PERFORMANCE ANALYSIS OF HYBRID RENEWABLE ENERGY SYSTEMS USED FOR RURAL ELECTRIFICATION IN MALAYSIA

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ABSTRACT

Finding the sustainable, reliable and environmentally-friendly source of energy for remote areas is regarded as one of the major issues in the last decade. However, extending the national grid considered as economically impractical or sometimes technically impossible due to harsh geographical terrains and dispersed population. Normally, such areas are used standalone diesel generators to supply electrical power, which partially covers the load demand. Such standalone systems suffer from several problems of transporting and storing the fuel beside discontinues operation due to maintenance concerns.

The alternative solution to solve these issues is to establish hybrid energy system contains; conventional and renewable energy sources with or without storage system. These systems have received greater attention in recent years, where many studies have performed to find the optimal design without analyzing the operational performance. Analyzing the operational data and performance metrics of two hybrid PV/diesel hybrid systems remotely located in Sabah – Malaysia at (Pulau Banggi and Tanjung Labian) are considered throughout this work. We first verified the collected data followed by the development of all possible scenarios of standalone diesel generators, existing hybrid PV/diesel/battery and 100% PV/batteries systems. Also, developing the optimum systems in both sites is also performed. The analysis examined the performance based on technical, economic and environmental aspects. Furthermore, the development of solar radiation prediction algorithms in addition to integrating a flexible hybrid renewable energy design are presented. HOMER software and MATLAB are used in this work.

The comparison of the existing systems with the optimized scenarios indicates that the existing systems have not optimally selected prior installation. Where the existing hybrid PV/diesel/battery system shows the best performance compared to standalone diesel

generators and 100% PV/batteries scenarios in terms of the technical aspects as well as supporting 24-hour energy access. Meanwhile, the standalone diesel generator system shows the best economic scenario. The inclusion of RE resources in power generation has resulted in improving the system performance and minimizing the dependence on fossil fuel and reducing the generated amount of harmful emissions towards the surrounding environment as well. It also resulted in increasing system sustainability. Accordingly, the results of predicting monthly global solar radiation showed a very good agreement between the predicted and measured data sets besides it demonstrated the high prediction capability of the developed hybrid models using standalone Adaptive Neuro-Fuzzy Inference System (ANFIS) and hybrid ANFIS models which include ANFIS-PSO (Particle Swarm Optimization), ANFIS-GA (Genetic Algorithm), and ANFIS-DE (Differential Evolution). The developed modules showed high accuracy in the prediction of solar radiation. In addition, it is considered as an effective tool in predicting solar radiation and deemed to be suitable for further use in various engineering and practical applications. Furthermore, the proposed flexible design is verified over different combinations and indicated the high capability in meeting the loads, support continuous operation and reduce the harmful emissions towards the environment overall conditions for both off-grid and on-grid connections. Besides, showing the importance of including storage system (batteries) to store excess energy and reducing the losses in the off-grid connections. An accurate analysis of the operational performance of hybrid renewable energy stations would enhance the optimal planning and designing of new projects around the world.

ABSTRAK

Pencarian sumber mampan, dipercayai dan mesra alam tenaga untuk kawasan pedalaman dianggap sebagai salah satu isu utama dalam dekad yang lalu. Walau bagaimanapun, lanjutan grid kebangsaan dianggap sebagai tidak praktikal dari segi ekonomi atau kadang-kadang dari segi teknikal mustahil kerana rupa bumi geografi kasar dan penduduk tersebar. Kawasan ini biasanya menggunakan penjanaan diesel sahaja untuk membekalkan kuasa elektrik yang sebahagiannya meliputi permintaan beban. Sistem tunggal seperti ini mengalami beberapa masalah mengangkut dan menyimpan bahan api selain memberhentikan operasi kerana proses penyelenggaraan.

Penyelesaian alternatif untuk menyelesaikan isu-isu ini adalah untuk mewujudkan sistem tenaga hibrid yang mengandungi; sumber tenaga konvensional dan sumber tenaga boleh diperbaharui dengan atau tanpa sistem penyimpanan. Sistem ini telah menerima perhatian yang lebih besar dalam tahun-tahun kebelakangan ini, di mana banyak kajian telah dilakukan untuk mencari reka bentuk optimum tanpa menganalisis prestasi operasi. Analisis data operasi dan metrik prestasi dua sistem hibrid PV / hibrid diesel di Sabah - Malaysia di (Pulau Banggi dan Tanjung Labian) dipertimbangkan dalam kerja ini. Kerja dimulakan dengan pengesahan data yang dikumpul, kemudian membangunkan semua senario yang mungkin terjadi terhadap penjana diesel tunggal, hibrid PV / diesel / bateri dan 100% PV / sistem bateri yang sedia ada. Pembangunan sistem yang optimum di kedua-dua laman web juga telah dilaksanakan. Analisis prestasi dilakukan berdasarkan aspek teknikal, ekonomi dan alam sekitar. Tambahan pula, pembangunan solar algoritma ramalan radiasi tambahan kepada integrasi hibrid reka bentuk tenaga boleh diperbaharui yang fleksibel akan dijelaskan dan dibincangkan. Sementara itu, perisian HOMER dan MATLAB digunakan dalam kerja-kerja ini.

Perbandingan sistem yang sedia ada dengan senario yang dioptimumkan menunjukkan bahawa sistem sedia ada tidak dipilih secara optimum sebelum pemasangan. Di mana, sistem PV / diesel / bateri hibrid yang sedia ada menunjukkan prestasi yang terbaik berbanding dengan penjana diesel yang beroperasi sendiri pada keadaan 100% PV / bateri dari segi aspek teknikal serta menyokong pembekalan tenaga 24 jam. Sementara itu, sistem penjana diesel tunggal menunjukkan keadaan ekonomi yang terbaik. Kemasukan sumber RE dalam penjanaan tenaga telah menyebabkan peningkatan prestasi sistem dan mengurangkan kebergantungan kepada bahan api fosil serta menghasilkan pelepasan yang merbahaya. Ia juga meningkatkan kemampanan sistem. Oleh itu, keputusan meramalkan radiasi solar global bulanan menunjukkan perjanjian yang sangat baik antara set data yang diramalkan dan diukur bersama menunjukkan keupayaan ramalan yang tinggi model hibrid. Di samping itu, ia dianggap sebagai alat yang berkesan dalam meramalkan radiasi solar dan beranggapan sesuai untuk kegunaan selanjutnya dalam pelbagai kejuruteraan dan aplikasi praktikal. Tambahan pula, reka bentuk yang fleksibel yang dicadangkan disahkan dengan kombinasi yang berbeza dan menunjukkan keupayaan yang tinggi dalam memenuhi beban, menyokong operasi yang berterusan dan mengurangkan pelepasan merbahaya terhadap alam sekitar, ke atas syarat-syarat untuk kedua-dua sambungan luar grid dan grid. Selain itu, ia juga menunjukkan betapa pentingnya kemasukan sistem penyimpanan (bateri) untuk menyimpan tenaga yang berlebihan dan mengurangkan kerugian dalam sambungan luar grid. Pemahaman yang mendalam berkaitan tingkah laku operasi perancangan untuk membangunkan stesen kuasa hibrid akan dipertingkatkan secara optimum dan reka bentuk projek-projek masa depan.

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LIST OF SYMBOLS AND ABBREVIATIONS

RE	:	Renewable Energy
RF	:	Renewable Fraction
PV	:	Photovoltaic
NPC	:	Net Present Cost
COE	:	Cost of Energy
O&M	:	Operating and Maintenance
FC	:	Fuel Cell
GIS	:	Geographic Information System
CC	:	Cycle Charging
LF	:	Load Following
ANN	:	Artificial Neural Network
ANFIS	:	Adaptive Neuro Fuzzy Inference System
PSO	:	Particle Swarm Optimization
GA	:	Genetic Algorithm
DE	:	Differential Evaluation
SVM	:	Support Vector Machine
HNN	:	Hybrid Neural Network
TB	:	Temperature Base
MLR	:	Multiple Linear Regression
RMSE	:	Root Mean Square Error
RRMSE	:	Relative Root Mean Square Error
R^2	:	Co-efficient of Determination
r	:	Correlation co-efficient

MABE : Mean Absolute Bias Error

MAPE : Mean Absolute Percentage Error

N : Daylight hour

δ : Solar declination angle

w_s : Sunset hour angles

Igs : Solar constant

φ : The latitude of the location

n : The average number of days for each month

Kt : Clearness Index

H_0 : Monthly Extraterrestrial Solar Radiation

H : Monthly Horizontal Solar Radiation

Tmax : Monthly Mean Maximum Temperature (°C)

Tmin : Monthly Mean Minimum Temperature (°C)

R(mm) : Monthly Rainfall

S(hr) : Sunshine Duration

SOC : State of Charge

DGs : Diesel Generators

CHAPTER 1: INTRODUCTION

1.1 Background

In the last decade, the need of a sustainable and reliable source of energy has been increased in both developed and developing countries, to avoiding the harmful effects of fossil fuels towards the environment and supply remote areas with a stable source of energy. In the developing countries, a significant percentage of the population is living in remote areas without having any electrical access. In this regard, renewable energy (RE) resources offer a suitable solution for electrifying the isolated micro-communities. For example, in Malaysia, 3.8% of the population live below the poverty line and most of them settled in rural areas. Where the lowest electrification level are found in Sabah and Sarawak states of 67.05% and 66.91%, respectively (Borhanazad, Mekhilef, Saidur, & Boroumandjazi, 2013). However, to extend the national electrical grid into such areas is unfeasible and not economical due to thick jungle, difficult terrains and far distances (Lau, Yousof, Arshad, Anwari, & Yatim, 2010). Moreover, the dispersed population is considered as another reason for prevent extending the national electrical grid to the remote locations. In the meantime, such locations are used stand-alone diesel generators to cover the electrical load demands (Ajan, Ahmed, Ahmad, Taha, & Zin, 2003).

Standalone generators depend on fossil fuels to work (e.g. diesel). Meanwhile, the overall fuel prices in remote locations are opposed to cost increments due to expensive transportation and storage requirements' costs. Conventional diesel generators have their distinct advantages in generating adequate power with acceptable cost. In contrast, the associated operational and maintenance (O&M) costs are considered high in addition to, the inefficient supply when running at low load factor (Lena, 2013; Phuangpornpitak & Kumar, 2007). Low load factor comes from being most rural communities use biomass and kerosene to provide lighting, heating and cooking applications (Neves, Silva, & Connors, 2014). On the other hand, RE resources have the potential to provide sufficient energy to cover the load demand for a specific period during the day. Besides it has the capability of replacing or upgrading the conventional power systems (Neves et al., 2014).

Unfortunately, standalone RE systems are a little far from being economically feasible in comparison to conventional fossil fuel sources, mainly due to high capital and replacement costs. Providing sustainable generation performs a major issue regarding the mismatch of RE energy generation with load demands distribution times (Lanre Olatomiwa, Mekhilef, Huda, & Sanusi, 2015; Phuangpornpitak & Kumar, 2007). To overcome this problem, an optimum solution involving hybrid RE/conventional energy sources with or without storage system is proposed. Figure 1.1 shows a simplified hybrid system block diagram.

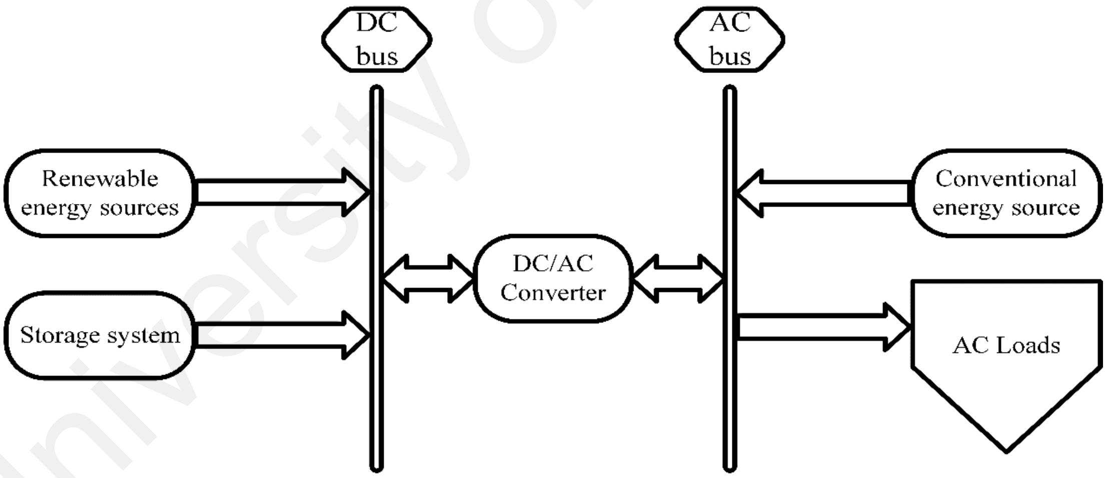


Figure 1.1: Simplified hybrid system block diagram

Hybrid systems have several advantages than standalone systems in improving the reliability, reducing harmful CO_2 emissions and air pollutions, minimizing the operational cost, easy to expand, and offer more efficient use of the generated energy. Moreover, the maintenance cost associated with RE technologies without moving parts (e.g. Photovoltaic (PV) is negligibly small and could be assumed as a maintenance-free after its installation (Khatib, Mohamed, Sopian, & Mahmoud, 2011; Lau et al., 2010). The combination of several energy sources allows to improve the system efficiency and reduces the energy storage requirements. For any complete hybrid system, there are many aspects need to be considered at the design stage to achieve the proposed benefits. All social, institutional, environmental, and economic sides should cooperate with respect to technical side otherwise; the system would be ineffective and worthless. A comprehensive planning and proper system management would support higher reliability and produce lower Cost of Energy (COE). Meanwhile, local conditions and availability of natural resources are the most important conditions that decide the suitable technological combinations for each location.

1.2 Problem statement

Hybrid RE/diesel systems set up in rural areas were designed and implemented in different parts of the world. Most works in this field have been established to find the optimal design, examine the potential or investigate the techno-economic feasibility based on different factors and comparisons for typical hybrid systems. In the meantime, most studies introduce the designing of hybrid systems using different topologies such as PV/wind/battery (Rajkumar, Ramachandaramurthy, Yong, & Chia, 2011), PV/wind/diesel/battery systems (Baneshi & Hadianfard, 2016), PV/diesel (Khatib et al., 2011; Neves et al., 2014), PV/diesel/battery/fuel-cell (Karakoulidis et al., 2011) and grid connected PV/fuel-cell (Bayrak & Cebeci, 2014). Where the optimization techniques are differed according to the proposed topology and site location. Generally, such works show hybrid systems offering a higher level of reliability as well as lower COE compared to single source energy. However, analyzing the operational behavior of hybrid systems once it is built and commissioned has not been taken into consideration, despite the high importance associated with such practical evaluation.

Among the different configurations of hybrid RE/diesel systems set up in rural areas, there is no comprehensive study established to identify the benefits and risks that are associated with such projects. Where, all electrification projects for rural areas in Malaysia are developed based on the optimal use of RE resources (Borhanazad et al., 2013). Thus, the analysis of an implemented system based on real operation data sets would enhance the developments of other future projects. Where forming a general frame that investigates the technical and economic feasibility of hybrid systems in Malaysia and other locations with similar conditions neither employed nor established previously. Consequently, this work proposed to analyze the performance metrics of PV/diesel generators/battery hybrid system located in two locations; Pulau Banggi Island and Tanjung Labian, Sabah, Malaysia. This work would analyze the operational data that were collected from each site that is reported in (JB Hazelton, Bruce, & MacGill, 2015). Furthermore, the designing of most solar applications requires long-term or accurate solar radiation data. Without proper and precise data, the design would be inaccurate and unreliable (Lanre Olatomiwa, Mekhilef, Shamshirband, Mohammadi, et al., 2015). Meanwhile, there are a deficiency in the recoded solar radiation, due to the complex structure, improper calibration and high-maintenance cost of the measuring equipment (Lanre Olatomiwa, Mekhilef, Shamshirband, & Petković, 2015). In these regards, finding accurate artificial intelligence methods to predict solar radiation data would provide the best solution to overcome incomplete or inaccurate data.

1.3 Research objectives

The overall aim of this study is to analyze the operational data and investigate the performance metrics of two decentralized PV/diesel hybrid stations located in two specific remote locations in Sabah - Malaysia (Pulau Banggi and Tanjung Labian). That would enhance the benefits and reduce the risks for designing and establishing new projects in the future. While the specific objectives are as follows:

1. To develop an accurate solar radiation prediction technique with hybrid soft computing algorithms (hybrid ANFIS models).
2. To investigate the potential of using standalone RE systems (PV and batteries) for Pulau Banggi and Tanjung Labian site locations.
3. To design an optimum hybrid PV/diesel/battery system for rural electrification in Sabah, Malaysia.
4. To analyze the performance of the proposed hybrid power stations and evaluate the environmental impact towards the surrounding environment.

1.4 Dissertation outline

The remaining parts of the dissertation are prepared and organized as follows: Chapter 2 includes, the RE potential in meeting the load demand in the world and Malaysia. A review of hybrid RE systems by including optimum designing and sizing methodology that would ensure best technical and economical utilization of standalone hybrid RE systems as well as review various utilizations of on-grid hybrid RE systems. The chapter also includes a review of different solar radiation prediction approaches and proposes the performance and operation of the prediction models. In Chapter 3, the methodology employed in carrying the study objectives is presented. In this chapter, the method of modeling and analyzing the two decentralized hybrid stations are performed including the derivation and verification of collecting the data sets, followed by a description of the operating strategies, then the methodology of the used solar radiation prediction models. Followed by the adopted approach of designing a flexible hybrid RE system. In Chapter 4, the result and discussion of the prepared methodology are presented. This includes the performance analysis of the hybrid PV/diesel/battery stations. Finally, Chapter 5 includes the conclusion and the main recommendation based on the upon findings in this work.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

In this chapter, the potential of using RE resources in energy generation is discussed, followed by a brief description of the potential of using RE in Malaysia. In addition, a review of numerous hybrid system optimization techniques and different solar radiation prediction models that highlight the recent developments in these fields is included and explained. Finally, it discussed various approaches of finding the optimal design of hybrid RE systems for electrifying remote places in both off-grid and on-grid system.

2.2 Renewable energy potential assessment

The need of clean, reliable and sustainable source of energy has become essential in the last century in different fields. This needs were raised mainly to overcome the harmful effects of fossil fuels that cause sequences of harmful concerns such as air pollution and global warming, in addition to the danger of leakage and explosion on the surrounding environment (Abdullah et al., 2010). Consequently, the extensive use of the fossil fuels has exposed it to shortage crises and cost increments (Ong, Mahlia, & Masjuki, 2011). Out of all RE technologies that can be used in decentralized applications, solar energy has the widest applications in energy generation. It provides sustainable and low COE mostly when utilized in remote areas (Zhou, Lou, Li, Lu, & Yang, 2010). In addition, it offers the best reliable and environmentally friendly solution, as well as most freely available and in-exhaustible energy source around the world (Banos et al., 2011). It has many advantages in providing sustainable energy and can be considered as maintenance free due to the absence of moving parts beside offering unlimited energy source. It significantly reduces the harmful emissions, environmental pollutions. Where, the positive effects towards the surrounding environments have enhanced the wide applicability in different fields (Lovins, 2002). Moreover, it also leads to reducing the need for transporting and storing fossil fuels, thus minimizing the dependence on such conventional resources (Lau et al., 2010).

In these regards, the advantages and disadvantages of different optimization methods were reviewed in (Neves et al., 2014). A comparison of energy demand between European and Asian islands using several hybrid RE systems was also performed. The results indicate that the use of PV systems has a high potential, mainly for areas with low demand sites. The results have also demonstrated the effective usage of RE resources in rural areas as well as indicated that the most preferred hybrid RE configuration in rural areas is PV/diesel systems. Generally, the RE resources have the potential to be used in remote areas, especially for replacing or upgrading the conventional fossil fuels system (Neves et al., 2014). Currently, the national trends are moving towards using RE for future developments and meeting world energy demand (Hohmeyer & Bohm, 2015). Accordingly, RE technologies enhance the local development by offering new jobs and training opportunities.

Table 2.1 indicates that solar and wind energies are regarded as the most-used resources of RE around the world; due to their ease accessibility and abundance availability. Despite the high availability, a series of challenges would affect the system performance because of the random nature of the RE resources. Besides, some practical difficulties represented in synchronizing the connections of different system components (X. Li, Song, & Han, 2007).Therefore, deep analyses of all technical, economical, and environmental conditions along with socio-cultural aspects are requested to maintain reliable implementation and sustainable electrical generation. To do this, a feasibility study based on metrological data and cost analysis is required prior implementing any hybrid RE systems.

Table 2.1: Most used hybrid RE systems' configurations

No.	System configuration	Reference
1	PV/diesel/battery	(Ghasemi, Asrari, Zarif, & Abdelwahed, 2013; Hrayshat, 2009; Rezzouk & Mellit, 2015)
2	PV/wind/diesel/ battery	(Baneshi & Hadianfard, 2016; Hossain, Mekhilef, & Olatimiwa, 2016)
3	PV/diesel	(Adaramola, Paul, & Oyewola, 2014; Ismail, Moghavvemi, & Mahlia, 2012; Khatib et al., 2011; Lau et al., 2010)
4	Wind/diesel	(Mynavathi, Chinnaiyan, Venkatesh, & Balamurugan, 2015)
5	PV/wind-diesel	(Belfkira, Zhang, & Barakat, 2011; Maheri, 2014; Rashid, Rana, Shezan, AB Karim, & Anower, 2016)
6	PV/wind-battery	(C. Li et al., 2013; J. Li, Wei, & Xiang, 2012; Ma, Yang, & Lu, 2014)
7	Hydro/PV/wind	(Bekele & Tadesse, 2012; Bhandari et al., 2014)
8	PV/micro hydro/diesel	(Das, Yatim, Tan, & Lau, 2016)
9	PV/fuel-cell/battery	(Isa, Das, Tan, Yatim, & Lau, 2016; Ren, Wu, Gao, & Zhou, 2016)
10	PV/super capacitor/battery	(Hassan et al., 2016)
11	PV/wind/fuel-cell/battery	(Cano, Jurado, Sanchez, Fernandez, & Castañeda, 2014)
12	PV/fuel-cell/electrolyzer-battery/grid connected	(Hassan, Mumtaz, Kamal, & Khan, 2015)

2.3 Potential of renewable energy in Malaysia

In the developing countries, different RE technologies offer greater potential for energy generation, particularly where significant percentages of the population are living with limited or no electrical access. In such places, RE resources are considered the most suitable solution for rural electrification. This type of energy generation could play an important role in energy provision. In Malaysia, a certain portion of the population lives below the poverty line; this is mostly found in remote places of Sabah and Sarawak, with a 92.94% and 88.01% electrification levels, respectively (Mahmud & Blanchard, 2016). Malaysia has a good potential of solar energy, due to the abundance of solar radiation averaging of 4.8-6.7 kWh/m^2/day. Based on this, solar energy has always been considered as a sensible approach in Malaysia (Lau et al., 2010; Wong & Chai, 2012). Malaysia has lots of remote areas located away from the main grid, surrounded by rugged terrains and dense jungles. Grid extension through these remote locations is not feasible and economical. Meanwhile, standalone diesel generators are usually used to provide electricity for these areas (Nandi & Ghosh, 2010). However, Malaysia has a low potential of using wind energy in general, since the average wind speed is about 2 m/s, this power is not a good option for finding the reliable or functional source of energy in remote areas (Borhanazad et al., 2013).

The Malaysian government adopted the National Energy Policy in 1979 to achieve three primary objectives; adequacy of supply, efficient utilization, and mitigating environmental effects. In 1981, the fossil fuel diversification strategy was introduced to reduce dependence on oil, mainly in the power generation sector. This policy was aimed to provide a mixed supply of natural gas, hydropower, oil, and coal. It has drastically minimized oil dependence from almost 90% in 1980, to less than 15% in 2000 (Mustapa, Peng, & Hashim, 2010). RE in Malaysia was introduced in 8th Malaysia Plan (8MP; 2001-2005), where it expanded the Malaysian strategy to consider RE as the fifth source of power generation. 8MP was originally intended to yield 5% (600MW) of the country's electricity demand with RE by 2005, but, only two plants with total capacities of 12MW were commissioned. Later, the 9th Malaysia Plan (9MP; 2006-2010) was targeted toward producing 300MW in Peninsular Malaysia and 50MW in Sabah by 2010, whereas greater attention was placed on energy efficiency in the 10th Malaysia Plan (10MP; 2011–2015) (Mekhilef et al., 2012). Malaysia aimed to attain 2,000MW of RE production by 2020. The Malaysian Government is endorsing RE usage, especially in power generation throughout its comprehensive policies and support. This comes about as the country plans to be one of the leading countries that produce RE in the world by 2020 (Ahmad, Ab Kadir, & Shafie, 2011; Mekhilef et al., 2012). Meanwhile, according to (Izadyar, Ong, Chong, Mojumder, & Leong, 2016), oil and natural gas are the most used sources for generating electrical energy with 87.4% from the total production. On the other hand, RE penetrates only 9.4% from the total production, despite the high availability of RE resources in Malaysia. Whereas, hydropower shares 8.7% versus all other RE sources (such as solar and wind resources) as shown in Figure 2.1.

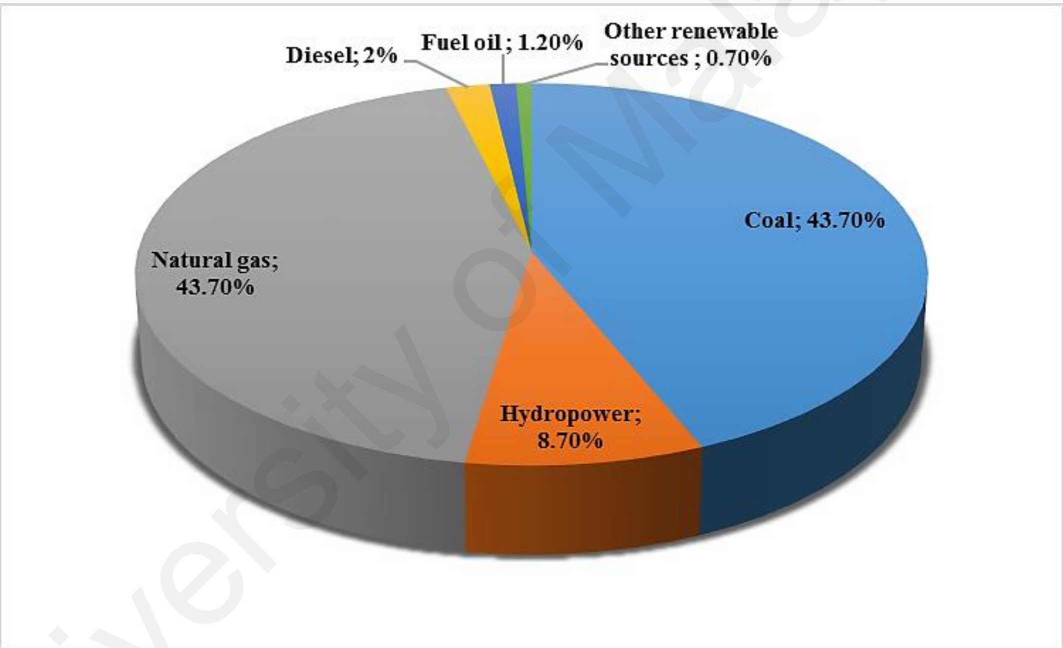


Figure 2.1: Electricity generation share from several sources in Malaysia. Source (Izadyar et al., 2016)

2.4 Hybrid renewable energy systems

Total replacement of conventional diesel generators by RE sources in rural/remote communities is an unfeasible solution due to unstable nature of RE resources (Phuangpornpitak & Kumar, 2007). Hybrid energy systems could be a suitable solution to provide the best in each system (Lanre Olatomiwa, Mekhilef, Huda, & Sanusi, 2015).

Hybrid systems usually include different types of energy sources (Normal diesel generators, Hydro, Wind, Solar, etc.) with or without storage system working together to meet the load demand. The main advantage of the hybrid system is the presence of more than one source of energy, which would enhance system's reliability and stability. Moreover, the current reduction of RE resources prices and it is high availability almost everywhere on the planet make it an attractive solution for energy investors. Thus, the attention has drawn in recent years towards developing and using RE systems for electrifying remote areas (Baneshi & Hadianfard, 2016). O&M costs are regarded as an important parameter in designing the optimum system. For example, solar systems require low maintenance costs and considered as almost free compared with other technologies with moving parts. Therefore, solar systems are preferred in most rural electrification projects (Lau et al., 2010). However, local conditions and availability of natural resources determine the suitable technology combinations of each location. Where, the design of any hybrid RE system needs the consideration of different factors, such as the social, institutional and technical factor in order to obtain the desired results otherwise; the system would be unreliable and inefficient (Lena, 2013).

2.4.1 **Hybrid renewable optimization techniques**

Several studies have reported the optimal systems of using a different hybrid combination of PV/wind/diesel/battery systems (Lanre Olatomiwa, 2016; LJ Olatomiwa, Mekhilef, & Huda, 2014). Meanwhile, PV has shown lower cost and is more applicable compared to wind turbines (James Hazelton, Bruce, & MacGill, 2014). Hybrid PV/diesel systems for rural electrification was recommended in most studies (Khatib et al., 2011; Lena, 2013; Neves et al., 2014; Wong & Chai, 2012). Some studies have discussed the optimal designing methods of hybrid systems in order to assess suitable sizing and appropriate operating strategies for different approaches and configuration (Belfkira et al., 2011; Erdinc & Uzunoglu, 2012; Haidar, John, & Shawal, 2011; Zahboune et al., 2016).

A study has described a PV/diesel hybrid power system with battery backup for a village in Saudi Arabia (Rehman & Al-Hadhrami, 2010). The proposed hybrid system seems to be more favorable, especially when there is a hike in fuel price. A study conducted in Palestine indicated that utilizing PV/diesel hybrid system in remote locations is more economically feasible than standalone diesel generators or grid extension (Mahmoud & Ibrik, 2006). Some studies have also evaluated the techno-economic feasibility and the potential of utilization different hybrid system configurations in remote places (Baneshi & Hadianfard, 2016; Ohijeagbon & Ajayi, 2015; Rajkumar et al., 2011). The results demonstrate the feasibility and high potential of using hybrid RE system in rural electrification. Based on these facts, hybrid RE systems were considered a promising technology and have the tendency to reduce environmental pollution, and improve system stability while simultaneously reducing the overall system cost.

Many studies were performed to find the optimum solution using several methods at different locations in world. A study was carried out to find the cost benefits of standalone solar/battery/diesel in a different part of the world using Geographic Information System (GIS) software (Cader, Bertheau, Blechinger, Huyskens, & Breyer, 2016). The result finds hybrid PV/battery/diesel reduced the COE than standalone diesel generators in many regions. Another study analyzed the potential of hybrid solar and wind energy systems in Saudi Arabia using HOMER and MATLAB software (Ramli, Hiendro, & Al-Turki, 2016). The results have found PV system generates more and cheaper energy compared to a wind turbine of the same size. Besides, indicating the need for a more reliable system would result in increasing the overall system cost. Moreover, a study was performed in Egypt to examine the feasibility of introducing Fuel Cell (FC) in energy system along with PV, wind turbines, and battery banks. Six different combinations were employed and tested using HOMER software and were compared to gird extension solution. The results have found that hybrid system of PV/FC offers the best COE and Net Present Cost (NPC) over all possible solutions, including grid extension and wind/battery systems. Different surveys of about 800 samples were reported to measure the user's willingness to pay in residential and commercial sectors as shown in (Dagher & Harajli, 2015; Harajli & Gordon, 2015; Mahmud, 2010). Among all scenarios, higher willingness to pay was found toward RE sources, particularly when it can displace the need of diesel gen-sets completely in both sectors. Generally, users show greater satisfaction for better energy services (such as fewer blackouts) and are found to be more willing to pay for reliable RE sources (James Hazelton et al., 2014).

