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Isolation Microgrid Design for Remote Areas with the Integration of Renewable Energy: A Case Study of Con Dao Island in Vietnam

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Abstract: In remote areas, extending a power line to the primary electricity grid can be very expensive and power losses are high, making connections to the grid almost impossible. A well-designed microgrid that integrates renewable energy resources can help remote areas reduce investment costs and power losses while providing a reliable power source. Therefore, investigating the design of an independent and economically practical microgrid system for these areas is necessary and plays an important role. This paper introduces a design procedure to design an isolated microgrid using HOMER software (HOMERPro 3.14.5) for remote areas. In Vietnam, due to the obstruction of the mountainous terrain or the isolated island location, many remote areas or islands need electrification. A simple case study of a hybrid system with a 60 kW peak load demand on Con Dao island in Vietnam is used to illustrate the proposed design method. Specifically, a hybrid system that includes a PV system, batteries, and a diesel generator is designed. To provide the full information of the designed hybrid system designed, each solution is analyzed and evaluated in detail according to the sensitivity parameters.

Keywords: clean energy; islanded microgrid; HOMER; hybrid system; microgrid design

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Citation: Tran, Q.T.; Davies, K.; Sepasi, S. Isolation Microgrid Design for Remote Areas with the Integration of Renewable Energy: A Case Study of Con Dao Island in Vietnam. *Clean Technol.* **2021**, *3*, 804–820. https://doi.org/10.3390/cleantechnol3040047

Academic Editor: Patricia Luis

Received: 23 September 2021
Accepted: 29 October 2021
Published: 3 November 2021

1. Introduction

Recently, energy consumption has increased quickly due to the fast development of the global economy. The fossil energy resources such as coal, oil, and natural gas cannot be recreated and pollute the environment [1]. To address these issues, new renewable energy resources have become a key factor of choice. In developed countries and regions, renewable energy development strategies have been developed to maximize the use of renewable energy resources and increase energy efficiency [2–4].

The electricity sector is among the industries that generate the most global emissions, mainly from coal-powered sources. The participation of renewable energy resources in the electricity sector may support a significant reduction in the consumption of fossil fuel and lowering global warming emissions [5]. Distributed power generation technology is the leading vehicle that uses various energy resources, such as wind, solar, and marine energy, to generate electricity effectively. However, challenges exist in the development of these new energy systems. For example, providing a continuous and stable power supply using wind or solar energy is complex because these sources are random and intermittent. The instability of these energies significantly undermines the role of the distributed power plant and the reliability of the power system [6–8].

The microgrid (MG) concept, as a group of connected renewable energy resources, loads, and battery energy storage modules, first appeared in the United States [6]. They ensure maximum benefits of small grid models and promote the development of the entire power system [7]. Initially, the small grid was designed to operate independently to fight against common natural disasters, mainly based on fossil energy sources such as oil generators, microturbines, and diesel generators. Realizing the great benefits of integrating microgrids with renewable energy sources, many studies have been carried out to investigate and evaluate the optimal microgrid operating models while still taking advantage of maximum use of renewable energy sources [8–10] towards the development of a sustainable energy system [11,12].

In [13–16], the control system of the MG was designed to optimize the operation and minimize losses. In [17,18], the MG's energy management systems are mentioned to schedule the MG operation in each time step. For designing the MG approach, in [19], a power balance method for optimizing distributed energy resources investments in the intra-hour variability of solar and demand of a residential MG is presented. This method helps to reduce the risks of intra-hour forecasting deviations, thus optimizing investment costs for inverter devices. Paper [20] presented a system function and topology MG design for a small village in Thailand with a peak load of about 76 kW. The system could operate and be maintained without human control. The work in [21] presents a ComμGrid sizing approach to design off-grid PV microgrid systems using a Mixed Integer Linear Programming (MILP) algorithm. The paper only focuses on designing a PV system for a small 100 household village with average load demand of about 485 kW. In [22], a planning framework is introduced to optimize the operation of the interconnected MGs considering the impact of the power imbalance, and the fluctuation of renewable generators and loads. Other similar research can be found in [23–25].

Currently, because the cost of installing rooftop solar power systems is decreasing, the case for independent microgrids in remote areas is becoming stronger. In deciding to construct microgrids, it is necessary to comprehensively consider technical, environmental, and economic issues. However, the above papers have not presented clear specific design procedures, and the proposed design methods are fairly complicated. Most of the studies only focus on designing an extensive system with high capacity for the entire region. However, the need to build an independent power grid with a small capacity is increasing to reduce installation costs for the power plants, utilities, and governments responsible, and to reduce electricity costs for end-users by taking advantage of renewable energy sources.

