A DUAL-BATTERY STORAGE IN MICROGRID SYSTEM USING PINCH ANALYSIS METHOD

NIK SYAZREEN BINTI YUNUS

UNIVERSITI TEKNOLOGI MALAYSIA

A DUAL-BATTERY STORAGE IN MICROGRID SYSTEM USING PINCH ANALYSIS METHOD

NIK SYAZREEN BINTI YUNUS

A project report submitted in fulfilment of the
requirements for the award of the degree of Master of Science
(Energy Management)

Faculty of Chemical and Energy Engineering
Universiti Teknologi Malaysia

FEBRUARY 2023

ACKNOWLEDGEMENT

First, I would like to thank Allah S.W.T for the love and grace without it would be impossible for me to have achieved any educational success let alone finishing this thesis.

I also would like to express my gratitude to my supervisor, Assoc. Prof. Ts. Dr. Ho Wai Shin for full support and guidance in my study and research. I also would like to thank to my friends for their helpful discussions and encouragement along the research periods.

Finally, I would like to express my deepest gratitude for constant support, emotional understanding, and love that I received from my family in finishing this project report. The profound support from my entire family and friends cannot be overemphasized.

ABSTRACT

The energy storage system plays a crucial role in maintaining the power balance between generation and consumption in the microgrid system. Most of the microgrid normally operated with a single built in battery which is not suitable to constantly charge and discharge the energy in short intervals. By having a dual battery storage, one for charging while the other one for discharging, it can be a better solution to prolong the battery lifespan and maintain the efficiency of the battery system. This study proposed that the battery storage is split into two portions for charge and discharge by putting a rule in pinch where the battery need to first be fully charged before discharging. The methodology has been constructed using Electric System Cascade Analysis (ESCA) to determine the efficiency and lifespan of the battery. The results showed that the microgrid system are able to obtain the optimum capacity of solar PV and the method used will be able to optimized the system by identifying the schedule of charging and discharging the batteries. The microgrid system with integration of renewable source and dual-battery energy storage system is economically feasible to meet the load demand especially during peak hours.

ABSTRAK

Sistem penyimpanan tenaga memainkan peranan penting dalam mengekalkan keseimbangan dalam penjanaan dan penggunaan tenaga di dalam sistem mikrogrid. Kebanyakan mikrogrid biasanya beroperasi dengan satu bateri yang mana ianya tidak sesuai untuk dicas dan dinyahcas dalam tempoh masa yang singkat. Dengan mempunyai dua bateri sistem untuk penyimpanan tenaga, satu untuk mengecas dan satu lagi untuk menyahcas, ia boleh menjadi penyelesaian yang lebih baik untuk memanjangkan jangka hayat bateri dan mengekalkan kecekapan sistem bateri. Kajian ini mencadangkan agar sistem penyimpanan tenaga dibahagikan kepada dua bateri sistem untuk cas dan nyahcas dengan meletakkan syarat dimana bateri perlu dicas sepenuhnya terlebih dahulu sebelum dinyahcas. Kaedah ini telah dibina menggunakan *"Electric System Cascade Analysis (ESCA)"* untuk menentukan kecekapan dan jangka hayat bateri. Hasil daripada kajian ini menunjukkan sistem mikrogrid mampu mencapai kapasiti yang optima bagi solar PV dan kaedah yang digunakan dapat mengoptimumkan sistem dengan mengenal pasti jadual pengecasan dan nyahcas bateri. Sistem mikrogrid dengan integrasi sumber boleh diperbaharui dan sistem penyimpanan tenaga menggunakan dua bateri mampu dilaksanakan dari segi ekonomi untuk memenuhi permintaan beban terutamanya semasa waktu puncak.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	-	Alternating Current
DC	-	Direct Current
BESS	-	Battery Energy Storage System
ESS	-	Energy Storage System
RES	-	Renewable Energy Sources
ESCA	-	Electric System Cascade Analysis
DG	-	Distributed Generation
IEA	-	International Energy Agency
RE	-	Renewable Energy
BMS	-	Battery Management System
SoC	-	State of Charge
DoD	-	Depth of Discharge
PoPA	-	Power Pinch Analysis
PBP	-	Payback Period
ROI	-	Return of Investment
PSE	-	Process System Engineering
EIA	-	Energy Information Administration
GHG	-	Greenhouse Gases Emission
CO_2	-	Carbon Dioxide
PV	-	Photovoltaic
SOH	-	State of Health
PCS	-	Power Conversion System
NaS	-	Sodium Sulphur
kW	-	Kilowatt
MW	-	Megawatt
CHP	-	Combined Heat and Power
UPS	-	Uninterruptible Power Supply
THD	-	Total Harmonic Distortion
DEG	-	Distributed Energy Generation

