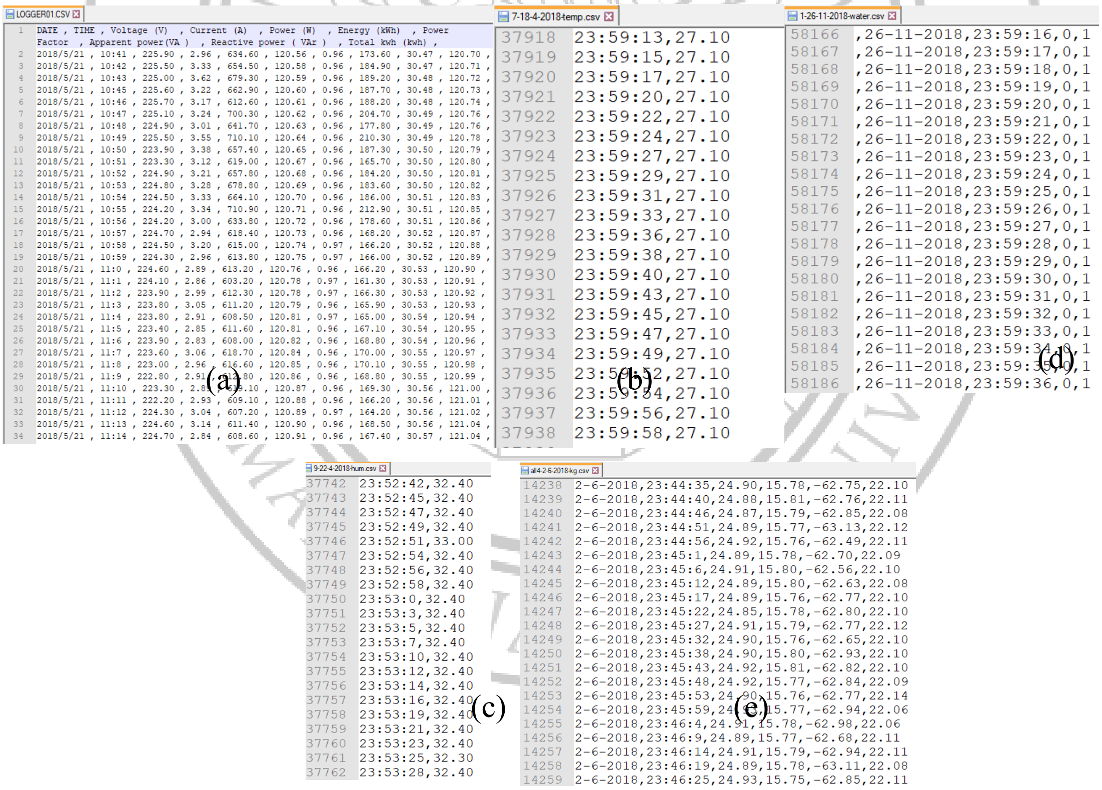


Figure 4.19 Raw data from CSV file for (a) electricity, (b) temperature, (c) humidity, (d) water usage and (e) waste

Table 4.8 Number of Collected Data Records and Units Calculated and Real Data Collection)

Energy Data Category	Time interval of data record collection	Calculated Maximum Number of record per day	Type of collected data unit for each data category	Number of data unit collected per record	Calculated Maximum number of data unit collected per day	Number of buildings that sensors were installed	Calculated Maximum Number of data unit per day for each category	Calculated Data: Maximum number of record per day for each data category	Real Data: Number of total record collected per day imported to database	
									Minimum	Maximum
Power Consumption	1 second	86,400	Date, Time, Voltage, Current, Power, Energy, Power Factor, Apparent power, Reactive power, Total kwh, kW	10	864,000	4	3,456,000	345,600	244	16,056
Temperature	2 seconds	43,200	Date, Time, degree Celsius (°C)	3	129,600	9	1,166,400	388,800	30	265,627
Humidity	2 seconds	43,200	Date, Time, percent (%)	3	129,600	9	1,166,400	388,800	1,353	37,951
Water	1 second when in use	86,400	Date, Time, Liter (L)	3	259,200	2	518,400	172,800	6,344	74,764
Garbage	5 minutes	17,280	Date,Time, General waste, Hazardous waste, Recycle waste, Wet waste (kg)	6	103,680	1	103,680	17,280	1,986	16,731

Table 4.9 Projections Energy Data File Sizes

Energy Data Category	Time interval of data record collection	Record	Size	Number of buildings that sensor ware installed per household	Calculated Maximum Number of data size for each category			Number of buildings that sensor ware installed per household	Calculated Maximum Number of data size for each category		
					per day	per mouth	per year		per day	per mouth	per year
Power Consumption	1 second	86,400	3.60 MB	1	3.60 MB	108 MB	1.27 GB	12	43.2 MB	1.27 GB	15.24 GB
Temperature	2 second	43,200	1.09 MB	1	1.09 MB	32.7 MB	392.4 MB	12	13.08 MB	392.4 MB	4.6 GB
Humidity	2 second	43,200	1.09 MB	1	1.09 MB	32.7 MB	392.4 MB	12	13.08 MB	392.4 MB	4.6 GB
Water	1 second	86,400	2.20 MB	1	2.20 MB	66 MB	792 MB	12	26.4 MB	792 MB	9.28 GB
Garbage	5 minutes	17,280	872 KB	1	872 KB	25.55 MB	306.6 MB	2	10.22 MB	306.6 MB	613.2 MB
				Total	**8.86 MB**	**264.95 MB**	**3.10 GB**		**105.98 MB**	**3.11 GB**	**34.32 GB**

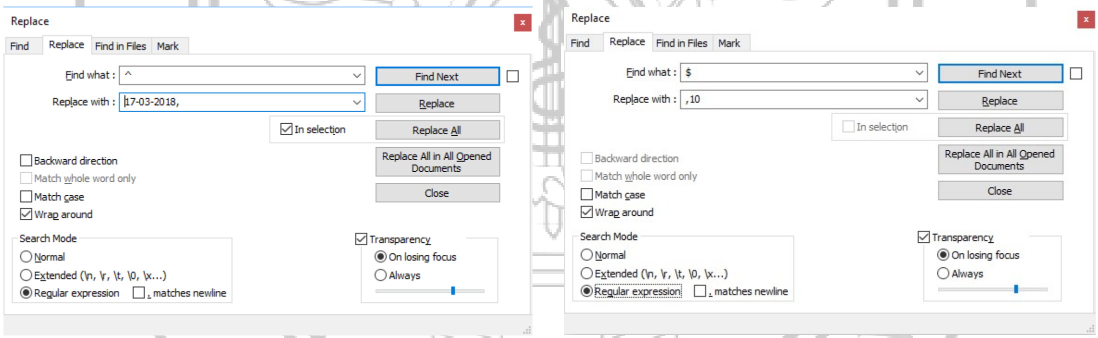
Data Verification

From the files of the data capturing process, the data were different depending on the type of collected data unit for each data category. Table 4.8 indicated the types of data unit for each data category. The electricity data file contained data unit information for Date, Time, Voltage, Current, Power, Energy, Power Factor, Apparent power, Reactive power, Total kwh, and kW. For temperature, humidity and water data files, the information format are similar as Date, Time, and the individual category collected value as Celsius (°C), percent humidity (%), and Liter (L), respectively. Wastes data file also provide information as Date, Time, Weight of waste: General waste, Hazardous waste, Recycle waste, and Organic waste (kg).