The choice of any technique is dependent directly on the purpose of optimization; such as the type of hybrid system, optimum component size and operating strategy by focusing either on the technical, economical or environmental impact. Table 2.2 shows various optimization techniques available in the literature. In this table, different optimization techniques that have been widely reported in the literature are shown. Meanwhile, for each technique shown, the proposed approaches (methods) that have been used are clarified and highlighted. Moreover, the compensation of the proposed hybrid system in each study is explained as well as to show the type of used system (off-grid or on-grid). In these regards, it is shown the main reason behind choosing the appropriate optimization techniques/tools.

Table 2.2: Different hybrid RE systems optimization techniques

No.	Optimization technique/tool	Approach 8(method)	System configuration	Connection type	Reference
1	Deterministic approach	• By determining specific values using constant factors	PV/wind/diesel/ battery	Off-grid	(Mahmoud & Ibrik, 2006)
2	Iterative approach	• Using loss of power supply probability (LPSP) with the lowest cost	PV/battery	Off-grid	(Shen, 2009)
3	MATLAB software	• Based on an evaluation technique to find the optimum system over various combinations	PV/diesel/ battery	Off-grid	(Wies, Johnson, Agrawal, & Chubb, 2005)
4	Artificial intelligence	• Using long term PSO evaluation algorithm, training the system, learning from previous states to find the optimum component size.	PV/wind/fuel-cell/ electrolyzer/battery/ hydrogen tank/grid connected	On-grid	(García-Triviño et al., 2014)
		• Using multi-objective evolutionary algorithm (MOEA) and a genetic algorithm (GA) to design the optimum system	PV/wind/diesel/ hydrogen/battery	Off-grid	(Dufo-López & Bernal-Agustín, 2008)
5	Optimization software	• using HOMER software, by comparing the technical, economical and environmental performance of different combinations	PV/wind/diesel/battery/ grid connected	On-grid	(Asrari, Ghasemi, & Javidi, 2012)
			PV/wind/battery	Off-grid	(Ma et al., 2014)
		• Using other software tools (HYBRID2, etc.) to classify the most optimum solution with the lowest cost based on economic analysis.	PV/wind/hydro/ fuel-cell etc.	Off/On-grid	(Erdinc & Uzunoglu, 2012)

2.4.2 Off-grid and on-grid hybrid system approaches

The use of PV panels can be used in two main schemes. Off-grid and on-grid connections with or without storage batteries. The off-grid systems with storage system have a high potential to be used in isolated islands and remote locations (Borhanazad et al., 2013). Likewise, on-grid systems with storage system are regarded as a stable solution, but with less feasibility due to additional storage requirements. On the other hand, on-grid systems without storage system would reduce the storage costs (Adaramola & Vågnes, 2015). Different hybrid RE systems optimization techniques in both off and on grid connection systems are shown in Table 2.2.

The current technological developments reduced the photovoltaic (PV) prices, which would significantly support developing new projects (Adaramola & Vågnes, 2015). In the meantime, the positive environmental impact of RE sources enhances it used in power generation (Adaramola, 2015). In the recent years, many works were established to study the performance of PV plants around the world, at both small and large scales systems (Allouhi et al., 2016; Emziane & Al Ali, 2015; Polverini, Field, Dunlop, & Zaaiman, 2013). However, the extensive use of fuel oil and natural gas exposed these resources to the shortage crises which resulted in increasing the global fuel prices (Ong et al., 2011). Furthermore, dispersed populations, unstable climatic and geographical terrains also affect fuel supply route for remote areas and make grid extension impractical and impossible (Shaahid & Elhadidy, 2007). Nevertheless, many researchers studied the optimum combination of different hybrid RE systems over either off-grid or on-grid connections. To improve system reliability and to overcome standalone system's deficiencies as well as reduce the dependence on fossil fuels. There are two studies, which are particularly informative, discussing the difference between optimizing the off-gird and on-grid systems which are describing in the following sections (2.4.2.1 and 2.4.2.2).

2.4.2.1 Off-grid renewable energy systems optimization

Standalone hybrid RE systems have widely developed around the world for different purposes. A study have been conducted in Iran to find the optimal design for hybrid PV/wind/fuel cell system (Maleki, Pourfayaz, & Rosen, 2016). The authors have obtained the results based on minimizing the life-cycle cost with the maximum allowable losses of power supply probability. The results remark the most cost effective system among all configurations includes PV/wind/fuel cell. Similarly, MATLAB Simulink was used to develop the optimum standalone system (Belmili, Haddadi, Bacha, Almi, & Bendib, 2014). The authors were implemented an illustrated techno-economic analysis to find the optimal solution. Among the study, the results were found the optimum system includes PV/wind combination. Accordingly, a study was presented two different methods for optimizing hybrid RE systems. The proposed systems include a combination of PV, wind, and micro-hydro generators for two villages in Nepal (Bhandari et al., 2014). The results demonstrate the effectiveness of the developed methods as a practical guide for pre-implementing such projects at different places with similar conditions.

The techno-economic feasibility for PV/diesel without battery storage system at the north of Ouagadougou (Burkina Faso) was integrated using HOMER software (Tsuanyo, Azoumah, Aussel, & Neveu, 2015). The results have indicated that the best combination includes two scenarios in terms of minimizing the costs. In the meantime, the effects of the different seasons (winter and summer) in distinct times (weekends and weekdays) were investigated in (Tazvinga, Xia, & Zhang, 2013). The analysis showed that the weekend energy consumption exceeded that of the weekdays, where higher consumption was found during the winter season. The results showed the important effects of the seasonal loads on the operation cost and flow of energy. However, most studies reported in the literature were maintained to develop various hybrid system configurations based on the stable power supply, minimum COE and lower harmful CO_2 emissions over off-grid conditions.

The feasibility of using different off-grid systems was widely investigated at different parts in the world (Ghasemi et al., 2013; Rezzouk & Mellit, 2015). The results recommend the advantages of using off-grid hybrid RE systems in electrifying remote areas and reducing the dependence on the regular diesel generator systems. This would result in reducing the fuel consumption and harmful CO_2 emissions as well as minimizing the O&M costs. In addition, such projects would assess continuous operation of the loads and increase the reliability and efficiency of the system. A study carried out in Malaysia for investigating the performance evaluation of large resort using PV/wind/diesel with the battery storage hybrid system (Hossain et al., 2016). A similar result was achieved in Jordan (Hrayshat, 2009). The results found the hybrid system offers the most suitable system based on economic, technical and environmental aspects.

2.4.2.2 On-grid renewable energy systems optimization

This section addresses hybrid systems that use the on-grid connection. In this regard, many studies are informative in which developed to find the optimal system based on different operating conditions over off-grid and on-grid connections separately as presented in (Asrari et al., 2012) and (Hafez & Bhattacharya, 2012). In (Asrari et al., 2012), the authors were used HOMER software to evaluate the feasibility of various combinations of diesel generators and RE sources (off-grid). In the meantime, the authors developed different combinations that include grid connection and RE sources (on-grid). The results demonstrate the advantage of adding RE sources to the off-grid connection in reducing the operational costs and generating cleaner energy. However, including grid in the system would result in lower COE compared to the off-grid system.

In (Hafez & Bhattacharya, 2012), four different topologies were presented, which include; standalone diesel generators, standalone RE, hybrid diesel generators, RE source and hybrid grid-connected systems. Optimal sizing and planning were carried out for each scenario to satisfy the best design. The results show the different configuration for each scenario. Hybrid diesel generators/RE source exhibits the lowest NPC. In contrast, standalone RE system generates zero CO_2 emissions with the higher NPC. Another study was investigated various combinations of hybrid PV/wind/battery systems over off-grid and on-grid systems (Baneshi & Hadianfard, 2016). A range of PV, wind turbines was reported in a range of (0-1000) kW and (0-600) kW for PV modules and wind turbines respectively. Different Renewable Fraction (RF) values of (0-43.9) % for off-grid connection, alongside with (0-53) % of RF for on-grid connection. These results obtained a range of possible scenarios for off-grid and on-grid based on different combinations for each scenario. The techno-economic feasibility for on-grid connection was carried out in (Nacer, Hamidat, & Nadjemi, 2016). The results indicate that introducing RE hybrid system to the grid would enhance the reliability of the national grid at peak load period and reduce the harmful emissions to the environment.

2.5 Solar radiation prediction approaches

The design of most solar applications requires long-term and accurate solar radiation data that considered as the main input for such applications in designing both thermal and photovoltaic systems. Without proper and precise data, the design would be inaccurate and unreliable (Lanre Olatomiwa, Mekhilef, Shamshirband, Mohammadi, et al., 2015). Meanwhile, many meteorological stations have no solar radiation records or have records with many missing intervals, which may happen due to the complex structure, improper calibration and high-maintenance cost of the measuring equipment. It is worth to mention that special instruments with high celebration and maintenance costs are usually used to measure the solar radiation (Lanre Olatomiwa, Mekhilef, Shamshirband, & Petković, 2015).

Artificial intelligence and other prediction methods provide the best solution to overcome incomplete or inaccurate data. The motivation behind selecting any method is based on each method features like; reliability, efficiency, and complexity. The most common method is the empirical method proposed by many researchers (Besharat, Dehghan, & Faghih, 2013; Halawa, GhaffarianHoseini, & Li, 2014). such methods as, Angstrom–Prescott linear equation method (Manzano, Martín, Valero, & Armenta, 2015), stochastic algorithm model (Adel Mellit, 2008) and Satellite-derived model (Janjai, Pankaew, & Laksanaboonsong, 2009). Besides, various artificial intelligence techniques such as artificial neural network (ANN) (Rezrazi, Hanini, & Laidi, 2016), adaptive neuro-fuzzy inference system (ANFIS) (Lanre Olatomiwa, Mekhilef, Shamshirband, & Petković, 2015), particle swarm optimization (PSO) (Mohandes, 2012), support vector machine (SVM) (Ramli, Twaha, & Al-Turki, 2015), hybrid neural network (NN) (Gani et al., 2015) had received high attention in solar radiation prediction to support a wide range of agriculture and industrial applications. Moreover, enhancing the prediction accuracy over complex environments such as mobile cloud computing and industrial conditions, resource utilization (Idris, Wahab, Qabajeh, & Mahdi, 2016; Javanmardi, Shojafar, Shariatmadari, Abawajy, & Singhal, 2014), and improving the energy management (Cordeschi, Shojafar, Amendola, & Baccarelli, 2015; Shojafar, Cordeschi, & Baccarelli, 2016) have also received the attention to embrace the wide range of applications.

Some researchers have found sunshine duration and air temperature as the best combination to predict solar radiation using different empirical models (Chen & Li, 2013; Gani et al., 2015). Similarly, satellite methods have the advantage of collecting and estimating solar radiation where there are rare special collecting stations (Pinker, Frouin, & Li, 1995). Satellite methods suffer from the high cost and deficit of historical information and the prediction of solar radiation mainly affected by the clouds (Adam & Ahmed, 2016). However, over long-term basis prediction of solar radiation, these methods (empirical and satellite) show low performances and both required full data sets without any missing data.

Many studies developed to estimate solar radiation from routinely measured meteorological data, including temperature and geographical parameters in different parts around the world (M.-F. Li, Fan, Liu, Guo, & Wu, 2013; Ramedani, Omid, Keyhani, Khoshnevisan, & Saboohi, 2014). A study applied comparison between ANN technique and TB empirical method to predict global solar radiation from air temperatures, where maximum and minimum air temperatures and extraterrestrial radiation have used as input for training purposes. The results showed the ANN technique exhibit higher accuracy than TB method (Rahimikhoob, 2010). Similar work is done in Turkey, using ANN, ANFIS, multiple linear regression (MLR) models and empirical equations' methods and showed ANN has better performance than all other methods for that location (Citakoglu, 2015).

ANFIS system constructs hybrid system combined the learning technique of the ANNs with the knowledge of fuzzy logic (Jang, 1993). This method has been applied in many studies and it revealed good learning technique and high prediction capability in different engineering fields (El-Shafie, Jaafer, & Akrami, 2011). Furthermore, a recent study used a special hybrid approach called FUGE that based on fuzzy theory and genetic algorithm (GA) (Shojafar, Javanmardi, Abolfazli, & Cordeschi, 2015). This study was performed distinct fields of artificial intelligence in order to find the optimal load balancing by considering the lowest execution cost and time. The study demonstrated the widely used of artificial intelligence algorithms in different fields and the high developing capability. Table 2.3 summarizes different methods which were used for predicting solar radiation data.

Table 2.3: Different techniques used for predicting solar radiation data.

No.	Prediction technique	Parameters	Reference
1	Empirical method	• If the sunshine duration is available; Monthly average daily atmospheric water vapor pressure, and relative humidity. • If the sunshine duration is not available; Monthly average daily atmospheric water vapor pressure, relative humidity, and multiplication maximum, and minimum ambient temperatures.	(Chen & Li, 2013)
2	Angstrom–Prescott (A–P)	• 25 time series of daily global radiation and sunshine hours.	(Manzano et al., 2015)
3	Satellite-derived model	• Hourly digital data from channel (0.55–0.90 μm) of the GMS5 satellite (navigated images), ambient temperature, and relative humidity.	(Janjai et al., 2009)
4	Artificial Neural Network (ANN)	• Air temperature, relative humidity, global, direct and diffuse solar radiation.	(Rezrazi et al., 2016)
5	Adaptive Neuro-Fuzzy Inference System (ANFIS)	• Monthly mean sunshine duration, monthly mean maximum, and minimum temperature.	(Lanre Olatomiwa, Mekhilef, Shamshirband, & Petković, 2015)
6	Particle Swarm Optimization (PSO)	• Month of the year, latitude, longitude, altitude, and sunshine duration.	(Mohandes, 2012)
7	Support Vector Machine (SVM)	• The average global, direct beam radiation, normal radiation and the latitude of the location.	(Ramli et al., 2015)
8	Hybrid Neural Network (NN)	• The day of the year only.	(Gani et al., 2015)
9	Multiple Linear Regression (MLR)	• Month number, extraterrestrial radiation, average air temperature, average relative humidity, average sunshine duration, and daylight hours.	(Citakoglu, 2015).

As seen throughout the literature including hybrid algorithms would result in better prediction result and would lead to add more practical usage on these techniques. To cover the deficiency in of metrological data sets availability, the development of hybrid models would add more reliable and accurate estimation capability. Also, it is deemed to support efficient predicting techniques in various agricultural, environmental and industrial applications.

2.6 Chapter summary

This chapter addressed the assessment of RE potential in providing sustainable energy and meeting the energy demand. Then a particular review on the RE potential in Malaysia is presented. Furthermore, a review of different hybrid RE topologies and configurations, where most recent studies within this field are deeply investigated. Numerous optimization techniques are explained and discussed, which is concluded the importance of proper planning, designing and implementation. While, there is no study has been carried out to analyze the operational performance of the hybrid renewable station based on real operational data in Malaysia. Despite, it is importance role in designing and operating of new projects. Besides, it is influence by ensuring the best utilization and continues the supply of the load demands. Furthermore, a review of solar prediction technique methods is presented in this chapter. The significance of this work comes from the necessity of more accurate solar radiation data that can be used in various applications in different fields, among the available measured meteorological parameters. It has shown the high capability of soft computing algorithms in different engineering fields. Also, the need of accurate prediction techniques is highlighted, where most metrological station suffers from leakage of long term metrological data sets due to a faulty sensor and high maintenance and calibration costs. Where the literature has showed the usage of different artificial algorithms for predicting proposes in different agricultural and industrial fields.

Hence hybrid ANFIS models combined with PSO, GA and DE have been considered for predicting solar radiation algorithms using MATLAB software.

Finally, this chapter also includes a comprehensive evaluating of standalone (off-grid) and grid connection (on-grid) studies that represented the most efficient economic and technical utilization of RE resources in power generation. It is found that currently there is no study carried out to find a flexible design which could operate over major factors that might influence the project configuration over both off-grid and on-grid connections. This is considered a very important to investors and customers as well due to it is benefits on the technical, economical and environmental sides. Among all studies, it has shown HOMER software is the most preferred tool. Hence, HOMER software has been regarded for techno-economic-environmental analysis in this study.

CHAPTER 3: METHODOLOGY

3.1 Introduction

In this dissertation, two standalone hybrid systems include PV/diesel generators/battery hybrid systems are proposed. These systems are located at two different places in Sabah, Malaysia at Pulau Banggi and Tanjung Labian. In this chapter, the employed methodology is presented and explained as shown in Figure 3.1.

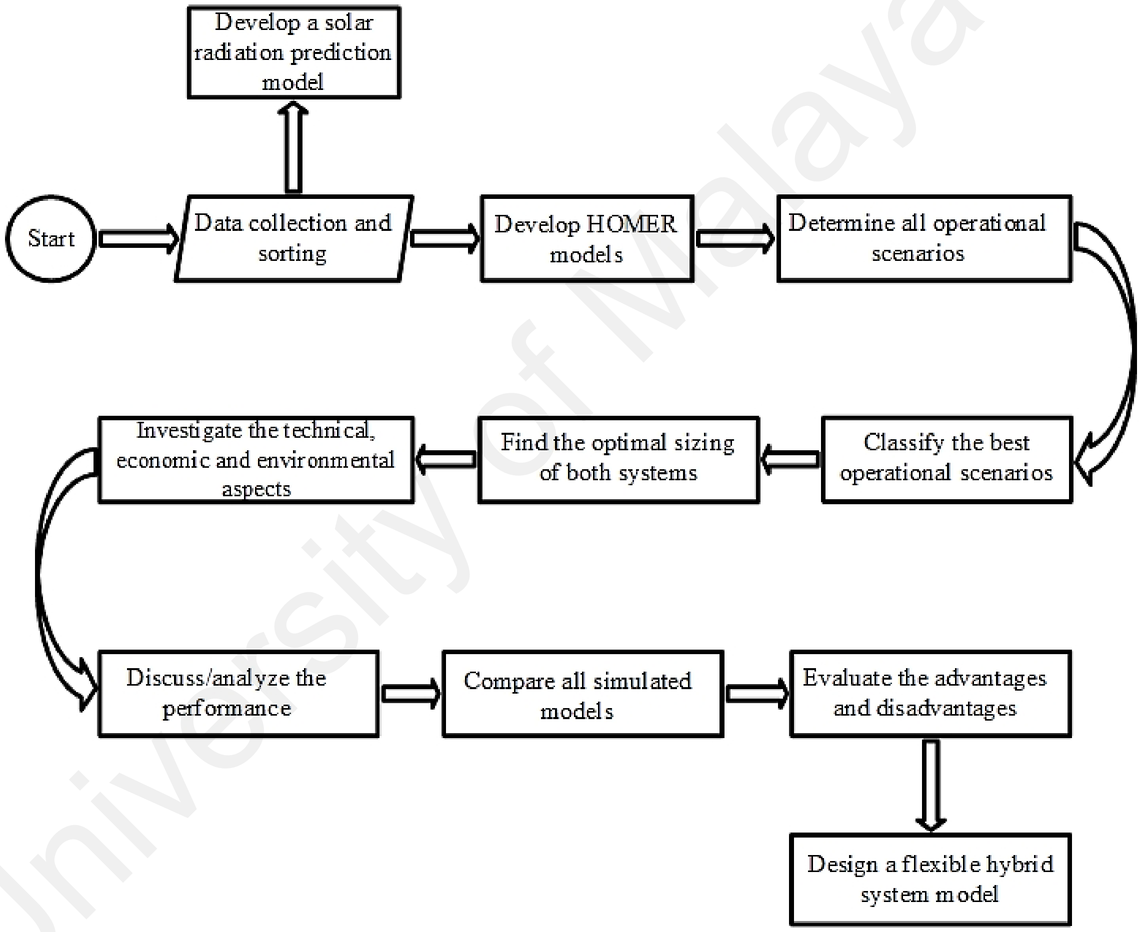


Figure 3.1: Methodology process

3.2 Data collecting and sorting

In RE projects, successful evaluation requires appropriate criteria to be applied on site data in order to correctly analyze the operational behavior of all possible scenarios. The analysis framework employed in this section includes; site specifications, derivation, and verification of modeled data sets (solar energy, temperature and load demand) and description of system components' specifications.

Collected data from each site is illustrated and investigated under these criteria. Each site specification is discussed and analyzed to describe the entire system.

3.2.1 Site specifications

Sabah, the second largest state in Malaysia with an area span of about 72,500 km^2. Sabah located in the eastern part of Malaysia generally contains mountainous hills with dense jungles hosted a diverse array of plant and animals, coupled with an extensive network of river valleys. This study considered two stations in two specific locations in Sabah named Pulau Banggi Island and Tanjung Labian. General description for both locations has been shown in a previous study (JB Hazelton et al., 2015). The first location, Pulau Banggi is the third largest island in Malaysia, located on the northern coast of Sabah with latitude 7.25° N / 117.16667° E, where the main source of income is agriculture, fishery, and tourism. Tanjung Labian, on the other hand, is a small area located on the eastern side of Sabah, with latitude 5.10° N / 119.13° E where major sources of income are; timber, tourism and seafood exports. Figure 3.2 shows the proposed site locations at Sabah, Malaysia.

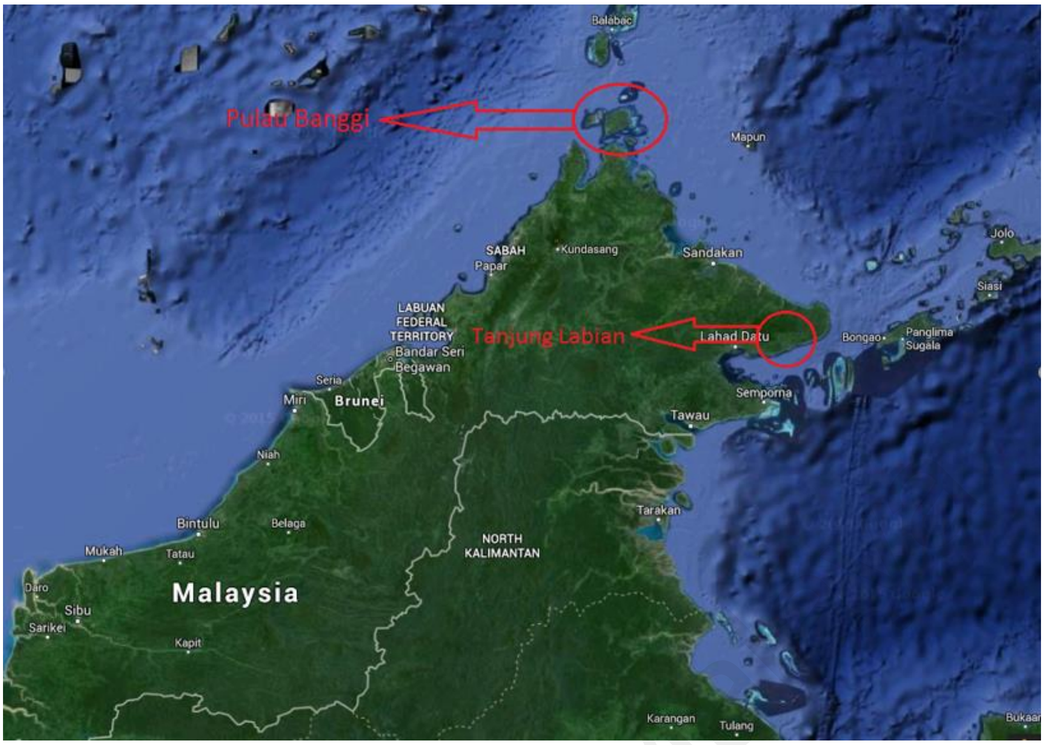


Figure 3.2: The proposed site locations at Sabah, Malaysia (Source: Google Maps)

3.2.2 Derivation and verification of modeled data sets

Site's surveys described in (JB Hazelton et al., 2015) were carried out in both locations to collect the required measured data for each site. It includes solar radiation, ambient temperature, and load profile data sets. In order to assess system performance, real-time measurements of solar irradiation and ambient temperature data are needed. Unfortunately, the measured data was limited due to faulty sensors and measuring tools. To overcome these challenges, the metrological data obtained from National Aeronautics and Space Administration website (NASA) was verified as shown in the following sections.

3.2.2.1 Solar Resource

The measured solar radiation data obtained from each site location was available for 8-months in Pulau Banggi and 11-months in Tanjung Labian. On the other hand, NASA data draws an accurate and close behavior to the measured data with a slight variation due to the differences in the recorded periods. Therefore, NASA data is used in this analysis, where satellite-based data such as (NASA) could be employed in the event of unavailability of sufficient measured data in the desired locations (Sinha & Chandel, 2015). Solar radiation data obtained from NASA's website for both locations is shown in Figure 3.3.

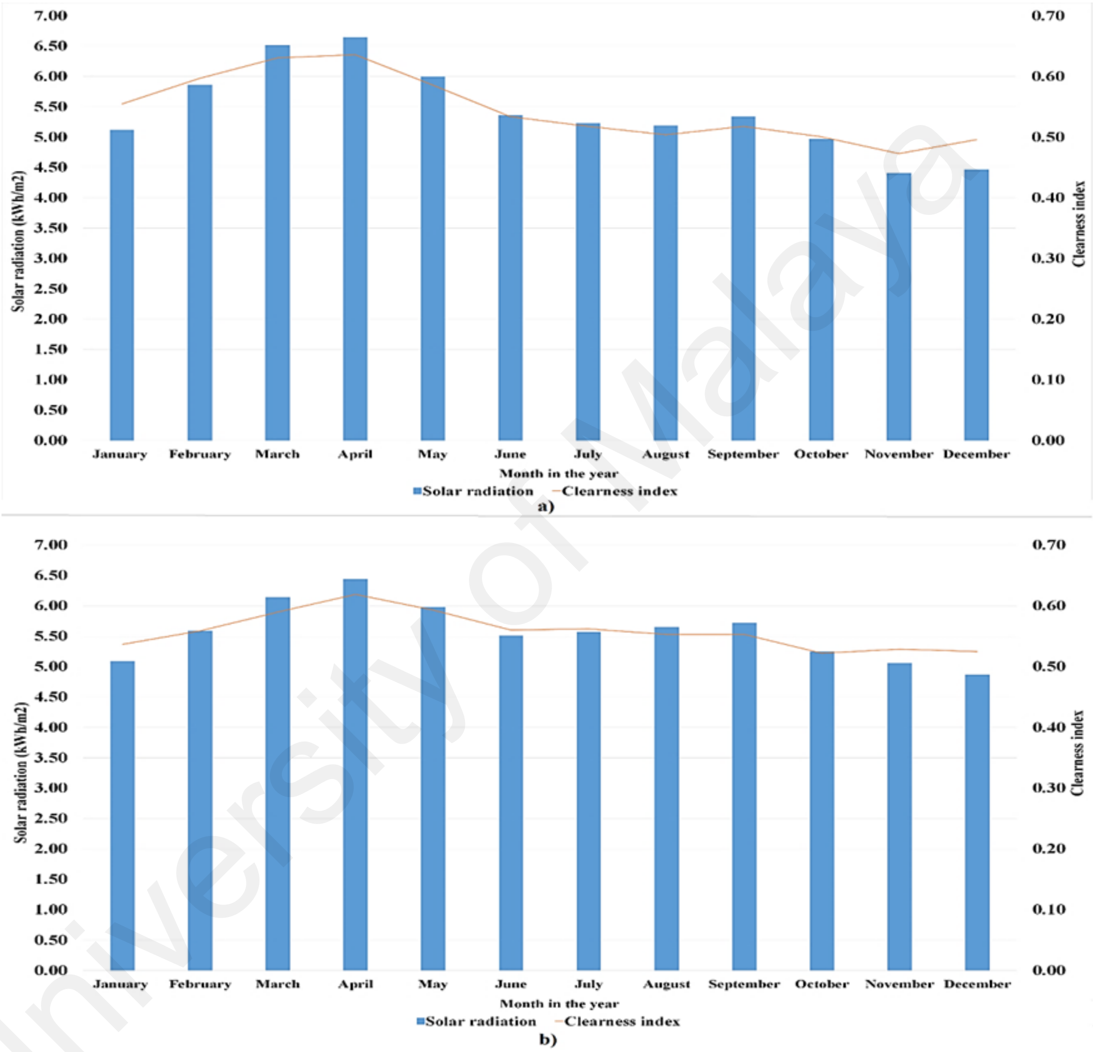


Figure 3.3: Solar irradiation comparison at: (a) Pulau Banggi (b) Tanjung Labian

Monthly solar radiation data for both locations are generally in the range of 4.41 – 6.65 kWh/m^2/day, with an annual average of 5.43 and 5.57 kWh/m^2/day for Pulau Banggi and Tanjung Labian, respectively.

3.2.2.2 Temperature

The measured temperature data for each site was found in short term, 3-months for Pulau Banggi and 4-months for Tanjung Labian. This data is less than a year, thus it is impractical to analyze the overall performance using such data. For this reason, NASA temperature data is used in this work. However, it can be seen in some literature that the used of artificial intelligence to predict ambient temperature by using the direct relation between solar irradiation, and temperature is possible and could be employed as a proper solution for future works (Mohammadi, Shamshirband, Danesh, Abdullah, & Zamani, 2015; Lanre Olatomiwa, Mekhilef, & Shamshirband, 2016; Shamshirband et al., 2015). In this regard, using artificial intelligence to create accurate prediction technique is proposed in section (3.5) of this work. Meanwhile, temperature data obtained from NASA's website for both locations is shown in Figure 3.4.