DBESS	-	Dual Battery Energy Storage System
RM	-	Ringgit Malaysia
kWp	-	Kilowatt Peak
C2	-	Commercial Tariff
Wh	-	Watt Hour
mm	-	Millimetre
m^2	-	Meter Square
℃	-	Degree Celcius
W	-	Watt
tCO_2	-	Tonne Carbon Dioxide

LIST OF SYMBOLS

t	-	Time
hr	-	Hour
L_d	-	Household Demand
G_t^s	-	Electricity Generation
N	-	Efficiency of Installed Solar PV
A	-	Area of Installed Solar PV
R_t	-	Average Solar Radiation
N_t	-	Net Energy from Household Demand
f_i	-	Inverter Efficiency
C_t	-	Net Energy Charged into Storage System
D_t	-	Net Energy Discharged
f_D	-	Discharge Efficiency of the Battery
E_t	-	Cumulative Energy
f_c	-	Charging Efficiency of the Battery
$E_{t(initial)}$	-	Initial Energy Added to the Start of the Analysis
$E_{t(final)}$	-	Cumulative Energy at time, t = 24hrs
p	-	Percentage Error
%	-	Percentage
S_{PV}	-	Size of Solar PV
M	-	Number of Required Modules
Q	-	Required Area to Install 1kWp Solar PV
W	-	Power of Single Solar PV Module
S_{BAT}	-	Actual Size of Battery
$S_{BAT(estimated)}$	-	Size of Battery from Cascade Table
H	-	Depth of Discharge of Battery
I_{BAT}	-	Actual Initial Content of the Battery After Considering the Shift due to DoD
$I_{BAT(estimated)}$	-	Initial Content of Battery from Cascade Table
S_{INV}	-	Size of Inverter
L_L	-	Load with Largest Magnitude

LIST OF APPENDIXES

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces an overview of the battery energy storage system (BESS) incorporate in a small-scale of microgrid which enable the system to operate separately from or alongside the electric grid. The energy storage system (ESS) refers to a transformation of electrical energy from a power network or renewable energy sources (RES) into a form that can be stored and utilized during peak hours, or when the generating source is unavailable (Nengroo, et al., 2018). The battery energy storage system (BESS) are now widely used for continuously matching the power generation and consumption. The integration of the power system normally used a single battery storage, both for charge and discharge in short intervals which is not suitable. This study proposed to have a dual-battery storage that will be split into two portions for charge and discharge to enhance the operation condition (Joshua & Vittal, 2022).

The new systematic framework and methodology based on pinch analysis which Electric System Cascade Analysis (ESCA) for designing of microgrid integrated with dual-battery storage is constructed to determine the efficiency and lifespan of the battery. Economic and environmental analysis also was performed by calculating the payback period and return on investment using Microsoft Excel Trend function. A sensitivity analysis test was performed by using the Microsoft Excel Table function (Zamhuri, 2021). It is essential to determine the minimum total energy cost, the energy generation and consumption, also the most important part is to determine the efficiency and lifespan of battery to reduce the operation cost and environmental effects.

1.2 Research Background

A microgrid is a local energy grid with control capability, which it can disconnect from the grid and operate autonomously. It is defined as a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode (Berkeley Lab, 2019) . Microgrid system is a configuration of single or multiple renewable energy sources with even non-conventional sources as main energy generation source. It also incorporates energy storage and power electronic circuitry. Some of the component produce direct current (DC) and alternating current (AC) power directly with no use of converter.