There is also discrepancy from the information data file of the same data category. For example, in humidity files, some files have the column for date, time, and % humidity, however, some files only have time and % humidity. In addition, there were a large number of data collected. For example, the temperature raw file had approximately 34,753 records per file which was time consuming to verify if the data were correct or error. Therefore, the main issues during the verification process were that the large amount of data in the raw csv file was not in the same format and the data was not clearly separated or grouped into column for examining. The verification process focused on generating good and usable data files to be imported to the database. In this step, all CSV raw files were examined via Notepad++. The files would be deleted if they did not have data which was caused from sensor error or electrical blackout/instability.

Data Arrangment

The data arrangement was the most difficult part because the files had different formats and different number of records. The files must be in the structure compatible to be imported to the designed database. Each file had been arranged in chronological order and set the structure to similar row and column via Notepad++. The files were processed with Replace with Regular Expression with “^” command by inserting date in the first column of each file (Figure 4.20(a)) and then inserting the building code at the end of the record with “$” command (Figure 4.20(b)). After file structure arrangement, all the files in one month must be combined according to the data category to be uploaded to the database. The Batch file command was used to combine the files.



(a) (b)

Figure 4.20 Replace with Regular Expression (a) Insert first text of line and (b) Insert text at the end

Figure 4.21 showed an example of file combining process into a new file called combinehum.csv. Once all the files collected in one month were captured, verified, arrange, and combined, they combined monthly file could be uploaded to the database of the energy data management system.

Figure 4.21 Command and Symbol Batch File

Database File Input

The time for uploading the data files depended on the number of records in the data file. On average, it took approximately 1 second to upload 2,088 records as shown in Figure 4.22.

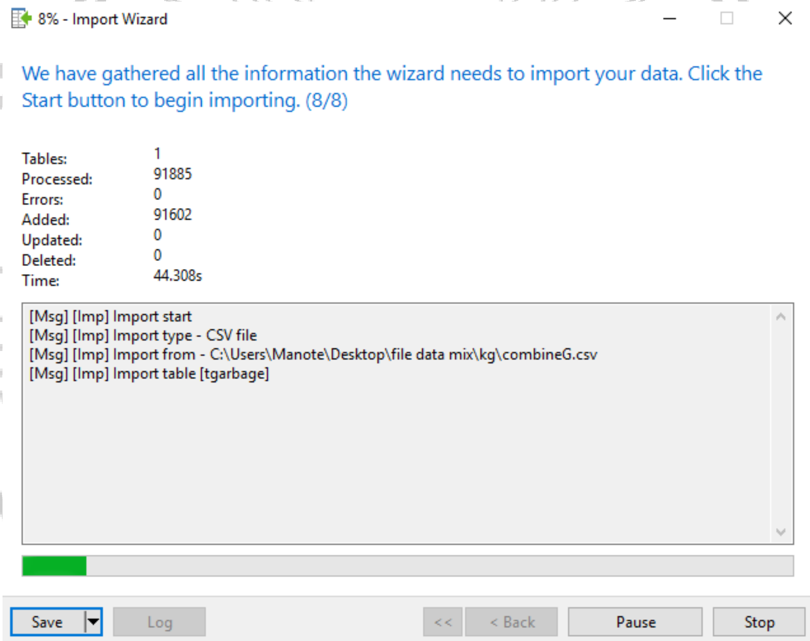


Figure 4.22 Data transfer window

After the data were uploaded, the data could be retrieved for use by SQL language. Function SQL SUBSTRING() and AVG() were used to gather and split the data interval time period to be 1 hour (Figure 4.23). Query time was applied in 12.148

second to achieve Crosstabs by apply command such as IF…ELSE, SQL COUNT(), AVG() and SUM(). The data were displayed horizontally which was easier to understand and report (Figure 4.24). In this work, Query Data method was kept in View for ease in usage, reduce the operation of Query and faster data retrieval.

```sql
SELECT
SUBSTRING_INDEX(timeskeep,":",1) AS timekeep,
FORMAT(AVG(temps),2) AS Dtemp,
ttemp.id_place,
ttemp.timedata,
rplace.name_color,
rplace.name_place
FROM
ttemp
INNER JOIN rplace ON rplace.id_place = ttemp.id_place
GROUP BY
SUBSTRING_INDEX(timeskeep,":",1),
ttemp.timedata,
ttemp.id_place
ORDER BY
ttemp.id_temp ASC
```

Message | Result1 | Profile | Status

timekeep	Dtemp	id_place	timedata	name_color	name_place
0	27.99	2	2018-01-10	c14	บ้าน เพชร
1	27.95	2	2018-01-10	c14	บ้าน เพชร
2	27.94	2	2018-01-10	c14	บ้าน เพชร
3	27.94	2	2018-01-10	c14	บ้าน เพชร
4	27.88	2	2018-01-10	c14	บ้าน เพชร