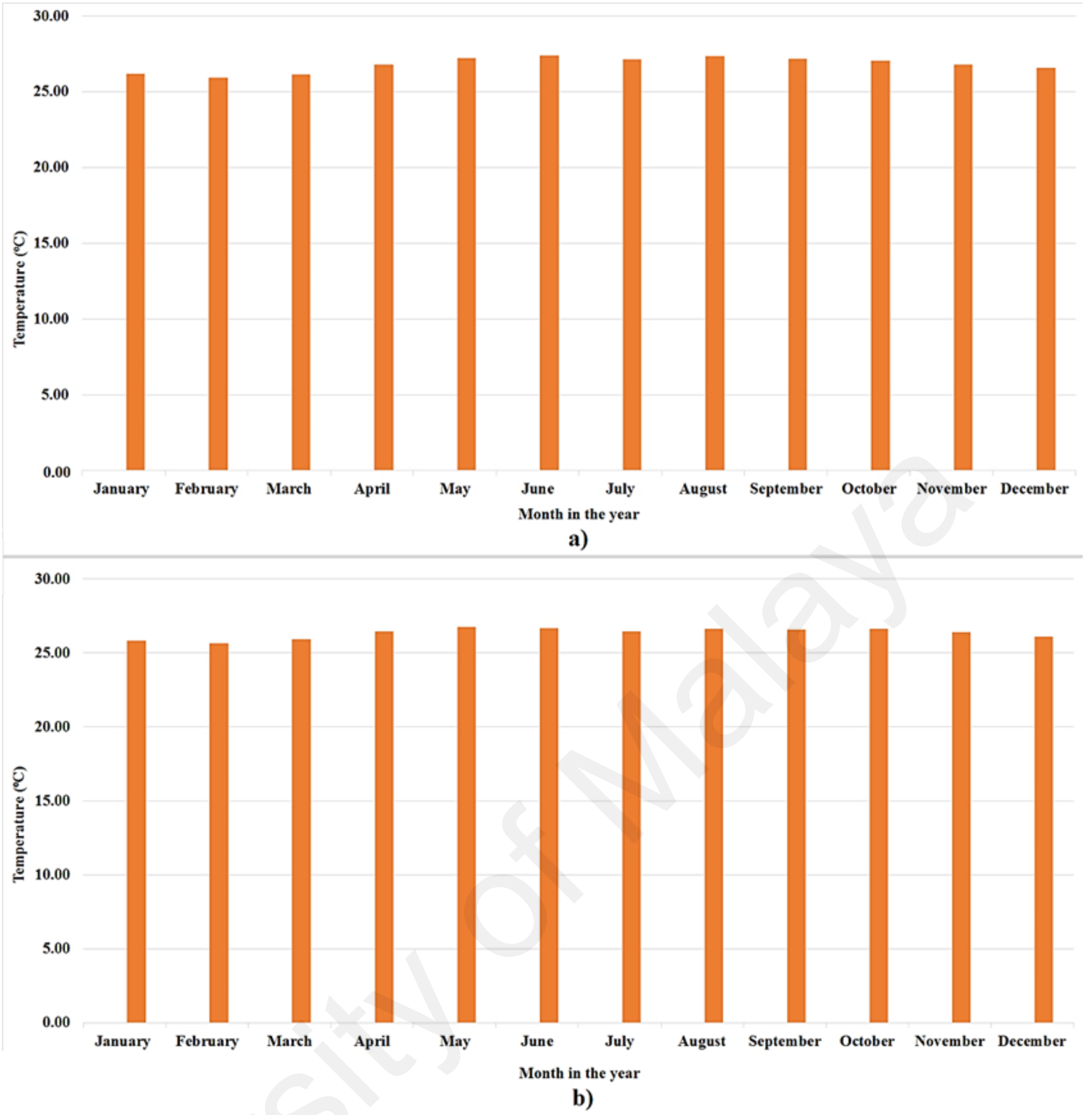


Figure 3.4: NASA temperature data at (a) Pulau Banggi (b) Tanjung Labian

The obtained data for both locations are generally in the range of (25.64 – 27.38) °C with an annual average of 26.8 °C and 26.3 °C in Pulau Banggi and Tanjung Labian respectively.

3.2.2.3 Load demand

In remote areas, the majority of residents spend most of their time outside their homes for work purposes. At noon, increase in loads can be observed, as some family members usually come home for lunch and other activities. However, maximum demand takes place at night, when the entire family is at home. Demand profiles were constructed using load data sets collected during the site visits described in (JB Hazelton et al., 2015). It was found that due to communication errors in measuring equipment, service interruptions and continuing load growth in these new energy access sites is prevalent. Therefore, the data sets had to be modified to give a more accurate representation of community demand for the modeled period. Firstly, erroneous data points were identified – these could be as a result of communications and computation errors in the SCADA system or incorrect equipment calibration. Filters were used to eliminate values that seem unreasonable (less than 10kW and more than 900kW) before establishing the average profiles as shown in Figure 3.5.

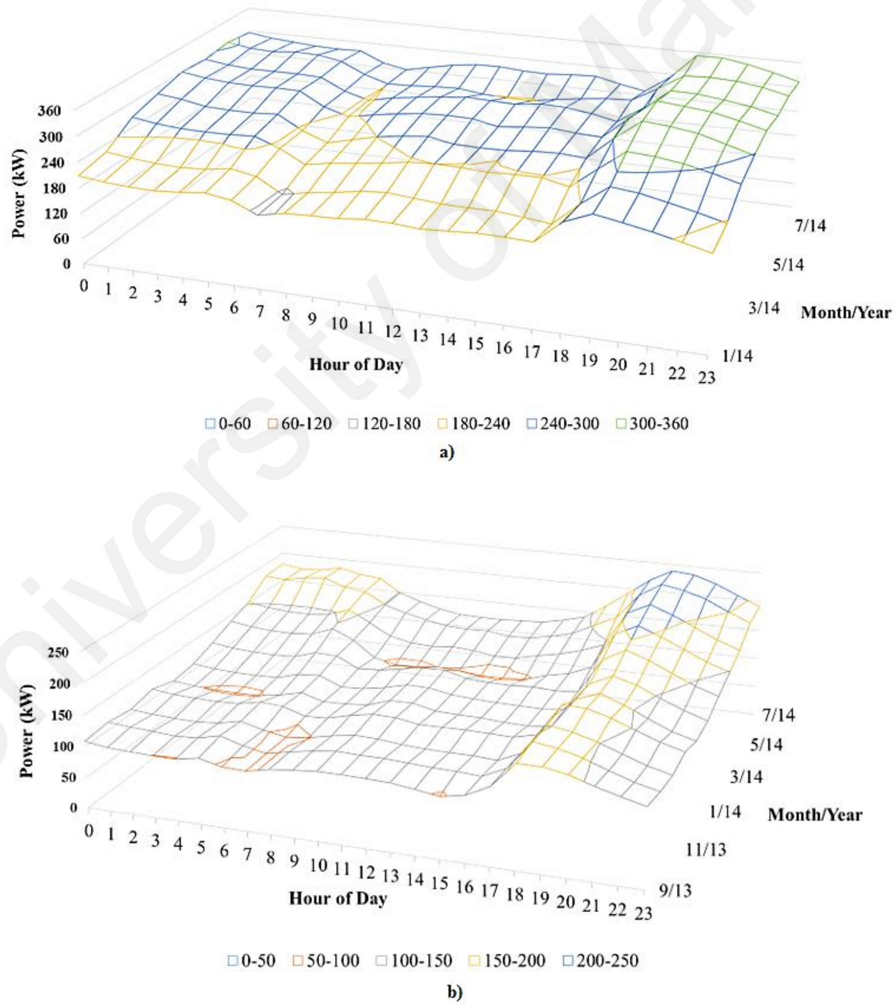


Figure 3.5: Measured average load profiles (a) Pulau Banggi (b) Tanjung Labian

To derive the demand input data sets in the models, the measured data also needed to be used to estimate data in months, since monthly data is not available. This presented some challenges. Firstly, as different seasons will affect demand, there are some difficulties in approximating a full year based on size. Therefore, monthly data would have to be done for Pulau Banggi site. Secondly, the sites were experiencing significant monthly load growth as new customers receive access via expanding distribution lines. To account for these, a temperature dependent regression model was used to take into account the seasonal variation. From the measured data sets, the relationship between daily peak load and daily peak temperature were correlated. Temperature variations for the remaining months were taken from section (3.2.2.2) and average load scaled accordingly. Load growth was considered by taking the most recent month as a baseline, then scaling this based on sensitivity analysis in HOMER. The reduced loads at weekends were accounted by using the measured data sets and comparing peak and average load values. The resulting baseline cases for weekdays and weekends are shown in Figure 3.6.

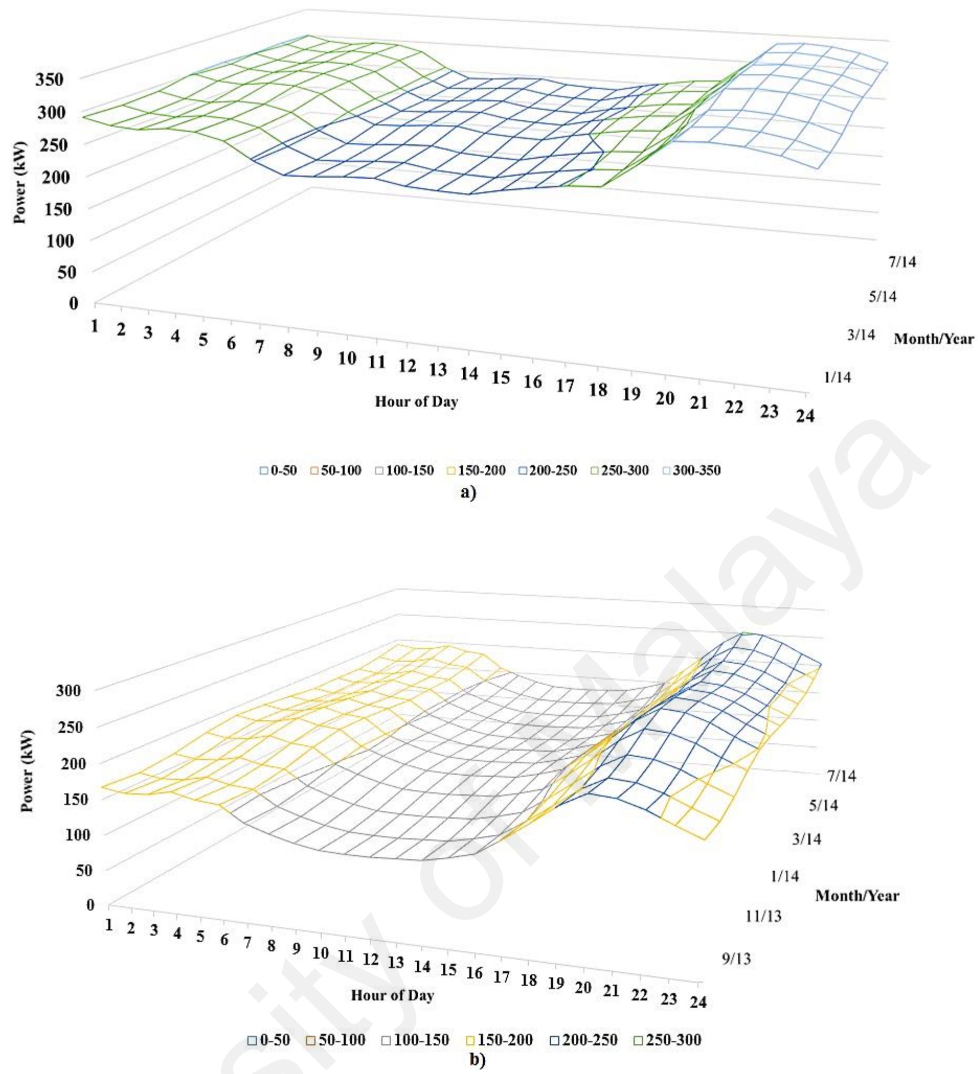


Figure 3.6: Average load profiles (a) Weekdays (b) Weekend

Once average load datasets were inputted into the model, variability must be introduced using HOMER's time step variability and day to day variability functions. Appropriate values of these functions were determined to be 10.88% and 7.48% respectively in Pulau Banggi and 14.22% and 16.26% respectively in Tanjung Labian.

3.2.3 System components

Both stations were implemented in two phases, and each consists of several components (PV arrays, batteries, converters and diesel generation system) (JB Hazelton et al., 2015). Pulau Banggi Island was commissioned in February 2014 and expected to serve about 1200 houses. On the other hand, Tanjung Labian was commissioned in

November 2012 and expected to serve about 800 houses. Table 3.1 summarized all components of each system in both locations.

Table 3.1: Summary of installed equipment

PV Hybrid Station	Connected Houses	Solar Photovoltaic		Diesel Genset		Battery Bank	
		kWp	Brand	kW	Brand	kWh	Brand
Pulau Banggi Phase 1	1,200	200	Mitsubishi	2x200, 1x250	Cummins	720	Fiamm
Pulau Banggi Phase 2		1,000	Mitsubishi	2x400	Caterpillar	2,160	Fiamm
Tanjung Labian phase 1	800	700	Mitsubishi	2x500, 1x350	Cummins	4,320	Fiamm
Tanjung Labian phase 2		500	Mitsubishi	-	-	-	-

A brief description of the system parameters and components used in each location are presented as follows:

3.2.3.1 Diesel Generators

Diesel generators usually employed to meet the peak demand, mainly when there is no output from the PV panels (Nfah & Ngundam, 2008). Capital and replacement costs in this study were considered to be 220 $/kW and 200 $/kW respectively, where maintenance cost was 0.030 $/hour (Hossain et al., 2016). All specifications are shown in Table 3.2 Diesel price depends on the location of each site, 2.9 RM/L in Tanjung Labian and 3.3 RM/L in Pulau Banggi. In such rural areas, fuel price could be more than 1.5 times the normal price because of the high cost of fuel transportation and storage problems (Anwari, Rashid, Muhyiddin, & Ali, 2012). The fuel prices in both locations are equal to 0.7 $/L and 0.8 $/L, respectively.

3.2.3.2 PV Module

PV system is employed to supply electrical power during the day from 7 am to 7 pm with a 20 minutes difference, when there is sunshine, otherwise, the diesel generators or battery banks take the role to supply the load. In this study, all specifications are shown in Table 3.2 where the capital cost and replacement costs of the PV in addition to a small maintenance cost of 10 $/year were considered to be 2,000 $/kWp (Hossain et al., 2016).

3.2.3.3 Converter

Converters size are compatible with the PV arrays size to ensure a full supply of PV power. Capital and replacement cost of the converter are 890 $/kW and 800 $/kW respectively, while 10 $/year is considered for maintenance. The operational lifetime was considered to be 15 years (Hossain et al., 2016).

3.2.3.4 Battery energy storage

Fiamm type batteries are employed in both sites (Pulau Banggi and Tanjung Labian). The capacity curve of the batteries is shown in Figure 3.7.

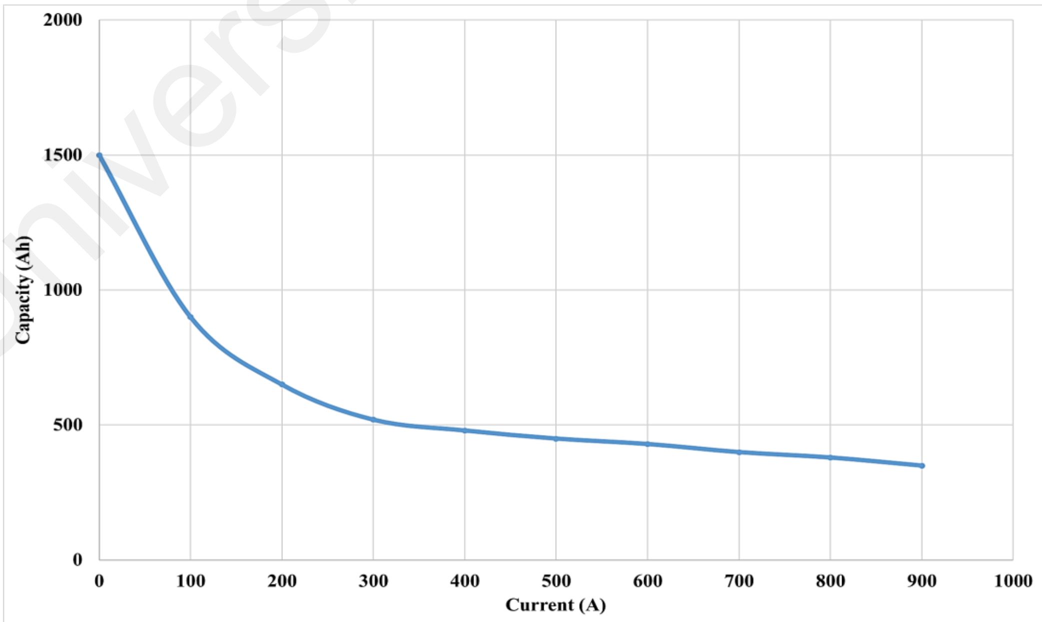


Figure 3.7: Batteries' capacity curve Capacity (Ah) VS discharge current (A)

Each cell is made up of 2V and connected as follows:

I. In Pulau Banggi: Four strings, each string with capacity 1,500 Ah and contains 240 units.

II. In Tanjung Labian: Six strings, each string with capacity 1,500 Ah and contains 240 units. Battery's prices were taken according to the local market of 1,200 $/unit for capital cost and 1,170 $/unit for replacement where all specifications are shown in Table 3.2.

Table 3.2: Technical parameters for all system components

<table>
<tr><th>Equipment</th><th>Factor</th><th>Value</th><th>Equipment</th><th>Factor</th><th>Value</th></tr>
<tr><td rowspan="7">PV</td><td>Rated power (kWp)</td><td>1,200</td><td rowspan="4">Converter</td><td>Rated Power (kW)</td><td>1,200</td></tr>
<tr><td>Temperature co-efficient (/°C)</td><td>-0.5</td><td>Lifetime (Years)</td><td>15</td></tr>
<tr><td>Derating factor (%)</td><td>80</td><td>Rectifier Efficiency (%)</td><td>85</td></tr>
<tr><td>Operation temperature (°C)</td><td>47</td><td>Inverter Efficiency (%)</td><td>90</td></tr>
<tr><td>Lifetime (Years)</td><td>25</td><td rowspan="7">Diesel generators</td><td>Rated power (kW)</td><td>350, 400 & 500</td></tr>
<tr><td>Efficiency (%)</td><td>13</td><td>Load minimum Ratio (%)</td><td>30</td></tr>
<tr><td>Nominal capacity (Ah/Cell)</td><td>1,500</td><td>Minimum running hours (hour)</td><td>30,000</td></tr>
<tr><td rowspan="4">Battery</td><td>Nominal capacity (kWh/Cell)</td><td>3</td><td>Rated power (kW)</td><td>200 &250</td></tr>
<tr><td>Nominal voltage (V/Cell)</td><td>2</td><td rowspan="2">Load minimum Ratio (%)</td><td rowspan="2">25</td></tr>
<tr><td>Lifetime per battery (Years)</td><td>7</td></tr>
<tr><td>Round trip efficiency (%)</td><td>80</td><td>Minimum running hours (hour)</td><td>15,000</td></tr>
</table>

3.3 Evaluation criteria

The modeling concepts and theoretical calculations that are used by HOMER mainly depend on minimizing the costs. Each dispatchable energy source in HOMER are economically represented by two main values; fixed cost in ($\hour), and a marginal cost of energy in ($\kWh). These values represent all costs associated with producing energy with that power source that hour. Based on these values, HOMER searches for the best solution which can cover electrical\thermal loads as well as the operating reserve at the lowest cost. Satisfying the loads' demand and operating reserve is regarded as critical roles for HOMER, meaning that any cost will be accepted to avoid capacity shortage. On the other hand, if the proposed combinations of the dispatchable sources can equally supply the loads demand, then HOMER will choose the lowest cost combination. Furthermore, HOMER uses different algorithms to calculates the environmental impact as well as the technical evaluation process.

3.3.1 Economic evaluation

HOMER evaluates the economics for different combinations of renewable and nonrenewable energy resources using the following parameters:

I. Net Present Cost (NPC): HOMER the life-cycle cost is represented by the total NPC which includes capital, replacement, O&M, and fuel costs (Lanre Olatomiwa, Mekhilef, Huda, & Ohunakin, 2015). NPC is expressed in equation (3.1) (Lambert, Gilman, & Lilienthal, 2006):

$$\boldsymbol{C_{NPC}} = \frac{\boldsymbol{C_{ann,tot}}}{\boldsymbol{CRF(i,R_{proj})}} \tag{3.1}$$

Where, $C_{ann,tot}$, CRF, $i, and\ R_{proj}$ are the total annualized cost, capital recovery factor, annual real interest rate, and project life time respectively. Meanwhile, CRF is giving by equation (3.2) (Lambert et al., 2006):

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (3.2)$$

Where, N is the total number of years.

II. Cost of energy (COE): Represents the average cost per kilowatt-hour of the produced energy. COE is expressed in Equation (3.3) (Lambert et al., 2006):

$$COE = \frac{C_{ann,tot}}{E_{served}} \quad (3.3)$$

Where E is the total produced energy that include the total served loads, and the amount of energy sold to the grid per year. In this study, the interest rate and the project lifetime are considered as 6% and 25 yr, receptively. Based on the literature, these values were considered as the best values of the interest rate and lifetime of the project in most studies in this field in different parts of the world in general and in Malaysia in particular. Thus, a comparison with the other studies would be much effective and informative. Besides, discount and inflation rates on the investment costs are 8.12% and 2%, respectively. All prices that included in the simulation are in US dollars ($) at a rate of 1$=4.08 Malaysian ringgit.

3.3.2 Environmental evaluation

In any hybrid system which includes nonrenewable energy sources, an amount of CO_2 emissions would generate by the nonrenewable energy sources. Equation (3.4) is used to calculate this amount (Shezan et al., 2016):

$$tCO_2 = 3.667 \times m_f \times HV_F \times CEF_f \times X_c \quad (3.4)$$

Where, tCO_2 is the total amount of CO_2 emissions, m_f is the fuel quantity in (liter), HV_F is the fuel heating value in (MJ/L), CEF_f is the carbon emission factor in (ton carbon/TJ), and X_c is the oxidized carbon fraction. Meanwhile, 3.667 g of CO_2 includes 1 g of carbon.

3.4 Operating strategies

There are two main operating strategies employed in hybrid RE systems. Namely; Load Following (LF) and Cycle Charging (CC) dispatch strategies. In LF strategy, diesel generators are configured to supply the loads only in the event of unavailability of PV power output, while the PV arrays supply the load and charge the batteries in the event of excess electricity. On the other hand, diesel generators are used to meet load's demand and at the same time charge the batteries in CC strategy. LF strategy seems to be the optimal strategy as it helps to reduce excess energy and total NPC (Ngan & Tan, 2012), hence considered in this study analysis. However, the flowchart shown in Figure 3.8, illustrates the flow of energy in various cases of supplying the loads by the PV, diesel generators, and batteries in addition to the batteries charging cycles according to the system operating strategy.

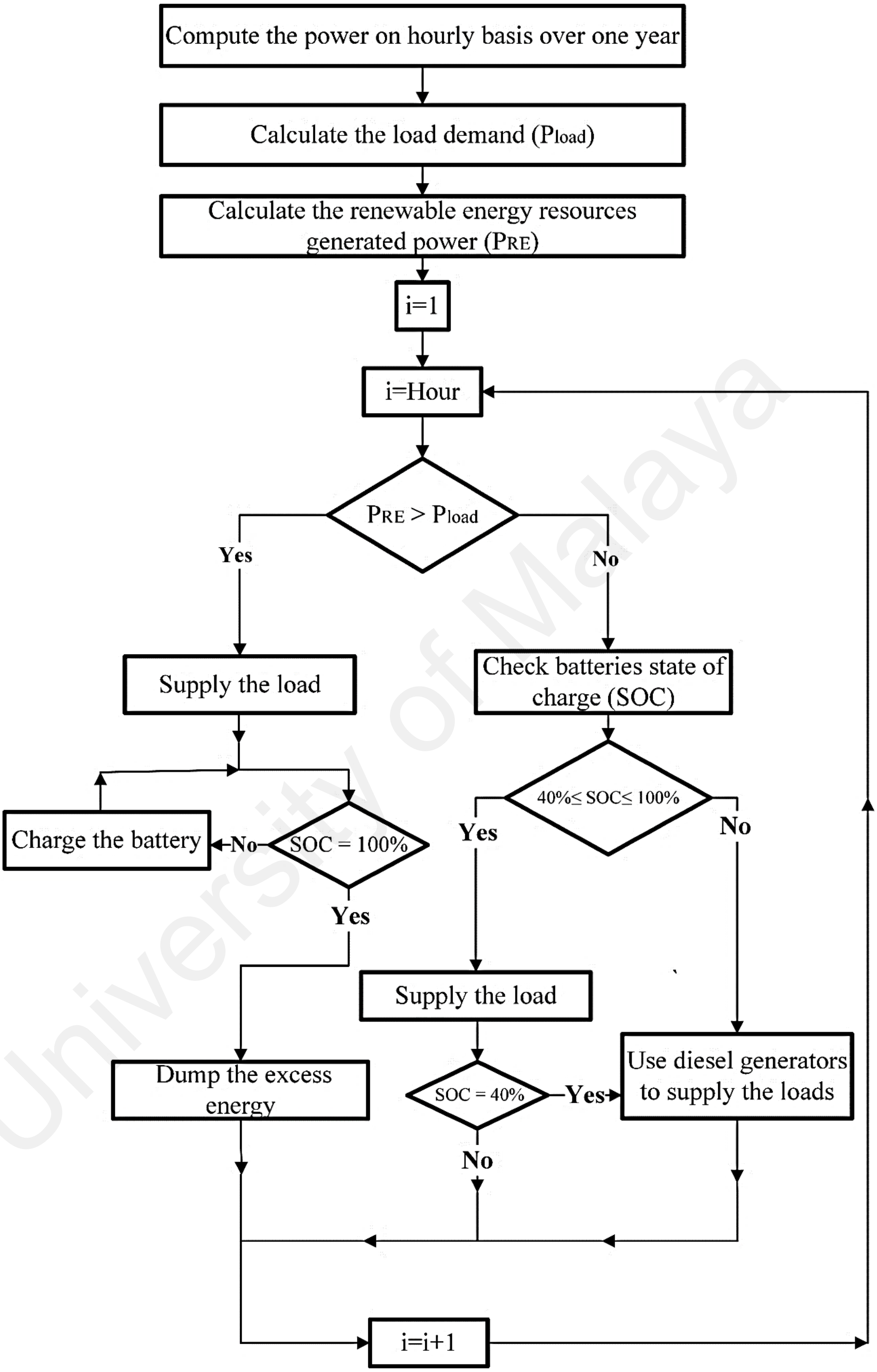


Figure 3.8: System's operating strategy

According to Figure 3.7, an overall energy management system is needed to control the flow of energy, where the system operates in different modes according to the surrounding atmospheric conditions. At normal operating conditions, where the sun is available, the control system gives the PV arrays the highest priority to supply the loads. Meanwhile, in the case of excess energy, the system will charge the battery using State of Charge (SOC) as an indicator. Once the battery is fully charged (SOC=100%), where any further excess energy can be used by dumped loads. In case of insufficient energy from the PV system, the battery will supply the loads until the minimum level (SOC = 40%) is reached, then the conventional diesel generators will supply the loads. The decision of the control system to operate any of the energy sources and charging/ discharging the battery takes place every hour based on the energy balance computation.

The operating reserve described by HOMER as the reliable amount of power that should supply if the RE supply suddenly decreased or the load demand suddenly increased. In this study, the operating reserve values are set to 10% of hourly loads and 25% of solar output. Meanwhile, these values are considered as the best average values by the designer of HOMER software, thus they were selected in this study. While the RF represents the fraction of the energy delivered to the load which produced from renewable power sources. HOMER calculates the RF using the following equation (3.5):

$$RF = \left(1 - \frac{E_{non-ren} + H_{non-ren}}{E_{served} + H_{served}}\right) x\ 100\% \qquad 3.5)$$

Where $E_{non-ren}$, $H_{non-ren}$ are the electrical and thermal energy produced by non-renewable in (kWh/yr) and E_{served}, H_{served} are the total served electrical and thermal loads in (kWh/yr), respectively. Meanwhile, the RE production represents the total amount of electrical energy that produced annually by the RE components of the power system.

3.5 Solar radiation prediction

In this section, standalone ANFIS (adaptive neuro-fuzzy inference system) and hybrid ANFIS models have been developed to predict monthly global solar radiation H(MJ/m^2) from sunshine duration $S(hr)$, maximum $T_{max}(°C)$, minimum $T_{min}(°C)$ air temperature, monthly rainfall $R(mm)$ and clearness index (K_t). The proposed hybrid models include ANFIS-PSO (particle swarm optimization), ANFIS-GA (genetic algorithm) and ANFIS-DE (differential evolution). To evaluate the capability and efficiency of the proposed models, several statistical indicators including; root mean square error (RMSE), relative root mean square error (RRMSE), correlation coefficient (r), co-efficient of determination (R^2), mean absolute bias error (MABE) and mean absolute percentage error (MAPE) are used.

A favorable correlation between (K_t), sunshine duration (n/N) and air temperature (T_{max}, T_{min}) is found as seen in (Yohanna, Itodo, & Umogbai, 2011). Where the K_t can be considered as an indicator for the atmospheric effects on the radiation, where the atmospheric extinction depends on the path length that radiation is used (Diagne, David, Lauret, Boland, & Schmutz, 2013) for a specific site, since it is a function of time of year, season, climatic condition and geographic location. Therefore, K_t is a vital measure to show the atmospheric effects on a given location (Kumar & Umanand, 2005). Where K_t also represents the ratio between monthly horizontal solar radiation (H) and extraterrestrial solar radiation (H_0). Air pollution has a significant effect on the atmospheric transmission thus, the clearness index is highly region dependence (Pan, Wu, Dai, & Liu, 2013). The following mathematical expressions (from 3.6 to 3.9) showed the relation between extraterrestrial and the other factors (Allen, Pereira, Raes, & Smith, 1998):

$$\delta = 23.45 \, sin\left(\frac{(n+284)360}{365}\right) \quad (3.6)$$

$$\omega s = cos^{-1}[-\, tan(\varphi) + tan(\delta)] \quad (3.7)$$

$$Ho = \frac{24\times3600}{\pi} Igs\left[1 + 0.033\, cos\left(\frac{360n}{365}\right)\right] \times \left[\left((cos(\varphi)cos(\delta)sin(ws)\right) + \left(\frac{\pi\, ws}{180} sin(\varphi)\, sin(\delta)\right)\right] \quad (3.8)$$

$$N = \frac{2}{15}\, cos^{-1}[-tan(\varphi)\;\; tan(\delta)] \quad (3.9)$$

Where, (N) is the daylight hour, δ and w_s are the solar declination and sunset hour angles respectively. Igs represents the solar constant equal to 1367 W/m^2, φ is the latitude of the location and n is the average number of days for each month. The value of Ho for each specific day at any geographical location is a constant value as it is irrespective factor of the yearly change (Shamshirband et al., 2015).

The collected data is classified into training and testing class. Then, these data are proposed to basic ANFIS alongside with hybrid ANFIS-PSO, ANFIS-GA and ANFIS-DE algorithms. A general schematic diagram of the proposed prediction models based upon the considered input parameters is shown in Figure 3.9.

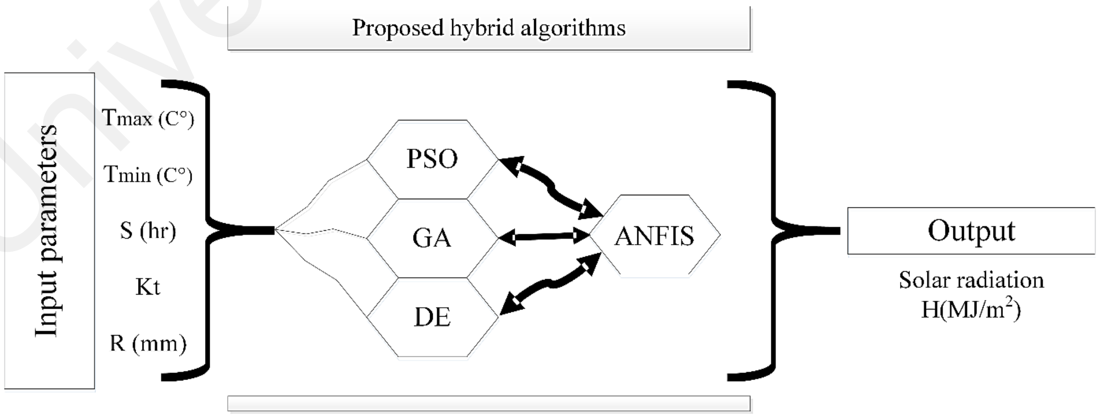


Figure 3.9: Schematic diagram of the proposed basic ANFIS and hybrid ANFIS- PSO, GA and DE algorithms

Fixed number of hidden layers are used, where the ANFIS is trained to model the input-output data relationship. Real data is obtained when the system achieved stable performance. After that, the performance processing is tested over the measured and predicted data. The general simulation process according to different algorithms is shown in Figure 3.10.

