TECHNO-ECONOMIC RESILIENT PLANNING STRATEGY IN MICROGRID ISLANDED SYSTEM WITH MULTIPLE RENEWABLE ENERGY AND ENERGY STORAGE SYSTEM IN MALAYSIA

ATIKAH JOHARI

UNIVERSITI TEKNOLOGI MALAYSIA

TECHNO-ECONOMIC RESILIENT PLANNING STRATEGY IN MICROGRID ISLANDED SYSTEM WITH MULTIPLE RENEWABLE ENERY AND ENERGY STORAGE SYSTEM IN MALAYSIA

ATIKAH JOHARI

A project report submitted in 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 beloved parents, family and to every kind soul that had supported me throughout my postgraduate journey.

ACKNOWLEDGEMENT

First and foremost, I would like to give my thanks to Allah SWT for giving me the strength and ability to complete this project report from the beginning until the end. Without His assistance and permission, this project will not be successful to complete.

I would like to express my deepest appreciation to my supervisor, Assoc. Prof. Ts. Dr. Jasrul Jamani Jamian, for the guidance, encouragement, and kindness. With the guidance and encouragement, I was able to gain new knowledge and inspired me to work harder to appreciate the knowledge that I have learnt. With the kindness, had helped me to keep going with my master project.

Not to forget my postgraduate friends in UTM, who have always been helpful during my studies although most of us may had never met in person due to the Covid-19 pandemic situation. Their views and tips are useful indeed. Thanks also to those who had involved directly and indirectly throughout this project development and my studies.

Last but not least, special thanks to my parents for the continuous support and prayers. I am grateful to all my family member. This accomplishment would not have been possible without them.

Alhamdulillah. May this project report be beneficial.

ABSTRACT

The purpose of this study is to enhance the conventional power distribution system's resiliency via critical loads survival metric. A two-stage framework is proposed for this project, where each stage uses a different tool. In stage 1, the viability of using Hybrid Optimization of Multiple Energy Resources (HOMER) Grid software is explored to model a resilience and economic hybrid microgrid (MG) in Malaysia environment and subsequently the optimal distributed generation (DG) sizing is determined. The modeled MG that consists of Renewable Energy System (RES) and Energy Storage System (ESS) contributes to lowering the total net preset cost (NPC), levelized cost of energy (COE), as well as the carbon emissions. In stage 2, power flow study is performed by using Power World software. Optimal DG placement and switching strategy are applied together with the optimal DG size, to see the effectiveness compared to a benchmark system. IEEE 33-bus test system model is used to validate the proposed strategy. The resilience improvement of the proposed strategies was assessed under five worst-case scenarios and validated through nine case study. Finally, the resiliency of the power network is quantified by using a proposed resilient index (RI) formula. Numerical simulations and technical data demonstrate the effectiveness of the proposed resiliency planning strategies in a radial distribution system.

ABSTRAK

Projek ini bertujuan untuk meningkatkan daya tahan sistem pengagihan kuasa konvensional melalui kemandirian metrik beban kritikal. Rangka kerja dua peringkat dicadangkan untuk projek ini, di mana setiap peringkat menggunakan alat yang berbeza. Pada peringkat 1, kemampuan daya maju dalam menggunakan perisian Grid Pengoptimuman Hibrid Sumber Tenaga Berbilang (HOMER) diterokai untuk memodelkan mikrogrid hibrid yang berdaya tahan serta bagus ekonomi, dalam persekitaran Malaysia dan seterusnya saiz penjanaan teragih (DG) yang optimum ditentukan. MG model yang terdiri daripada Sistem Tenaga Boleh Diperbaharui (RES) dan Sistem Penyimpanan Tenaga (ESS) menyumbang kepada pengurangan jumlah kos pratetap bersih (NPC), kos tenaga (COE), serta pelepasan karbon. Pada peringkat 2, kajian terhadap aliran kuasa dilakukan dengan menggunakan perisian Power World. Penempatan DG yang optimum dan strategi pensuisan digunakan bersama-sama saiz DG yang optimum, untuk melihat keberkesanan berbanding sistem penanda aras. Model sistem ujian IEEE 33-bas digunakan untuk mengesahkan strategi yang dicadangkan. Peningkatan daya tahan strategi yang dicadangkan telah diakses di bawah lima senario terburuk dan disahkan melalui sembilan kajian kes. Akhir sekali, daya tahan rangkaian kuasa dikira dengan menggunakan formula indeks daya tahan (RI) yang dicadangkan. Simulasi berangka dan data teknikal menunjukkan keberkesanan strategi perancangan daya tahan yang dicadangkan dalam system pengagihan jejari.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