SELECT SUBSTRING_II | Read Only | Query time: 12.148s | Record 1 of 5820

Figure 4.23 Function SQL SUBSTRING ()

```sql
Sum(IF(timekeep=3,Dtemp,0)) AS T4,
Sum(IF(timekeep=4,Dtemp,0)) AS T5,
Sum(IF(timekeep=5,Dtemp,0)) AS T6,
Sum(IF(timekeep=6,Dtemp,0)) AS T7,
Sum(IF(timekeep=7,Dtemp,0)) AS T8,
Sum(IF(timekeep=8,Dtemp,0)) AS T9,
Sum(IF(timekeep=9,Dtemp,0)) AS T10,
Sum(IF(timekeep=10,Dtemp,0)) AS T11,
Sum(IF(timekeep=11,Dtemp,0)) AS T12,
Sum(IF(timekeep=12,Dtemp,0)) AS T13,
Sum(IF(timekeep=13,Dtemp,0)) AS T14,
Sum(IF(timekeep=14,Dtemp,0)) AS T15,
Sum(IF(timekeep=15,Dtemp,0)) AS T16,
Sum(IF(timekeep=16,Dtemp,0)) AS T17,
Sum(IF(timekeep=17,Dtemp,0)) AS T18,
Sum(IF(timekeep=18,Dtemp,0)) AS T19,
Sum(IF(timekeep=18,Dtemp,0)) AS T20,
Sum(IF(timekeep=20,Dtemp,0)) AS T21,
Sum(IF(timekeep=21,Dtemp,0)) AS T22,
Sum(IF(timekeep=22,Dtemp,0)) AS T23,
Sum(IF(timekeep=23,Dtemp,0)) AS T24,
FORMAT(SUM(Dtemp)/COUNT(Dtemp),2) AS AvgTemp,
vqtemp.name_color,
```

Message | Result1

timedata	id_place	T1	T2	T3	T4	T5
2018-01-10	2	27.99	27.95	27.94	27.94	27.88
2018-01-11	2	26.41	26.47	26.52	26.57	26.42

SELECT vqtemp.timeα | Read Only | Query time: 12.102s | Record 5 of 293

Figure 4.24 Crosstabs for the horizontal data

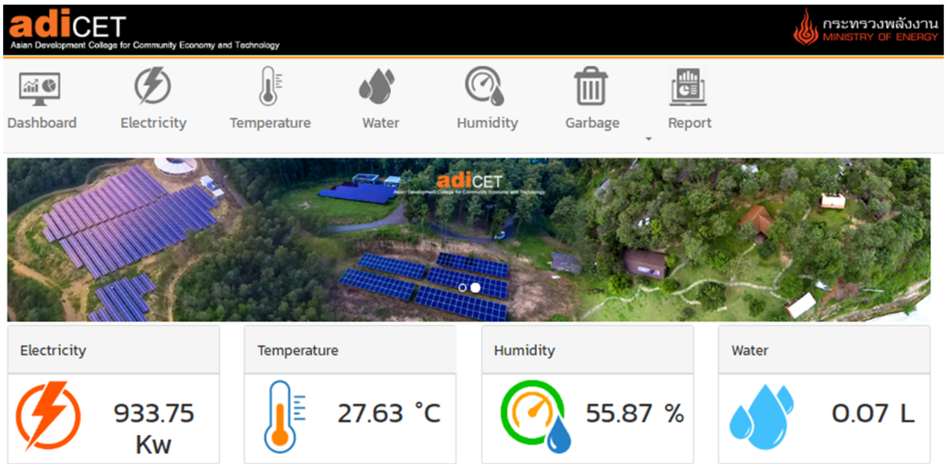
The technique developed for data capture, verification, and arrangement provided the data with the same format to be transferred to the database. The data management process was aligned with the work from Yang and coworkers (Yang, 2015) regarding the effective management of large data to reduce the uncertainty by verify the raw data and reformat the data structure. The functions from SQL were used to retrieved data for display. The Query was stored in View to reduce the operation of Query Data which corresponded with the work from Mithani and coworker (Mithani, Machchhar, & Jasdanwala, 2016) to modify the Query for faster and more efficient retrieval of large and complicated data.

User Interface for Smart Community Energy Data Management System

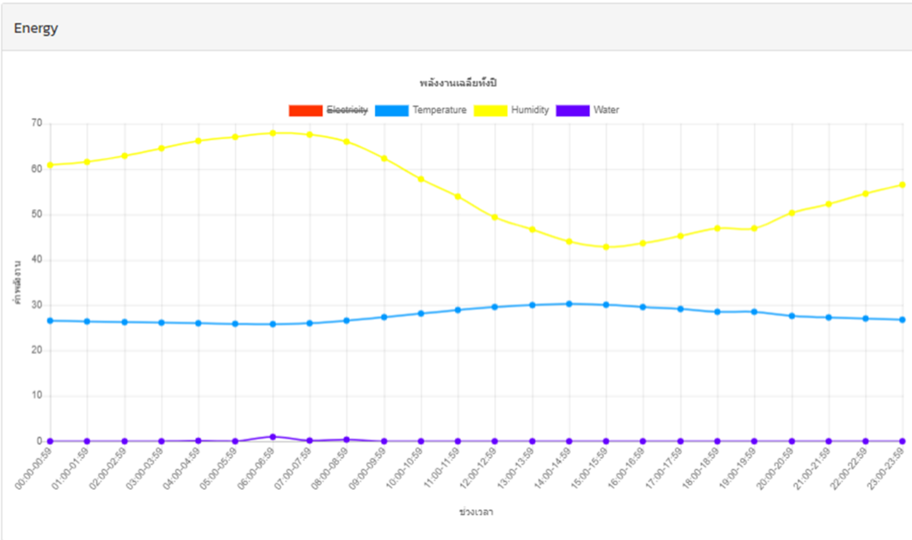
The design of The User Interface of this work applied the Responsive Web Design with Bootstrap to define the operation scope. PHP, SQL and JavaScript Language was applied with Chart.js to report as graph and figures. The website for user interface was divided to 4 pages including Main Page, Detailed Data Display Page, Building Data Page and Reporting Page.

Main page

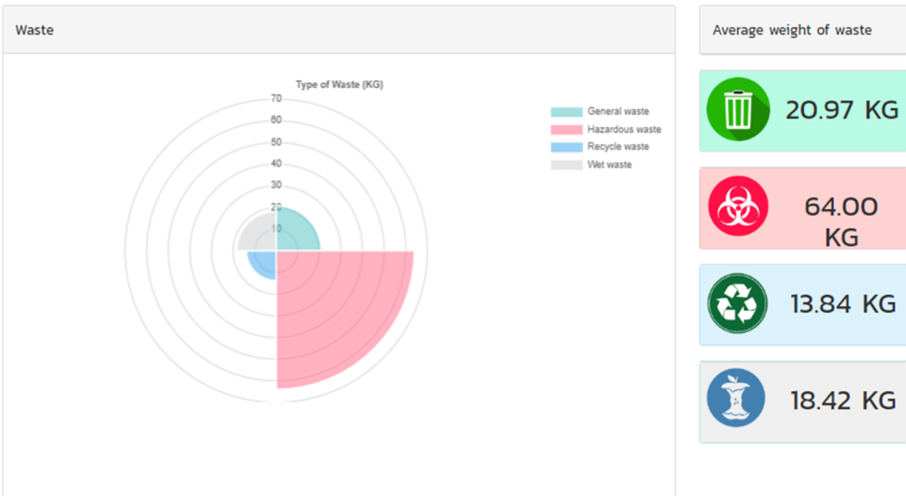
The main page retrieved all averaged information from the Smart Community by displaying in comparison graph for Electricity, Temperature, Humidity, Water and Waste data in Figure 4.25.