This article presents a simple but flexible method that can be easily applied for designing an isolated microgrid, reducing the complicated calculation work for the designer. A simple case study is simulated for a stand-alone microgrid model, on Con Dao island in Vietnam, to illustrate the effectiveness of the proposed approach using HOMER software. The article also provides an overview of the microgrid, including necessary definitions, MG operation modes, MG control, and energy management in an MG.

The remainder of this paper is organized into four sections. Section 2 introduces microgrids and provides an overview of their definition, operation modes, and energy control and management systems. Section 3 presents the methodology used to design the microgrid. Section 4 describes the case study and shows the results. Section 5 presents the discussion and the conclusion is presented in Section 6.

2. Overview of the Microgrid

2.1. Microgrid Defination

According to The Consortium for Electric Reliability Technology Solutions (CERTS) in the United States, an MG consists of loads and micro-power supplies that provide electrical and thermal energy according to the user's requirements [6]. The energy sources in an MG can be small turbines, solar or wind power generation systems, fuel cells, or stored energy sources. The MG is linked to the main power network through a Point of Common Coupling (PCC). The goal of the MG system is to provide electricity in a sustainable, safe, and economical manner with intelligent monitoring and control technologies [26,27]. Although there are many different types and configurations of MGs, all of them are similar in nature, as shown in Figure 1.

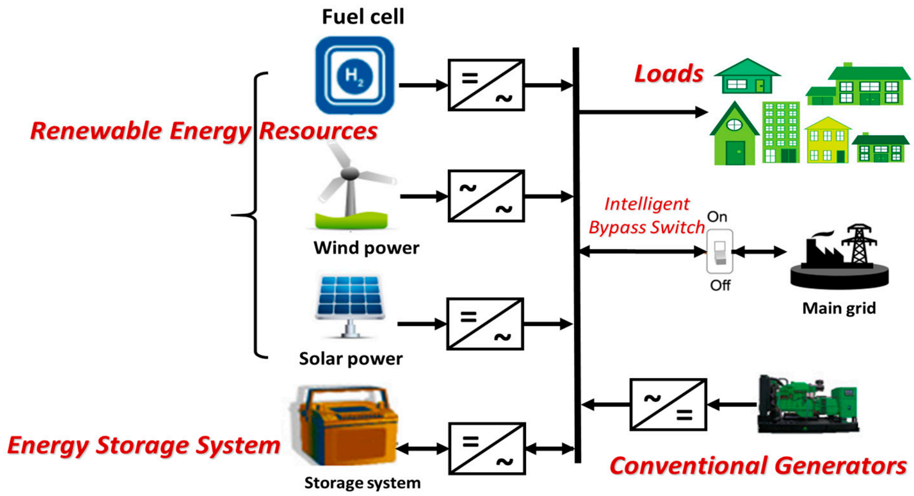


Figure 1. Microgrid components.

2.2. Microgrid Operation Modes

An MG can operate in isolated mode or grid connection mode [28,29].

- Grid-connected operation mode: The MG is interconnected to the main network. This operating mode is divided into two types: grid connection but not supplying excess power to the grid, and grid connected but providing excess power back to the grid. The frequency of MG is synchronized with the frequency of the main grid without any technical problems. If the load is high and the distributed sources in the MG cannot meet the demand, the main grid will support the supply through the PCC. In this mode, the MG grid is guaranteed to operate safely even if distributed sources fail [30,31]. Figure 2 depicts the grid-connected microgrid model.

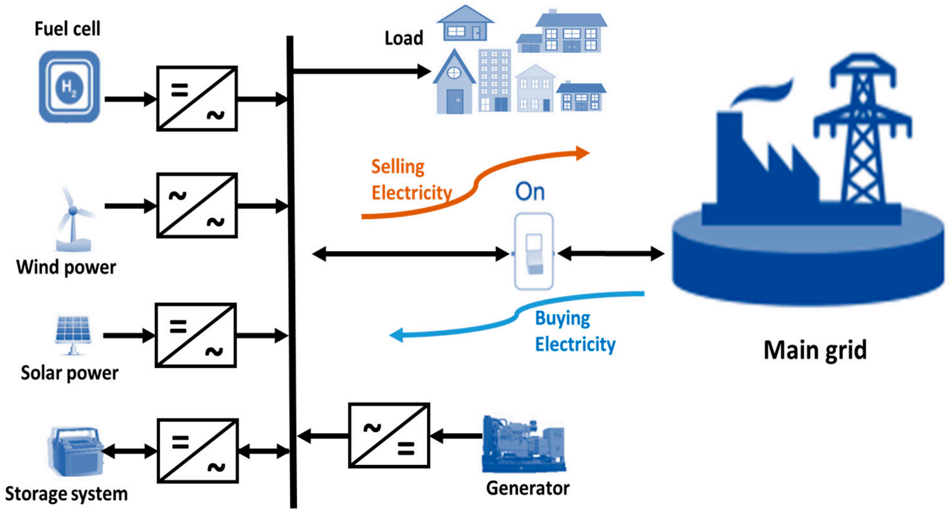


Figure 2. The model of the grid-connected microgrid.