UTM	-	Universiti Teknologi Malaysia
HOMER	-	Hybrid Optimization of Multiple Energy Resources
MG	-	Microgrid
RES	-	Renewable Energy System
ESS	-	Energy Storage System
DG	-	Distributed Generation
DER	-	Distributed Energy Resources
RI	-	Resilient Index
NPC	-	Net Present Cost
COE	-	Cost of Energy
RM	-	Ringgit Malaysia
P.U	-	Per Unit
W	-	Watt (metric unit for real power, P)
VAr	-	Volt-Ampere Reactive (metric unit for reactive power, Q)
V	-	Voltage / Volt (standard metric unit for Voltage)
I	-	Electrical current
k	-	Kilo (a standard prefix representing 1,000)
M	-	Mega (a standard prefix representing 1,000,000)
kg	-	Kilogram

LIST OF SYMBOLS

%	-	Percentage
i_0	-	Nominal interest/discount rate
i	-	Real interest rate
k	-	Number of iteration
n	-	Number of bus in power system network
$*$	-	Conjugate
$\angle$	-	Angle
θ_{ij}	-	Admittance angle between two interconnected bus (in degrees)
δ_j	-	Phase angle for bus voltage
$\lvert V_j \rvert$	-	Bus voltage magnitude
$\lvert Y_{ij} \rvert$	-	Admittance magnitude between two interconnected bus
Δ	-	Mismatch / rate of change
$\sum CL$	-	Sum of critical loads at all bus in a distribution system network
$\sum UCL$	-	Sum of unrestored critical loads at all bus in a distribution system network

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Project Background

Many extreme disaster events had occurred worldwide and thus the studies on resilient have gained high interest from many countries around the world since the recent past decade [1, 2]. It is already well known that a power grid's performance in terms of reliability of its safety infrastructure and efficient operation are the essential keys to ensure less interruption of electricity supply to end users. However, reliability itself is not sufficient to guarantee a continuous power supply during an extremely unfortunate event. Hence, the concept of resilient of power system was introduced, as an extended to the traditional principle of reliability. Extremely unfortunate events or disasters could come in various ways such as weather-based (natural disasters), man-made attack, and equipment failure. An 'unprepared' power grid would easily collapse upon such disasters and cause severe impacts and creating multiple outages [2, 3]. Power system resilience is a relatively new concept, and it has gained a lot of attention in the recent years. Although there are numerous definitions of resilience, so far there is no standard definition for power system context [4]. Resilient are commonly defined as the ability of the power grid to adapt, withstand, and quickly recover (response) from any rare disaster events [1-3]. The IEEE Task Force Members also concluded the same definition, as well as define it as the ability to limit the severity and/or length of disruptive events [5].

1.1.1 Past Resilience Events

The need to have a resilient power grid has becoming more obvious and crucial, following many unexpected events and severe disturbances that had happened worldwide which had caused major blackouts. To name several disaster events that happened worldwide in the recent past decade; in 2008, severe ice storm had hit China which had caused power loss for 14.66 million households due to 129 line faults. In 2011, a strong earthquake hit the north-east region of Japan, which had caused more than four million households experienced blackout for seven to nine days. In 2010-2011, major flooding happened in the north-east of Australia which had cause about 150,000 end users to experience power outages due to the damage of six zone substations and many of poles, transmission lines, and transformers. In 2012, Hurricane Sandy hit the east-coast of the United States, which had caused power outages to millions of people due to more than 100,000 primary electrical wires were destroyed, transformer explosion, and flooding [1, 2]. The California wildfires in 2017 also had put an increase emphasis on electric grid resiliency [6]. Some other worldwide examples of disaster with the number of affected people experienced blackout, are summarized in Figure 1.2 [2].