adiCET
Asian Development College for Community Economy and Technology
กระทรวงพลังงาน
MINISTRY OF ENERGY
Dashboard
Electricity
Temperature
Water
Humidity
Garbage
Report
Electricity
933.75 Kw
Temperature
27.63 °C
Humidity
55.87 %
Water
0.07 L

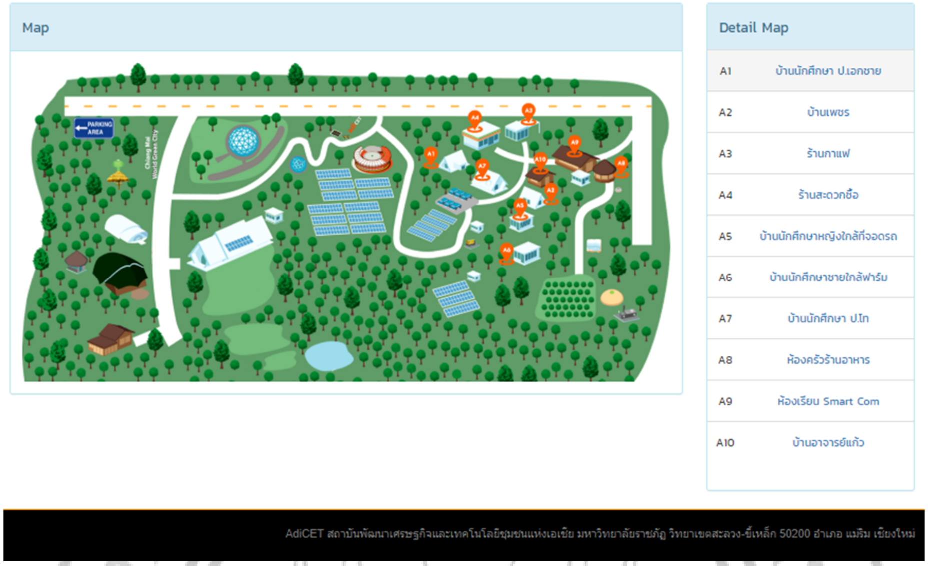
(a)


Energy
Electricity
Temperature
Humidity
Water
70
60
50
40
30
20
10
0

(b)


Waste
Type of Waste (KG)
General waste
Hazardous waste
Recycle waste
Wet waste
Average weight of waste
20.97 KG
64.00 KG
13.84 KG
18.42 KG

(c)



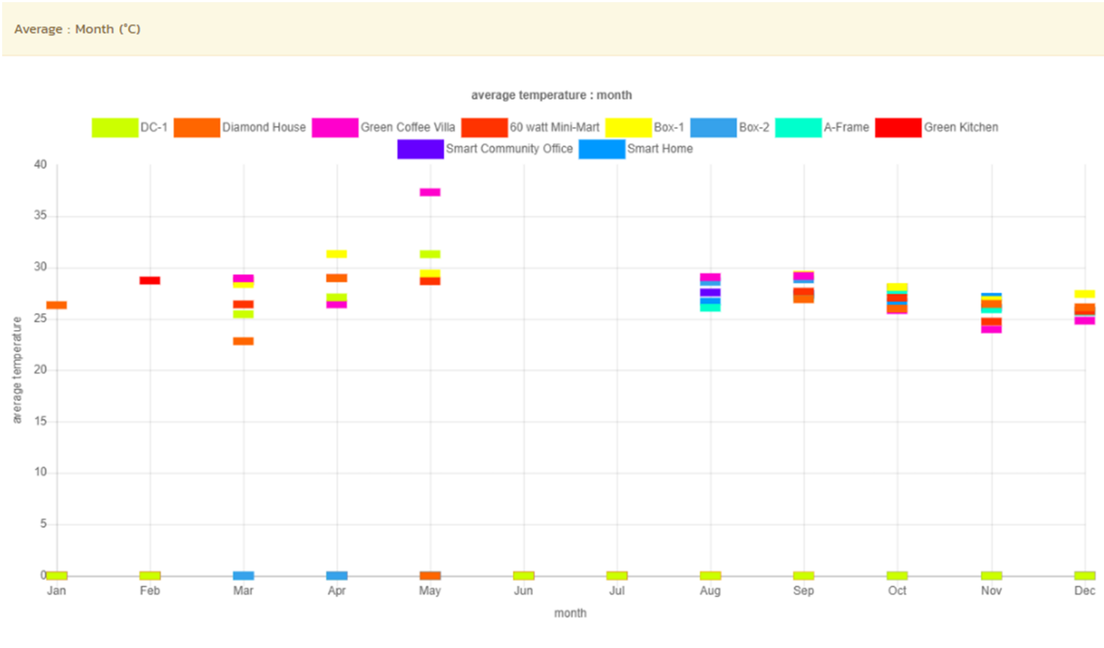
(d)

Figure 4.25 Dispage webpage for Smart Community Energy Data Management System (a) Main Page, (b) Data Comparison Graph, (c) Waste Data Graph, and (d) Map of Buildings