- Islanded operating mode: The MG, when not connected to the main grid, is called a stand-alone MG. This operating model is commonly applied to grids built in mountainous areas, on islands, or in completely isolated areas, where the main grid cannot supply electricity. The model is also applied when the main power grid fails and cannot supply power to an area [32,33]. The island separation of a small grid system helps reduce power outages, ensure the safe operation of the fault grid area, and improve the quality of power supply services. The disadvantage of this model is that the power source depends mainly on distributed energy sources, is unstable, and often changes suddenly depending on weather conditions. Figure 3 depicts the model of an islanded microgrid.

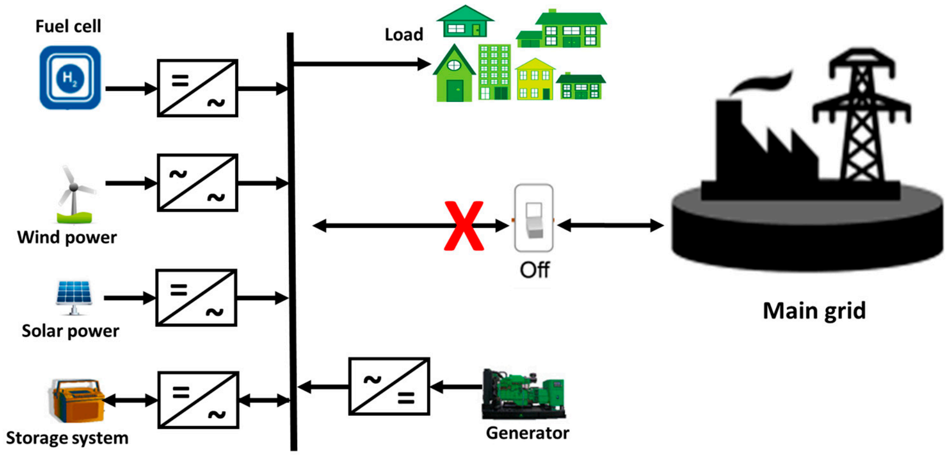


Figure 3. The model of the islanded microgrid.

2.3. Microgrid Control

To maximize the benefits of distributed power sources, the enhancement of the power supply response and the operation of these power sources needs to be performed through the control system. In the MG grid, the control system is divided into three levels to be able to provide quality power [34]:

- Primary control: Usually designed to ensure voltage and frequency stability for microgrids and adjust the power sharing among distributed generators. This level of control also helps minimize circulation currents between paralleled converters of three-phase generators, causing overcurrent in electrical equipment.
- Secondary control: The function of this control level is to compensate for the voltage and frequency difference left by the primary control. This level of control has slower dynamics than the primary level, and is performed to satisfy power quality requirements.
- Tertiary control, also known as the energy management system: This is the final control level that regulates the power of the MG, and between the MG and the main network. The third level of control also provides an economically optimal operation to minimize the electricity costs.

2.4. Energy Management in MG

Energy management is one of the critical components in the MG system, and operates the MG to meet various economic, technical, and environmental objectives as required by the operator [35]. The main objectives often include managing forecast load demand compared to the actual demand, power generation management, reactive power flow management, or loss reduction in the MG system [36].

An MG's energy management system will communicate with all other components to monitor and control the equipment to ensure optimal operation of the entire system. The controller and related components to manage the microgrid are hardware and software of the main controller, a power supply, an SCADA system, a system of renewable energy sources, a main power supply system such as a diesel generator, and a switching system.