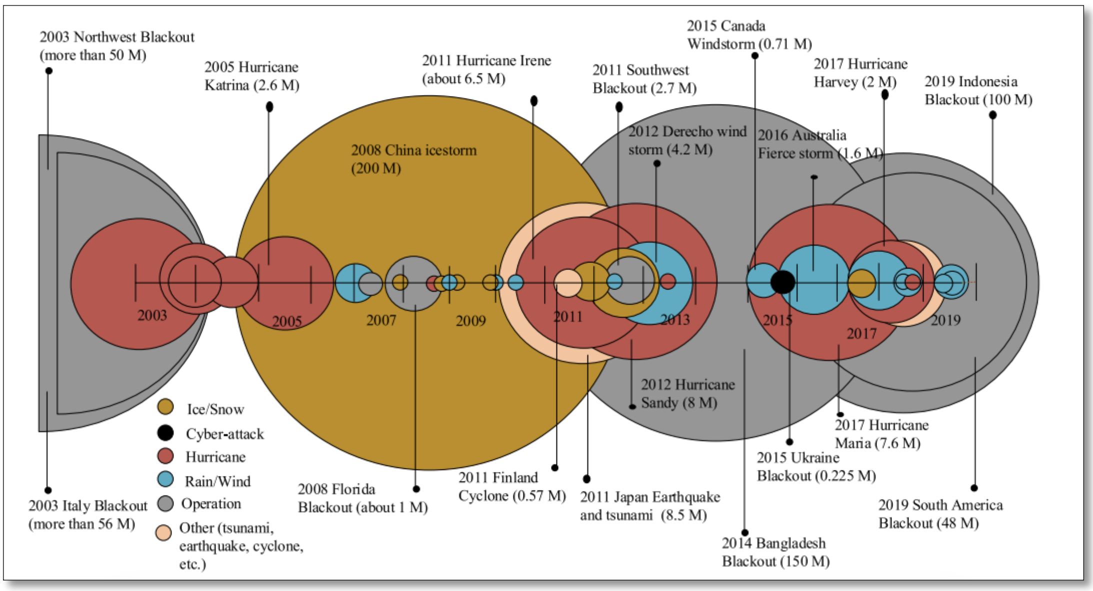

Figure 1.1 Examples of extreme events with respect to year, where M denotes million number of users that experienced power outages [2]

Malaysia has also recently seen several extreme natural disaster, regardless the country is geographically located just outside of the “Pacific Rim of Fire”. In Malaysia, flooding is the biggest natural threat. However, climate change results had caused even more destructions to the country, such as thunderstorms, major floods, and strong earthquake. One of the most common natural disasters in Malaysia is a monsoonal flood, which can vary in severity depending on where and when it occurs [7]. The December 2014 flood was the most significant and largest recorded flood in the history of Kelantan state, where 1,900 substations were affected by the floods, including five 132kV substations were completely submerged for five days long. More than 67% of supply in Kelantan was disconnected, along with 13% in Pahang, 6% in Terengganu and 1% in Perak. In flood-affected areas, supply was progressively restored; states like Pahang and Terengganu had their electricity back within days of the floodwaters receding. However, power supply restoration in Kelantan was more difficult due to the heavy infrastructure damage [8].

In December 2021, an unexpected disaster major flood hits many states of Peninsular Malaysia, including Selangor. The floods resulted from severe continuous heavy rain which lasted for two to three days. The utility company (TNB), had to shut down hundreds of power substations for safety purposes. In Selangor, at least 117 substations were affected and had caused 5062 homes affected. Power supply restoration were done in stages, which took several days to recover. Some electricity supply through TNB mobile generators were provided to temporary evacuation centres that were affected by the power disruption [9, 10]. In addition, one of the main electrical substations (PMU) in Shah Alam was reported exploded due to the flood disaster, thus caused blackout to the entire area [11].

Furthermore, Malaysia is also susceptible to tsunami and earthquake disasters. A strong earthquake has been shaking Ranau, Sabah, in June 2015 [7]. A massive tsunami had caused serious destruction to the coastal areas of Malaysia in December 2004. However, according to [12], the power stations along the coastline of Peninsular Malaysia were not hit by the tsunami and hence the security of the grid system was not affected. Whilst finalizing this project report writing, a latest resilient event happened at the west coast region of Sabah state in July 2022. The thunderstorm had caused the electricity poles to topple due to fallen trees, soil erosion and flash floods in some areas. Power supply failures occurs in several districts of the Sabah. Many utility's installations suffered severe damage due to the extreme weather, which had subsequently affected power supply to consumers. The power supply restoration had given priority to critical locations such as hospitals and locations involving public safety [13].