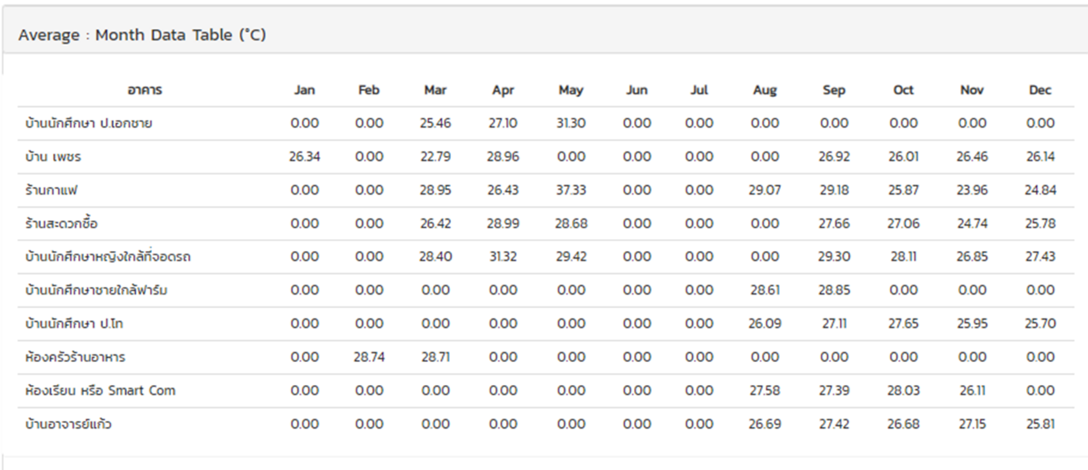
Detailed Data Display Page

This page would display the detailed information for each Energy Data Category. For example of temperature, the average, minimum and maximum temperature were displayed in a picture format that was easy to understand (Figure 4.26(a)). The average temperature for each month was also shown in Figure 4.26(b) with the data table in Figure 4.26(c). Lastly, the average hourly temperature from the data all year were showned as the bar graph Figure 4.26(d).

(a)



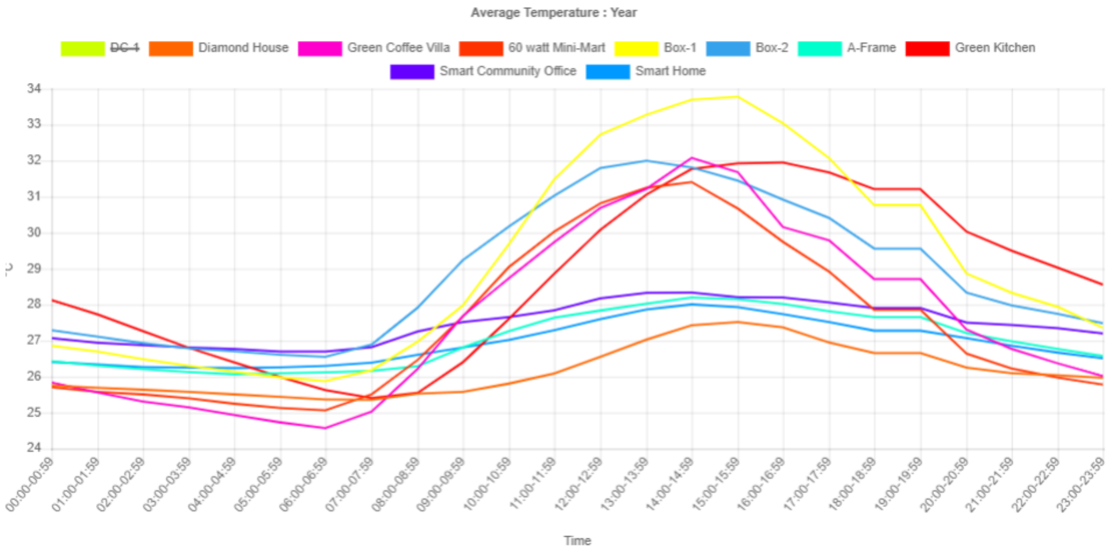
(b)



Average : Month Data Table (°C)

อาคาร	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
บ้านนักศึกษา ป.เอกชาย	0.00	0.00	25.46	27.10	31.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00
บ้าน เพชร	26.34	0.00	22.79	28.96	0.00	0.00	0.00	0.00	26.92	26.01	26.46	26.14
ร้านกาแฟ	0.00	0.00	28.95	26.43	37.33	0.00	0.00	29.07	29.18	25.87	23.96	24.84
ร้านสะดวกซื้อ	0.00	0.00	26.42	28.99	28.68	0.00	0.00	0.00	27.66	27.06	24.74	25.78
บ้านนักศึกษาหญิงใกล้ที่จอดรถ	0.00	0.00	28.40	31.32	29.42	0.00	0.00	0.00	29.30	28.11	26.85	27.43
บ้านนักศึกษาชายใกล้ฟาร์ม	0.00	0.00	0.00	0.00	0.00	0.00	0.00	28.61	28.85	0.00	0.00	0.00
บ้านนักศึกษา ป.โท	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.09	27.11	27.65	25.95	25.70
ห้องครัวร้านอาหาร	0.00	28.74	28.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ห้องเรียน หรือ Smart Com	0.00	0.00	0.00	0.00	0.00	0.00	0.00	27.58	27.39	28.03	26.11	0.00
บ้านอาจารย์แก้ว	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.69	27.42	26.68	27.15	25.81

(c)

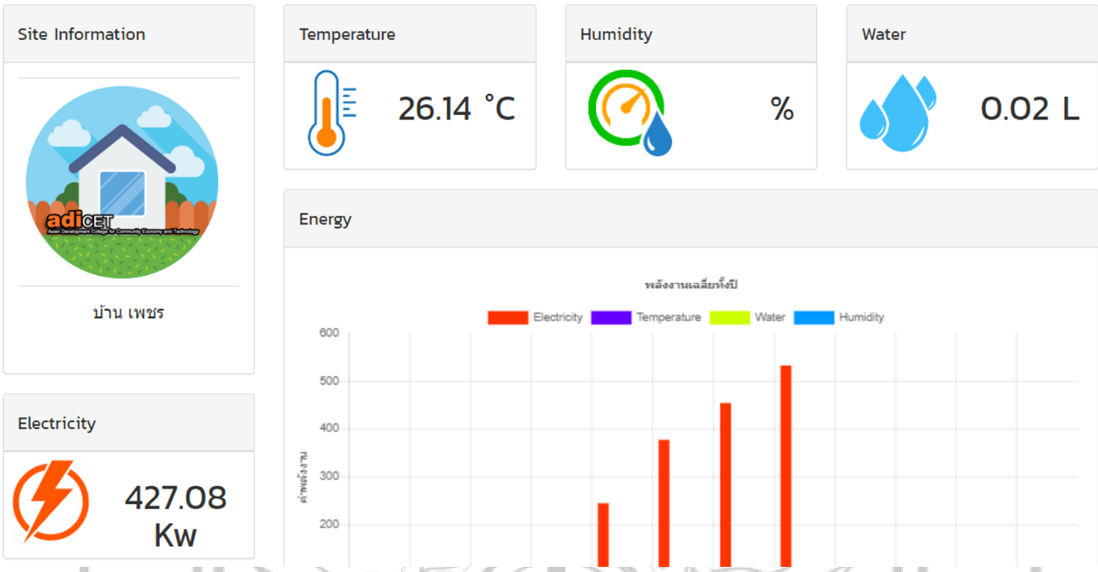


(d)

Figure 4.26 Detailed Temperature Display Page: (a) Average, Min, Max Value, (b)Average Monthly Chart, (c) Building Average Monthly Table, and (d) Average Daily Temperature Profile

Building Data Page

The building data page displayed the 4 data categories for each building. For example, the diamond house page showed the average data and monthly data for electricity consumption, temperature, water usage and humidity Figure 4.27.