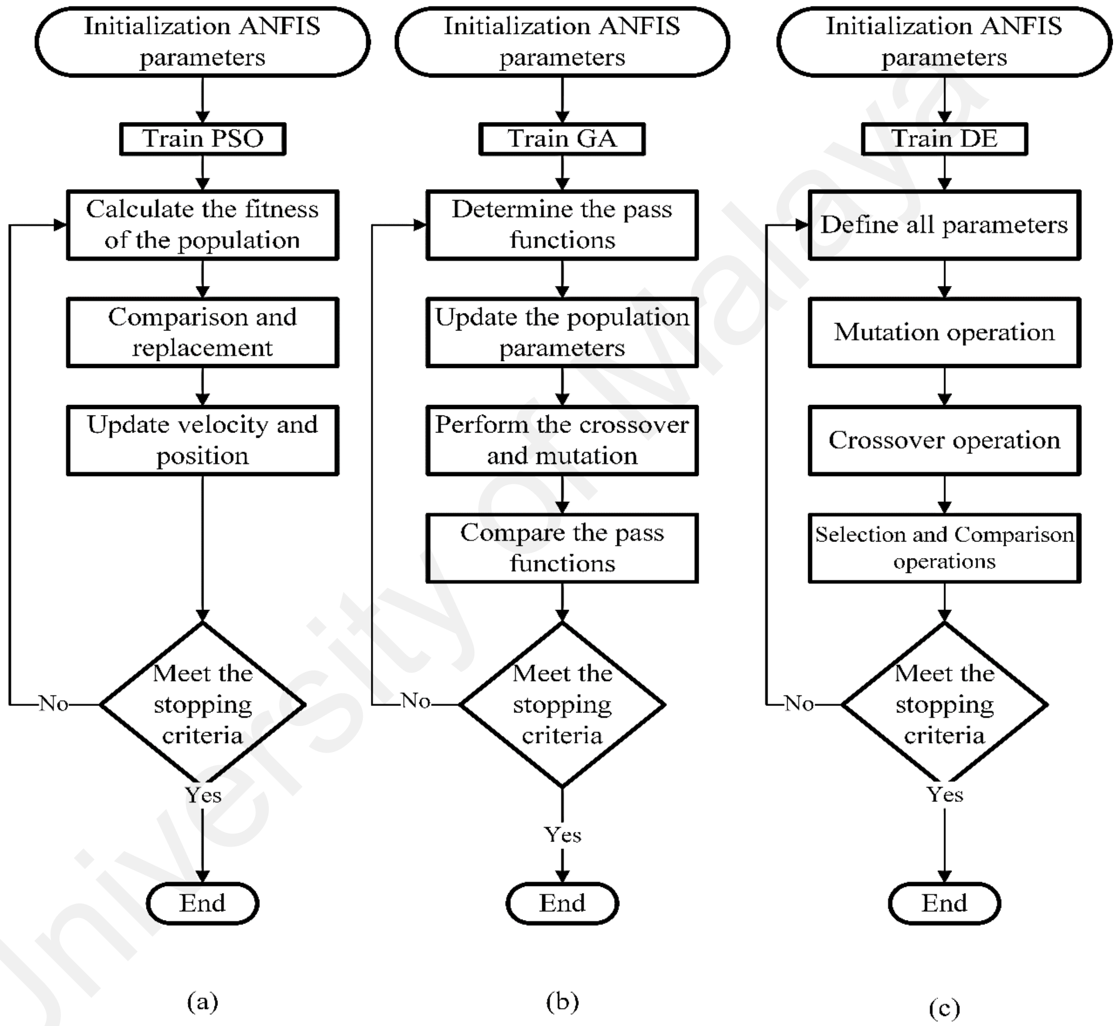


Figure 3.10: General simulation setup of all proposed models (a) ANFIS-PSO, (b) ANFIS-GA, and (c) ANFIS-DE

3.5.1 Site specifications

A measured dataset over the period starting from January 2006 to December 2014 (108 months) are used. The measured datasets were collected from Malaysian Meteorological Department (MMD) located at Kuala Terengganu (MMD, 2016) at 5° 23' N and 103° 6'

E where the latitude is 15 m above sea level. The selection of this location is come due to being the closet location to Sabah, (That contains the proposed locations in this study), with the recorded values of solar radiation as the recorded values of solar radiation are rarely found as illustrated in the literature. There is no common rule used for deciding datasets size. Meanwhile, the best choice was 84-month starting from 2006 for training (80%) and 24-month for testing (20%). Table 3.3 shows a portion of the input that used in this work.

Table 3.3: Description samples of monthly input data for training and testing process.

Training Data					
Indicator	$T_{max}(°C)$	$T_{min}(°C)$	K_t	**R(mm)**	**S (hr)**
Max.	30.10	27.00	0.62	1580.40	12.02
Min.	26.90	22.40	0.31	0.20	11.99
St. dev.	0.62	0.94	0.06	271.23	0.01
Mean	28.57	25.40	0.47	243.84	12.01
Testing Data					
Indicator	$T_{max}(°C)$	$T_{min}(°C)$	K_t	**R(mm)**	**S (hr)**
Max.	30.10	28.10	0.63	832.20	12.02
Min.	27.40	23.80	0.28	0.00	11.99
St. dev.	0.76	1.05	0.08	188.56	0.01
Mean	28.80	25.73	0.48	211.73	12.01

3.5.2 Artificial intelligence algorithms

Different types of artificial intelligence algorithms had been used. Where, the proposed hybrid models include ANFIS merged with PSO, GA and DE respectively. This addition creates hybrid models elicit the best in each model with the maximum allowable efficiency.

Precise and dependable solar radiation data are hard to find. Thus, accurate estimation of these data over different artificial intelligence techniques became really necessary, especially for future development purposes. In these regards, several hybrid algorithms based on ANFIS technique are performed to predict monthly solar radiation from widely used metrological data. In this regard, the basic procedure of controlling the quality and validating the data is based on the ANFIS technique then each hybrid model performed the data in different process with regard to the proposed hybrid algorithm in each model (PSO, GA and DE), which would be shown later in this section.

Basically, the ANFIS system controller is derived by the Linear Quadratic Gaussian (LQG) control method (Gu & Oyadiji, 2008). The process within this control technique entails the estimating the structure responses, then applying Kalman filter to classify the responses, and finally stating feedback optimal controller to control the response, where the controlled response data is used to train the ANFIS controller. Meanwhile, the first step is to divide the input data into class then, the second step is operating by adjusting the neurons number within hidden layers in order to efficiently training the network (A Mellit, Arab, Khorissi, & Salhi, 2007). The training process considered as a very important stage to learn the model the relation between the input and output. Then, the system is accompanied with the other modules to increase the reliability and accuracy of the prediction capability and outcomes. Finally, the data are classified to obtain real values when the proposed performance is achieved. However, in this study the final datasets (output and input) were collected and repeated several times – this step took long period to be completed, then they were compared and tested to ensure getting higher reliability results.

3.5.2.1 Adaptive neuro-fuzzy inference system (ANFIS)

ANFIS is a type of artificial neural network based on Takagi–Sugeno fuzzy inference system. It has the benefits of both fuzzy logic and neural networks in a single framework with learning capability. This work is used five inputs, x, y, z, s, t and one output f. The first-order Sugeno fuzzy model (Sugeno & Kang, 1988), has $f_{1,}\ f_{2\ \ldots\ldots}\ f_n$ rules, where n is the maximum number of rules (Nikolić, Petković, Shamshirband, & Ćojbašić, 2015) as follow:

Rule 1: if x is A and y is D and z is G and s is J and t is M then

$$f_1 = q_1x + p_1y + r_1z + g_1s + h_1t + l \quad (3.10)$$

Rule 2: if x is B and y is E and z is H and s is K and t is N a then

$$f_2 = q_2x + p_2y + r_2z + g_2s + h_2t + l \quad (3.11)$$

Rule n: if x is C and y is F and z is I and s is L and t is O then

$$f_{\mathrm{n}} = q_{\mathrm{n}}x + p_{\mathrm{n}}y + r_{\mathrm{n}}z + g_{\mathrm{n}}s + h_{\mathrm{n}}t + l \quad (3.12)$$

Five inputs, one output and multiple rules ANFIS structure shown in Figure 3.11.

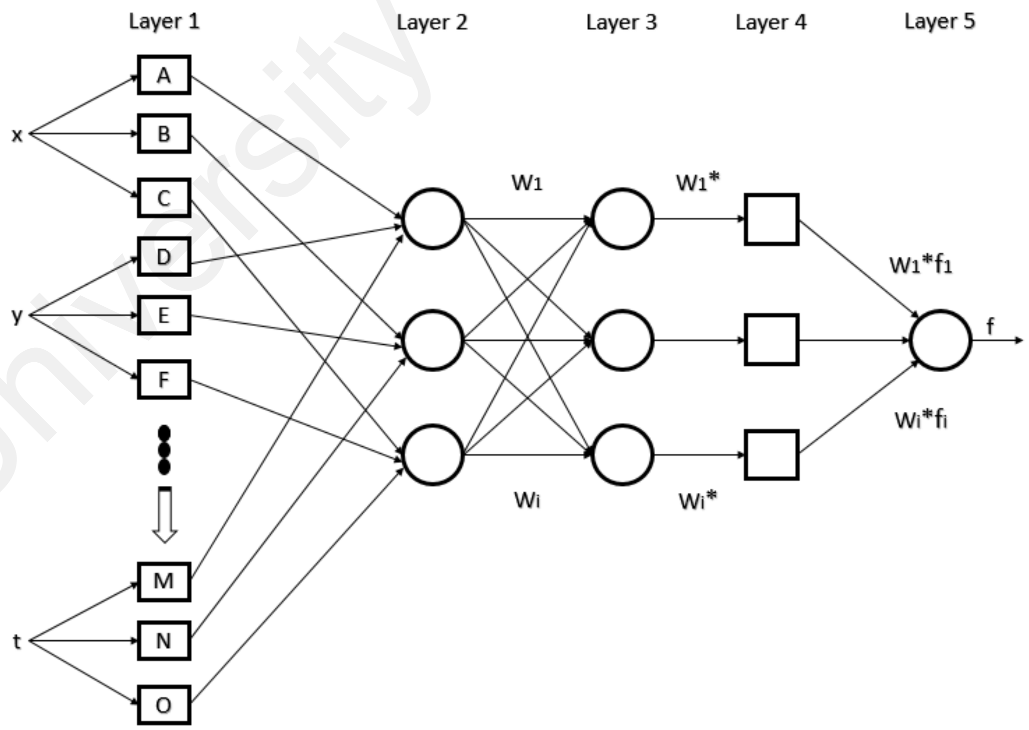


Figure 3.11: Five inputs, multiple rules and one output ANFIS structure

All Nodes at the same layer have similar functions. The i^{th} node output in layer l is chosen as $O_{l,i}$. where the first layer contains input membership functions (MFs) and delivers input values to the next layer. Every node i is an adaptive node with a node function:

$$o_{l,i} = \begin{cases} \mu_{A,i}(x), & i = 1,2,3 \\ \mu_{D,i-3}(y), & i = 4,5,6 \\ \mu_{G,i-6}(z), & i = 7,8,9 \\ \mu_{J,i-9}(s), & i = 10,11,12 \\ \mu_{M,i-12}(t), & i = 13,14,15 \end{cases} \tag{3.13}$$

Where x or y or z or s or t or u are the input of node i and Ai or $Di-3$ or $Gi-6$ or $Ji-9$ or $Mi-12$ are an associated linguistic label. In other words, $O_{l,i}$ is the membership grade of a fuzzy set *A*,*D*,*G*,*J* and *M* (*A1, A2, A3, D1, D2, D3, G1, G2, G3, J1, J2, J3, and M1, M2, M3*). The membership function can be any appropriate function where it represented here by $\mu_{A,i}(x)$, $\mu_{D,i-3}(y), \mu_{G,i-6}(z)$, $\mu_{J,i-9}(s)$ and $\mu_{M,i-12}(t)$. The generalized bell function used in which it has the best abilities for the generalization of nonlinear parameters.

$$\mu_{A,i}(x) = \frac{1}{1+(\frac{x-ci}{ai})^{2bi}} \tag{3.14}$$

Where a*i*, b*i* and c*i* are the variable set. Functions vary accordingly as the values of these variables changed.

The second layer (commonly called membership layer) multiplies first layer output to produce new out coming output. Each node in this layer (2nd) considered as fixed node and its output is the consequent of all input values.

$$o_{2,i} = w_i = \mu_{A,i}(x)\mu_{D,i-3}(y)\mu_{G,i-6}(z)\mu_{J,i-9}(s), \mu_{M,i-12}(t)\mu_{P,i-15}(u). \text{ For } i = 1,2,3. \tag{3.15}$$

In the third layer, all node i computes the rule's firing strength ratio to all rules sum of all firing strengths. The outputs known as the normalized weights (Landeras, López, Kisi, & Shiri, 2012).

$$o_{3,i} = w^*{}_i = \frac{w_i}{w_1+w_2+w_3}. \text{For } i = 1, 2, 3. \tag{3.16}$$

The fourth layer provides the output values resulting from the inference of the rules, combines the overall inputs of the previous layer and converts the classification results into the final output.

$$o_{4,i} = w_i^*. f_i = w_i^*. (q_i x + p_i y + r_i z + g_i s + h_i t + l_i) \tag{3.17}$$

The applied learning algorithm identified ANFIS structure. In this algorithm, the functional signals of the forward pass, proceed until the defuzzification layer (the fifth layer).

$$o_{5,i} = \sum_i w_i^*. f_i = \frac{\sum_i w_i^* . f_i}{\sum_i w_i} \tag{3.18}$$

Consequent parameters are identified by the least squares estimate. In the backward pass, the error rates propagate backward and Premise parameters are updated by the gradient descent. Later PSO, GA and DE optimization algorithms are used to tune the membership function of the ANFIS model to ensure minimum error in the solar radiation prediction.

3.5.2.2 Particle swarm optimization (PSO)

A novel computational approach founded earlier in 1995 by (Eberhart & Kennedy, 1995) as a method of continuous and discontinues decision-making optimized function. The PSO was initially developed by referring to biological and sociological animal behavior, like a school of fishes looking for their food. Moreover, PSO based to population search method as each potential solution is represented as a particle in a population (called swarm). The optimal state reached when each particle position changes in multidimensional search space until or when computation limitations are exceeded. The main swarm optimization problem related to N particles' positions, where it assigned to random swam in the D-dimensional space. Each position links to a candidate solution whereas, each particle in the swarm is counted by a scoring function that obtains values of how good it explains the problem. PSO has been applied in many literatures for optimization purposes (Mohandes, 2012), where the global optimal position is founded when all particles are in the D-dimensional space solution and reached its own best position overall knowing positions. The following rules update particles new assigned positions as well as it is velocity:

$$V_i(t) = \omega V_i(t-1) + \rho_1 \left(X_{Pbest_i} - X_i(t) \right) + \rho_2 \left(X_{Gbest_i} - X_i(t) \right) \tag{3.19}$$

$$X_i(t) = X_i(t-1) + V_i(t) \tag{3.20}$$

Where ρ_1 and ρ_2 represent random variables in which $\rho_l = r_l c_l$ with $r_l \sim U(0,1)$ and c_l is the positive acceleration constants. Meanwhile, ω is the weight of inertia (Pousinho, Mendes, & Catalão, 2011). Figure 3.12 summaries the functional procedure of PSO algorithm.

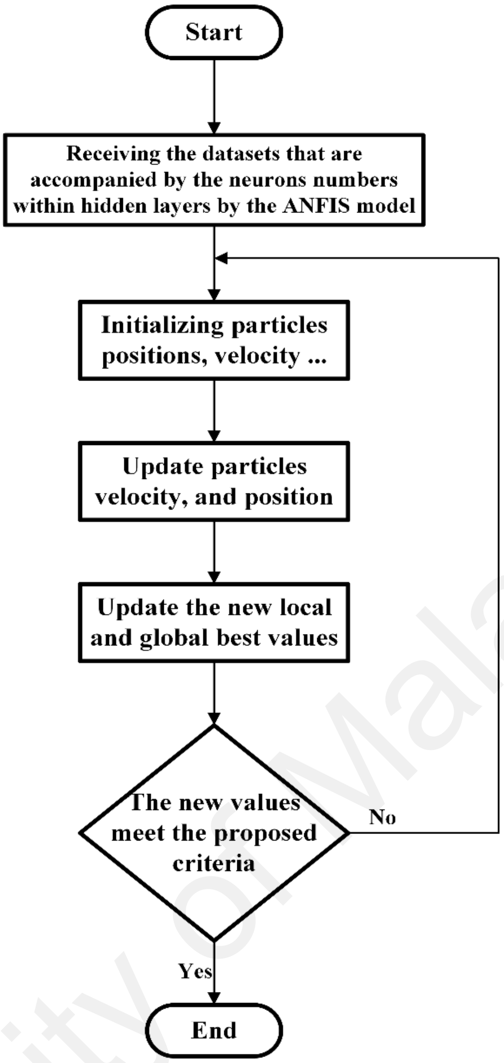


Figure 3.12: The functional Flowchart of PSO algorithm

Table 3.4 shows the main parameters of the proposed PSO model, which are the population size of the domain, damping ratio, the weight of inertia, personal, global learning coefficients, and the maximum number of iterations. For this case study, we determined these parameters' values over trial and error process.

Table 3.4: Parameter characteristics for ANFIS-PSO

Parameter	**Value**
Population	40
Damping ratio	0.99
Weight of inertia	1
Personal learning co-efficient	1
Global learning co-efficient	2
Number of iterations	1000

3.5.2.3 Genetic algorithm (GA)

An advanced search and optimization technique, originally settled by Holland (Holland, 1992), and applied in artificial intelligence topics by representing complex structures using vectors of 1's and 0's. GA emulates the principle of natural genetics development and established optimized functions by comparing two different common approaches such as direct exhaustive search. GA is much firm in finding global optimal solutions in the context of the optimal solution to a large combinatorial problem which is the main advantage of this system, and this property makes it mostly used in optimization multi-objective problems. GA emulates the natural evolution processes using three operators (selection, crossover and mutation). In the first step of optimization technique, it evaluates the pass's functions of the selected configuration (called a chromosome), then it provides services by maintaining a population of M solutions. If the evaluated chromosome has a lower annualized cost of the system (ACS) than the lowest known ACS value got at the prior iterations, the chromosome considered to be the optimal solution where this would minimize problem iteration. However, this optimum solution might be switched with any better solutions. After that, the selection procedure of best solution will subject to the crossover and mutation processes to produce a new number of generations. This procedure will continue until reached the pre-specified satisfied convergence.

In this study, there are some specific parameters are used in the proposed GA model which include, population size, mutation percentage, mutation rate, crossover percentage and selection pressure. These parameters are listed Table 3.5.

Table 3.5: Parameter structure for ANFIS-GA

Parameter	Value
Population	100
Creation function	Uniform
Mutation percentage	0.5
Mutation rate	0.1
Crossover percentage	0.7
Selection pressure	8
Number of iterations	1000

The functional flow chart for GA is shown in Figure 3.13.

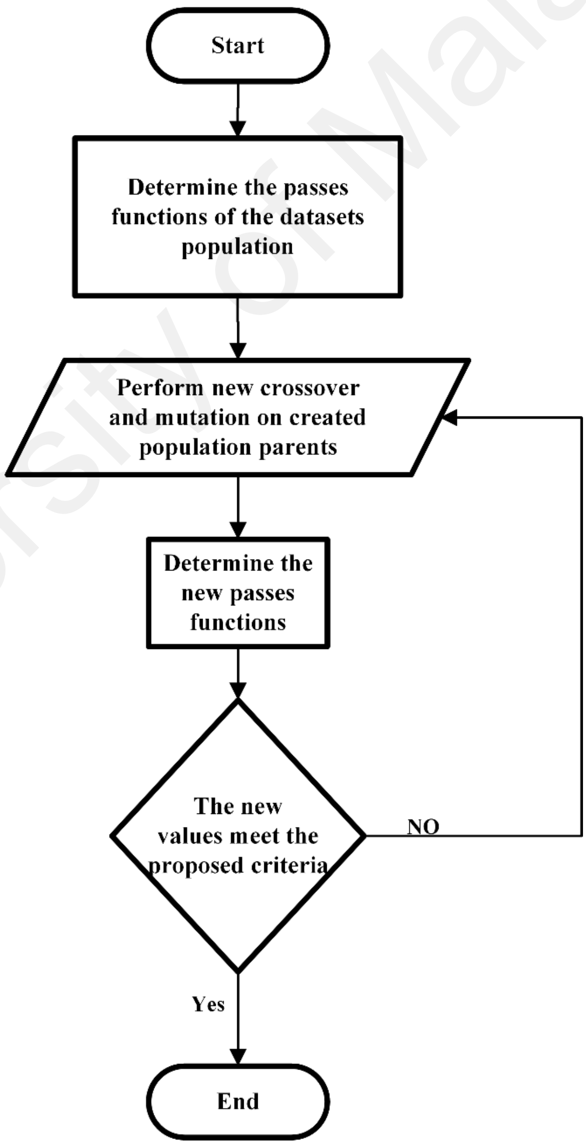


Figure 3.13: General description of GA work procedure flowchart

3.5.2.4 Differential evolution (DE)

An effective intelligent algorithm used for optimization purposes with respect to basic optimized operations of mutation, crossover and selection. This technique is a parallel direct search method, utilized NP, D-dimensional parameter vectors where it does not change over minimization procedure and acts as a population process for each generation G. A randomly initial population vector is chosen, which covers the entire parameter space and uniform probability distribution would assume for all random choices. If the preliminary solution is available, DE generates the difference weighted between two population vectors to a third vector to create new parameter vectors (mutation operation) as follows:

$$v_{i,G+1} = x_{i,G} + F(x_{r2,G} - x_{r3,G}) \quad (3.21)$$

Where $x_i, G, i = 1,2,3, \dots, NP$ are mutant vectors generated according to $v_{i,G+1}$ with $r_1, r_2 and\, r_3$ are randomly chosen integers $\in [1,2,3, \dots, NP]$ while NP should contain these values, where i and F should contains real values different from each other $\in [1,2,3, \dots, NP]$. Then trial vector founded by mixing the mutated vector's parameters with other predetermined vector parameters, in a mixing process (crossover operation) which is clarified as follows:

$$u_{i,G+1} = (u_{1\,i,G+1}, u_{2\,i,G+1}, \dots, u_{d\,i,G+1}) \quad (3.22)$$

$$u_{\,ji,G+1} = \begin{cases} v_{ji,G+1}\; if\; (randb(j) \leq CR\; or\; j = rnbr(i) \\ x_{ji,G+1} if\; (randb(j) > CR\; or\; j \neq rnbr(i) \end{cases} \quad (3.23)$$

Where $u_{i,G+1}$ and $x_{i,G}$ are the trailer and target vectors, respectively. $randb(j)$ is the J^th uniform random evaluation $\in [0.1]$, $rnbr(i)$ is a random value index $\in [1,2,3, \dots, d]$ and CR is the crossover constant that user specified . Finally, the selection operation used the trial vector that yields lower cost function value than the target vector, then it becomes the target value in the following generation. NP competitions considered like one generation procedure as each population vector have to serve once as the target vector. Deep description of standard DE can be found in (Storn & Price, 1997). Table 3.6 presents the main structure of the proposed DE model.

Table 3.6: Parameter structure for ANFIS-DE

Parameter	Value
Crossover probability	0.1
Scaling factor lower bound	0.2
Scaling factor upper bound	0.8
Number of iterations	1000

The functional flow chart for DE is shown in Figure 3.14.

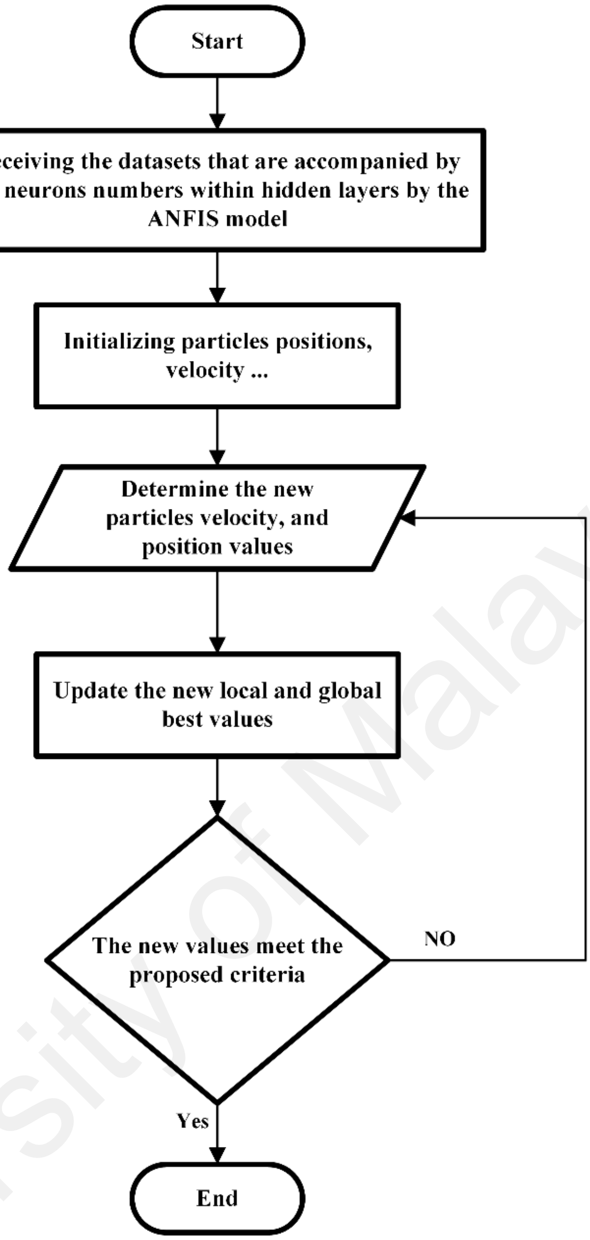


Figure 3.14: General description of DE work procedure flowchart

3.5.3 Performance evaluation

To describe the performance and to validate the precision accuracy of each model, seven statistical indicators were used, also a comparison between the proposed hybrid ANFIS models in this study and another model that were previously performed to predict solar radiation at different parts of the world. All statistical indicators used in this work are explained and verifies as follows (Mohammadi, Shamshirband, Anisi, Alam, & Petković, 2015):

a. The mean absolute percentage error (MAPE):

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{P_{i,c} - P_{i,m}}{P_{i,m}}\right| \times 100 \quad (3.24)$$

b. The mean absolute bias error (MABE):

$$MABE = \frac{1}{n}\sum_{i=1}^{n}\left|P_{i,c} - P_{i,m}\right| \quad (3.25)$$

c. The root mean square error (RMSE):

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_{i,c} - P_{i,m})^2} \quad (3.26)$$

d. The relative root mean square error (RRMSE):

$$RRMSE = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_{i,c} - P_{i,m})^2}}{\frac{1}{n}\sum_{i=1}^{n}P_{i,m}} \times 100\% \quad (3.27)$$

According to (Ertekin & Yaldiz, 2000), the precision capability of a model is founded in different ranges defined as follows:

$$\begin{pmatrix} \text{Excellent for RRMSE } < 10\%; \\ \text{Good for } 10\% < \text{ RRMSE } < 20\%; \\ \text{Fair for } 20\% < \text{ RRMSE } < 30\%; \\ \text{Poor for RRMSE } > 30\%. \end{pmatrix} \quad (3.28)$$

e. The correlation coefficient (r):

$$r = \frac{\sum_{i=1}^{n}(P_{i,c} - P_{i,c,ave}).(P_{i,m} - P_{i,m,ave})}{\sqrt{\sum_{i=1}^{n}(P_{i,c} - P_{i,c,ave}).\sum_{i=1}^{n}(P_{i,m} - P_{i,m,ave})}} \quad (3.29)$$

f. Co-efficient of determination (R^2):

$$R^2 = \frac{[\sum_{i=1}^{n}(P_{i,c} - P_{i,c,ave}).(P_{i,m} - P_{i,m,ave})]^2}{\sum_{i=1}^{n}(P_{i,c} - P_{i,c,ave}).\sum_{i=1}^{n}(P_{i,m} - P_{i,m,ave})} \quad (3.30)$$

Where $P_{i,c}$ is the i^{th} predicted value and $P_{i,m}$ is the i^{th} measured data. $P_{i,c,ave}$ and $P_{i,m,ave}$ are the mean of the predicted and measured values respectively, where n is the total number of observed data.

3.6 Flexible hybrid renewable energy system design

In this section, the proposed hybrid system is designed to correctly combine the best utilization of all parts to obtain the maximum possible benefits. HOMER software is used to model, optimize the system, and conduct sensitivity analysis. This system is designed according to the analysis which has carried out of the proposed hybrid systems in Pulau Banggi and Tanjung Labian and the analysis of on-grid PV modules in sections (3.2, 3.3, 3.4, and 3.5) as an effective measurement for the evaluated benefits and risk. This section proposed a typical remote village loads in Tanjung Labian thus, the designing analysis the explained analysis could be used as an effective tool for future projects over off-grid and on-grid connections.

3.6.1 Site specifications

The work examines a typical Malaysian village that is remotely located on the eastern side of Malaysia at Tanjung Labian, Sabah. This area is described in section (3.2.1) in deep details. All metrological parameters, including relative humidity, wind speed, and solar irradiation data were extracted from NASA website (NASA).

3.6.2 Load data

The load profile was calculated based on a previous study that determined the hourly load profile for a typical remote Malaysian village household in a tropical area. It took into account the consumer's behavior on a weekly basis (Ismail, Moghavvemi, & Mahlia, 2013). The loads used in such households usually contain lights, fan, TV, refrigerator, and another mini appliance. In this study, a small village comprises of 35 households is considered, and the load profile is shown in Figure 3.15 (a) and (b) of the hourly and yearly load profiles, respectively. In the morning, there are some small loads, which peaked at noon (213.60 kWh), then the loads decrease simultaneously. However, the total annual average load was 2,138.50 kWh/day. In the meantime, the day-to-day variability and time-step variability were assumed to be at low variation values of 5%, due to the equatorial location, since there is no distinction between summers and winters. The operating reserve is described by HOMER as the reliable amount of power that should supply if the RE supply suddenly decreased or the load demand suddenly increased. Meanwhile, 10% is calibrated for operating reserves of hourly loads and 25% solar energy output.