Figure 1.2 Example of the grid utility power distribution equipment affected due to severe flood disaster. (This photo is obtained from [10])

1.2 Problem Statement

The climate change issue nowadays can lead to an even more worrying natural disaster. Rapid development, unplanned urbanization, climate change and environmental degradation have caused worse occurrence of flash floods in Malaysia, especially in urban areas [7]. In Malaysia, the utility usually had opted to shut down hundreds and even thousands of substations at the affected locations, for safety purposes. Apart from that, electricity poles and power substations also could be affected by such disaster. The disaster impact is severe and causing multiple outages at a time.

Microgrid (MG) with renewable energy (RES) and energy storage system (ESS) has been identified as a viable solution to improve the conventional distribution power system resiliency [1, 4, 6, 14-16]. In order to utilize the advantages potential of

MG with RES and ESS, an optimal capacity of the RES and ESS as distributed generation (DG) needs to be identified. Optimal DG placement and switching strategy also need to be planned. There is a need to investigate on how much resilient improvement that the MG with RES and ESS could contribute to the distribution system, and how much resilient is the system under different worst-case scenarios.

For a sustainable resilient MG development, the technical, economical, and as well as the environmental aspects need to be under consideration. To have a resilient power grid is crucial not only to keep the lights on and to keep the operation running, but also to retain the power grid infrastructure. A resilient distribution power grid operation is expected to continuously serve critical loads even when disaster events occurred, and to secure as much as possible non-critical loads within the power system network.

1.3 Research Objectives

The aim of this project is to enhance the conventional power distribution system's resiliency by using critical loads survival as the resilience metric and use a Resilient Index (RI) to assess and quantify the performance of the proposed strategies. To achieve this aim, four objectives are listed as follows:

(a) To design and obtain an optimum distributed generation (DG) sizing for a hybrid microgrid that consist of renewable energy system (RES) and energy storage system (ESS).

(b) To investigate the optimal DG locations and switching control in a radial distribution system environment.

(c) To create a randomize worst-case scenarios and perform simulations.

(d) To calculate the resilience improvement compared to a benchmark system.

1.4 Scope of Project

The project is limited to the following scopes:

(a) The simulation and analysis works are limited by using HOMER Grid software (Trial version) and Power World simulator software (GOS 19 version).

(b) The components technical and economic data are limited to the availability in the HOMER Grid Library.

(c) Meteorological and environmental data are limited to the available resources in HOMER Grid.

(d) Temperature effects is not considered.

(e) The scope is limited to the radial power distribution network by using the standard IEEE 33-bus test system.

1.5 Project Report Outline

This project report consists of five chapters and further details are explained and presented in each chapter. Literature reviews related to this project work are presented and discussed in Chapter 2. The project research framework and methodology are presented in Chapter 3. Chapter 4 presents the results and discussions. Finally, the conclusion, project contribution, and recommendation for future works are presented in Chapter 5.

REFERENCES

[1] M. Panteli and P. Mancarella, "The grid: Stronger, bigger, smarter?: Presenting a conceptual framework of power system resilience," *IEEE Power and Energy Magazine,* vol. 13, no. 3, pp. 58-66, 2015.

[2] N. Bhusal, M. Abdelmalak, M. Kamruzzaman, and M. Benidris, "Power system resilience: Current practices, challenges, and future directions," *IEEE Access,* vol. 8, pp. 18064-18086, 2020.

[3] Z. Bie, Y. Lin, G. Li, and F. Li, "Battling the extreme: A study on the power system resilience," *Proceedings of the IEEE,* vol. 105, no. 7, pp. 1253-1266, 2017.

[4] A. A. Bajwa, H. Mokhlis, S. Mekhilef, and M. Mubin, "Enhancing power system resilience leveraging microgrids: A review," *Journal of Renewable and Sustainable Energy,* vol. 11, no. 3, p. 035503, 2019.

[5] A. Stankovic, "The definition and quantification of resilience," *IEEE PES Industry Technical Support Task Force: Piscataway, NJ, USA,* pp. 1-4, 2018.