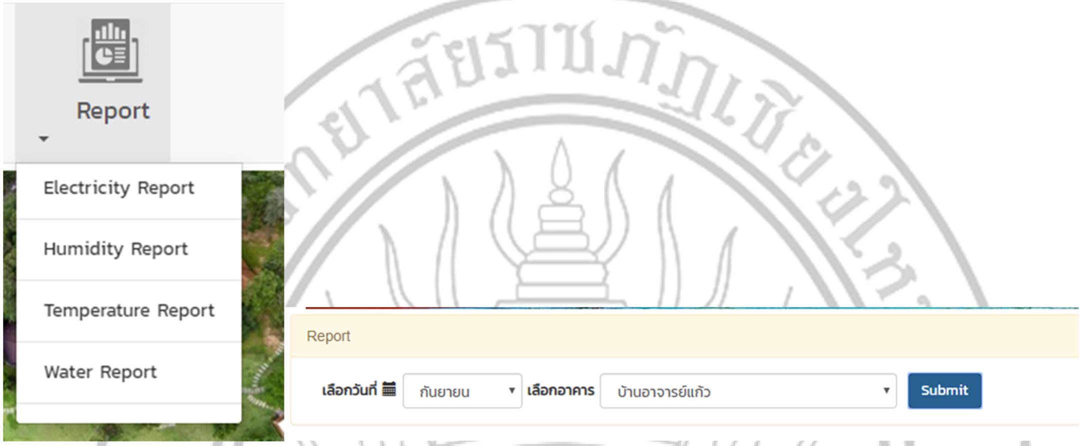
(a)

(c)

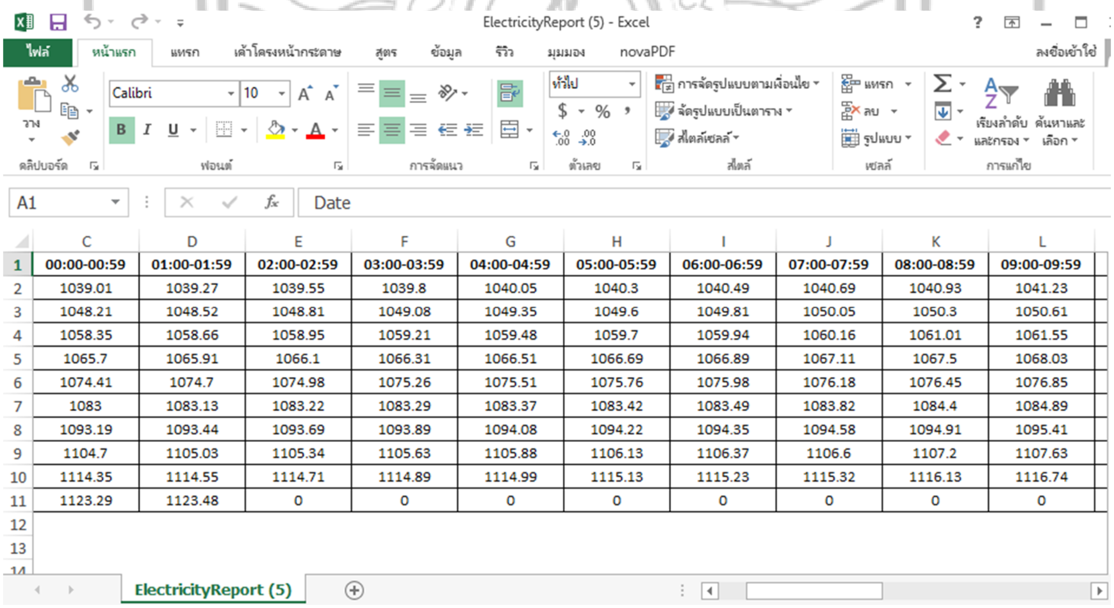
Figure 4.27 Building Page (a) Average power of factor (b) Average month chart (c) Data Table Average data per month of the building

Reporting Page

The reporting page provide the user with data exporting fuction as excel file for each month and each building as show in Figure 4.28.



(a)



	C	D	E	F	G	H	I	J	K	L
1	00:00-00:59	01:00-01:59	02:00-02:59	03:00-03:59	04:00-04:59	05:00-05:59	06:00-06:59	07:00-07:59	08:00-08:59	09:00-09:59
2	1039.01	1039.27	1039.55	1039.8	1040.05	1040.3	1040.49	1040.69	1040.93	1041.23
3	1048.21	1048.52	1048.81	1049.08	1049.35	1049.6	1049.81	1050.05	1050.3	1050.61
4	1058.35	1058.66	1058.95	1059.21	1059.48	1059.7	1059.94	1060.16	1061.01	1061.55
5	1065.7	1065.91	1066.1	1066.31	1066.51	1066.69	1066.89	1067.11	1067.5	1068.03
6	1074.41	1074.7	1074.98	1075.26	1075.51	1075.76	1075.98	1076.18	1076.45	1076.85
7	1083	1083.13	1083.22	1083.29	1083.37	1083.42	1083.49	1083.82	1084.4	1084.89
8	1093.19	1093.44	1093.69	1093.89	1094.08	1094.22	1094.35	1094.58	1094.91	1095.41
9	1104.7	1105.03	1105.34	1105.63	1105.88	1106.13	1106.37	1106.6	1107.2	1107.63
10	1114.35	1114.55	1114.71	1114.89	1114.99	1115.13	1115.23	1115.32	1116.13	1116.74
11	1123.29	1123.48	0	0	0	0	0	0	0	0

(b)

Figure 4.28 Reporting Page: (a) Select month to show energy consumption of building and (b) Reports in EXCEL file format

Energy Data Management System Evaluation

The evaluation of the developed Energy Data Management System for the Smart Community in CMRU were administered to 18 users as follows:

Manager	2	persons
Dean	1	person
Associate Dean	1	person
Instructors	3	person
Staffs	4	person
Students	9	person

Likert scale of 5 levels were used to evaluate the satisfaction of the Energy Data Management System as indicated in Table 4.10. The satisfaction level interval were shown in Table 4.11. From the satisfaction evaluation, the users of the program understood how to use the program and could effectively apply the program o their work. The summary of the user satisfaction was summarized in Table 4.12. The average satisfaction score was at 4.55 which was at “Very Good” scale. The usage factor for Appropriate of text color, background color and other elements, Menu style easy to use and Utilization from system had the satisfaction in the range of 4.6-5.0 which resulsted to “Excellent” scale. In summary, the user could be able to use the program, understand the reporting and interprete the data for future applications.