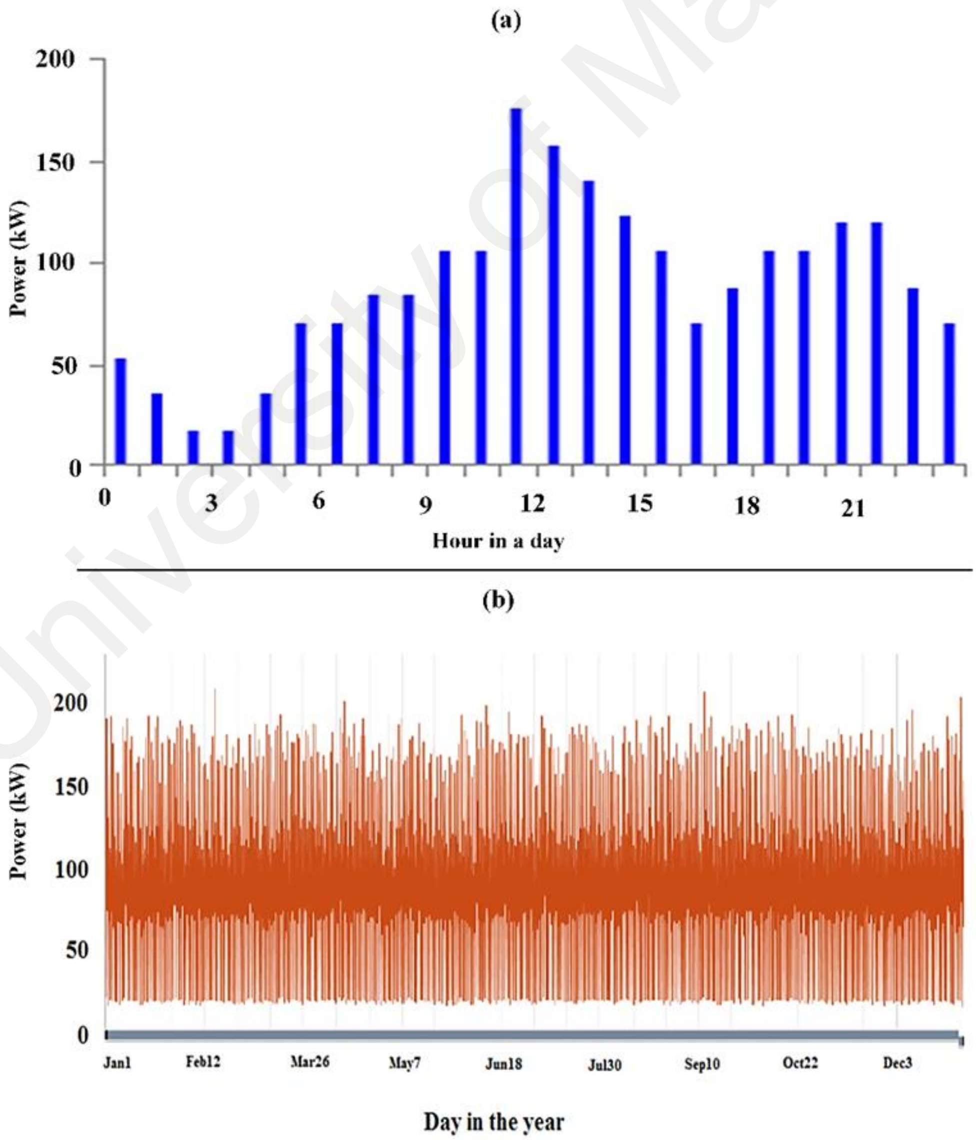


Figure 3.15: Load Profile: (a) Hourly load profile (b) Yearly load profile

The system is subjected to several changes including a grid connection to quantify the performance merits of the system mainly to find an optimal solution that can withstand over the whole period of the project's lifetime at both off-grid and on-grid connections. The system's procedure is detailed in Figure 3.16.

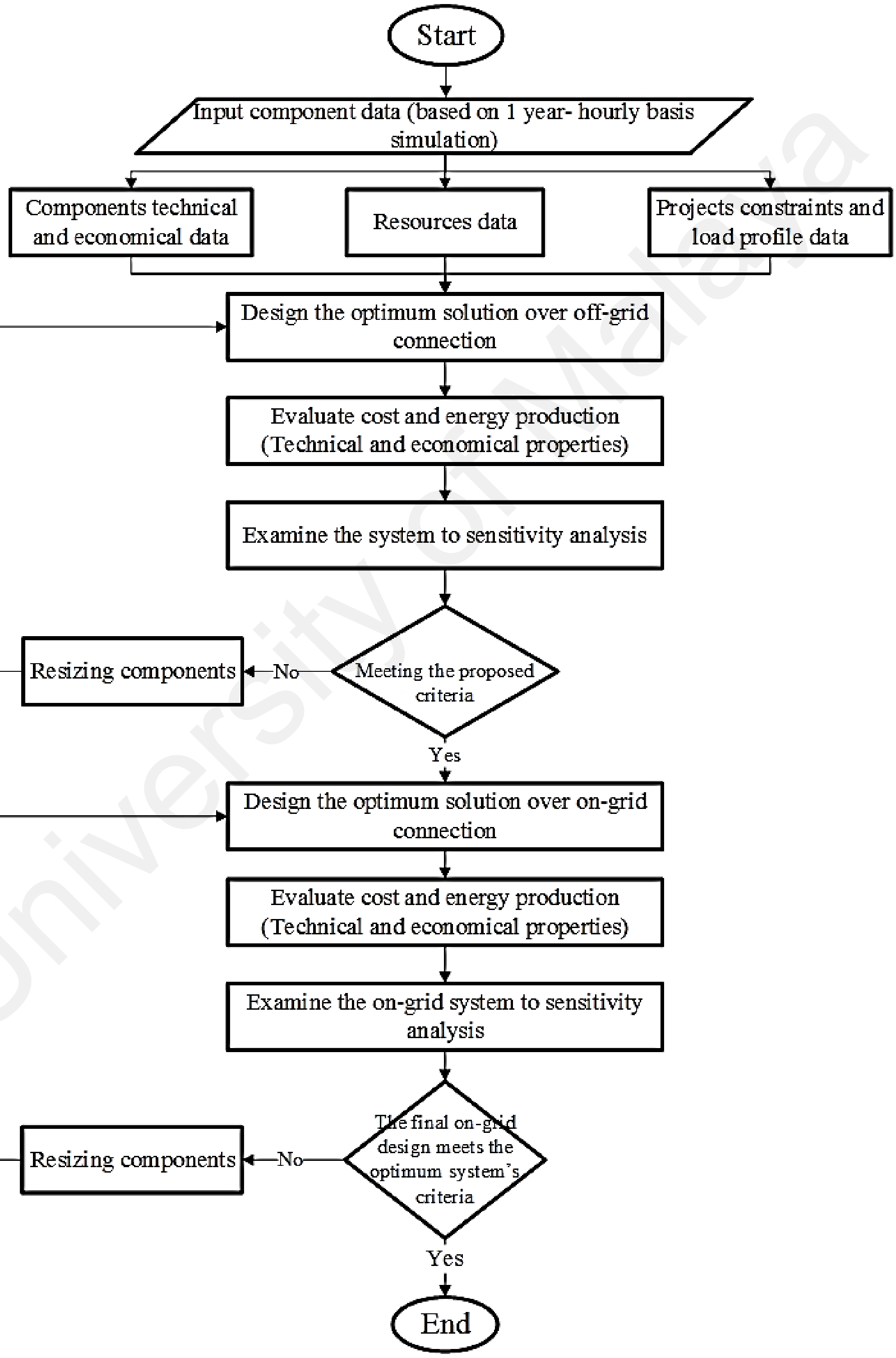


Figure 3.16: System procedure flowchart

3.7 Chapter summary

This chapter firstly, analyzes the data collection, derivation and preformation for the proposed sites in the study; this is followed by operating strategies using in this work and then the modeling and analyzing of operational performance, which includes all possible existing, hypothetical and optimized scenarios using HOMER software. Followed by discussing the method of predicting solar radiation using hybrid ANFIS mixed with GA, POS and DE algorithms since soft computing seems to exhibit good learning and prediction capabilities when used for various engineering applications.

Finally, a creative method of designing an optimal flexible system over both off-grid and on-grid systems is discussed. Where, the system design is opposed to the major conditions that may affect the project at any period during the it is lifetime in both off-grid and on-grid connections, by considering deep analysis overall technical, economical and environmental aspects.

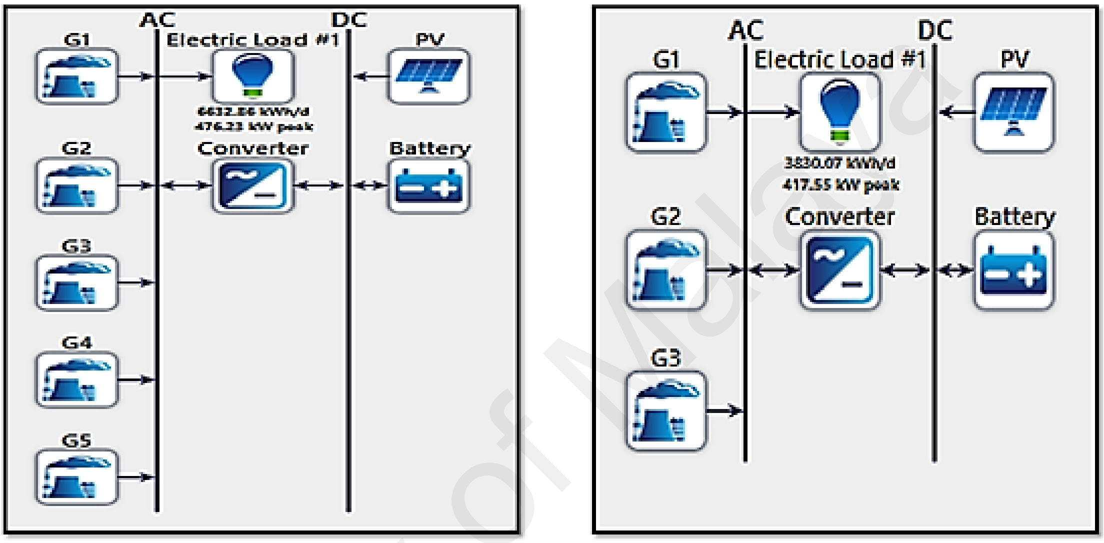
CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results of the methodology that earlier highlighted in the previous chapter. Also, this chapter includes a discussion of all results that are presented within this study. The results of analyzing the performance of the selected locations in Pulau Banggi and Tanjung Labian, including system modeling and simulation using HOMER software, description of all existing and possible scenarios, the optimum design, and investigating the potential of using standalone RE systems. In addition to investigate each scenario overall technical, economic, and environmental aspects. Moreover, the result of predicting solar radiation using hybrid ANFIS algorithms is explained and discussed in this chapter. Correspondingly, a comprehensive evaluation of the capability and efficiency of the proposed models using several statistical indicators such as; RMSE, R^2, and MABE. Meanwhile, a comparison with other benchmarked studies is carried out in order to validate the prediction accuracy and suitability of the proposed models. Furthermore, the results of designing the optimal-flexible hybrid RE system over off-grid and on-grid systems are also showed and explained. The effects of changing major parameters that might influence the system performance are investigated based on technical, economic and environmental aspects. Besides, a detailed sensitivity analysis is applied to the designed system at off-grid and on-grid connections to verify the optimum design.

4.2 Performance analysis of the hybrid PV/diesel/battery system

In this section, the results of the technical, economical and environmental analysis for different system configurations, including standalone diesel generators, existing hybrid PV/diesel/battery and hypothetical standalone RE scenario (100% PV/battery) systems were presented and discussed. Furthermore, included is the result of the sensitivity study applied to examine the effects of changes in fuel cost, PV cost, battery prices and demand growth over the years. According to Figure 4.1, an overall energy management system is needed to control the flow of energy, where the system is operated in different modes according to the surrounding atmospheric conditions as explained in section (3.4). The results for each station is discussed separately based on diagrams showed in Figure 4.1(a) and (b).



(a) Pulau Banggi **(b) Tanjung Labian**

Figure 4.1: Existing hybrid system in both location implemented in HOMER (a) Pulau Banggi (b) Tanjung Labian

4.2.1 Pulau Banggi

4.2.1.1 Standalone diesel system (Baseline model)

This scenario was simulated based on the existing PV/diesel/battery hybrid model using the available data. This is needed to accurately quantify the impact of injecting PV on NPC, COE, fuel consumption, running hours and other characteristics. Where both electrical penetration and diesel generator operation seems to be directly influenced using PV and batteries.

In this site, the system depended on the largest generators (both 400 kW) to deliver over 95% of the total energy production as shown in Table 4.1. The COE is 0.276 $/kWh and NPC is $8,545,703 which is the lowest COE compared to all other scenarios using the same operating conditions of fuel and component prices. The systems' capital, replacement, operation and maintenance, fuel, operational and salvage costs are $319,000, $239,453, $1,428,387, $6,595,138, $643,548 and $36,270 respectively, over the project period with 0% renewable penetration and excess energy.

Table 4.1: System operational behavior (Pulau Banggi)

Component	**Rated capacity (kW)**	**Production (%)**	**Running hours (hour/yr)**	**Fuel consumption (L/yr)**
Standalone diesel generator				
G1	400	48.75	4,314	309,142
G2	400	48.44	4,344	307,430
G3	250	2.04	672	19,715
G4	200	0.4	240	4,406
G5	200	0.39	227	4,201
Total	1,450	100	9,797	644,894
Hybrid PV/diesel/batteries				
PV	1,200	59.21	-	-
G1	400	18.65	1,950	143,342
G2	400	18.60	1,976	143,137
G3	250	1.39	672	171,86
G4	200	1.13	575	134,26
G5	200	1.02	509	121,04
Total	2,650	100	5,682	329,195
Optimized Hybrid PV/diesel/batteries				
PV	800	42.38	-	-
G1	200	16.53	2,367	115,769
G2	200	18.38	2,756	129,098
G3	100	13.15	5,339	122,562
G4	80	4.11	5,314	46,275
G5	50	5.45	5,736	52,920
Total	1,430	100	21,512	466,624

4.2.1.2 Existing hybrid PV/diesel with batteries

This scenario shows the effects of using PV/batteries in power generation. It shows the advantages of including PV arrays in improving the system performance in both sites. This scenario does not provide the best economical system in HOMER, but performs better in terms of technical and environmentally aspects, as well as lowest operating cost. This system demonstrates the need for including storage system (batteries) to store excess energy from the PV. This scenario shows the effects of using PV/batteries in power generation. The main operational characteristics are shown in Table 4.1. In this case, the system mainly depends on PV to produce 59.21% of the total production, while the largest generators (400 kW) produce around 37% and all other smaller generators provide only 3.54%. Meanwhile, the COE is 0.366$/kWh and NPC is $11,326,602, which is around 1.5 times larger than the previous system. The systems' capital, replacement, operation and maintenance, fuel, operational and salvage costs are $4,939,000, $2,054,044, $1,179,342, $3,366,568, $499,681 and $212,349 respectively, over the project period and 50.4% of RF was found with 9.3% of excess energy.

4.2.1.3 Optimized hybrid PV/diesel/batteries

This scenario was performed to examine whether the existing hybrid PV/diesel/batteries scenarios were optimally selected in both locations prior to installation or not. The results of the optimized system in this location are shown in Table 4.1. The results show the optimal selection of PV, diesel generators and battery banks. The COE is 0.302 $/kWh and NPC is $ 9, 345,510, which is lower than the existing system by 17.48% and 17.49%, respectively with two strings of 1,440 kWh batteries. However, the systems' capital, replacement, operation and maintenance, fuel, operational and salvage costs are $2,492,600, $1,098,347, $1,059,902, $4,772,016, $536,081 and $77,351 respectively, over the project period and 34.8% of RF was found with 6.2% of excess energy. As a consequence, it is clear that the optimum solution system tends to depend more on the diesel generators compared to the existing hybrid system, which results in a higher fuel consumption and operational cost.

4.2.1.4 100% PV and batteries (Standalone RE model)

Initiating this scenario required dramatic increment over the rated values of PV and the batteries. The existing rated capacity of the PV arrays in this site is 1,200 kW and 4 strings batteries, which consist of 960 battery cells and provides 2,880 kWh. The optimum 100% of RF system comes with 3,000 kWp PV arrays and 50 strings batteries, which consists of 12,000 battery cells and provide 36,000 kWh. The COE is 1.36 $/kWh and NPC is $42,140,180 which is four times larger than standalone diesel generators system and two times more than existing hybrid PV/diesel/battery system. The systems' capital, replacement, operation and maintenance, operational and salvage costs over the project period are $21,468,000, $20,077,838, $, $2,070,905, $1,617,117 and $1,476,548 respectively. This high price is due to the high battery replacement costs. Meanwhile, the excess energy is 29.2% of the total production, with no capacity shortage found.

4.2.2 Tanjung Labian

4.2.2.1 Standalone diesel system (baseline model)

The main operational characteristics of this scenario are shown in Table 4.2. The system depends on the largest generators (both 500 kW) to produce 78.55% of total energy production. The other generator acts as a backup generator and works normally in the low loads period. The COE is 0. 3303 $/kWh and NPC is $5,902,414 which is the lowest cost compared to all other scenarios based on the same operating conditions. The systems' capital, replacement, operation and maintenance, Fuel, operational and salvage costs are $297,000, $309,371, $1,518,548, $3,806,995, $438,493 and $29,498 respectively, over the project lifetime (25 years) with 0% renewable penetration but a small amount of excess energy was observed representing 1% of the total energy production.

Table 4.2: System operational behavior (Tanjung Labian)

Component	Rated capacity (kW)	Production (%)	Running hours (hour/yr)	Fuel consumption (L/yr)
Standalone diesel generator				
G1	500	38.55	2,938	152,634
G2	500	40.00	3,020	158,178
G3	350	21.45	2,802	114,628
Total	1,350	100	8,760	425,440
Hybrid PV/diesel/batteries				
PV	1,200	86.90	-	-
G1	500	4.66	511	26,849
G2	500	4.76	516	27,368
G3	350	3.68	878	30,249
Total	2,550	100	1,905	84,466
Optimized Hybrid PV/diesel/batteries				
PV	400	39.89	-	-
G1	250	27.23	2,510	107,062
G2	250	27.52	2,480	108,007
G3	200	5.36	1,877	33,238
Total	1,100	100	6,867	248,307

4.2.2.2 Existing hybrid PV/diesel with batteries

The main characteristics are shown in Table 4.2. In this case, PV arrays produce 86.90% of the total energy production, where the largest generators (500 kW) produced only 9.42% and the smaller generators provide only 3.68%. The COE is 0.5352$/kWh and NPC is $9,563,989 which is about two times more than standalone diesel generator system. The systems' capital, replacement, operation and maintenance, Fuel, operational and salvage costs are $5,493,000, $2,787,715, $805,659, $755,828, $318,460 and $278,210 respectively, over the project period and PV arrays provide 80.7% of the RF. However, 17.4% of excess energy was observed in this scenario.

4.2.2.3 Optimized hybrid PV/diesel/batteries

The results of the optimized system in this location are shown in Table 4.2. The optimal selection of PV, diesel generators, and battery banks are found in lower rated values, where the COE is 0.3118 $/kWh and NPC is $ 5, 571,168, which are lower than the existing system by 41.74% and 41.75% respectively, with two strings of 1,440 kWh batteries. However, the systems' capital, replacement, operation and maintenance, fuel, operational and salvage costs are $1,708,000, $978,872, $760,444, $2,221,939, $302,203 and $98,085 respectively, over the project period and 35.7% of RF was found with 0.3% of excess energy. It is clear that the optimum system shows a distinguished difference in the overall costs compared to the existing hybrid system, this occurred due to lower batteries, PV and diesel generators sizes.

4.2.2.4 100% PV and batteries (Standalone RE model)

This scenario was developed to examine the advantages/disadvantages of considering 100% RE system with different RE fractions in both locations based on the available data. The existing rated capacity of PV arrays at this site is 1,200 kW and 6 strings batteries, which consist of 1,440 battery cells and provide 4,320 kWh. The optimum 100% RF system requires an increment of the rated PV values and associated batteries to be 1,800 kW PV and 24 strings batteries, which consist of 5,760 battery cells and provide 17,280 kWh. The COE is 1.22 $/kWh, and NPC is $21,797,966 making this system four times larger than standalone diesel generator system and around two times more than the existing hybrid PV/battery system. The systems' capital, replacement, operation and maintenance, operational and salvage costs are $11,580,000, $9,845,661, $1,119,823, $799,318 and $747,514 respectively, over the project period and the amount of excess energy is 33.2% of the total production.

4.2.3 Sensitivity analysis

Sensitivity analysis was performed to investigate the effects of the changes in some factors such as; fuel price, PV cost, battery costs and load demand growth on the system performance. In this section, the fuel price was increased in a range from the current price (0.7$/L) until 3.3 $/L. The load demand growth considered 5% per year, whereas the cost of the PV and batteries opposed to cost variation as a portion of the total initial cost in a range starting from the current price to 60%. Meanwhile, diesel prices are expected to increase and the current technological development would lead to decrease PV and battery prices, as well as more utilization of new electrical devices would increase the future loads.

4.2.3.1 Pulau Banggi Island

In this location, it is seen from the comparison of Figure 4.2 and Figure 4.3 that the effects of increasing the load demand and fuel price would result in more dependence on the hybrid PV/diesel/battery system. Decreasing PV and Battery prices have the highest impact on reducing the dependence on the standalone diesel generator systems and depending more on hybrid RE systems (PV has more impact due to higher capital cost).

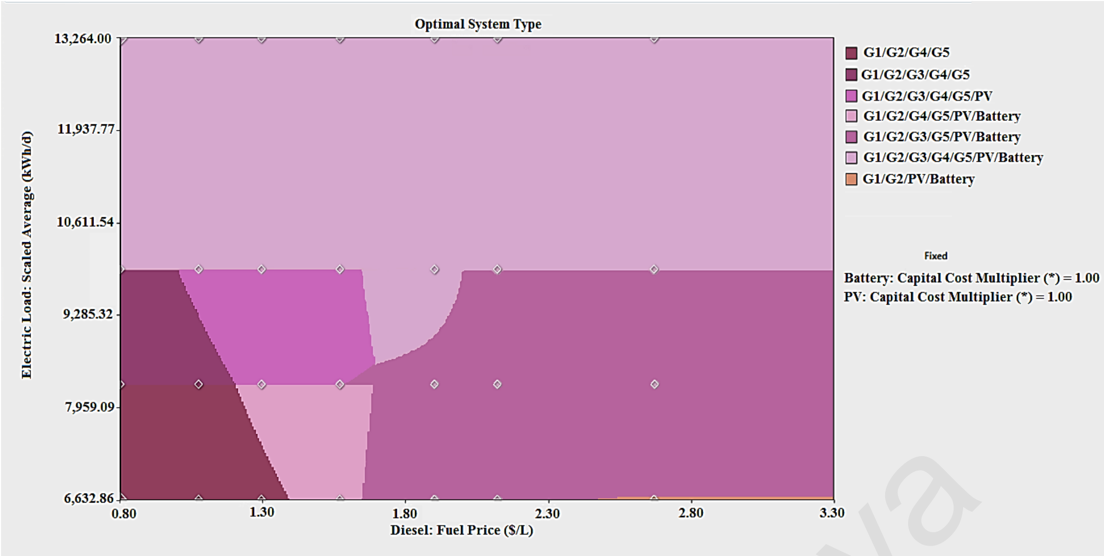


Figure 4.2: Pulau Banggi sensitivity with fixed PV and battery prices

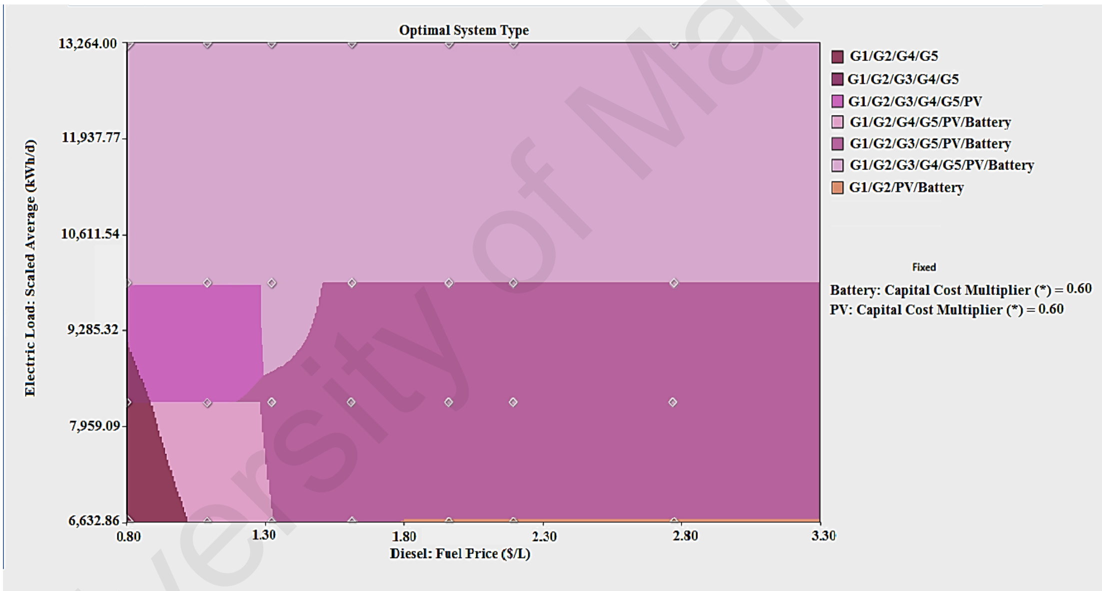


Figure 4.3: Pulau Banggi sensitivity with varied PV and battery prices

4.2.3.2 Tanjung Labian

Figure 4.4 and 4.5 shows the effects of increasing the load demand and fuel price on the operational behavior. This increment leads to more dependence on the hybrid system. In the same manner, decreasing PV and Battery prices reduce the dependence on the standalone diesel generators as well.

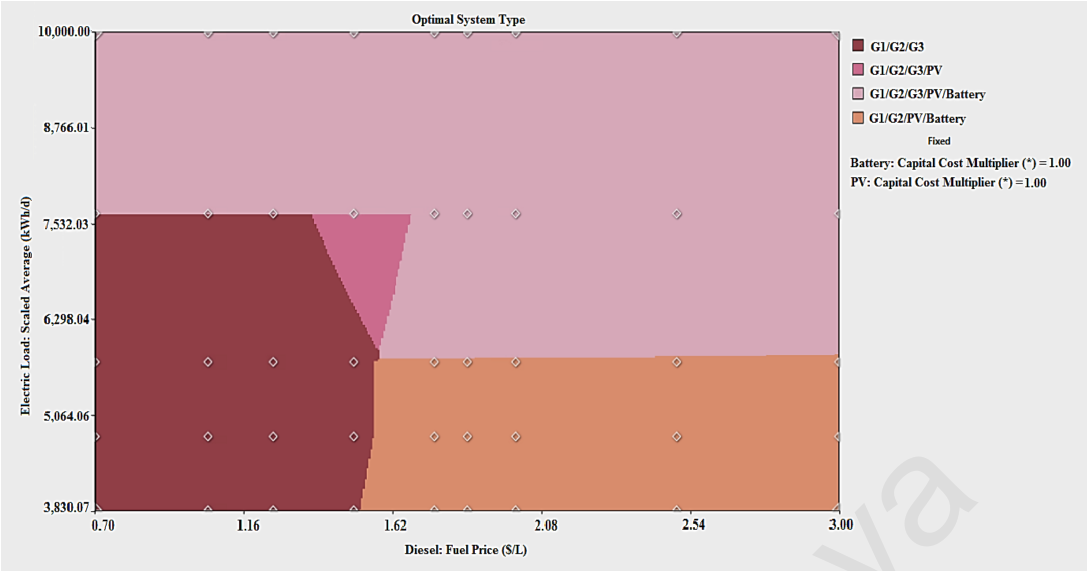


Figure 4.4: Tanjung Labian sensitivity with fixed PV and Battery cost

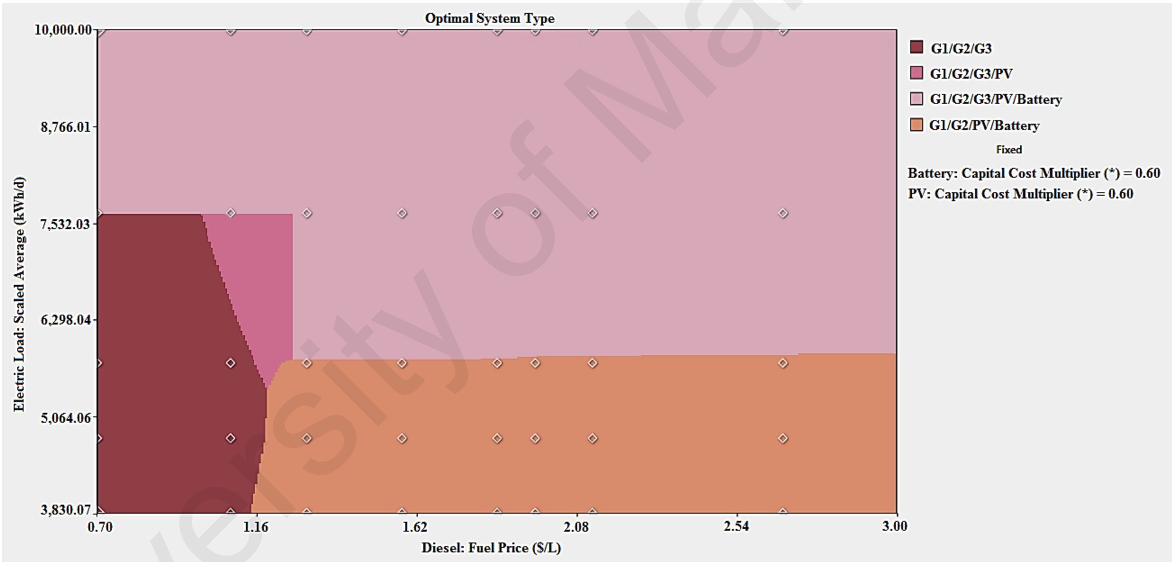


Figure 4.5: Tanjung Labian sensitivity with varied PV and Battery cost

4.2.4 Storage system - Batteries

Battery roles in hybrid RE system need to the highlighted, as it is usually charged at daytime and discharges at the beginning of the night, where the loads dramatically increased. The appearance of the batteries enhanced the system performance in both locations. The battery SOC procedure in Pulau Banggi and Tanjung Labian are shown in Figure 4.6. The lifetime of each battery is considered to be 7 years and the battery's SOC should be at least 40% according to manufacturer specifications. However, the maximum loads occur in August. During this period, the batteries would have the minimum charging and maximum discharging limits.

Figure 4.6: Batteries SOC performance in (a) Pulau Banggi (b) Tanjung Labian

The storage system is a very important towards ensuring system stability, without it leads to a large amount of excess energy. This energy is often regarded as losses, which could affect the operational behavior of the system. However, in both locations, the amount of excess energy was determined to be 9.3% in Pulau Banggi and 17.4% in

Tanjung Labian. 0% excess energy can only be achieved by feeding the generated power to the national grid in a grid-connected system. On the other hand, in the 100% PV/ battery, the system totally relies on the battery banks to provide energy when PV is unavailable. The SOC performance of this scenario showed a higher range of charging cycles, due to the higher demand on the battery banks only to supply the loads when the PV is unable to generate sufficient power, as shown in Figure 4.7.