[6] E. Lightner, J. Leader, S. Berdahl, K. Cory, J. Morgenstein, and P. Schwabe, "Voices of Experience: Microgrids for Resiliency," National Renewable Energy Lab.(NREL), Golden, CO (United States), 2021.

[7] M. Azis, "Malaysia Country Profile," Malaysian Meteorological Department (MMD), 2018.

[8] (2015) After the Storm - Improved Safety Measures in Hand,TNB Stands Ready for Future Floods *Tenaga Link*.

[9] "TNB shuts down 333 power substations in six states hit by floods," in *the Sun daily*, ed, 2021.

[10] Editor. "TNB: Power Will Not Be Restored Immediately." Business Today. (accessed 31 May 2022)

[11] A. Leong. "[Watch] Shah Alam Electrical Substation Explodes Due To Flood." The Rakyat Post. (accessed 31 May 2022)

[12] E. S. D. E. Commission, "Report on the Performance of the Electricity Supply Services in Malaysia," in "2005 Edition," Energy Commission, 13th Floor,

Menara TH Perdana,1001 Jalan Sultan Ismail, 50250 Kuala Lumpur, Malaysia, 2005.

[13] BERNAMA, "Bad Weather Caused Electricity Disruption in Sabah," ed: Malaysian National News Agency, 2022. (accessed 11 July 2022)

[14] V. B. Venkateswaran, D. K. Saini, and M. Sharma, "Approaches for optimal planning of energy storage units in distribution network and their impacts on system resiliency," *CSEE Journal of Power and Energy Systems,* vol. 6, no. 4, pp. 816-833, 2020.

[15] M. Borghei and M. Ghassemi, "Optimal planning of microgrids for resilient distribution networks," *International Journal of Electrical Power & Energy Systems,* vol. 128, p. 106682, 2021.

[16] J. Liu, L. Jian, W. Wang, Z. Qiu, J. Zhang, and P. Dastbaz, "The role of energy storage systems in resilience enhancement of health care centers with critical loads," *Journal of Energy Storage,* vol. 33, p. 102086, 2021.

[17] S. Poudel and A. Dubey, "Critical load restoration using distributed energy resources for resilient power distribution system," *IEEE Transactions on Power Systems,* vol. 34, no. 1, pp. 52-63, 2018.

[18] S. Chanda and A. K. Srivastava, "Defining and enabling resiliency of electric distribution systems with multiple microgrids," *IEEE Transactions on Smart Grid,* vol. 7, no. 6, pp. 2859-2868, 2016.

[19] Y. Lin, Z. Bie, and A. Qiu, "A review of key strategies in realizing power system resilience," *Global Energy Interconnection,* vol. 1, no. 1, pp. 70-78, 2018.

[20] M. Mahzarnia, M. P. Moghaddam, P. T. Baboli, and P. Siano, "A review of the measures to enhance power systems resilience," *IEEE Systems Journal,* vol. 14, no. 3, pp. 4059-4070, 2020.

[21] M. Panteli, C. Pickering, S. Wilkinson, R. Dawson, and P. Mancarella, "Power system resilience to extreme weather: fragility modeling, probabilistic impact assessment, and adaptation measures," *IEEE Transactions on Power Systems,* vol. 32, no. 5, pp. 3747-3757, 2016.

[22] E. D. Vugrin, A. R. Castillo, and C. A. Silva-Monroy, "Resilience Metrics for the Electric Power System: A Performance-Based Approach," Sandia National Lab.(SNL-NM), Albuquerque, NM (United States), 2017.

[23] S. Chowdhury, S. P. Chowdhury, and P. Crossley, *Microgrids and active distribution networks*. 2022.

[24] R. Syahputra, I. Robandi, and M. Ashari, "Performance improvement of radial distribution network with distributed generation integration using extended particle swarm optimization algorithm," *International Review of Electrical Engineering (IREE),* vol. 10, no. 2, pp. 293-304, 2015.

[25] Q. Fu, A. Hamidi, A. Nasiri, V. Bhavaraju, S. B. Krstic, and P. Theisen, "The Role of Energy Storage in a Microgrid Concept: Examining the opportunities and promise of microgrids," *IEEE Electrification Magazine,* vol. 1, no. 2, pp. 21-29, 2013.

