TECHNO-ECONOMIC ANALYSIS OF GRID CONNECTED PV-BATTERY SYSTEM IN SARAWAK, MALAYSIA

YAP YU VUN

UNIVERSITI TEKNOLOGI MALAYSIA

TECHNO-ECONOMIC ANALYSIS OF GRID CONNECTED PV-BATTERY SYSTEM IN SARAWAK, MALAYSIA

YAP YU VUN

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Electrical Power)

School of Electrical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JULY 2022

DEDICATION

This project report is dedicated to my father, who taught me that the best kind of knowledge to have been that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

ACKNOWLEDGEMENT

I would like to express my special appreciation to my supervisor Prof. Madya Eur Ing Ir. Ts. Dr. Lau Kwan Yiew from the School of Electrical Engineering, Universiti Teknologi Malaysia who has always been providing his kind support, excellent guidance and advice throughout the accomplishment of this Master final report.

I would like to thank and appreciate my family for the encouragement and support which had inspire me to continue my master studies. Also, I would like to thank my beloved wife, Ting Wei Ni for her support, love and encouragement throughout my master studies. Also, sincerely appreciate to my friends and course mates for their knowledge and advice during my studies. They have contributed and guidance during my research work and thesis writing.

Finally, I would like to express my appreciation to all my colleagues, especially my head of department for the opportunity for me to further studies.

ABSTRACT

Nowadays, energy use has become a very critical concern because of rapid increase in energy demand. The increased concerns for environmental impacts of conventional fossil fuels most importantly those related to global warming have been the major aspect driving the transformation towards green energy. However, the implementation of photovoltaic (PV) systems in Sarawak, East Malaysia, is still weak and has yet to be a common practice in Sarawak's construction industry. Furthermore, very limited research studies have been carried out to analyse the techno-economic feasibility of grid-connected PV-battery systems, especially in Sarawak. The main purpose of this study was to analyse the feasibility of grid-connected PV-battery systems to be implemented in towns of Sarawak, East Malaysia. This study also aimed to investigate the Levelized Cost of Energy (LCOE) and Net Present Cost (NPC), analyse the carbon emissions and determine the potentiality of the system. The proposed system will took into account several constraints such as the technical, economics and environmental impact of grid-connected PV battery system. The Hybrid Optimization of Multiple Energy Resources (HOMER) software was used to perform the simulation work to determine the economic and environmental effects and evaluate the feasibility of the proposed system in the towns of Sarawak. In addition, the technical features of the grid-connected PV-battery system were analysed using MATLAB/Simulink software.

ABSTRAK

Pada masa kini, penggunaan tenaga telah menjadi kebimbangan yang sangat kritikal kerana peningkatan pesat dalam permintaan tenaga. Kebimbangan yang meningkat terhadap kesan alam sekitar bahan api fosil konvensional yang mengakibatkan pemanasan global telah menjadi aspek utama yang memacu transformasi ke arah tenaga hijau. Walau bagaimanapun, pelaksanaan sistem fotovoltaik (PV) di Sarawak, Malaysia Timur, masih lemah dan masih belum menjadi amalan biasa dalam industri pembinaan Sarawak. Tambahan pula, kajian penyelidikan yang sangat terhad telah dijalankan untuk menganalisis kebolehlaksanaan tekno-ekonomi sistem PV-bateri bersambung grid, terutamanya di Sarawak. Tujuan utama kajian ini adalah untuk menganalisis kebolehlaksanaan sistem PV-bateri bersambung grid untuk dilaksanakan di pekan Sarawak, Malaysia Timur. Kajian ini juga bertujuan untuk menyiasat Kos Tenaga Bertingkat (LCOE) dan Kos Kini Bersih (NPC), menganalisis pelepasan karbon dan menentukan potensi system PV-bateri bersambung grid. Sistem yang dicadangkan itu akan mengambil kira beberapa kekangan seperti kesan teknikal, ekonomi dan alam sekitar sistem PV-bateri bersambung grid. Perisian Hybrid Optimization of Multiple Energy Resources (HOMER) digunakan untuk melaksanakan kerja simulasi untuk menentukan kesan ekonomi dan alam sekitar serta menilai kebolehlaksanaan sistem yang dicadangkan di bandar-bandar Sarawak. Selain itu, ciri teknikal sistem bateri PV bersambung grid juga dianalisis menggunakan perisian MATLAB/Simulink.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