Table 4.10 Scoring Table for the Energy Data Management System Satisfaction Evaluation

Score Level	
Satisfaction Level Indicator	Score
Excellent	5
Very Good	4
Good	3
Fair	2
Poor	1

Table 4.11 Satisfactory Level Interval

Satisfaction	Satisfaction Interval
Excellent	4.60-5.00
Very Good	3.60-4.59
Good	3.59-2.60
Fair	2.59-1.60
Poor	1.59-1.00

Table 4.12 Evaluation of the Usage of Energy Data Management Systems For Smart Community with PV Microgrid

Usage Factor	**User Reply Score and Percentage**					
	5	**4**	**3**	**2**	**1**	**Avg**
Convenience of Usage	8 (44.44)	6 (33.33)	4 (22.22)	-	-	4.22
Accuracy of information displayed	10 (55.56)	8 (44.44)	-	-	-	4.56
Clarity of information displayed	9 (50.00)	8 (44.44)	1 (5.56)	-	-	4.44
Appropriate of text color, background color and other elements.	11 (61.11)	7 (38.89)	-	-	-	4.61
Menu style easy to use	14 (77.78)	4 (22.22)	-	-	-	4.78
Appropriate of system components	12 (66.67)	4 (22.22)	2 (11.11)	-	-	4.56
Utilization from system	14 (77.78)	2 (11.11)	2 (11.11)	-	-	4.67
Average Satisfaction						**4.55**

CHAPTER 5

CONCLUSION

Renewable energy application is one of the fundamental key for the sustainable community development. However, renewable energies (RE) are considered as unreliable energy sources because it can not provide constant power generation like traditional fossil fuel based power plants. Therefore, RE distributed generations are connected together through the microgrid systems and the energy generation can be managed to provide stable power sources. Power generation sources should be appropriate for the community power consumption. Monitoring the realtime energy consumption data is very important for the RE and microgrid operations. The data can also be analyzed further to determine the appropriate sizing and configuration of the RE and microgrid systems for future planning of increase power need due to community expansion. The goal for future communities are based on the concept of Smart Community. Therefore, the main aim of this work is to develop the energy data management system for the Smart Community PV AC & DC Microgrid. The energy data management system will support the decision maker and future energy plans for the Smart Community. This dissertation is divided into 3 parts: 1) Analysis of DC & AC Microgrid potential with microgrid simulation; 2) Big energy data collection procedure; and 3) Development of big energy data management system for Smart Community.

For the first part, two parallel microgrid system AC microgrid and DC microgrid were evaluated for the potential energy sources for the Smart Community of Chiang Mai Rajabhat University. AC microgrid has the distributed generation as 25 kW PV system while DC microgrid has 25.5 kW PV system. The DC microgrid has 40 kW diesel generator. Both microgrids have their own battery bank system of 100 kWh each. Therefore, AC and DC power could be distributed to the 12 houses and buildings in the Smart Community. The AC load would average at 90.4kWh/d and DC load would average at 76.1 kWh/d. Homer Energy simulation program was used to model and analyze both systems to determine the optimal configuration. The modeling utilized real load from the community and simulated load with the assumption of full load operation. The simulation results revealed that both AC and DC systems were over designed for the current load and the overall cost for 25 years would be 226,132 USD and 173,392 USD, respectively. However, if the community reduce the load to 40-55 kWh/d from 90.4 kWh/d (AC microgrid) and 76.1 kWh/d (DC microgrid), only 25 kW PV system without diesel generator would be sufficient for the load and the overall cost would reduce at approximately 40, 000USD. The configuration with only PV usage will be considered as Low Carbon Community. For the scenario of community expansion to full load at 170kWh/d, both AC and DC microgrid optimized systems would be PV25 kW, diesel generator 10 kW and battery 52.8 kWh. The overall cost for DC microgrid would be 45,386 USD less than the AC microgrid.

The second part of this work focused on energy data collection procedure. In this work, the energy data is considered as direct energy data and indirect energy data. Direct energy data are energy generation and consumption data while indirect energy data are those data relating to the energy generation and consumption such as water usage, indoor temperature, humidity and waste generation. These data were collected via sensors installed in each building of the Smart Community. The data were then processed through 3 steps: Capture, Verification and Arrangement. The structure of the dataset were specified to be compatible with the database. Approximately 1,800 data files per month were processed. Each data file has the range of 17,280 – 86,400 data records depending on the data category and collection interval. The data collection from sensors installed in real building has several challenges. The sensors and data transmission has issues during blackouts and sometime animals such as ants and geckos damaged the sensors. The data verification part is very important to screen for the usable data and reject the bad data.

The third part of this work is the development of energy data management system which include the data analysis, database design, and user interface development. The datasets were systematically grouped and arranged in their category. Responsive Web Design was the concept used for designing the energy data database. Bootstrap was used to frame in user interface with PHP, SQL and JavaScript language. Chart.jswas applied for data reporting as graph or to compare the replationship between the data categories. Information can be exported as Excel files. The energy data management system can be used for the real small community data collection with easy to understand reporting format.

REFERENCES

Barnes, M., Kondoh, J., Asano, H., Oyarzabal, J., Ventakaramanan, G., Lasseter, R., . . . Green, T. (2007, 16-18 April). *Real-World MicroGrids-An Overview.* Paper presented at the System of Systems Engineering, 2007. SoSE '07. IEEE International Conference on.

Becker, D. J., & Sonnenberg, B. J. (2011, 9-13 Oct. 2011). *DC microgrids in buildings and data centers.* Paper presented at the Telecommunications Energy Conference (INTELEC), 2011 IEEE 33rd International.

Center of Excellence for Innovative Energy System, E. E. D., King MongKut Institute of Technlogy Ladkrabang. (2010). Retrieved from http://www.kmitl.ac.th/cines/

Chen, Z., Zhong, F., Yuan, X., & Hu, Y. (2016, 12-14 March). *Framework of integrated big data: A review.* Paper presented at the 2016 IEEE International Conference on Big Data Analysis (ICBDA).