[26] D. K. Mishra, M. J. Ghadi, A. Azizivahed, L. Li, and J. Zhang, "A review on resilience studies in active distribution systems," *Renewable and Sustainable Energy Reviews,* vol. 135, p. 110201, 2021.

[27] T. N. B. (TNB), "Energizing a Sustainable Tomorrow," 2020.

[28] S. Lei, J. Wang, C. Chen, and Y. Hou, "Mobile emergency generator pre-positioning and real-time allocation for resilient response to natural disasters," *IEEE Transactions on Smart Grid,* vol. 9, no. 3, pp. 2030-2041, 2016.

[29] G. Zhang, F. Zhang, X. Zhang, Z. Wang, K. Meng, and Z. Y. Dong, "Mobile emergency generator planning in resilient distribution systems: A three-stage stochastic model with nonanticipativity constraints," *IEEE Transactions on Smart Grid,* vol. 11, no. 6, pp. 4847-4859, 2020.

[30] M. Zare-Bahramabadi, A. Abbaspour, M. Fotuhi-Firuzabad, and M. Moeini-Aghtaie, "Resilience-based framework for switch placement problem in power distribution systems," *IET Generation, Transmission & Distribution,* vol. 12, no. 5, pp. 1223-1230, 2018.

[31] W. Yuan, J. Wang, F. Qiu, C. Chen, C. Kang, and B. Zeng, "Robust optimization-based resilient distribution network planning against natural disasters," *IEEE Transactions on Smart Grid,* vol. 7, no. 6, pp. 2817-2826, 2016.

[32] H. Farzin, M. Fotuhi-Firuzabad, and M. Moeini-Aghtaie, "Enhancing power system resilience through hierarchical outage management in multi-microgrids," *IEEE Transactions on Smart Grid,* vol. 7, no. 6, pp. 2869-2879, 2016.

[33] A. Hussain, V. H. Bui, and H. M. Kim, "Optimal operation of hybrid microgrids for enhancing resiliency considering feasible islanding and survivability," *IET Renewable Power Generation,* vol. 11, no. 6, pp. 846-857, 2017.

[34] A. Hussain, V.-H. Bui, and H.-M. Kim, "A resilient and privacy-preserving energy management strategy for networked microgrids," *IEEE Transactions on Smart Grid,* vol. 9, no. 3, pp. 2127-2139, 2016.

[35] M. Ghadimi and S.-M. Moghaddas-Tafreshi, "Interaction model in a resilient standalone multi-microgrid system," in *2019 7th International Istanbul Smart Grids and Cities Congress and Fair (ICSG)*, 2019: IEEE, pp. 56-60.

[36] A. Hussain, V.-H. Bui, and H.-M. Kim, "Resilience-oriented optimal operation of networked hybrid microgrids," *IEEE Transactions on Smart Grid,* vol. 10, no. 1, pp. 204-215, 2017.

[37] Z. Wang and J. Wang, "Self-healing resilient distribution systems based on sectionalization into microgrids," *IEEE Transactions on Power Systems,* vol. 30, no. 6, pp. 3139-3149, 2015.

[38] X. Liu, M. Shahidehpour, Z. Li, X. Liu, Y. Cao, and Z. Bie, "Microgrids for enhancing the power grid resilience in extreme conditions," *IEEE Transactions on Smart Grid,* vol. 8, no. 2, pp. 589-597, 2016.

[39] S. Yao, P. Wang, and T. Zhao, "Transportable energy storage for more resilient distribution systems with multiple microgrids," *IEEE Transactions on Smart Grid,* vol. 10, no. 3, pp. 3331-3341, 2018.

[40] Y. Lin and Z. Bie, "Tri-level optimal hardening plan for a resilient distribution system considering reconfiguration and DG islanding," *Applied Energy,* vol. 210, pp. 1266-1279, 2018.

[41] S. Ma, L. Su, Z. Wang, F. Qiu, and G. Guo, "Resilience enhancement of distribution grids against extreme weather events," *IEEE Transactions on Power Systems,* vol. 33, no. 5, pp. 4842-4853, 2018.

[42] Y. Wang *et al.*, "Coordinating multiple sources for service restoration to enhance resilience of distribution systems," *IEEE Transactions on Smart Grid,* vol. 10, no. 5, pp. 5781-5793, 2019.