PV	Photovoltaic
NPC	Net Present Cost
HOMER	Hybrid Optimization of Multiple Energy Resources
MATLAB	Matrix Laboratory
AC	Alternative Current
DC	Direct Current
LCOE	Levelized Cost of Energy
COE	Cost of Energy
IRR	Internal Rate of Return
ROI	Return of Investment
UTM	Universiti Teknologi Malaysia
CO2	Carbon Dioxide
GCPV	Grid-connected Photovoltaic
SOC	State of Charge
DOD	Depth of Discharge
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
IGBT	Insulated Gate Bipolar Transistor
US	United States
NREL	National Renewable Energy Laboratory
NASA	National Aeronautics and Space Administrative
POWER	Prediction of Worldwide Energy Resources
VSI	Voltage Source Inverter
CSI	Current Source Inverter
PCC	Point of Common Coupling
PLL	Phase Lock Loop

PWM	Pulse Width Modulation
STC	Standard Test Condition
PV	Photovoltaic
NPC	Net Present Cost
HOMER	Hybrid Optimization of Multiple Energy Resources

CHAPTER 1

INTRODUCTION

1.1 Research Background

The use of renewable energy has been growing rapidly in recent years. The unstable price of fossil fuel and greenhouse gases emission caused by conventional electricity has contributed to the introduction of latest technology by using clean and natural energy sources such as solar energy. As of today, approximately 85% of greenhouse gases have been emitted from fossil fuels such as oil, natural gas and coal for electricity generation has led to global warming. The two main challenges of global power systems are providing a sustainable electricity supply and ensuring minimal environmental impact. The conventional electricity needs to integrate with latest technologies to overcome the challenges [1].

Among many renewable energy technologies, solar photovoltaic (PV) technology is the most well-known, clean and sustainable energy harvested from sunlight. However, due to its high capital investment in the past, the implementation of PV system is not common in many countries. With the growth of PV technology, the reduction cost of PV has demonstrated the potential of PV to be installed either on residential or commercial basis worldwide. In Malaysia, the government has announced the target of 20%

renewable energy mix by year 2025. Hence, various programmes and policies has been introduced to empower the renewable energy especially solar energy. The implementation of solar energy is a good way to mitigate global warming by reducing the emission of carbon dioxide and other greenhouse gases. Solar energy is one of the most promising clean and natural energy sources available in future of this world. The technology of PV has been continuously developed in many applications and, today, it has been largely used in supplying the electrical grid power [2, 3].

1.2 Problem Statement

The implementation of PV panels in Sarawak, East Malaysia, is weak and not a common practice in Sarawak's construction industry. Furthermore, very limited research studies have been carried out to analyse the techno-economic feasibility of grid-connected PV-battery systems, especially in Sarawak. Although residential areas and commercial buildings can be installed with PV panels without or with battery backup storage along with the grid to continuously supply uninterrupted power, such feasibility has yet to be analysed. It is necessary to analyse the feasible of using the PV system in Sarawak, Malaysia to reduce energy costs and environmental impacts.

1.3 Research Objectives

The main objective of this project was to analyse the feasibility of the grid-connected PV-battery system in the towns of Sarawak, East Malaysia that will continue the supply of an uninterrupted power to residential and commercial buildings which is safe, environmentally friendly and economically viable. There objectives were as follows:

- To evaluate the feasibility of grid-connected PV-battery system on residential and commercial building of Sarawak
- To determine the economic and environmental effects through Levelized Cost of Energy (LCOE)
- To analyse the technical features of the proposed grid connected PV-battery system in Sarawak.

1.4 Research Scope

This project investigated the feasibility of grid connected PV-battery system in Sarawak. In this project, the economic and environmental analysis of a grid connected PV-battery system was performed using Hybrid Optimization of Multiple Energy Resources (HOMER) software, and the technical analysis was performed using Matrix Laboratory (MATLAB)/Simulink software. Three residential and commercial locations chosen in this project were in Kuching,

Sibu, and Miri. The project was simulation based and was solely done by using HOMER and MATLAB/Simulink software.

1.5 Research Contributions and Significances

The main research contributions of this project are as follows:

- Production of clean and affordable energy
- Reduction of energy usage / waste usage
- Increase economic growth / new business opportunity
- Strengthen the green technology innovation in Malaysia
- Environment conservation for future generation

1.6 Thesis Organizations/Outline

This report consists of 5 chapters, as follows:

- **Chapter 1** is the introduction for this project which mainly discuss the background of this project. All the objectives, scope and the research contributions are discussed in this chapter.
- **Chapter 2** is the literature review which is a review of conference papers, journals and theses related to this project. Some of the past works regarding this project have been reviewed and discussed in this chapter.