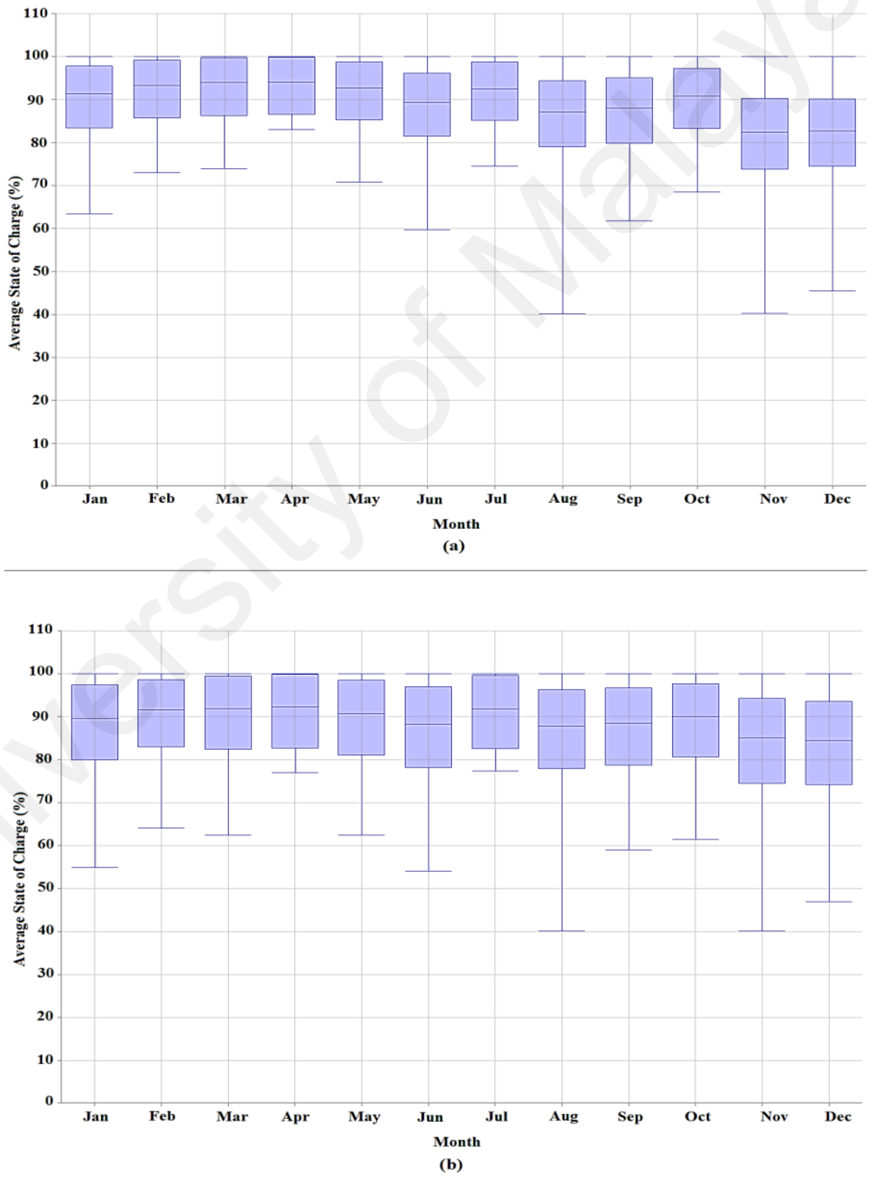


Figure 4.7: Batteries 100% PV operational behavior in (a) Pulau Banggi (b) Tanjung Labian

4.2.5 Estimating reduction in fuel consumption and generators running hours

The analyzed data provide a clear idea about fuel consumption and its related costs. Utilization of the hybrid system resulted in almost 49% and 80% fuel saving in Pulau Banggi and Tanjung Labian respectively. While, the utilization of 100% PV/battery system resulted in 100% fuel saving in both locations. However, from the sensitivity analysis, the system is moving to rely more on the hybrid scenario when fuel price and load growth are increased and components prices decrease as shown in Figure 4.3 and 4.5 for both locations. This led to the fact that a 100% PV/battery system would be more feasible in the future in the case of increasing fuel prices, load demand, and reducing in both PV and battery costs.

Furthermore, the simulation has shown that decreasing the running hours of the generators could lead to minimizing the dependence on the larger generators, thereby reducing the wear/tear, and leading to overall efficiency improvement. In Pulau Banggi, Figure 4.8 shows the reduction in the running hours of all generators for both locations. DG1 and DG2 were reduced by 54% and 54%, respectively. DG3 reports similar running hours and DG4 and DG5 running hours increased by 58% and 55%. This results in a maximized lifetime of the system component i.e. no need for component replacement at early stages of the project lifetime. Lower loading on the generator is generally regarded to be good for fuel consumption and reducing wear/tears, but within a limit specified by the manufacturer, otherwise, the system would be inefficient. Most generator's manufacturers recommended that their product work at least at25% of the rated power. In the same manner, Tanjung Labian generators' running was greatly reduced. DG1, DG2, and DG3 were reduced by 83%, 83%, and 67%, respectively, as seen in the figure. In summary, it should be pointed out that the generators are not only working less, but also running at lower loads.

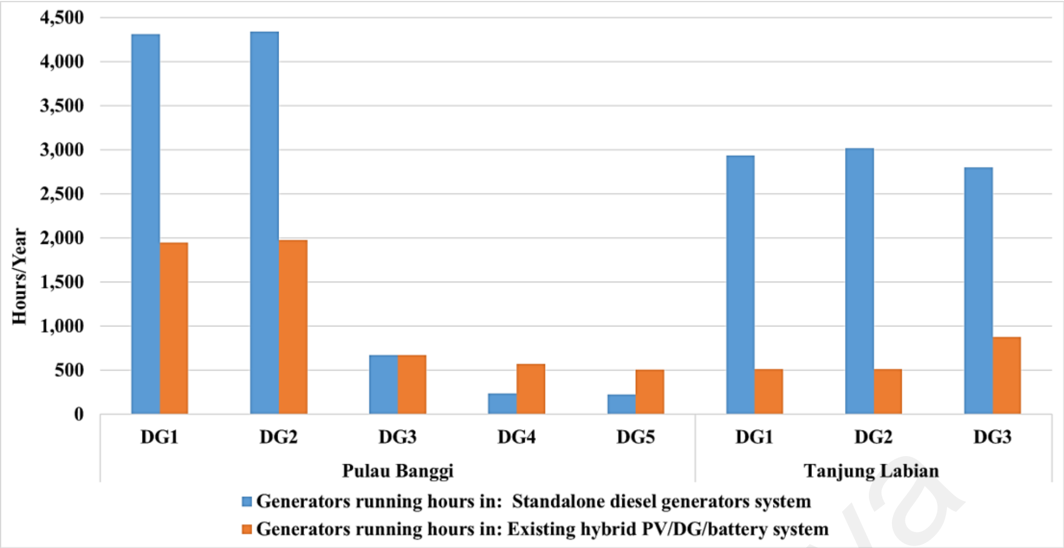


Figure 4.8: Pulau Banggi and Tanjung Labian generators running hours before and after adding PV/batteries

4.2.6 Economic analysis

Table 4.3 summarizes the NPC, operating and COE costs of all scenarios. As seen from this table, standalone diesel generators provide the lowest NPC and COE, followed by the optimized and existing hybrid than 100% RE system. The 100% PV/battery system has the highest operating cost due to high battery replacement costs. It was assumed to be replaced every 7 years (battery lifetime). Also, no fuel is required by this system (100% RE). Meanwhile, the optimized and existing hybrid systems report lower operating cost compared to the standalone diesel generator, as less use of the diesel generators is required, yet reported higher COE than standalone diesel generator system. From the sensitivity analysis in section (4.2.3), it is clear that when the loads and fuel price increased, the system tends to depend more on the hybrid system, which provides a good indicator of the availability towards using such system in future projects. Furthermore, referring to current technologies, it is expected to see decreases in PV and battery's prices in the future, which endorses the idea of implementing totally RE projects.

Table 4.3: Economic summary for all existing and hypothetical scenarios

Site	System description	NPC ($)	Operational Cost ($)	COE ($/kWh)
Pulau Banggi	Standalone diesel (0% RE)	8,545,703	643,458	0.2761
	Hybrid PV/DG/battery (59.21% RE)	11,326,602	499,681	0.366
	Optimized Hybrid PV/DG/battery (42.38% RE)	9,345,510	536,081	0.302
	PV/battery (100% RE)	42,140,180	1,617,117	1.36
Tanjung Labian	Standalone diesel (0% RE)	5,902,414	438,493	0.3303
	Hybrid PV/DG/battery (86.90% RE)	9,563,989	318,460	0.5352
	Optimized Hybrid PV/DG/battery (39.89% RE)	5,571,168	302,203	0.3118
	PV/battery (100% RE)	21,797,966	799,318	1.22

4.2.7 Reduction of pollutant emissions

The addition of PV in the standalone power systems would significantly reduce harmful carbon emission. This reduction justifies eliminating the inefficient use of diesel generators, based on the results reported in Table 4.4. The utilization of PV and battery banks in the system enhanced the reduction of carbon emissions by 49% in Pulau Banggi, and 80% in Tanjung Labian. These values were simply calculated by finding the difference between the amount of the generated emissions in the standalone diesel generator scenario to the existing hybrid renewable energy scenario divided to the basic case to find the percentage of reduction. This shows that upgrading standalone diesel generation systems in mini-grids with PV and batteries reduced harmful emissions, as well as fuel consumption. However, 100% PV/battery system offers zero emissions and considered as the best system from an environmental perspective, while the standalone diesel generators systems are considered as the worst systems as it generates the highest amount of the harmful emissions. In this study, no penalties over CO_2 emissions were considered.

Table 4.4: System pollutant harmful emissions

Site	Description	Emissions (Kg/yr)					
		Carbone dioxide	**Carbone monoxide**	**Unburned hydrocarbons**	**Particular matters**	**Sulfur dioxide**	**Nitrogen oxide**
Pulau Banggi	Standalone diesel (0% RE)	1,705,774	289.04	23.66	18.75	3,486.60	3,762.70
	Existing hybrid PV/DG/battery (59.21% RE)	870,387	326.41	32.27	23.19	1,776.30	3,462.5
	Optimized Hybrid PV/DG/battery (42.38% RE)	1,231,77	1,483.1	160.96	110.60	2,497.9	1,370.40
	PV/battery (100% RE)	No Emissions					
Tanjung Labian	Standalone diesel (0% RE)	1,124,134	797	84.18	58.62	2,288.3	7,717.10
	Existing hybrid PV/DG/battery (86.90% RE)	223,090	205.85	22.07	15.25	453.38	1,940.90
	Optimized Hybrid PV/DG/battery (39.89 % RE)	656,509	252.62	25.07	17.99	1,339.70	2,667.30
	PV/battery (100% RE)	No Emissions					

4.2.8 Discussion on the operational analysis in both locations

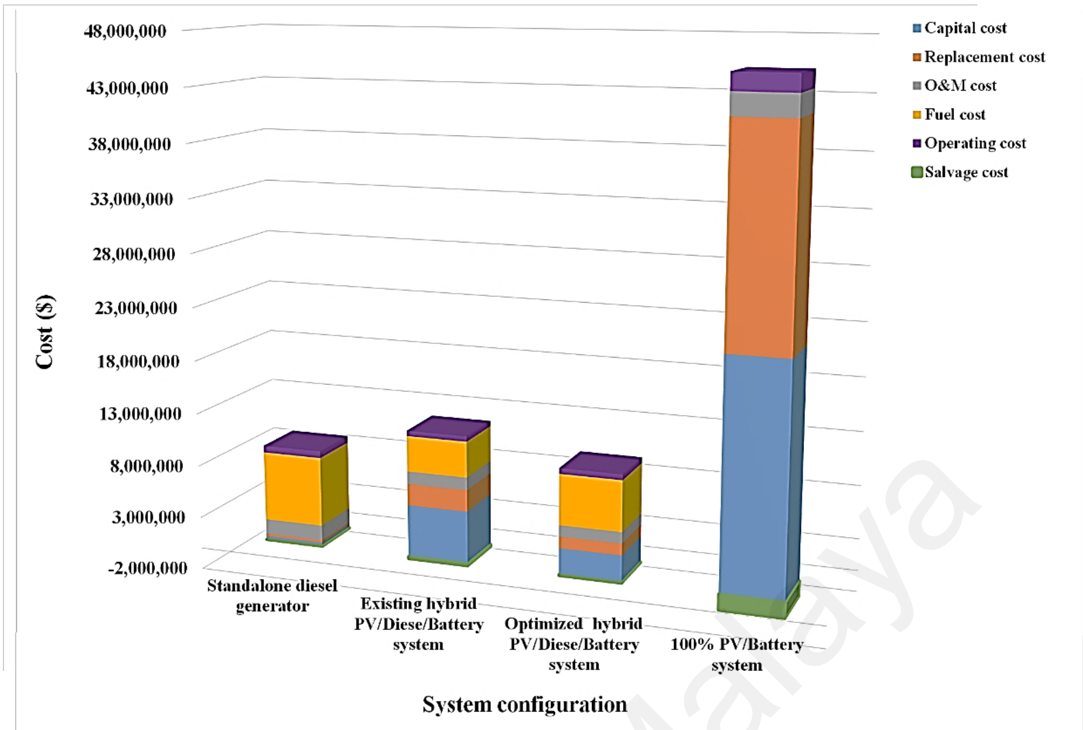
In this section, the main findings of section (4.2) are discussed and explained. The results are connected together to show the relationship between different system components and the effects of changes in the main system parameter on the system performance. In addition, this study place emphasis on comparative cost and environmental analysis of each scenario.

Four different scenarios were analyzed in sections (4.2.1 and 4.2.2). These include the standalone diesel generators, existing hybrid PV/diesel/battery, 100% PV/battery, and the optimum solution scenarios. The effects of changing major parameters, such as fuel price and load growth on the system operation were investigated throughout the sensitivity analysis (section 4.3). Each scenario shows and quantifies the impact of injecting PV on NPC, COE, power penetration, excess energy, fuel consumption, running hours and other characteristics.

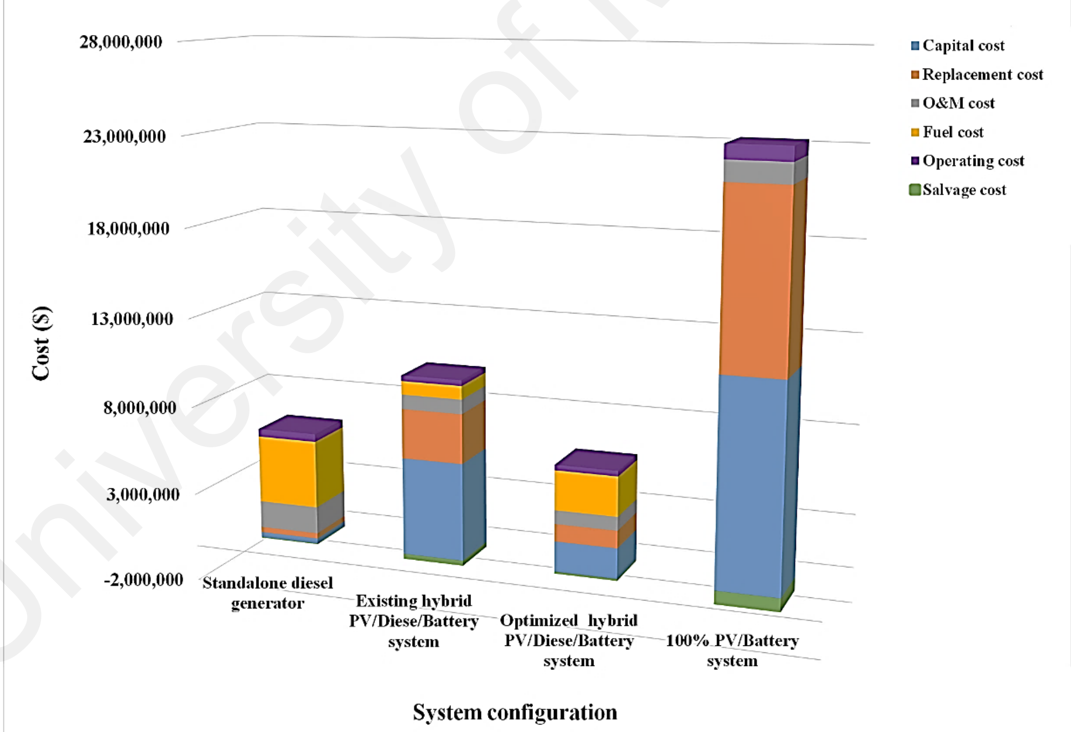
4.2.8.1 **Techno-economic impact**

The results obtained showed that standalone diesel system offers the best economic properties over the project period, in contrast to the 100% PV/battery system that reports the highest cost. However, hybrid PV/diesel/battery system shows the best technical, and very good economic characteristics based on the overall system cost. The hybrid PV/diesel/battery system is costlier than the standalone diesel system over capital, replacement, operation and maintenance, fuel, operational and salvage costs. Where, hybrid PV/diesel/battery system shows lower costs compared to 100% PV/battery system as shown in Figure 4.9 (a and b). The results of both locations indicate that using 100% PV/battery would involve high cost due to high capital and battery replacement costs. But, if a price reduction is found for these components, it would be a feasible solution.

Correspondingly, a comparison with the optimized scenarios shows that both existing PV systems are not optimally selected prior to installation for the same load profiles, solar irradiation, and temperature data. Due to the extremely remote location of both areas, the designers of these projects prefer to depend more on the PV and batteries than the diesel generators for the existing systems. Thus, the optimal systems show lower PV penetration levels, where the RE share is 42.38% in Pulau Banggi and 39.89% in Tanjung Labian from the total production. Furthermore, the batteries' strings are reduced to two strings in both locations. This is compared to 59.21% of RE sharing with four strings and 86.9% of RE sharing with six strings in the existing hybrid systems of Pulau Banggi and Tanjung Labian, respectively.



(a)



(b)

Figure 4.9: Cost analysis over all combinations: (a) Pulau Banggi (b) Tanjung Labian

The sensitivity analysis examined the effect of changes in major parameters, such as fuel price, load growth, PV, and battery banks prices on the overall system performance.

The results show more trend towards using hybrid systems that include PV, battery, and diesel generator, particularly when the fuel prices and loads increase. Furthermore, reducing PV and battery banks costs would enhance the use of PV arrays and battery as lower NPC and COE would associate with such system.

The storage battery system is crucial towards the stability of the of the system. The battery system offers a sufficient technique to minimize excess energy. Thus, the utmost usage of this energy to the current design is found. Meanwhile, the SOC of the battery system reports high charging cycles for both systems, but higher cycles are found in the 100% PV/battery system, where the system depends mainly on the batteries to provide adequate energy to loads when the PV is unavailable. Furthermore, the hybrid system is compared to the standalone diesel generators to quantify the effects of using such systems on fuel consumption, diesel generators running hours, harmful emission and economic aspects.

The results indicate that hybrid systems would reduce the fuel consumption and generate less harmful emission to the surrounding environment. Diesel generators' running hours would also reduce, as the system depends more on smaller generator units to supply the loads at different times during the day. The generators are working less at lower loads, which results in decreasing the replacement, maintenance, operational, fuel costs and the overall wear/tear of the system, hence leading to a reduction in total NPC and COE.

4.2.8.2 **Environmental impact**

The results showed that standalone diesel system offers the highest rate of harmful emissions into the surrounding environment, in contrast to the 100% PV/battery system that reports the best environmental properties with no harmful emissions to the environment. However, hybrid PV/diesel/battery system shows a very good economical and environmental characteristic. The relation between the PV penetration and CO_2 emissions is shown in Figure 4.10 for both locations.

Figure 4.10: PV penetration level vs CO_2 emissions in both locations

As seen in Figure 4.10 by increasing the energy produced by RE sources would result in reducing the harmful emissions generated by the system. It is also clear that the reduction of harmful emission depends on the system configuration and the amount of the generated energy.

4.3 Solar radiation predication

This study began by training the basic ANFIS system using the measured data, then ANFIS was tested, according to the experimental procedure to examine the capability of determining monthly global solar radiation. After finishing ANFIS training and testing process, other operating systems were applied using hybrid ANFIS-PSO, GA and DE systems, each system was trained and tested with the same input data. Finally, the models' proficiency was examined to evaluate the operation in predicting the solar radiation upon the actual and predicted solar radiation.

4.3.1 Models analysis

The input parameters used in this study include (the sunshine duration, maximum and minimum air temperature clearness index and monthly rainfall quantity), and the output is (monthly solar radiation). These data were defined to the learning techniques in which, 80% for training 20% for testing. As presented in section (3.5.1), Table 3.3 part of the used data is shown. The measured and estimated data sets in Figure 4.11 and Figure 4.12 show a high correlation between the inputs and it performs accurate output results.

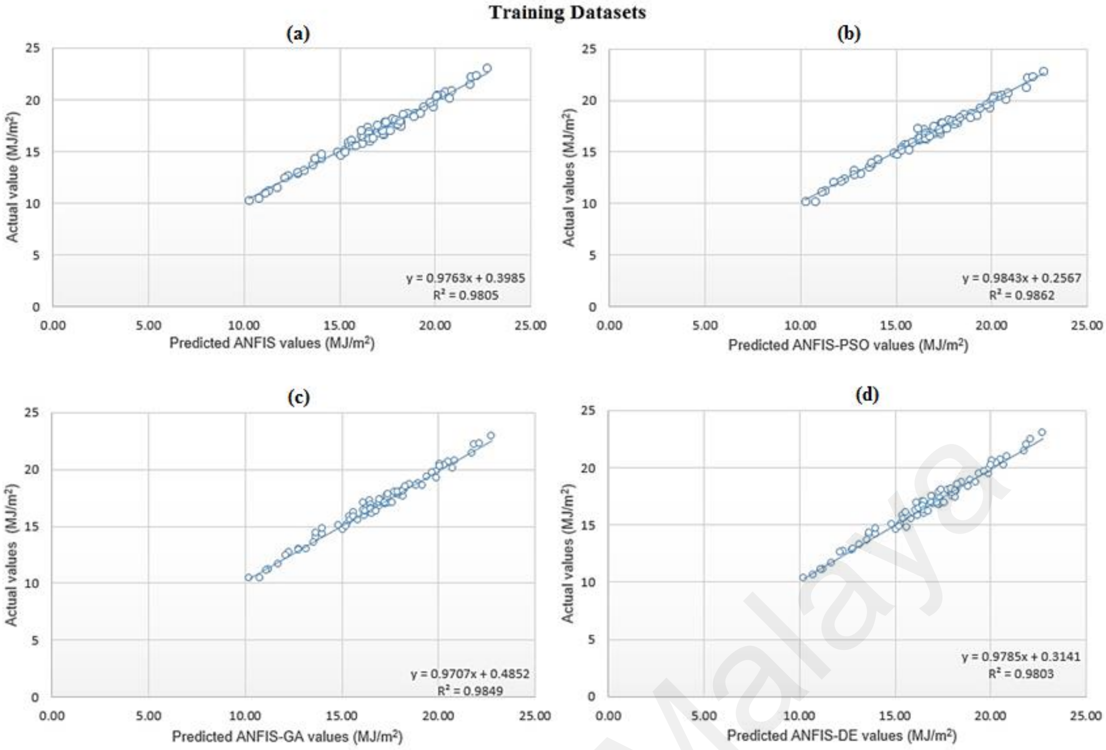


Figure 4.11: Predicted Vs Actual value while training datasets (a) ANFIS (b) ANFIS-PSO (c) ANFIS-GA (d) ANFIS-DE

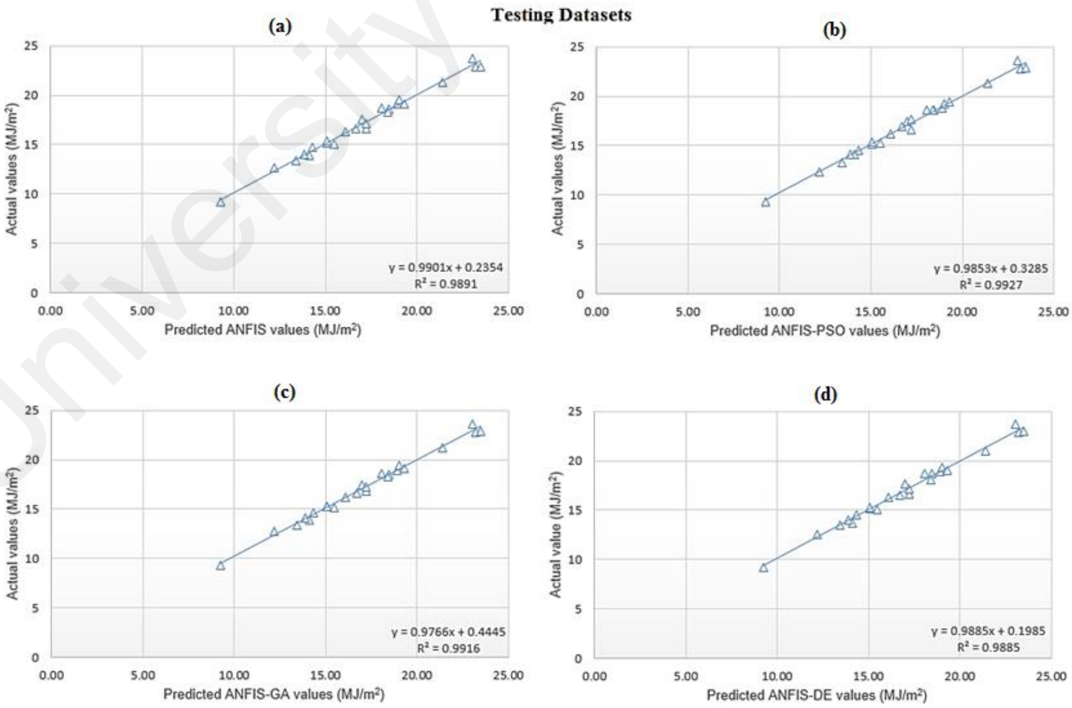


Figure 4.12: Predicted Vs Actual value while testing datasets (a) ANFIS (b) ANFIS-PSO (c) ANFIS-GA (d) ANFIS-DE

The estimated training and tested solar radiation data using basic ANFIS are represented in Figure 4.11 (a) and Figure 4.12 (a) for the both training and testing process. The results show very good correlation between measured and prediction data, as the value of R^2 is very high. Consequently, ANFIS high correlation coefficient value confirms that the observation of the predicted data has a very good relationship with the measured values.

On the same manner, the proposed ANFIS system has been integrated and improved by created hybrid models using different algorithms, including PSO, GA and DE respectively. Each hybrid system used the same input-output datasets for training and testing purposes. Figure 4.11 (b), (c), (d) and Figure 4.12 (b), (c), (d) show the scattered plots for both training and testing for each ANFIS-PSO, ANFIS-GA and ANFIS-DE models respectively. It's obviously seen that all hybrid systems have a very good correlation between the estimated values and real measured data. Meanwhile, ANFIS-PSO showed in Figure 4.11 (b) and Figure 4.12 (b) has the best correlation in both training and testing datasets among all systems, as it got the highest values of R^2 and r and the smallest errors calculations in terms of RMSE, MABE, MAPE, and RRMSE followed by ANFIS-GA system as illustrated in section (4.3.2).

Figure 4.13 (a) and (b) shows the high prediction accuracy of the input and the output by compared the actual measurements to the predicted results using ANFIS-PSO model in both training and testing data.

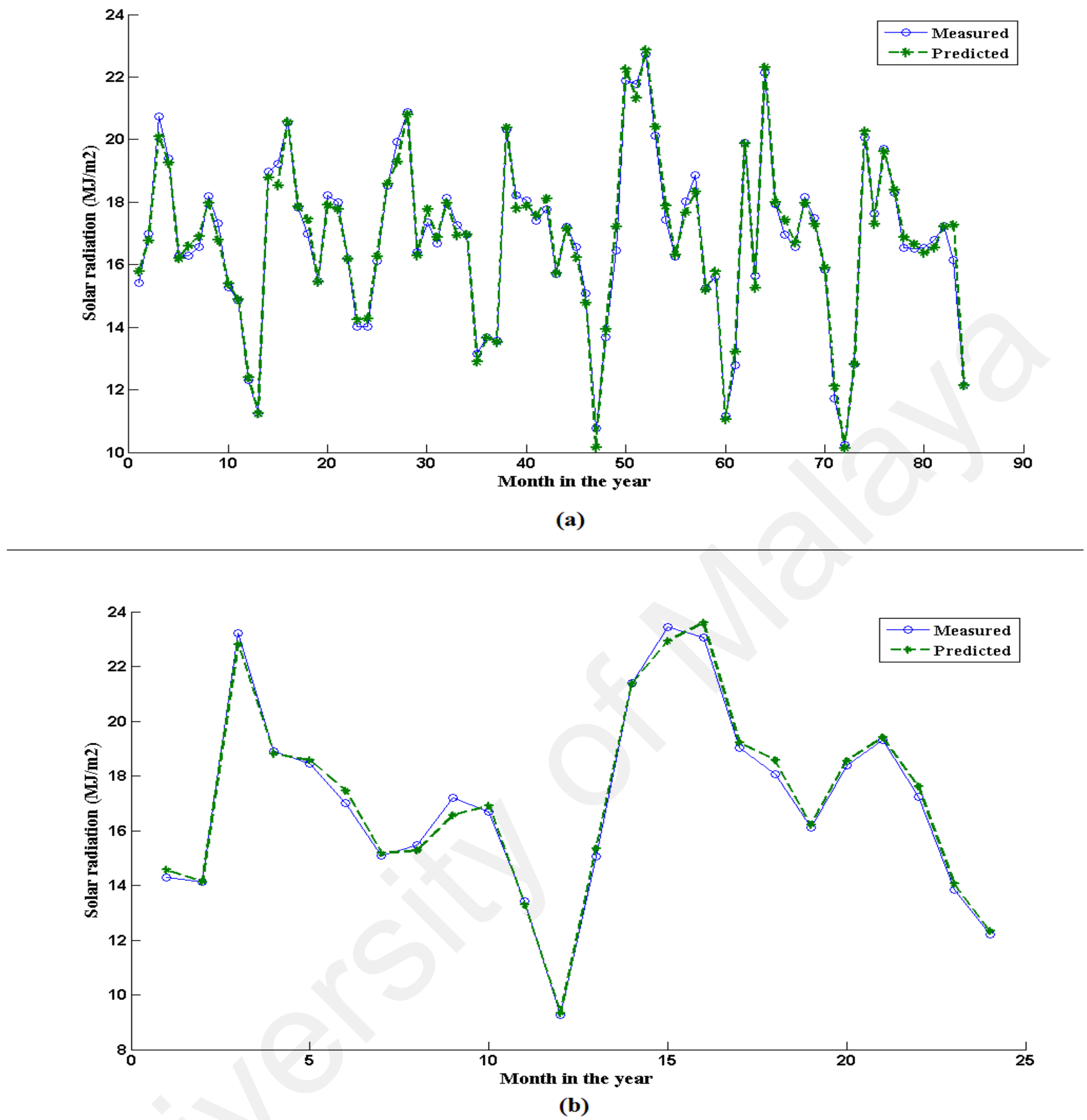


Figure 4.13: Actual measured data vs ANFIS-PSO predicted data for (a) training and (b) testing datasets

Thus, the proposed hybrid ANFIS models would fulfill an important role in different industrial, agricultural and resources management allocating applications.

4.3.2 Model validation (statistical performance evaluation)

To evaluate the performance of the proposed models, six reliable statistical indicators were used in order to compare all models. In this section, the used examined indicators are; MAPE, MABE, RMSE, RRMSE, the r and R^2. It also functioned to evaluate the variances of the predicted and measured data set. All values are showed in Table 4.5.