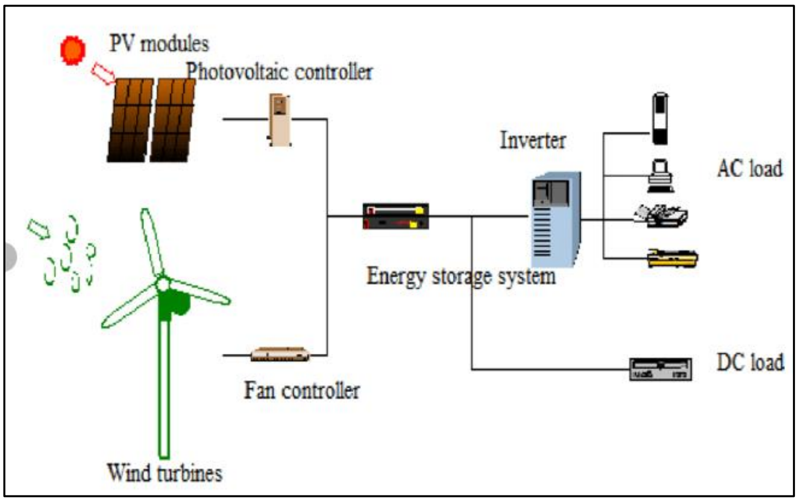

Figure 1.1: Microgrid Power System Configuration

Most of the existing microgrid power system overall cost is becoming more expensive in the near future. With the renewable energy system (RES) technological improvement and the advancement in energy storage systems, it can help the new microgrid system based on the distributed generation (DG) to become economically viable to consumer. Not only provides backup for the grid in case of emergencies, but can also be used to cut costs, or connect to a local resource that is too small or unreliable for traditional grid use. This new microgrid system also are almost pollution-free and thus environmentally friendly.

The grid connects homes, businesses and other buildings to central power sources. However, this interconnectedness means that when part of the grid needs to be repaired, everyone is affected. This is where a microgrid can help, it generally operates while connected to the grid and it can break off and operate on its own using local energy generation in times of crisis like power outages and etc (Lantero, 2014). To meet the electricity demands of its users, a microgrid must have a generation source. A microgrid normally utilizes renewable energy sources such as solar panels, battery storage and diesel gensets. Diesel generator sets may also be included, along with battery banks to store electricity and deliver it when needed (Ponstein & Mueller, 2021).

Integrating battery energy storage systems with intermittent renewable energy sources opens the door to inexpensive electricity continuously available to on-grid, off-grid, and hybrid systems. According to the International Energy Agency (IEA), renewables increased their share in global electricity generation from 27% in 2019 to 29% in 2020. Moreover, it is projected to reach 45% by 2040 (Solovev & Petrova, 2021). Battery energy storage system (BESS) has been widely used for the expansion of the electricity grid. It plays an important role in smoothing the operation of the system by transforming the renewable energy (RE) such as solar energy to the grid and improving the flexibility of the electricity grid. Lithium-ion batteries have been extensively selected for energy storage due to their inherent advantages such as high energy density, long lifespan and for safety purposes.

Therefore, it is significantly important to develop effective battery state estimation in battery management system (BMS) to monitor the state of battery for security and reliability. The state of charge (SOC) also needs to take into consideration to indicate a battery's remaining capacity and hence effectively prevent over-charge or over-discharge (Wang, et al., 2022). In order to cater the energy demand, the effective energy storage is designed to have constant power generation with higher efficiency. To optimize the system performance, many previous studies has been conducted. Among the studies, Power Pinch tool named Electric System Cascade Analysis (ESCA) was applied to design an optimal power system. ESCA analysis is conducted by assuming that the system generates constant power as it is more efficient.