- **Chapter 3** contains the research methodology in this project, including the research method to analyse the grid connected PV-battery system. The procedures will be shown in block diagram and research planning for this overall project will be shown in Gantt chart.
- **Chapter 4** discusses all the simulation results based on the objectives as well as analysis and its justification. Besides that, benchmarking also will be conducted by comparing and verifying the simulation results with other journals and articles.
- **Chapter 5** presents the overall conclusions for this project. Some recommendations and suggested for future work will be also discussed and reviewed in this chapter.

REFERENCES

[1] N. Mat Isa, C.W. Tan, A.H.M Yatim, "A techno-economic assessment of grid connected photovoltaic system for hospital building in Malaysia," International Conference on Materials Technology and Energy, 217 (2017) 012016.

[2] H. Shekhar Das, C.W. Tan, A.H.M. Yatim, K.Y. Lau, "Feasibility analysis of hybrid photovoltaic/battery/fuel cell energy system for an indigenous residence in East Malaysia," Renewable and Sustainable Energy Reviews 76 (2017) 1332–1347.

[3] Malaysia needs US$8 billion investment to achieve 20% renewable energy target by 2025. (2019) [online] Available at https://www.power-technology.com/comment/malaysia-needs-us8-billion-investment-to-achieve-20-renewable-energy-target-by-2025/

[4] French physicist Edmond Becquerel. (2022) [online] Available at https://en.wikipedia.org/wiki/Edmond_Becquerel

[5] American inventor Charles Fritts. (2022) [online] Available at https://en.wikipedia.org/wiki/Charles_Fritts

[6] Comprehensive Guide to Solar Panel Types. (2021) [online] Available at https://www.aurorasolar.com/blog/solar-panel-types-guide/

[7] How A Solar Panel Works. (2020) [online] Available at https://pitech.com.my/how-a-solar-panel-works/

[8] Monocrystalline vs Polycrystalline Solar Panels. (2021) [online] Available at https://ases.org/monocrystalline-vs-polycrystalline-solar-panels/

[9] B. Parida, S.Iniyanb, Ranko Goicc, "A review of solar photovoltaic technologies," Renewable and Sustainable Energy Reviews 15 (2011) 1625–1636.

[10] What are Thin Film Solar Panels. (2016) [online] Available at https://understandsolar.com/thin-film-solar-panels/

[11] Calculating Current Ratings of Photovoltaic Modules. (2012) [online] Available at https://www.ecmweb.com/renewables/article/20896977/calculating-current-ratings-of-photovoltaic-modules

[12] N. Mohammad, M. Quamruzzaman, M. R. T. Hossain, M. R. Alam, "Parasitic Effects on the Performance of DC-DC SEPIC in Photovoltaic Maximum Power Point Tracking Applications," Smart Grid and Renewable Energy, 2013, 4, 113-121.

[13] D. M. Tobnaghi, R. Madatov, D. Naderi, "The Effect of Temperature on Electrical Parameters of Solar Cells," International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 2, Issue 12, December 2013.

[14] What are the common type of solar PV. (2015) [online] Available at https://www.solarpowerworldonline.com/2015/10/what-are-some-common-types-of-solar-pv-and-storage-installations

[15] A. kit, S. K. Sahoo, S. Sukchai, F. F. Yanine, “Review and comparative study of single-stage inverters for a PV system,” Renewable and Sustainable Energy Reviews 91 (2018) 962–986.

[16] B. Sørensen, "Chapter 33: Battery storage," in Renewable Energy Conversion,
Transmission and Storage, 2007.

[17] D. Linden and T. B. Reddy, “Handbook of Batteries, 3rd ed,” McGraw-Hill, 2002, p. 1.8.

[18] E. Bullich-Massagué, F.J Cifuentes-García, I. Glenny-Crende, M. Cheah-Mañé, M. Aragüés-Peñalba, F. Díaz-González, O. Gomis-Bellmunt, “A review of energy storage technologies for large scale photovoltaic power plants,” Applied Energy 274 (2020) 115213.

[19] M. R. Maghami, H. Hizam, C. Gomes, A. R. Mohd, I. R. Mohammad, S. Hajighorbani, “Power loss due to soiling on solar panel: A review,” Renewable and Sustainable Energy Reviews 59 (2016) 1307–1316.

[20] C.W.A. Baltus, J.A. Eikelboom, R.J.C. van Zolingen, “Analytical Monitoring of Losses in PV Systems,” 14th European Photovoltaic Solar Energy Conference Barcelona, 30 June - 4 July 1997.

[21] K.Y. Lau, C.W. Tan, K.Y. Ching, “The implementation of grid-connected, residential rooftop photovoltaic systems under different load scenarios in Malaysia,” Journal of Cleaner Production 316 (2021) 128389.