Data cleansing, National Science and Technology Development Agency. (2012). Retrieved from https://www.nstda.or.th/th/nstda-knowledge/2910-data-cleaning

David P. Chassin, Jason C. Fuller, & Djilali, N. (2014). GridLAB-D: An agent-based simulation framework for smart grids. *Applied Mathematics*, 12-24.

Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J., & Williams, P. (2010). Foundations for Smarter Cities. IBM Journal of Research and Development, *54*(4), 1-16. doi: 10.1147/JRD.2010.2048257

Hatziargyriou, N., Asano, H., Iravani, R., & Marnay, C. (2007). Microgrids. Power and Energy Magazine, IEEE, *5*(4), 78-94. doi: 10.1109/MPAE.2007.376583

Hafez, O. & Bhattacharya, K. (2012). Optimal planning and design of a renewable energy based supply system for microgrids. *Renewable Energy,* 7-15.

Iamsomboon, P., Tangtham, N., Kanchanasunthorn, S. & Lert, S. B. (2013). Modeling appropriate solar home system operations for optimal quality of life in remote areas. *Kasetsart J. (Soc. Sci),* 34, 92-104.

Jin, S. & Chassin, D. P. (2014). *Thread Group Multithreading: Accelerating the computation of an Agentbased Power System Modeling and Simulation Tool – GridLAB-D.* Paper presented at the International Conference on System Science, Hawaii.

Khomfoi, S. (2011). A Control and Protection System for a DC Mirogrid Using Photovoltaic and Combined Heat Power as Distributed generator. Thammasat University Digital Collections.

Khosri, S. & Plangklang, B. (2010). *Smart Grid Application for Renewable Energy Distributed Generation.* Paper presented at the The 3rd Thailand Renewable Energy for Community Conference, Rajamangala University of Technology Thanyaburi.

Ku, T., Park, W., & Choi, H. (2018, 15-17 Jan). *Energy Peak Reduction Mechanism with Prediction of Demand and PV Generation on Big Data.* Paper presented at the 2018 IEEE International Conference on Big Data and Smart Computing (BigComp).

Magazine, E. (2013). *DG control and operating with Smart Grids*. Retrieved from http://issuu.com/eitmagazine/docs/nov-dec2010/73

Mahmud, N., Hassan, A., & Rahman, M. S. (2013, 17-18 May). *Modelling and cost analysis of hybrid energy system for St. Martin Island using HOMER*. Paper presented at the 2013 International Conference on Informatics, Electronics and Vision (ICIEV).

Maria, A. (1997). Introduction to modeling and simulation. *Proceedings of the 1997 Winter Simulation Conference*, 7-13.

Mithani, F., Machchhar, S., & Jasdanwala, F. (2016, 15-17 Dec). *A novel approach for SQL query optimization.* Paper presented at the 2016 IEEE International Conference on Computational Intelligence and Computing Research (ICCIC).

Mohanty, S. (2016). *Everything You Wanted to Know About Smart Cities*. IEEE Consumer Electronics Magazine. (Vol. 5). 60-70.

NREL. (2011). HOMER The Micropower Optimization Model, Getting Started Guide for HOMER Legacy (Version 2.68). U.S. Department of Energy Office of Energy Efficiency and Renewable Energy : Midwest Research Institute.

PNNL. (2012). GridLAB-D a unique tool to design the smart grid. U.S. Department of Energy Office of Energy Efficiency and Renewable Energy : Midwest Research Institute.

Prodan, I., & Zio, E. (2014). A model predictive control framework for reliable microgrid energy management. *International Journal of Electrical Power & Energy Systems, 61*(0), 399-409. doi: http://dx.doi.org/10.1016/j.ijepes.2014.03.017

Sen, R. & Bhattacharyya, S. C. (2013). Off-grid electricity generation with renewable energy technologies in India: An application of HOMER. *Renewable Energy*, 388-398.

Smart cities information center. (2015). Retrieved from https://smartcitiescouncil.com/smart-cities-information-center/definitions-and-overviews

Smart city. (2006). Retrieved from https://en.wikipedia.org/wiki/Smart_city

Taylor-Sakyi, K. (2016). Big data: Understanding big data. Retrieved from https://www.researchgate.net/publication/291229189_Big_Data_Understanding_Big_Data

Toppeta, D. (2010). The smart city vision: How innovation and ICT can build smart, "livable", sustainable cities. *Think! Report*, 005, 1-9.

XU, Y. (2015, 26-28 Aug. 2015). Knowledge management in big data times. Paper presented at the 2015 IEEE Fifth International Conference on Big Data and Cloud Computing.

Yunjie, G., Xin, X., Wuhua, L., & Xiangning, H. (2014). Mode-adaptive decentralized control for renewable DC microgrid with enhanced reliability and flexibility. *Power Electronics, IEEE Transactions on, 29*(9), 5072-5080. doi: 10.1109/TPEL.2013.2294204

CURRICULUM VITAE

Name	Mr. Manote Tonsing	
Position	Computer Technical Officer.	
Work Place	Faculty of Science Maejo University	
Address	63 Sansai-Phrao Road, Nongharn, Sansai District, Chiang Mai, 50290 Thailand	
Email	Tonsing009@gmail.com	
Education		
	2003	Bachelor of Business Administration (Business Information Technology) Maejo University, Chiang Mai
	2007	Master of Science Program in Information Technology and Management Chiang Mai University, Chiang Mai
Work Experience		
	Current	Computer Technical Officer, Faculty of Science Maejo University

APPENDIX

APPENDIX

Assessment for Satisfaction of
Energy Data Management Systems for Smart Community with PV Microgrid
Asian Development College for Community Economy and Technology

Explanation:

Would you please complete the assessment as the following expectation by write ✓ down on only one box of each question you agree? Your kind cooperation to evaluate our quality of systems will be more highly appreciate of us. Thank you.

Part I General detail.

1. Gender: ☐ 1) Male ☐ 2) Female
2. Position:
   ☐ 1) Dean ☐ 2) Associate Dean
   ☐ 3) Instructors ☐ 4) Staffs
   ☐ 5) Students

Part II Satisfaction for using the systems.

Point: 5 = Excellent 4 = Very Good 3 = Good 2 = Fair
1 = Poor

Title	Point				
	5	**4**	**3**	**2**	**1**
1. Convenience of Usage					
2. Accuracy of information displayed					
3. Clarity of information displayed					
4. Appropriate of text color, background color and other elements.					
5. Menu style easy to use					
6. Appropriate of system components					

7. Utilization from system					

<u>Part III</u> Recommendation.

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Thank you.