However, further analysis using ESCA shows that with a minimal system capacity would result in a trade-off that the energy storage system would be larger and leads to higher energy charging and discharging tendency (result in higher energy lost). Considering the time change of heat rate with the corresponding load factor, this study incorporates new algorithm for flexible power generation into the existing ESCA methodology (Liu, et al., 2019).

1.3 Problem Statement

Microgrids offer greater opportunities for including renewable energy sources (RES) in their generation portfolio to mitigate the energy demand reliably and affordably. However, there are still several issues such as microgrid stability, power and energy management, reliability and power quality that make microgrids implementation challenging even though various of energy storage technologies has been introduced in the previous study (Nazaripouya, et al., 2018).

The current application process of battery storage in microgrid is typically a single built in battery which is not suitable to charge and discharge in a short period of time. In some cases, this regime prevents the battery bank from being fully charged which leading to the formation of lead sulphate, with consequent loss of useful life, efficiency and possible battery failure (Neto, et al., 2018). In order to overcome the challenges, one of the solutions is to implement dual battery storage that will be split into two portions. One for charging and the other one is for discharging. The proposed solution will also have a set of pinch rules where the battery needs to fully charged first before discharging.

According to previous case study, another important parameter of battery management system is state of charge (SOC). It reflects the battery performance, so accurate estimation of SOC cannot only protect battery, prevent overcharge or discharge, and improve the battery life, but also let the application make rationally control strategies to achieve the purpose of saving energy. However, the SOC cannot directly measured and various factors such as ambient temperature, battery aging levels and charging/ discharging current rate will affect the accuracy of SOC estimation.

As for depth of discharge (DoD), it is one of the factors to keep in mind that need to be evaluated as it shows how much of the battery can be use and how long it will last to meet the energy demands. To define the DoD, first must establish the term of battery capacity. Battery capacity is the total electrical energy supply available from the battery, expressed as a unit of power over time, such as kilowatt-hours (kWh). It indicates the percentage of the battery that has been discharged relative to the total battery capacity (IPS, 2021). PoPA method was still lack of practicality since the methodology assumed a 100% power transfer and battery storage efficiency. While the proposed methodology seems to be compromised, the solution was still unreasonable to an isolated power system since the system would be far beyond the reach of any national grid. Thus, selling the surplus electricity to the grid as an alternative to the energy dump was not possible.

Hence, to further improve the methodology, (Ho, W. S., et al., 2012) took a step to introduce Electric System Cascade Analysis (ESCA) for power targeting in an isolated power system. This approach enabled the method to avoid the need of a huge battery size and minimized the energy dump of the system. ESCA also was considered the inverter efficiency and the power transfer efficiency to further improve the practicality of the methodology (Zamhuri, 2021). However, these method does not consider to fully charged the battery before discharging and its usually just base on surplus and deficit which may result in reduced of battery efficiency after a certain period of time. Thus, it is required to include a heuristic or procedure in the existing pinch analysis technique.

1.4 Objectives

The objectives of this research are included as following:

1) To develop new framework and methodology based on Pinch Analysis (ESCA) for Microgrid with Solar PV and Dual-Battery Storage System.

2) To perform Techno Economic and Environmental Analysis using simple payback period (PBP) and return of investment (ROI).

1.5 Scope of Study

To attain the objectives, the research scope must include and be divided into the following:

a) Electric System Cascade Analysis (ESCA)
    i. Obtained the data from previous case study.
    ii. Develop new ESCA technique based on Pinch Analysis.
    iii. ESCA framework for dual-battery sizing and its lifespan.

b) Techno Economic and Environmental Analysis
    i. Calculate payback period (PBP) and return of investment (ROI) to perform an economic and environmental analysis.

1.6 Significance of the Study

The significance of this study is to improve and develop new framework based on Pinch Analysis and ESCA technique, which can prolong the battery lifespan.

1) Advancement in Process System Engineering (PSE) for optimization of Battery Storage System.
    - A development of new method for dual-battery storage system by extending the original Pinch Analysis method.

2) The development of new ESCA technique based on Pinch Analysis for optimum operation of Dual-Battery Energy Storage System.
    - A new methodology in designing and optimizing the dual battery for energy storage.