[22] N. M. Isa, H. S. Das, C. W. Tan, A.H.M. Yatim, K. Y. Lau, "A techno-economic assessment of a combined heat and power photovoltaic/fuel cell/battery energy system in Malaysia hospital," Energy 112 (2016) 75-90.

[23] H. S. Das, C. W. Tan, A.H.M. Yatim, K. Y. Lau, "Feasibility analysis of hybrid photovoltaic/battery/fuel cell energy system for an indigenous residence in East Malaysia," Renewable and Sustainable Energy Reviews 76 (2017) 1332–1347.

[24] N. Anang, S.N.A. S. N. Azman, W.M.W. Muda, A.N. Dagang, M. Zalani Daud, "Performance analysis of a grid-connected rooftop solar PV system in Kuala Terengganu, Malaysia," Energy & Buildings 248 (2021) 111182.

[25] K.Y. Lau, N.A. Muhamad, Y.Z. Arief, C.W. Tan, A.H.M. Yatim, "Grid-connected photovoltaic systems for Malaysian residential sector: Effects of component costs, feed-in tariffs, and carbon taxes," Energy 102 (2016) 65-82.

[26] M. Usman, M. T. Khan, A. S. Rana, S. Ali, "Techno-economic analysis of hybrid solar-diesel-grid connected power generation system," Journal of Electrical Systems and Information Technology 5 (2018) 653–662.

[27] H. Taghavifar, Z. S. Zomorodian, "Techno-economic viability of on grid micro-hybrid PV/wind/Gen system for an educational building in Iran," Renewable and Sustainable Energy Reviews 143 (2021) 110877.

[28] C. Li, D. Zhou, Y. Zheng, "Techno-economic comparative study of grid-connected PV power systems in five climate zones, China," Energy 165 (2018) 1352-1369.

[29] K.Y. Lau, M.F.M. Yousof, S.N.M. Arshad, M. Anwari, A.H.M. Yatim, “Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions,” Energy 35 (2010) 3245-3255.

[30] S. Marais, K. Kusakana, S.P. Koko, “Techno-economic feasibility analysis of a grid-interactive solar PV system for South African residential load,” Proceedings of the 27th Domestic use of Energy Conference (2019).

[31] J. Atiq, P. Kumar Soori, “Modelling of a Grid Connected Solar PV System Using MATLAB/Simulink,” ISSN: 1473-804x online, 1473-8031.

[32] G. Alvarez, H. Moradi, M. Smith, and A. Zilouchian, “Modeling a Grid-Connected PV/Battery Microgrid System with MPPT Controller,” IEEE Smart Village Volunteer, Piscataway, NJ, 08854, USA.

[33] M. C. Argyrou, C. Spanias, C. C. Marouchos, S. A. Kalogirou and P. Christodoulides, “Energy management and modeling of a grid-connected BIPV system with battery energy storage,” 2019 IEEE 978-1-7281-3349-2/19.

[34] T. M. N. T. Mansur, N. H. Baharudin and R. Ali, “Design of 4.0 kWp Solar PV System for Residential House under Net Energy Metering Scheme,” Journal of Engineering Research and Education Vol. 9 (2017) 95-106.

[35] M. Taylor, P. Ralon and A. Ilas (IRENA), “The Power to Change: Solar and Wind Cost Reduction Potential to 2025,” The International Renewable Energy Agency (IRENA), June 2016.

[36] S. O. Sanni, J. Y. Oricha, T. O. Oyewole and F. Bawonda, “Analysis of backup power supply for unreliable grid using hybrid solar PV/diesel/biogas system,” Energy 227 (2021) 120506.

[37] G. Liu, M.G. Rasul, M.T.O. Amanullah, M.M.K. Khan, “Techno-economic simulation and optimization of residential grid-connected PV system for the Queensland climate,” Renewable Energy 45 (2012) 146-155.

[38] M. H. Rashid, “Power Electronics Handbook, Third, Ed,” Butterworth-Heinemann pu, 2011.

[39] N. Mohan, T. M. Undeland and W. P. Robbins, “Power Electronics. Converters, Applications, 2nd, Ed,” John Wiley and Sons, Inc, 1995.

[40] A. Pazynych, "A study of the harmonic content of distribution, Msc Thesis," Tampere University of Technology, 2014.

[41] N. Sommerfeldt, H. Madani, “Revisiting the techno-economic analysis process for building-mounted, grid-connected solar photovoltaic systems: Part one – Review,” Renewable and Sustainable Energy Reviews 74 (2017) 1379–1393.