[43] M. Amirioun, F. Aminifar, and H. Lesani, "Resilience-oriented proactive management of microgrids against windstorms," *IEEE Transactions on Power Systems,* vol. 33, no. 4, pp. 4275-4284, 2017.

[44] A. Khodaei, "Resiliency-oriented microgrid optimal scheduling," *IEEE Transactions on Smart Grid,* vol. 5, no. 4, pp. 1584-1591, 2014.

[45] S. Sepúlveda-Mora and S. Hegedus, "Design of a Resilient and Eco-friendly Microgrid for a Commercial Building," *Aibi revista de investigación, administración e ingeniería,* vol. 9, no. 1, pp. 8-18, 2021.

[46] V. Vita, "Development of a decision-making algorithm for the optimum size and placement of distributed generation units in distribution networks," *Energies,* vol. 10, no. 9, p. 1433, 2017.

[47] M. E. Baran and F. F. Wu, "Network reconfiguration in distribution systems for loss reduction and load balancing," *IEEE Power Engineering Review,* vol. 9, no. 4, pp. 101-102, 1989.

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

[49] B. N. Malaysia, "Monetary Policy Statement," ed.

[50] "Development of inflation rates in Malaysia." WorldData.info. (accessed 31 May 2022)

[51] B. Dursun, "Determination of the optimum hybrid renewable power generating systems for Kavakli campus of Kirklareli University, Turkey," *Renewable and Sustainable Energy Reviews,* vol. 16, no. 8, pp. 6183-6190, 2012.

[52] "Tariff A - Domestic Tariff." Tenaga Nasional Berhad. https://www.tnb.com.my/residential/pricing-tariffs (accessed 31 May 2022)

[53] "Tariff B - Low Voltage Commercial Tariff." Tenaga Nasional Berhad. https://www.tnb.com.my/commercial-industrial/pricing-tariffs1/ (accessed 31 May 2022)

[54] H. Energy. "HOMER Grid Optimization Setting." https://www.homerenergy.com/products/grid/docs/1.2/optimization.html (accessed 31 May 2022)

[55] M. W. Mustafa, *Teaching Module Power System Analysis*. Desktop Publisher.

[56] M. Albadi and K. Volkov, "Power flow analysis," *Computational Models in Engineering,* pp. 67-88, 2020.

[57] J. J. Jamian, H. Mokhlis, M. W. Mustafa, M. N. Abdullah, and M. A. Baharuddin, "Comparative learning global particle swarm optimization for

optimal distributed generations' output," *Turkish Journal of Electrical Engineering and Computer Sciences,* vol. 22, no. 5, pp. 1323-1337, 2014.

[58] *Distribution Code For Peninsular Malaysia, Sabah & F.T. Labuan (Amendments) 2017,* M. E. Commission ELECTRICITY SUPPLY ACT 1990 [Act 447]

[59] W. S. W. Abdullah, M. Osman, M. Z. A. Ab Kadir, and R. Verayiah, "The potential and status of renewable energy development in Malaysia," *Energies,* vol. 12, no. 12, p. 2437, 2019.

[60] S. T. E. Commission, "Report on Peninsular Malaysia Generation Development Plan 2020 (2021-2039)," ed, 2021.

[61] H. Energy. "How HOMER Calculates Emissions." https://www.homerenergy.com/products/grid/docs/latest/how_homer_calculates_emissions.html (accessed 31 May 2022)

[62] J. Marqusee and D. J. Don II, "Reliability of emergency and standby diesel generators: Impact on energy resiliency solutions," *Applied energy,* vol. 268, p. 114918, 2020.

[63] M. P. Lalitha, V. V. Reddy, and V. Usha, "OPTIMAL DG PLACEMENT FOR MINIMUM REAL POWER LOSS IN RADIAL DISTRIBUTION SYSTEMS USING PSO," *Journal of Theoretical & Applied Information Technology,* vol. 13, 2010.

[64] V. Calderaro, A. Piccolo, and P. Siano, "Maximizing DG penetration in distribution networks by means of GA based reconfiguration," in *2005 International Conference on Future Power Systems*, 2005: IEEE, pp. 6 pp.-6.