3) Performed techno economic and environmental analysis based on the case study.
    - An economic assessment using Payback Period (PBP) and Return of Investment (ROI).

REFERENCES

Bandyopadhyay, S. (2011). Asia-Pac J Chem Eng. *Design and Optimization of Isolated Energy Systems through Pinch Analysis*, 518-526.

Berkeley Lab. (8 November, 2019). *Microgrids – What Are They and How Do They Work?* Retrieved from N-Sci Technologies: https://nsci.ca/2019/11/08/microgrids-what-are-they-and-how-do-they-work/

Border States. (2 June, 2021). *The Main Benefits and Challenges of Microgrids for Utilities*. Retrieved from Border States Supply Chain Solutions: https://solutions.borderstates.com/benefits-of-microgrids/

C2ES. (3 May, 2022). *Microgrids*. Retrieved from Center for Climate and Energy Solutions: https://www.c2es.org/content/microgrids/

Chen, X. (2015). *Sodium Sulfur Battery*. Retrieved from Zhang's Research Group: https://ziang.binghamton.edu/sodium-sulfur-battery/

Energy Watch. (5 November, 2021). *Planning for Malaysia's Future Energy Demand*. Retrieved from https://www.energywatch.com.my/blog/2021/11/05/planning-for-malaysias-future-energy-demand/

Ho, W., Hashim, H., Mohammad Rozali, N., Ab. Muis, Z., & Lim, J. (2015). Chemical Engineering Transactions. *Electric System Cascade Analysis (ESCA): cost and efficiency trade-off and optimization*, 517-522.

Ho, W., Hassim, M., Hashim, H., Ab Muis, Z., & Shamsuddin, L. (2012). Applied Energy. *Design of distributed energy system through Electric System Cascade Analysis (ESCA).*

Ho, W., Mohd Tohid, M., Hashim, H., & Abdul Muis, Z. (2014). Electrical Power and Energy Systems. *Electric System Cascade Analysis (ESCA): Solar PV system*, 481-486.

IPS. (25 January, 2021). *Battery Storage 101: What Is Depth of Discharge?* Retrieved from Independent Power Systems: https://www.solarips.com/blog/2021/january/battery-storage-101-what-is-depth-of-discharge-/#:~:text=Most%20modern%20lithium%2Dion%20batteries,and%20a%20much%20longer%20lifespan.

J. Wang, P. L.-G. (2011). "Cycle-life model for graphite-LiFePO4 cells". *Journal of Power Sources.*, 3942-3948.

Joshua, A., & Vittal, K. (2022). Electric Power Systems Research. *Protection schemes for a battery energy storage system based microgrid*, 204.

Kim, D. K., Guild, R., & Zhai, Y. (2018). *Handbook on Battery Energy Storage System.* Manila: Creative Commons Attribution 3.0 IGO license.

Koh, K., & Mohd Fauzi, A. (2019). Chemical Science And Biomolecular Engineering. *An Overview of Renewable and Non-Renewable Energy Demand as Well as Development Status in Malaysia*.

Lantero, A. (17 June, 2014). *Energy.gov*. Retrieved from How Microgrids Work: https://www.energy.gov/articles/how-microgrids-work

Leite Neto, P., S. Ribeiro, L., & Saavedra, O. (2018). A Dual-Battery Storage Bank Configuration for Isolated Microgrids Based on Renewable Sources. *IEEE Transactions on Sustainable Energy*.

Liu, W., Lee, M., Hashim, H., Lim, J., Klemes, J., Wan Alwi, S., . . . Ho, W. (2019). Energy Procedia 158. *Extended Electric System Cascade Analysis (ESCA) for optimal power system targeting considering generation flexibility and heat rate factor*, 1-8.

Mulholland, B. (1 June, 2018). *Pinch Analysis: Process Improvement Tips From Thermodynamics, Cars, and Cooking*. Retrieved from process.st: https://www.process.st/pinch-analysis/

Nazaripouya, H., Chung, Y.-W., & Akhil, A. (2018). Energy Storage In Microgrids: Challenges, Applications and Research Need. *International Journal of Energy and Smart Grid*.