Table 4.5: Statistical indicators for training and testing process achieved by all models

Training						
System	**RMSE**	**RRMSE %**	**r**	**R^2**	**MABE**	**MAPE %**
ANFIS	0.3712	2.2096	0.9902	0.9805	0.3033	1.8274
ANFIS-PSO	0.3121	1.8580	0.9931	0.9862	0.2354	1.4159
ANFIS-GA	0.3285	1.9554	0.9924	0.9847	0.2535	1.5476
ANFIS-DE	0.3765	2.2410	0.9901	0.9799	0.3060	1.8421
Testing						
System	**RMSE**	**RRMSE %**	**r**	**R^2**	**MABE**	**MAPE %**
ANFIS	0.3667	2.1453	0.9945	0.9887	0.2957	1.7186
ANFIS-PSO	0.3065	1.7933	0.9963	0.9921	0.2482	1.4097
ANFIS-GA	0.3228	1.8886	0.9958	0.9912	0.2618	1.5146
ANFIS-DE	0.3701	2.1654	0.9942	0.9885	0.3133	1.7980

It is clearly shown in this table that ANFIS-PSO model has the best capabilities in predicting the solar radiation according to training and testing model's indicators based on all statistical indicators that are shown in Table 4.5, followed by with ANFIS-GA, then ANFIS and finally ANFIS-DE systems. This showed standalone ANFIS is better than hybrid ANFIS-DE, which indicates that hybrid system may not be always the best solution for solar prediction. However, other factors affect the system's accuracy, mainly depending on the parameters. They should be tuned properly to produce the best performance for each model, where in this study the system was maintained and tuned to produce the best performance as much as possible. While, it is clear in the results that sometimes the combination between different algorithms shows good outcomes, but not as the basic model; for example, the case of standalone ANFIS and hybrid ANFIS-DE. The prediction depends directly on each algorithm proprietary that affected by the correlation between combined algorithms, and the type of input parameters used. The RMSE value denotes the accuracy of proposed models by comparing the differences between estimated and actual observed values, while RRMSE value elucidates the precision capability of the model. The MAPE refers to the accuracy of prediction deviation from the model where MABE represents the absolute bias errors between predicted and measured data. Whereas, r and R^2 represent the strength of the linear relationship between predicted and measured variables. The smaller RMSE, RRMSE, MAPE, MABE values show better performance model and vice versa in the case of r and R^2. Based upon RRMSE analysis, the capability of all developed ANFIS hybrid approaches considered as excellent correlation of predicting solar irradiation data for training and testing measurements, as all values fall below the range of (RRMSE $< 10\%$). As a result, the applied statistical parameters show that all proposed hybrid ANFIS systems are capable to provide promising results with higher accuracy. According to the above analysis, it can be concluded that the practical implementation of ANFIS-PSO technique for prediction monthly global solar radiation would ensure precise and more accurate data.

4.3.3 Statistical comparison

Table 4.6 shows a statistical comparison between the results obtained from this study and other benchmark studies that conducted previously for solar radiation prediction. Although, each study considered different datasets and input/output parameters. The usage of RMSE and r have been used to compare the prediction accuracy and linear relationship between the input/output of each model. In this way, the comparison would reflect the prediction precision of each proposed model in each location. The examined studies used different input parameters for distinct regions over disparate climates, terrains and weather conditions. This comparison indicates that the proposed models have better performance than the benchmark studies, and it also demonstrates the high capability of providing promising results with higher accuracy.

Table 4.6: Statistical indicators comparison between the proposed study and other studies

<table>
<tr><th rowspan="2">Model</th><th colspan="2">Statistical indicators</th><th rowspan="2">Study location</th><th rowspan="2">Proposed models in this study</th><th colspan="2">Statistical indicators</th><th rowspan="2">Study location</th></tr>
<tr><th>RMSE</th><th>r</th><th>RMSE</th><th>r</th></tr>
<tr><td>ANFIS (Mohammadi, Shamshirband, Tong, Alam, & Petković, 2015)</td><td>1.0482</td><td>0.9869</td><td>Iran</td><td rowspan="2">ANFIS</td><td rowspan="2">0.3712</td><td rowspan="2">0.9902</td><td rowspan="8">Malaysia</td></tr>
<tr><td>SVM-FFA (Lanre Olatomiwa, Mekhilef, Shamshirband, Mohammadi, et al., 2015)</td><td>0.6988</td><td>0.8956</td><td>Nigeria</td></tr>
<tr><td>SVR-RBF (Ramedani et al., 2014)</td><td>3.20</td><td>0.90</td><td>Iran</td><td rowspan="2">ANFIS-PSO</td><td rowspan="2">0.3121</td><td rowspan="2">0.9931</td></tr>
<tr><td>SVR-poly (Ramedani et al., 2014)</td><td>3.50</td><td>0.883</td><td>Iran</td></tr>
<tr><td>Empirical (Mubiru & Banda, 2008)</td><td>1.522</td><td>0.958</td><td>Uganda</td><td rowspan="2">ANFIS-GA</td><td rowspan="2">0.3285</td><td rowspan="2">0.9924</td></tr>
<tr><td>ANN (Mubiru & Banda, 2008)</td><td>0.385</td><td>0.974</td><td>Uganda</td></tr>
<tr><td>KELM (Shamshirband et al., 2015)</td><td>2.5243</td><td>0.863</td><td>Iran</td><td rowspan="2">ANFIS-DE</td><td rowspan="2">0.3765</td><td rowspan="2">0.9901</td></tr>
<tr><td>SVR (Shamshirband et al., 2015)</td><td>2.4033</td><td>0.8663</td><td>Iran</td></tr>
</table>

4.4 Flexible hybrid renewable energy system design analysis

The simulation was executed for the proposed site on both off-grid and on-grid connections. Several scenarios were performed. Each contains different technical and economic configurations. Figure. 3.15 shows the procedure of finding the optimum system for off/on-grid connections. The proposed system is designed to serve the whole period project, over numerous changes such as components' prices and load demand. Meanwhile, the system would also be flexible to serve under almost all conditions, including changing main variables that directly affect hybrid RE systems. The system is tested over the off-grid connection to find the optimum solution.

The analysis of all technical, economic and environmental aspects is deeply explained and clarified in this section. The system is examined over sensitivity analysis to quantify the impact of changing fuel prices and load demand on the optimal design. Correspondingly, the optimum design is also investigated over the on-grid connection, where the effects of this addition to the component combination and operational performance are shown and clarified. Then, the optimum design is examined over sensitivity analysis by changing some main variables in the on-grid connection such as power purchase, sellback, fuel prices and load demand. The final system obtained an optimum system that is capable to supply a continuous operation in both off and on grid connections with no need of replacing the system component or modifying the system with any major changes.

4.4.1 System components

Multiple sizes of all components were considered when determining the optimum solution as shown in Table 4.7. HOMER assumes a certain step size for each system component when considering sizing. In this work, multiple step sizes are considered to find the optimum solution. Meanwhile, no solar charge regulator is considered as an individual component in this study. Accordingly, HOMER allocates the results into two main classifications, which are called (Overall) and (Categorized). In the overall choice, HOMER shows the top-ranked system configurations according to NPC, which does not always reflect the optimal solution of different system combinations. In contrast, the categorized choice shows the least-cost system of each type, which includes the optimum solution for each system topology. Thus, Table 4.7 presents specific step sizes, which have been chosen by HOMER. Simulation results show different combinations of the optimal scenarios that include RF, COE and NPC values. Each system is designed to supply the load profile with continuous power supply.

Table 4.7: Multiple ranges of component's combinations

System	PV (kWp)	DG1 (kW)	DG2 (kW)	Battery (kWh)	Converter (kW)	RF (%)	COE ($/kWh)	NPC ($)
System 1	300	100	50	330	150	50	0.281	2.80 M
System 2	350	100	50	330	150	52	0.283	2.82 M
System 3	350	110	40	330	150	52	0.285	2.84 M
System 4	400	100	50	330	200	54	0.287	2.87 M
System 5	250	100	60	330	150	45	0.288	2.87 M
System 6	300	130	40	330	150	50	0.290	2.89 M
System 7	350	100	60	660	150	57	0.302	3.01 M
System 8	400	130	80	990	300	63	0.329	3.28 M
System 9	350	120	80	990	300	60	0.330	3.29 M
System 10	450	100	40	1,320	300	71	0.341	3.40 M
System 11	400	110	60	1,320	350	67	0.345	3.44 M
System 12	500	110	70	1,320	350	73	0.349	3.49 M
System 13	500	140	50	1,320	400	74	0.351	3.50 M

The optimum size of each component is shown in Table 4.8. In off-grid connection diesel generators, PV, batteries, and power converters are all necessary to ensure a continuous supply. However, in the on-grid connection the battery banks are regarded unnecessary to ensure continued operation and excess energy utilization.

Table 4.8: Optimal system specifications**.**

Component	Capacity	Lifetime	**Prices** (Hossain et al., 2016)		
			Capital ($/kW)	**Replacement ($/kW)**	**Maintenance**
DG 1&2	100& 50 (kW)	15,000 h	220	200	0.030 $/h
PV	300 (kWp)	25 yr	2,000	2,000	10 $/kW/ yr
Battery	330 (kWh)	7 yr	1,200	1,170	10 $/kW/ yr
Converter	150 (kW)	15 yr	890	800	10 $/kW/ yr

The optimum system includes two DGs with capacities of 100 kW and 50 kW. The best choice of the converter, PV, and batteries was 150 kW, 300 kWp, and 330 kWh, respectively. In the meantime, DGs in remote locations request higher maintenance price compared to non-remote locations due to the transportation difficulties which add extra costs for acquiring replacement tools and technical experts into such locations.

The system is designed to provide continuous operation (i.e., 24 hours/day) with no interruption. Several changes are subjected to the system to ensure meeting the proposed criteria of finding flexible design and evaluating the operational performance of the system. The optimal design is supposed to withstand against all changes over the project's lifetime. In this work, two different schemes are examined, which include off-grid and on-grid systems. Sensitivity analysis is also conducted to ensure meeting the flexibility of the optimum design over major changes that may face the system at disparate periods. Figure 4.14 presents a general description of the proposed models in this section.

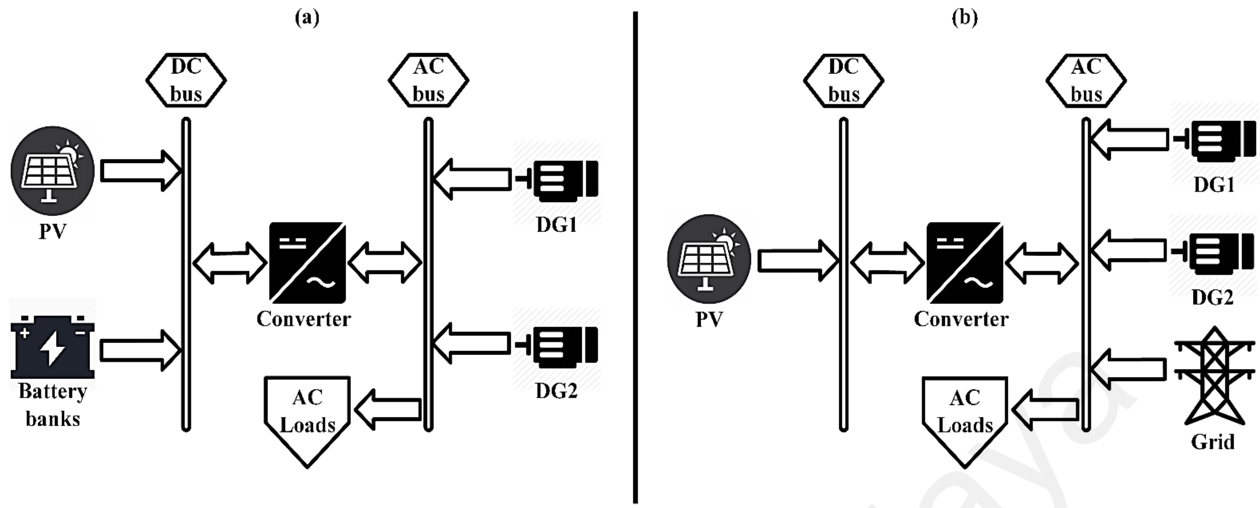


Figure 4.14: System components including all parts (a) Off-grid system (b) On-grid system

4.4.2 Off-grid hybrid system

In this section, a standalone system includes DG, batteries, converters, and PV which are proposed to meet load demand without any technical interruption. Figure 4.14 (a) shows the proposed system topology in this section. In this scenario, the system is designed to depend mainly on PV arrays to produce electric power, while DGs is used as a backup system when the PV and battery cannot meet load requirements according to LF dispatch strategy that has shown in section (3.4). Table 4.9 shows the produced energy by each component. Meanwhile, HOMER calculates the RE production that represented in the table by dividing the annual amount of produced electrical energy by the RE components to the total production of all components at the system (Lambert et al., 2006).

Table 4.9: Annual energy production

Component	Production	
	kWh/yr	%
PV	489,149	55.43
DG1 (100 kW)	305,799	34.66
DG2 (50 kW)	87,459	9.91
Total	882,407	100

The minimum load ratio of each DG is 25%; this ratio is recommended by most generators' manufacturers to reduce the wear/tear of the generators and thus increasing the life-cycle as well as reducing the fuel consumption that is needed to supply the loads at low demand ration (Hossain et al., 2016). This ratio would not prevent the generators from being switched off, but would prevent working at low loads (Lambert et al., 2006). A small portion of excess energy was found to be 5.4% from the total production, which reports 47,254 kWh/ yr. This excess energy is always regarded as one of the main drawbacks of the off-grid systems. Using dumb loads or connect the system to the national network are regarded as the most effective solutions in order to totally consume this energy. Excess energy could be reduced by adding more batteries to the system, but this would increase the NPC of the system. Nevertheless, reducing the excess energy can be done by reducing the minimum load ratio, but this would affect the system performance by increasing the operating, maintenance costs, and decreasing the generator’s lifetime. While, increasing the generated energy by RE sources would result in increasing the amount of excess energy, which is regarded as system loss.

In this scenario, the optimum design includes 300 kW of PV modules, two DGs of 100 kW and 50 kW, 150 kW power converter, and one string batteries of 330 kWh, as shown in Table 4.8. The total NPC of the system is $2,802,919, and the COE is 0.281 $/kWh. The total operating and salvage costs of the system are $148,976 and $28,109, respectively. The NPC, COE and operating costs are considered high values, but there is a reasonable basis for these high values. The reason is due to remote locations of this station, which add further costs for transportation, storing the fuels as well as maintenance costs. Generally, in remote areas, the fuel prices reached 1.5 times of the normal price (Anwari et al., 2012).

4.4.2.1 System generators

Figure 4.15 (a) and (b) describe the DGs procedure based on the monthly evaluation. Each generator works for 4,213 and 4,445 h/ yr for the 100 kW and 50 kW DGs, respectively. The 100 kW generator works mostly for at higher load demands normally at earlier in evening, when the PV or batteries are unavailable to produced sufficient power. While, 50 kW generator works at lower load demands lately at night and early in morning, and at a different period during the day where the loads have lower values, thus the monthly generation graph represented in Figure 4.15 (b) shows lower production amounts. Furthermore, the total amount of CO_2 emissions of this scenario is 377,517 kg/ yr.

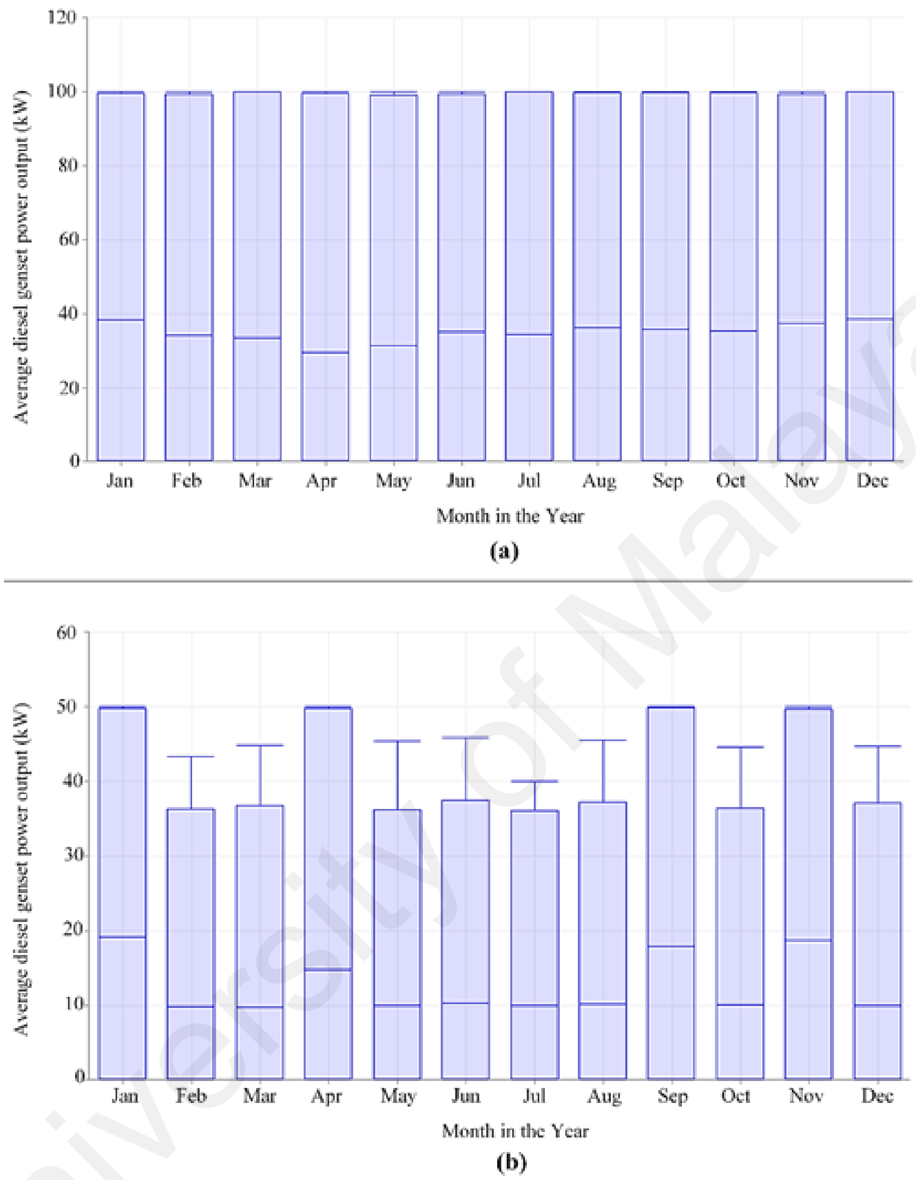


Figure 4.15: DG monthly procedure (a) 100 kW (b) 50 kW

4.4.2.2 Storage system

The presence of batteries in the system supports the system performance and results in reducing uncertainty problems of RE resources. Hours of autonomy represent the maximum number of hours that the storage system can continuously supply loads. One string battery of 330 kWh with 2.22 hours of autonomy represents the optimal size of the storage system. Figure 4.16 shows the monthly

SOC of the battery banks. It indicates that months from June to August have the lowest charging cycles, which reveal the high demand upon the stored energy, hence these months are the hottest months during the year with lowest rains among the year. Thus more energy is needed for cooling purposes such as air fans. In contrast, months from March to May include the highest charging cycles, where the system tends to depend more on the other components to cover the load demands.

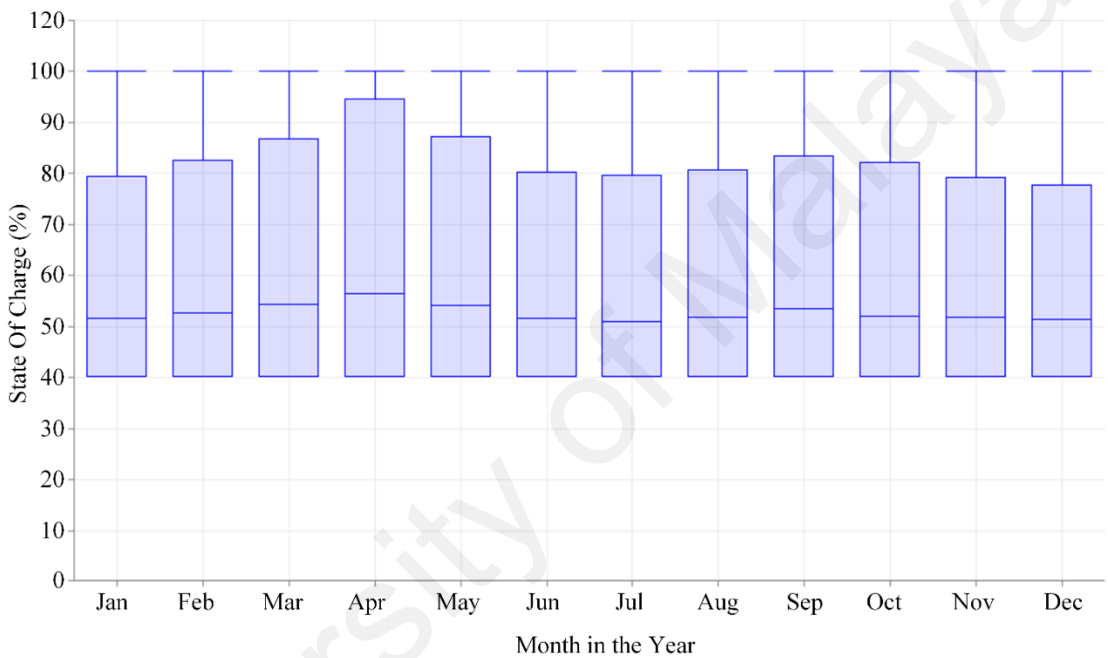


Figure 4.16: Batteries SOC on Monthly basis

4.4.2.3 Sensitivity analysis

Sensitivity analysis is performed to examine the system behavior over changing the main parameters in any standalone system that directly affect the system's performance. Figure 4.17 shows the result of the sensitivity analysis over changing the diesel price from the current price (0.7 $/L) up to (2.0 $/L), along with increasing the average load demand (+5% per year).

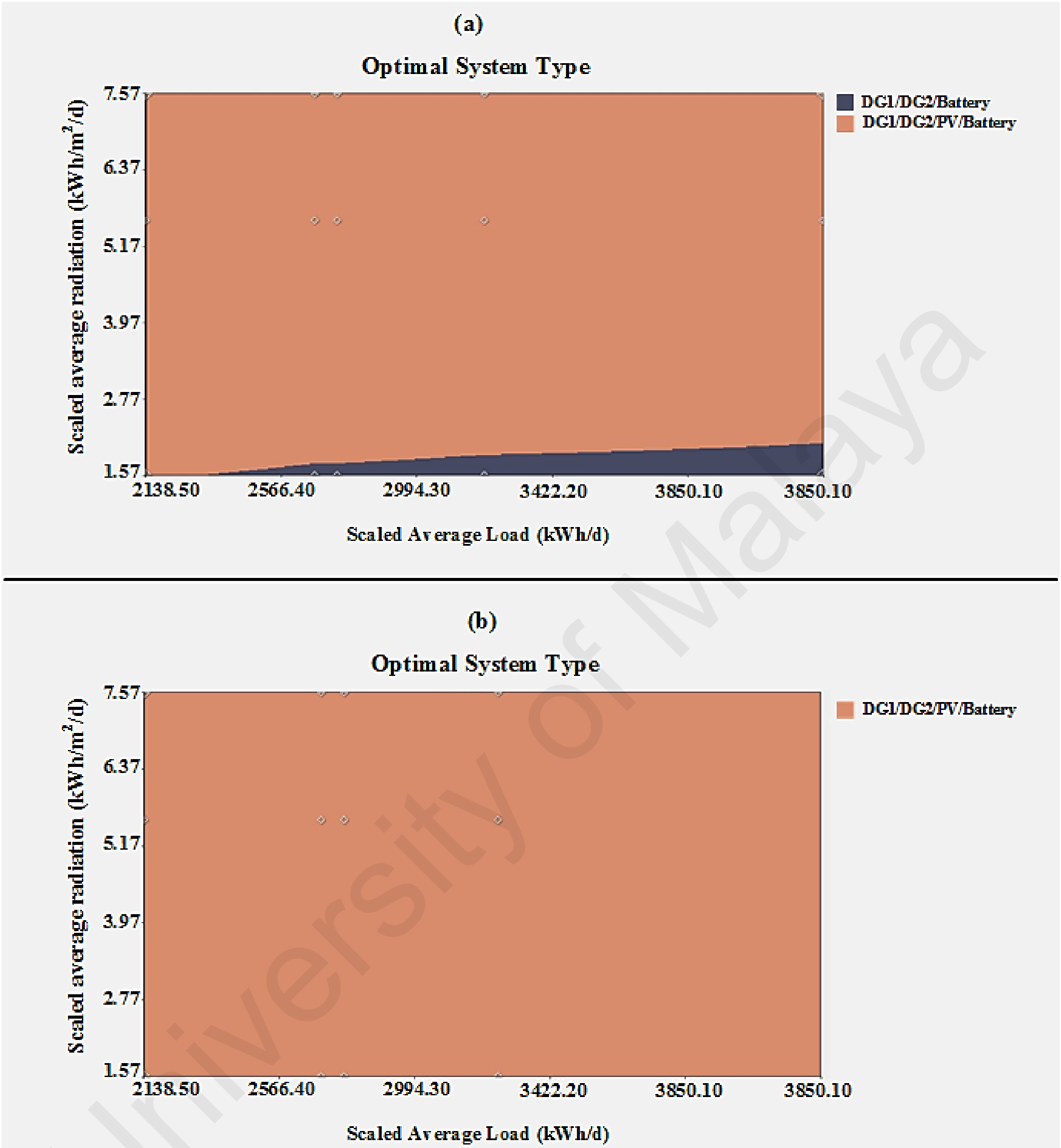


Figure 4.17: Off-grid hybrid system sensitivity analysis of average loads VS average solar radiation at (a) 0.7 $/L and (b) 1.5 $/L.

The sensitivity analysis creates different combinations of the proposed system equipment according to the available parameters of scaled loads, fuel price, and etc. Once the system meets the required criteria, HOMER chooses the system as the optimum design for specific conditions.

For this scenario, which is shown in Figure 4.17 (a) and (b), HOMER chose the optimum combination which has been found and showed in Table 4.8.

The results showed in Figure 4.17 (a) and (b), demonstrate the high flexibility of the optimum design over changing the diesel price, increasing the scaled average loads (load growth), and the average solar radiation. The design shows a high capability to serve these changes (which are regarded as major variables) under off-grid connection (standalone conditions). From Figure 4.17 (a), there are two main combinations of the generation systems which seems to be the best choices by HOMER; The first includes two diesel generators and battery banks. This combination is preferred only when the average loads increased to more than 2138 kWh/d and the average solar radiation reported low values of less than 1.6 kWh/m^2/d. Otherwise, the designed hybrid combination of two DGs, PV arrays, and batteries (which represent the proposed optimum solution) are preferred over the standalone DGs system and all other combinations during the project's lifetime as shown in Figure 4.17 (b). In the meantime, the effects of using the on-grid connection and different parameters are presented and explained in the following section (4.4.3).

4.4.3 On-grid hybrid system

In this section, the optimum design is assigned to a grid connection. Therefore, the system should be flexible to include this addition without making any change to the system configuration. Figure 4.14 (b) shows the system configuration that is considered in this section. Usually inserting a grid connection after running the standalone system requests a critical change in addition to the possibility of re-designing the whole system due to incompatibility between the system components as shown in the literature. Consequently, finding a flexible design would reduce investment cost hence no modifications' adaptations are needed. This would encourage promoting these projects for rural development without any fear of future challenges.

In this scenario, two main parameters have a direct impact on any on-grid connection, which is the power purchase and sells back prices. Currently, the national grid is unavailable at the proposed location. Therefore, there are no specific values that could be considered for setting the sell back and power purchase prices. In this regard, it is assumed that the power purchase price should be higher than the nearest location with a grid connection, due to its apart distance. Meanwhile, the sell back price should be higher than the power purchase prices as well as the off-grid system COE. This rise is due to feed-in tariff policies and governmental subsidies, which is usually are offered by the government for such projects, as reported throughout the literature. In order to study the operational performance under grid connection conditions, the system was assigned to a detailed sensitivity analysis, thus the impacts of all main parameters of the system are quantified and evaluated as represented in the following section (4.4.3.1).

4.4.3.1 Sensitivity analysis

This section is performed to include a detailed sensitivity analysis that comprises major changes on the system operation. To establish a comprehensive study that includes all variables that directly affect the system performance at any period. The applied changes include the load demand (load growth), power purchase, sellback and fuel prices. Figure 4.18 shows the effects of changing the load demand against power purchase and sellback prices.

In Figure 4.18 from (a) to (d) a fixed diesel price of (0.7 $/L) is used; it shows the effects of changing the sell back price simultaneously with the power purchase prices at different rates, besides increasing the load demands by 5% of load growth on the optimum system configurations. The results demonstrate the direct impact of these parameters on choosing the optimal system.

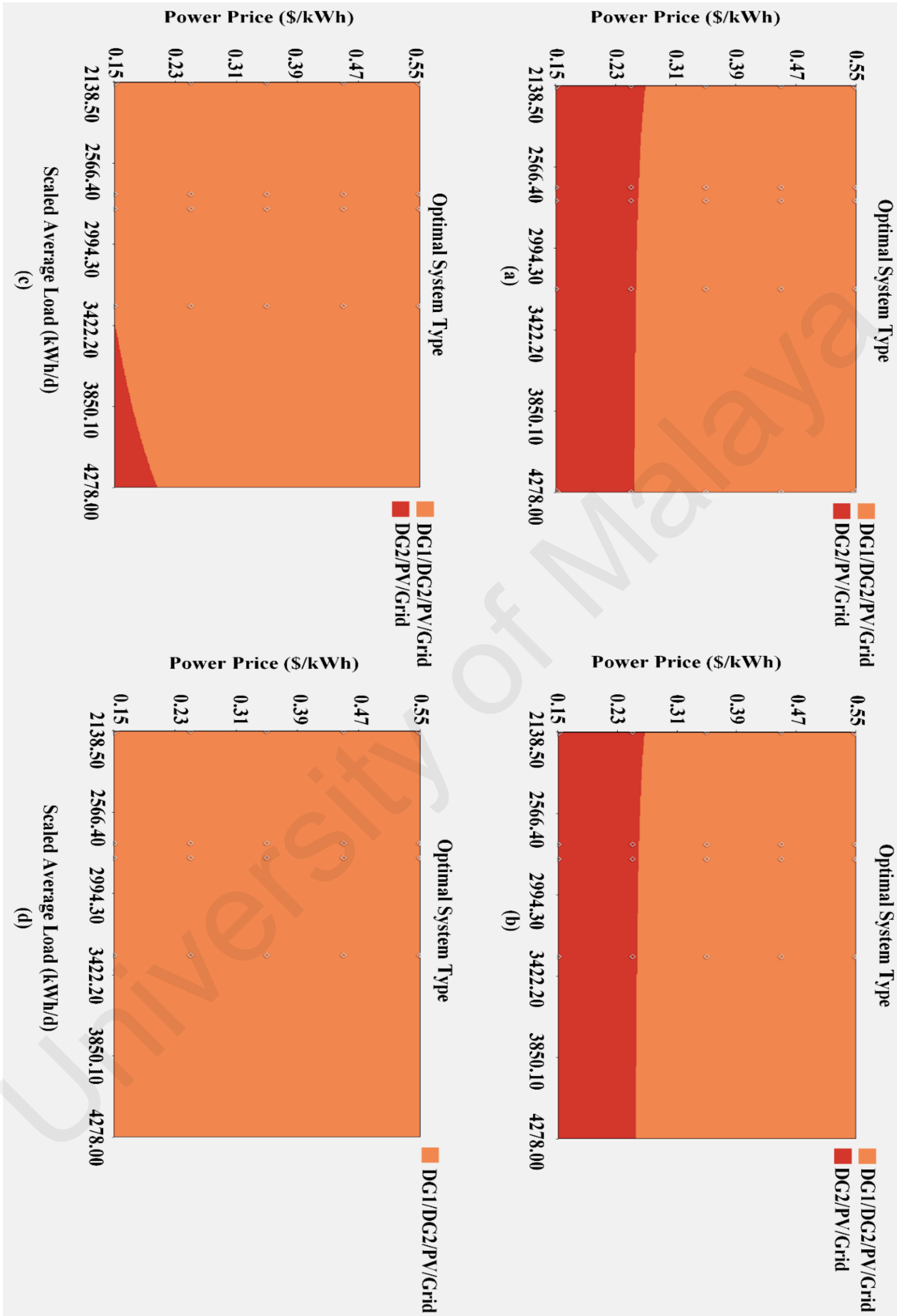


Figure 4.18: On-grid hybrid system sensitivity analysis showing power price VS average loads at different sell back prices in ($/kWh) (a) 0.15 (b) 0.25 (c) 0.30 and (d) 0.35 and above

Correspondingly, it is clear in this figure that the system configuration which was found earlier in section (4.4.2) is still preferred, which contains two DGs, PV and Grid with the same components' configurations but without the storage system (battery banks). The elimination of the battery banks mainly appeared due to the following two reasons:

I. Backup system: The grid connection provides a reliable backup system, thus no need to add batteries, which would increase the total NPC and COE.