[42] M. A. G. de Brito, L. P. Sampaio, L. G. Junior, C. A. Canesin, “Evaluation of MPPT Techniques for Photovoltaic Applications,” 2011 IEEE 978-1-4244-9312-8/11.

[43] M. Abdulkadir, A. S. Samosir and A. H. M. Yatim, "Modelling and simulation of maximum power point tracking of photovoltaic system in Simulink model," IEEE

International Conference on Power and Energy (PECon), pp. 325-330, 2012.

[44] F. Blaabjerg, R. Teodorescu, M. Liserre and A. Timbus, “Overview of Control and Grid Synchronization for Distributed Power Generation Systems,” IEEE Transactions on Industrial Electronics, vol. 53, no. 5, pp. 1398-1409, 2006.

[45] M. H. Mahlooji, H. R. Mohammadi and M. Rahimi, "A review on modeling and control of grid-connected photovoltaic inverters with LCL filter, In Renewable and Sustainable Energy Reviews," vol. 81, no. 1, pp. 563-578, 02 aug 2017.

[45] S. Ahmad, S. Mekhilef, H. Mokhlis, “DQ-axis Synchronous Reference Frame based P-Q Control of Grid Connected AC Microgrid,” 2020 IEEE International Conference on Computing, Power and Communication Technologies (GUCON), Oct 2-4, 2020.

[46] U.A. Miranda, M. Aredes and L.G.B. Rolim, “A DQ Synchronous Reference Frame Control for Single-Phase Converters,” 2005 IEEE 0-7803-9033-4/05

[47] S. Yang, Q. Lei, F. Z. Peng and Z. Qian, "A Robust Control Scheme for Grid-Connected Voltage-Source Inverters," IEEE Transactions on Industrial Electronics, vol. 58, no. 1, pp. 202-212, January 2011.

[48] K. Ahmed, S. Finney and B. Williams, "Passive Filter Design for Three-Phase Inverter Interfacing in Distributed Generation," in Compatibility in Power Electronics, Gdansk, 2007.

[49] B. K. Das, M. A. Alotaibi, P. Das, M.S. Islam, S. K. Das, Md. A. Hossain, "Feasibility and techno-economic analysis of stand-alone and grid-connected PV/Wind/Diesel/Batt hybrid energy system: A case study," Energy Strategy Reviews 37 (2021) 100673.

[50] T. Givler and P. Lilienthal, "Using HOMER® Software, NREL's Micropower Optimization Model, to Explore the Role of Gen-sets in Small Solar Power Systems," Technical Report NREL/TP-710-36774 May 2005.

[51] M. Ul Hassan, S. Saha, M. E. Haque. "PVAnalytX: A MATLAB toolkit for techno-economic analysis and performance evaluation of rooftop PV systems". Energy 223 (2021) 120074.

[52] Y.L. Teo and Y.I. Go, "Techno-economic-environmental analysis of solar/hybrid/storage for vertical farming system: A case study, Malaysia," Renewable Energy Focus, Volume 37 (2021).

[53] Sarawak Energy Customer Tariffs. (2022) Available at https://www.sarawakenergy.com/customers/tariffs

[54] F. Gao, D. Li, P. C. Loh, Y. Tang, and P. Wang, "Indirect dc-link voltage control of two-stage single-phase PV inverter," in 2009 IEEE Energy Conversion Congress and Exposition, 2009, pp. 1166–1172.

[55] B. Abdessamad and C. E. Mohamed, "Boost converter system modelling and incremental conductance algorithm for

photovoltaic system via Matlab/Simulink," ICCWCS 2019, April 24-25, Kenitra, Morocco.

[56] A. Reznik, M. G. Simões, A. Al-Durra and S. M. Muyeen, "LCL Filter Design and Performance Analysis for Grid-Interconnected Systems," IEEE Transactions on Industry Applications, Vol. 50, No. 2, March/April 2014.

[57] A.E.W.H. Kahlane, L. Hassaine and M. Kherchi, "LCL filter design for photovoltaic grid connected systems," Revue des Energies Renouvelables SIENR'14 Ghardaïa (2014) 227 – 232.

[58] S. Jadhav, N. Devdas, S. Nisar and V. Bajpai, "Bidirectional DC-DC converter in Solar PV System for Battery Charging Application," IEEE 2018 International Conference on Smart City and Emerging Technology (ICSCET).

[59] M. M. Iqbal and K. Islam, "Design and Simulation Of A PV System With Battery Storage Using Bidirectional DC-DC Converter Using Matlab Simulink," International Journal of Scientific & Technology Research Volume 6, Issue 07, July 2017.