Nazaripouya, H., Chung, Y.-W., & Akhil, A. (2018). Energy Storage In Microgrids: Challenges, Applications and Research Need. *International Journal of Energy and Smart Grid*.

Nazaripouya, H., Chung, Y.-W., & Akhil, A. (2018). International Journal of Energy and Smart Grid. *Energy Storage In Microgrids: Challenges, Applications and Research Need*, 2-3.

Nengroo, S., Kamran, M., Ali, M., Kim, D.-H., Kim, M.-S., Hussain, A., & Kim, H. (2018). Electronics. *Dual Battery Storage System: An Optimized Strategy for the Utilization of Renewable Photovoltaic Energy in the United Kingdom*, 7(9), 177.

Neto, P., Saavedra, O., & S. Ribeiro, L. (2018). Article in IEEE Transactions on Sustainable Energy. *A Dual Battery Storage Bank Configuration For Isolated Microgrids Based on Renewable Sources*, 2.

nik. (2023). dfdrsdf.

Ponstein, B., & Mueller, C. (2021). Power generation. *An Introduction to Microgrids; Combining Multiple Power Sources*, 1-7.

Rahman, A., Hanaffi, F., Abu Bakar, N., & Khamis, A. (2011). *Study of Renewable Energy Potential in Malaysia*.

S. Andrey, P. A. (2021). Integra Sources. *Efficient Energy Management and Energy Saving with a BESS (Battery Energy Storage System)*.

Shamsuddin, A. (2012). Evolving Energy-IEF International Energy Congress (IEF-IEC2012). *Development of renewable energy in Malaysia strategic initiatives for carbon reduction in the power generation sector*, 1-2.

Sodium Sulfur (NaS) Batteries. (2023). Retrieved from Energy Storage Association: https://energystorage.org/why-energy-storage/technologies/sodium-sulfur-nas-batteries/

Solovev, A., & Petrova, A. (16 August, 2021). *Integra Sources*. Retrieved from Efficient Energy Management and Energy Saving with a BESS (Battery Energy Storage System): https://www.integrasources.com/blog/energy-management-and-energy-saving-bess/

T. Aaron. (2015). Mobile Technology. *New battery tech gives 10 hours of talk time after only 5 minutes on charge*.

Wang, Z., Feng, G., Liu, X., Gu, F., & Ball, A. (2022). Journal of Energy Storage. *A novel method of parameter identification and state of charge estimation for lithium-ion battery energy storage system*, 49.

Weber, M. (2022). *14 Advantages and Disadvantages of Solar Energy (Explained)*. Retrieved from Eco Redux: https://www.ecoredux.com/advantages-disadvantages-of-solar-energy

Wilkins, A. (5 April, 2022). *Solar panels that work at night produce enough power to charge a phone*. Retrieved from New Scientist Ltd.: https://www.newscientist.com/article/2314957-solar-panels-that-work-at-night-produce-enough-power-to-charge-a-phone/

Woodford, C. (10 April, 2022). *Lithium-ion batteries*. Retrieved from Explain That Stuff: https://www.explainthatstuff.com/how-lithium-ion-batteries-work.html

Yuksel, A. (23 September, 2021). *Benefits Of Microgrids, and Why Do Businesses Need Them?* Retrieved from Cummins Newsroom: Our Innovation, Technology and Services: https://www.cummins.com/news/2021/09/23/benefits-of-microgrids

Yunus, M. Y. (24 May, 2022). Retrieved from Premium Sinar Harian: https://premium.sinarharian.com.my/article/190845/fokus/semasa/suhu-malaysia-dijangka-40-darjah-celsius-pada-julai-ini

Z. Wang, G. F. (2022). Journal of Energy Storage. *A novel method of parameter identification and state of charge estimation for lithium-ion battery energy storage system*, 1.

Zamhuri, M. (2021). *Integrated Framework Of District Cooling System For Commercial Buildings*, 36-37.