II. Excess energy: Excess energy is selling back to the grid which would add an income to the system and thus reducing the COE as well as consume all excess energy.

Meanwhile, in the case of disconnecting the grid connection – temporary, the elimination of the battery banks would not have a huge impact on ensuring continues supply as the system would depend on the diesel generators and PV arrays (if available – daytime) to supply the loads. Furthermore, if the value of the sell back price is lower than the COE of the off-grid system (0.281 $/kWh) and power purchase price, the system tends to depend more on the DG2/PV/Grid choice while the load keeps increasing. In the meantime, increasing the sellback price to exceed the COE of the off-grid system (0.281 $/kWh) and power purchase as well, the system tends to depend more on the optimum design (DG1/DG2/PV/Grid) choice. Therefore, the system demonstrates the high flexibility of the optimal design for the case of fixed fuel price.

To validate the results, the effects of changing diesel price on the system with regard to load demands, power purchase, and sellback prices need to be elucidated. In this regard, diesel price is varied a range of (0.7 - 2.0 $/L), power purchase in a range of (0.15 – 0.55 $/kWh), and sell back prices in a range of (0.15 – 1.00 $/kWh). This would alleviate quantifying the influences of adjusting these main parameters on the operational performance of the system.

The results presenting in Figure 4.19 from (a) to (f) show two topologies that are preferred, which are DG2/PV/Grid and the DG1/DG2/PV/Grid. These two hybrid scenarios are chosen as the best scenarios despite the high diesel prices. The optimum system which was found in section (4.4.2) offers higher ability to serve through different conditions, mainly when the diesel fuel increased as well as power purchase prices. Meanwhile, higher values of sellback prices would result in more depending on the hybrid systems due to selling the excess energy back to the grid. Consequently, more income to the hybrid system would be found, which assist in reducing the total COE. In contrast, the other choice of the hybrid system which contains only one DG (DG1/PV/Grid) offered less reliability as the system is preferred mainly at higher load demands and lower diesel, and power purchase prices.

As a result, the optimum system is regarded as the best option in all cases, which demonstrates the high flexibility of the proposed design over in both off-grid and on grid connections.

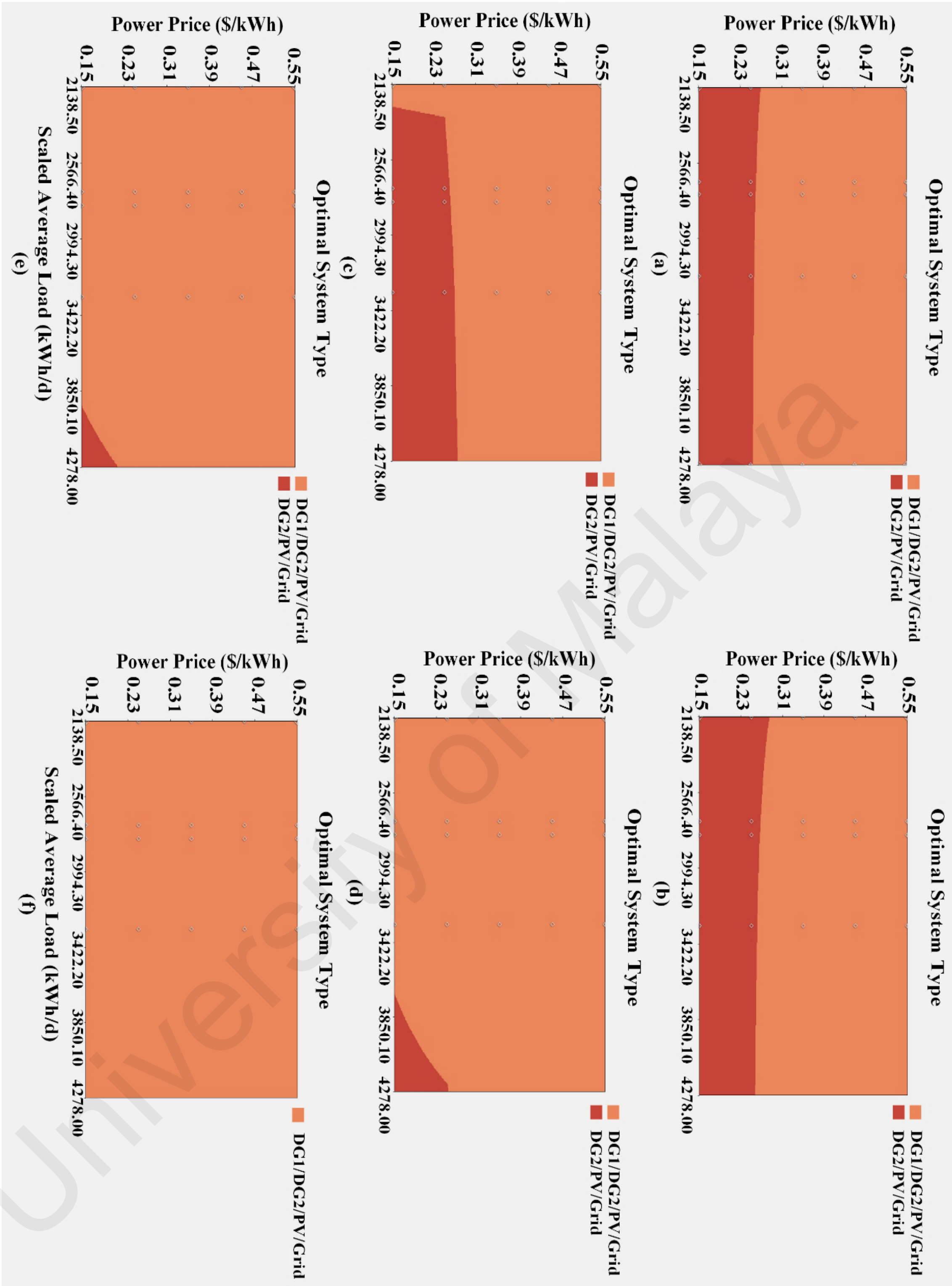


Figure 4.19: On-grid hybrid system sensitivity analysis showing power price VS average loads at different sell back($/kWh) and diesel prices ($/L) (a) 0.15($/kWh), 0.7($/L) (b) 0.25($/kWh), 0.8($/L) (c) 0.35($/kWh), 0.9($/L) (d) 0.40($/kWh), 0.95($/L) (e) 0.43($/kWh), 1.0($/L) and (f) 1.0($/kWh), 1.5($/L) and above

Among different rates of RF, the relation between RF and different system prices is shown in Figure 4.20. RF is changing based on different power purchase and sellback prices. The highest RF was found at the off-grid system at 55.43%. Accordingly, the RF is inversely proportional to the power purchase price, while higher sell-back prices are accompanied with higher dependence on the hybrid system. That the result indicates that the operational performance of the system is directly affected by power purchase and sellback prices. In this study the RF varies within the range of (23-55.43)%. The analysis of the system indicates that lower power purchase, as well as higher sellback prices, are preferred in any hybrid system under grid connection conditions.

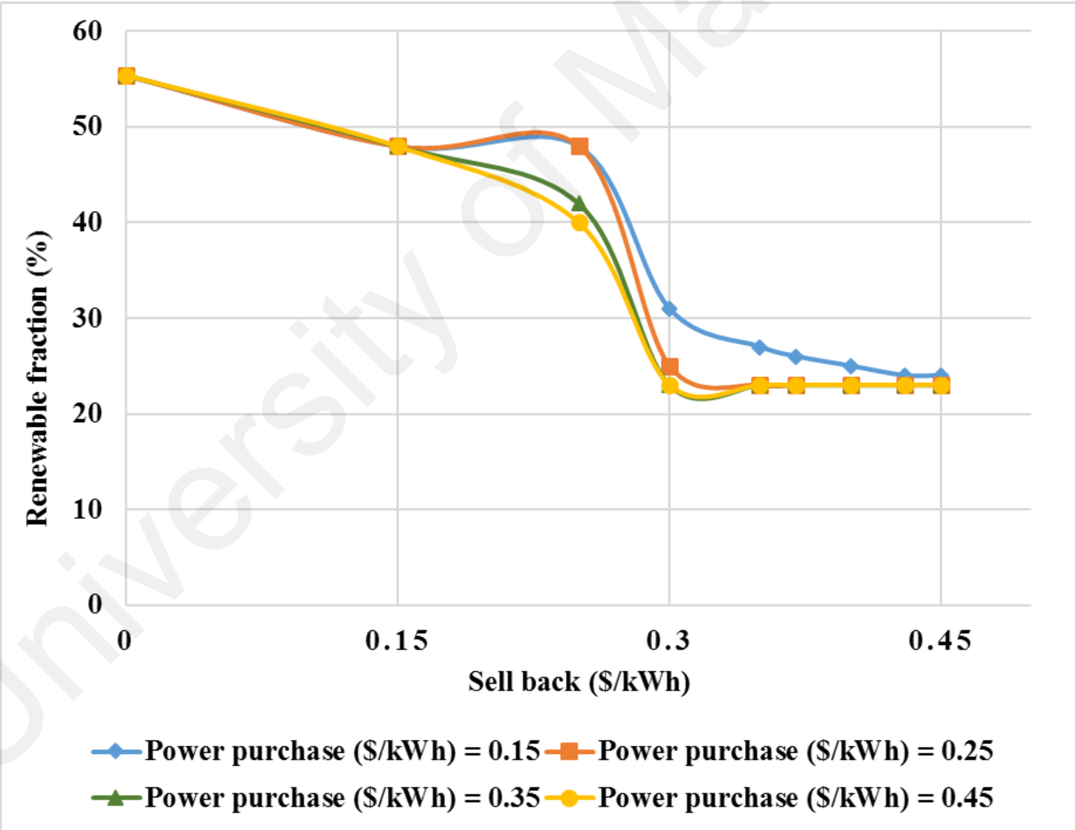


Figure 4.20: Renewable energy fraction VS. Different power purchase and sell back prices

4.4.3.2 Economic impact

The effects varying the sellback and power purchase prices on the COE, NPC, and operating cost is shown in Figure 4.21. Different power prices for both power purchase and sellback prices of 0.15, 0.25, 0.35, 0.45 and 0.55 $/kWh are considered in this figure.

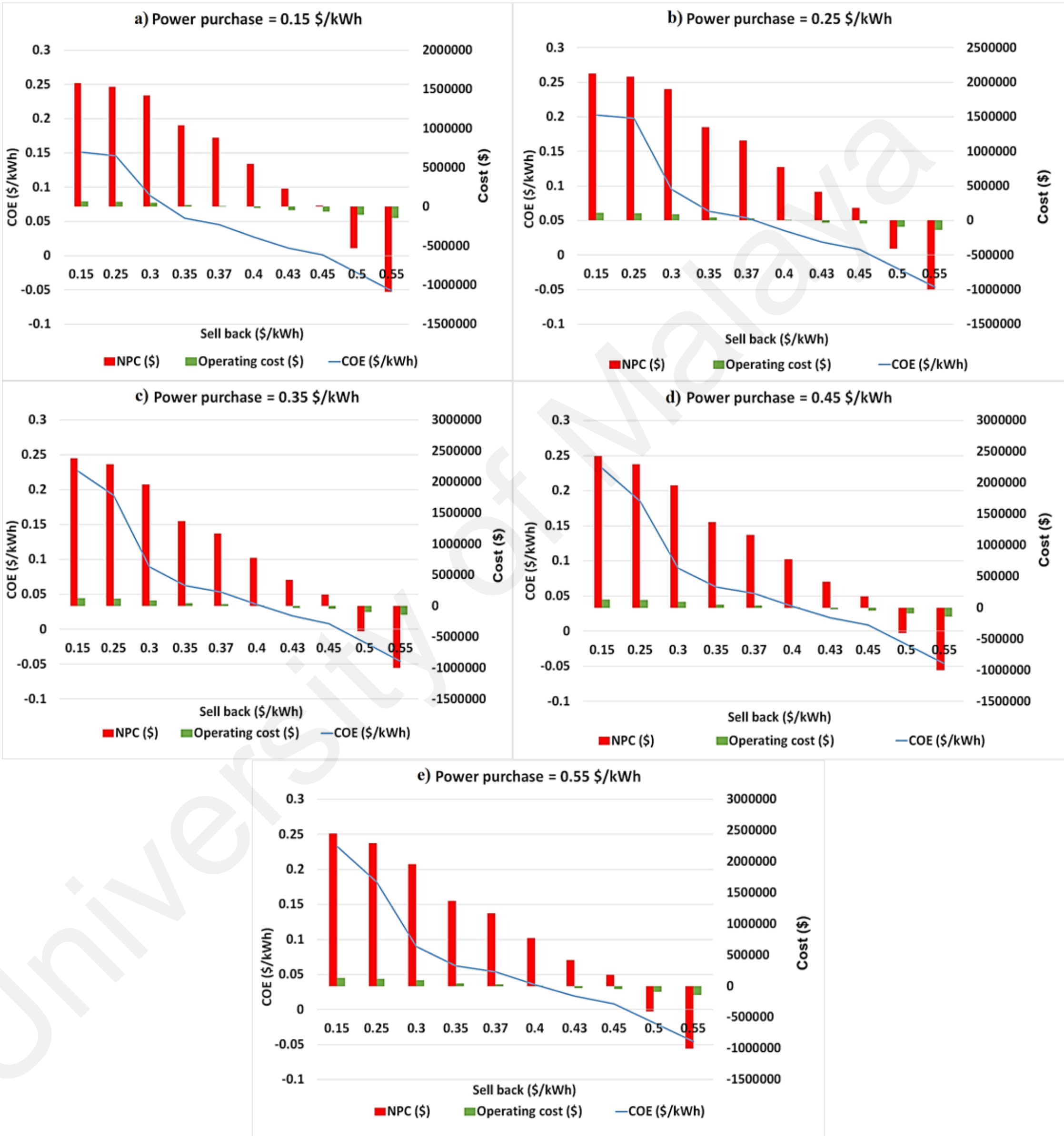


Figure 4.21: Power purchase price Impact on COE, NPC and operating cost over (a) 0.15 kWh/$ (b) 0.25 kWh/$ (c) 0.35 kWh/$ (d) 0.45 kWh/$ (e) 0.55 kWh/$

From the results, it is clear that COE, NPC, and the operating increased when the power purchase price increased, for example, when the power purchase is 0.15, 0.25, 0.35, 0.45, and 0.55 $/kWh, respectively, with fixed sellback price are of 0.15 $/kWh.

The impact on the COE is clear as COE values got 0.151, 0.203, 0.227, 0.232, and 0.233 $/kWh respectively. On the other hand, increasing the sellback prices would lead to reducing the COE, NPC, and operating cost. The results demonstrate the direct impact of these two parameters on the overall system's performance. Understanding the performance of any hybrid system according to these variables in remote areas is very important and would influence the whole system, mainly in updating standalone systems with grid connections.

4.4.3.3 Environmental impact

The environmental impact of each system is also considered throughout this work. The result of exhausting different power purchase and sellback prices is shown in Figure 4.22 High power purchase prices lead to less dependence on the grid to meet the load demand and increase the usage of the hybrid system – which includes diesel generators and renewable energy components – in this case; the diesel generators would work more mainly when the renewable energy sources are unavailable. Thus, higher amount of the CO_2 emissions is found. While, in this case of considering higher sell-back prices (for the same power price) then, the system would depend more on the grid as the main source of energy thus, higher amount of CO_2 emissions towards the surrounding environment would be generated. HOMER software calculates the CO_2 emissions in the grid connection by multiplying it with a special factor described in (Lambert et al., 2006).

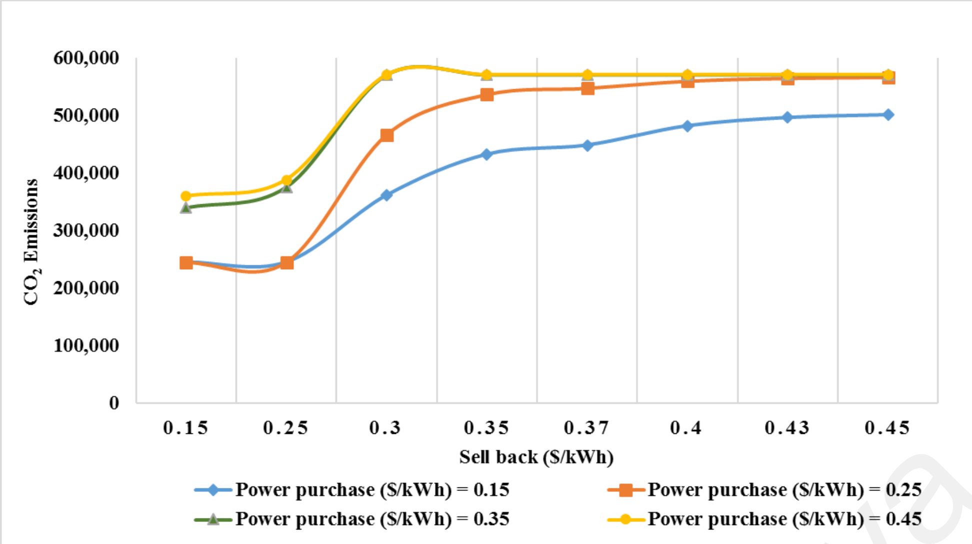


Figure 4.22: CO_2 Emissions VS. Different power purchase and sell back prices

4.4.4 Discussion of the main operational analysis

In this section, the major findings of sections (4.4.2 and 4.4.3) are discussed and explained. The results are connected together to show the relationship between different system components and the effects of changes in the main system's parameters on the system performance.

4.4.4.1 Technical impact

Among the different configurations of off-grid and on-grid connections, each scenario has distinct properties. These differences affect the operational behavior and the economic side as well. In this regard, the results show that the off-grid system depends upon the storage system (battery banks) as the main backup system and to store the excess energy for further use. However, the on-grid system replaces the battery by using the grid connection. Battery banks seem to be economically inefficient in the on-grid connection due to selling back the excess energy into the grid where the system depends mainly on the DGs and PV to supply the load. In this case, the grid is operated to perform two main tasks:

I. Backup system in case DGs and PV are inefficient to supply useful energy to the loads.

II. Consuming the excess energy that generated by the system, which adds another source of income.

Meanwhile, in the case of disconnecting the grid connection – temporary, the system would depend on the diesel generators and PV arrays (if available – daytime) to supply the loads. However, the battery may support the system in supplying a continue operation, but this would add more cost to the system NPC.

4.4.4.2 Economic impact

The costs of the system directly related to the operation procedure and system configuration. Figure 4.23 shows different costs to the system which includes capital, replacement, O&M, fuel, operating and salvage costs. Both off-grid and on-grid systems are considered, and the results indicate that the fuel cost performs huge impact on the system followed by the capital, O&M costs, and then the replacement cost. Meanwhile, the off-grid system shown in Figure 4.23 (a) has higher costs than the on-grid system that is shown in Figure 4.23 in (a), (b) and (d), mainly due to the large fuel costs. Furthermore, using different power purchase and sellback prices leads to dissimilar system costs. Besides, it results in excluding the usage of some components such as DGs as shown in Figure 4.23 (c) in the case of higher sellback prices.

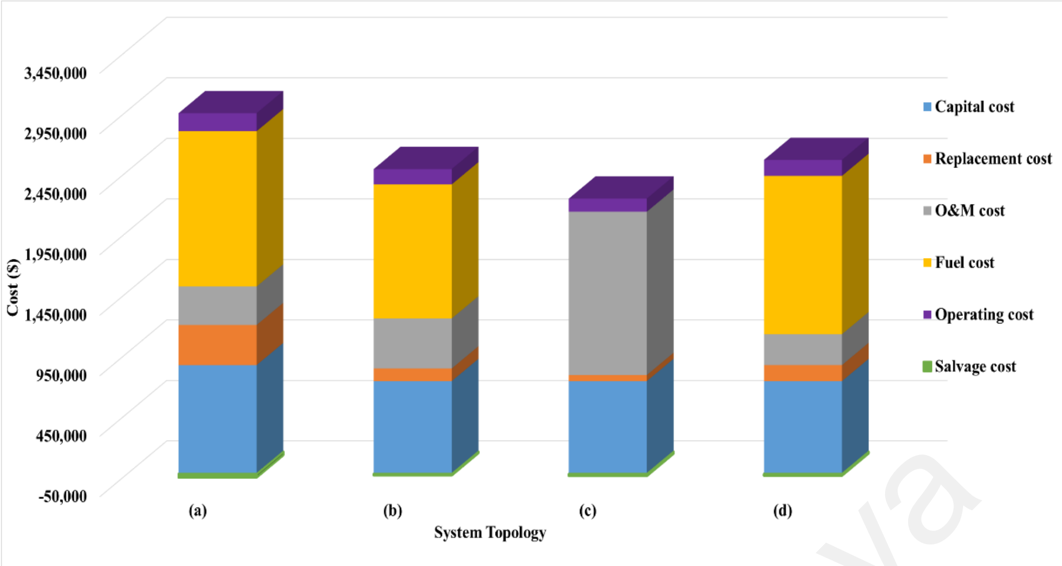


Figure 4.23: Details cost analysis of (a) off-grid system and on grid system with different power purchase and sellback prices of (b) 0.350 $/kWh and 0.150 $/kWh (c) 0.250 $/kWh and 0.350 $/kWh (d) 0.550 $/kWh and 0.150 $/kWh respectively

4.5 Chapter summary

In this chapter, the results of the collected data from both sites which highlighted in chapter 3 are presented and discussed. The analysis includes all possible scenarios of standalone diesel generators and the existing PV/diesel/battery hybrid systems over different RE penetration levels. Besides, 100% PV/battery hypothetical scenario is also discussed. Meanwhile, the optimal sizing system is included to examine whether the system is optimally selected prior installation or not. The results indicate that the existing systems have not optimally selected prior installation. Hybrid PV/diesel/battery system shows the best performance compared to all other scenarios in terms of the technical aspects as well as supporting 24-hour energy access.

The result of using hybrid ANFIS algorithms to predict monthly global solar radiation is also showed and explained throughout this chapter. Hybrid ANFIS-PSO, ANFIS-GA and ANFIS-DE as well as standalone ANFIS system are used to create an accurate prediction technique. Different evaluation parameters are used to describe the performance and to demonstrate the precision capability of each model, which include RMSE, RRMSE, r, R^2, MABE and MAPE. Each model has validated using these statistical parameters, where ANFIS-PSO offers the best performance and the highest learning capability based on the results of the statistical evaluation parameters. The results demonstrate the high capability of ANFIS in predicting the global solar radiation as well as the capability to be combined with other soft computing techniques. In addition, the performance of the developed models is compared with other artificial intelligence (AI), hybrid AI and empirical techniques that carried out by other researchers for predicting global solar radiation in different parts around the world.

The optimum hybrid energy system was designed to meet load demand of a typical remote Malaysian village located Sabah, Malaysia. Several scenarios for off-grid and on-grid connections were performed. The operational behaviors for all configurations were investigated and quantified to show the benefits and risks associated with each system, and then finding a flexible design. In addition, a detailed sensitivity analysis was performed the system behavior over some main factors. The results have found the optimum system has high flexibility in the off-grid system. The optimum design was also examined for the presence of a grid connection. Several sensitivity analyses were used to adequately quantifying the effects on the system performance of the optimal design. The results show the effects of various values of the power purchase and sellback prices on the system performance.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusions

This dissertation focused on investigating the operational performance metrics of two decentralized PV/diesel hybrid power located in remote locations in Malaysia. Usually, in such areas, there is no grid connection or have an unreliable power supply. This has often led to many problems, including obstetric complications, which is one of the root causes of preventing the socio-economic developments in the rural areas. Therefore, the provision of portable hybrid RE power supply would enhance the benefits and reduce the risks for designing and establishing new projects in the future.

To this aim, the performance matrices of the current and proposed scenarios of two power stations located in Pulau Banggi and Tanjung Labian, Sabah, Malaysia are analyzed and investigated. This is followed by analyzing all existing operational scenarios, optimal configurations' assessment, sizing of system components as well as techno-economic analysis of the employed hybrid systems in these areas. To assess the techno-economic analysis of the hybrid RE system comprising diesel generators, PV modules and battery banks, hybrid optimization software (HOMER) has been used. This software has the capability to simulate, optimize and conduct sensitivity analysis on different parameters of the load demand and offer the best performance. Therefore, the main findings in this study are summarized as follows:

- The impact of injection of PV into mini-grids based on important operational procedures over different RE penetration levels (0%, 39.89%, 42.38%, 59.21%, 86.90% and 100%) is shown and explained. The existing systems in both locations were compared to the optimum sizing of the PV system in order to examine whether the systems are optimally selected prior the installation for the same load profiles, solar radiation and temperature data sets. The effects of changing RE penetration levels on NPC, COE and associated technical properties, the influences of different PV penetration levels on the harmful emissions' generation were also shown and discussed. In addition, the study put emphasis on all costs associated with the systems through comparative cost analysis between distinct configurations.

- The comparison with the optimal system indicates that the existing systems have not optimally selected prior installation. Meanwhile, hybrid PV/diesel/battery system shows the best performance compared to all other scenarios in terms of the technical aspects as well as supporting 24-hour energy access. For example, the existing hybrid PV/diesel/battery system result in reducing 49% and 80% of the total fuel consumption by comparing it with standalone diesel generator system. On the other hand, the standalone diesel generator system shows the best economical characteristics overall other scenario. In contrast, 100% RE scenario considered the best system by providing clean energy with no emissions.
- Sensitivity analysis was carried out based on a variation of some parameters, including fuel, PV, battery prices and load demand (load growth by 5%). The results showed more trends towards using RE sources in energy generation and less dependence on the standalone diesel generators. The inclusion of RE resources in power generation has resulted in improving the system performance and minimizing the dependence on fossil fuel and harmful emissions as well. In addition, it demonstrates the importance of including storage system (batteries) to store excess energy and reducing the losses.
- Modeling and predicting of global solar radiation using hybrid ANFIS merged with PSO, GA and DE respectively are shown and illustrated. Different meteorological parameters, including sunshine duration, minimum and maximum ambient temperature, rainfall and clearness index are used. Different evaluation parameters are used to describe the performance. The results demonstrate the high capability of

ANFIS in predicting the global solar radiation as well as the ability to be combined with other soft computing techniques. The analysis of the results signifies that the developed models showed considerable prediction improvements and proved that the proposed hybrid systems bring higher reliablity in estimating the non-linear nature of solar radiation. Where, the hybrid ANFIS-PSO model showed the best performance overall models with in terms of the RMSE, RRMSE, r, R^2, MABE, and MAPE with 0.3121, 1.8580, 0.9931, 0.9862, 0.2354, and 1.4159 for training datasets, respectively. Besides, 0.3065, 1.7933, 0.9963, 0.9921, 0.2482, and 1.4097 for testing datasets, respectively.

- The flexible hybrid RE system was designed to meet load demand of a typical remote Malaysian village. Several scenarios for off-grid and on-grid connections were performed. The operational behaviors for all configurations were investigated and quantified to show the benefits and risks associated with each system. The results have found the optimum system has high flexibility in the off-grid system. However, in on-grid system battery banks regarded as an uneconomical choice, because the grid would take over the role of the battery banks. Moreover, power purchase and sell back prices are performed the main factors which directly affect the system performance.

5.2 Recommendations

In view of the above findings, the following points are recommended:

- Using hybrid system includes different RE and conventional sources to power remote areas would comprise the best technical merits of each system with regarding of good economical and environmental aspects. However, this need to be clarified by examinning the performance of recent/different technologies in electrifying the remote areas such as; discussing and analyzing the operational performance of hydrogen tanks and electrolyzer in deep details under similar conditions as a future work.
- There is still a gap of considering different types of the loads (i.e. commercial and industrial loads) to check the potential over technical, economical, environmental, and social aspects in order to examine the potential of the hybrid RE systems in different aspects and surrounding conditions. Hence, the benefits of RE projects in local communities appear in enhancing the socio-economic developments by creating new job opportunities for the local residents at different fields.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

- **Journals**

I. **Laith M. Halabi**, Saad Mekhilef, Lanre Olatomiwa, James Hazelton (2017). Performance analysis of hybrid PV/diesel/battery system using HOMER: A case study Sabah, Malaysia. Published in **"*Energy Conversion and Management*"** (Elsevier). ISSN: 0196-8904. Vol. 144 pp: 322-339 (ISI-cited publication, I.F: 5.589, **Q1**).

II. **Laith M. Halabi**, Saad Mekhilef (2017). Flexible hybrid renewable energy system design for a typical remote village located in tropical climate. Submitted to ***"Journal of Cleaner Production"*** (Elsevier). ISSN: 0959-6526. (I.F: 5.715, **Q1**)- **Under review**.

III. **Laith M. Halabi**, Saad Mekhilef, Monowar Hossain (2016). Performance evaluation of hybrid ANFIS models for predicting monthly global solar radiation Submitted to **"*Applied Energy Journal*"** (Elsevier). ISSN: 0306-2619. (I.F: 7.182, **Q1**)- **Under review**.

- **Conference**

I. **Laith M. Halabi, and** Saad Mekhilef. Performance analysis of multi-photovoltaic (PV)-grid tied plant in Malaysia. ***Accepted for presentation*** at 2nd International Conference on Energy and Environmental Science (ICEES 2018 to be held in Kuala Lumpur, Malaysia (16th - 18th , January, 2018).

II. **Laith M. Halabi,** Saad Mekhilef. Energy management for a gird connected hybrid renewable energy system. ***Accepted and presented*** at the Australasian Universities Power Engineering Conference 2017 (AUPEC2017) held in Melbourne, Australia (19th – 22nd, November, 2017).