3. A Methodology for Designing Microgrid Using HOMER

Unlike in the case of the main power system, the optimal design and calculation of the structure parameters of an MG aim to adapt the load demand and operate the system efficiently, achieving benefits such as saving money, saving energy, and protecting the environment. In order to properly design the MG, it is important to investigate the factors affecting the design and the optimization of MG grid operation based on the system grid operation data. Typically, the design process of an MG grid structure involves three stages as shown in Figure 4 [37]:

- Stage 1—Design of distributed energy sources: The objective of this stage is to evaluate the feasibility of the designed system. Questions that need to be answered at this stage include: How much backup power does the model need? This includes a rough assessment of operating costs and how that changes the design paradigm.
- Stage 2—Detailed design: At this stage, the design options are narrowed down and focused on concretizing the equipment for the design model. It is necessary to update the data about the supplier's products, thereby refining the design by comparing supplier's information.
- Stage 3—Final design: At this stage of the project, the contractor will produce detailed technical drawings and address site-specific issues such as equipment size, wiring, protection scheme, and construction challenges.

Figure 4. The microgrid design procedure.

The design phase of distributed energy sources is the most critical stage, and is used as a basis for developing detailed designs in this paper. Hybrid Optimization Model for Electric Renewable (HOMER) is a software tool that was originally developed by the US National Renewable Energy Laboratory (NREL), and can be used to evaluate economic and technical models for hybrid systems. The software models the physical characteristics of the power generation system and the life cycle costs of the system components [38]. HOMER allows users to compare and evaluate many different options to choose the most suitable solution while achieving optimal economic efficiency. It includes a large database and updated information about supplier products to aid in this process [39,40].

3.1. Model of Power Supply Components in the MG

An MG usually contains different power supply sources, such as small generators (microturbines), fuel cells, solar power, and wind power, or storage batteries. Depending on the requirements of each different project, the designer will choose suitable models to include in the calculation.

- Wind turbine model: Data related to wind speed are needed to calculate the power output (P_{WT}) of a wind turbine at each time t. The wind speed is measured over 24 h considering the minimum wind speed to put the turbine into operation (cut-in wind speed), and the maximum wind speed that must stop the turbine from running (cut-out wind speed) [2].

$$P_{WT(t)} = \begin{cases} a \cdot V^3(t) - b \cdot P_R & V_{Ci} < V < V_r \\ P_R & V_r < V < V_{co} \\ 0 & V < V_{Ci} V_{co} < V \end{cases} \tag{1}$$

where: a, b are wind coefficients and can be calculated as shown in the following equations:

$$a = P_R / \left(V_r^3 - V_{ci}^3\right) \tag{2}$$

$$b = V_{ci}^3 / \left(V_r^3 - V_{ci}^3\right) \tag{3}$$

P_R: wind turbine's rated power
V: wind speed
V_{ci}: cut-in wind speed

V_{co}: cut-out wind speed

- PV model: Solar power generation at date i, time t can be modeled according to the following equation [41]:

$$P_{PV}(i,t) = \eta_m \cdot \eta_{Conv} \cdot A_m \cdot G_t(i,t) \cdot (1 - \beta_t(T_c(i,t) - T_r)) \tag{4}$$

where:

A_m: Solar panel surface area (m^2)
η_m: Module efficiency
η_{Conv}: Power conversion efficiency
T_r: Reference temperature of the solar cell
β_t: Heat coefficient
G_t: Solar irradiance (W/m^2)
T_c: Solar cell temperature

The energy supplied by the PV system, E_{PV} at date i, time t will be calculated according to the following formula:

$$E_{PV}(i,t) = P_{PV}(i,t) \cdot \Delta t \tag{5}$$

- Microturbine model: To assess the cost of a microturbine, two main cost components are considered: fuel cost C_{fuel} and maintenance cost $C_{O\&M}$ at time t

$$C_{microturbine}(t) = C_{O\&M}(t) + C_{fuel}(t) \tag{6}$$

- Battery model: The battery energy at date i, time t will be calculated based on the following equation [42]:

$$E_{bat}(i,t) = V_{bat} \cdot C_{bat}(SOC(i,t-1) - SOC(i,t)) \tag{7}$$

where:

V_{bat}: Battery's nominal voltage
C_{bat}: nominal capacity of the battery (Ah)
SOC: Battery's stage of charge, which can be calculated in the following equation:

$$SOC(i,t) = SOC(i,t-1) \cdot (1-\delta) - I_{bat}(i,t) \cdot \Delta t \cdot \eta_{ch}^{k} / C_{bat} \tag{8}$$

where:

δ: Capacity available in battery
η_{ch}: Charging efficiency of the battery
k: battery's status. $k = 1$ while charging and $k = 0$ while discharging
I_{bat}: Charging current

3.2. Optimization Problem for Designing Microgrid

The design of the power supply resources is performed based on the construction of the optimization problem, which can have a single objective or multiple objectives. Factors such as distributed power resources and batteries should be considered when selecting variables. Depending on different MG design and planning strategies, the relevant parameters need to be changed accordingly.

The basic model is usually expressed as follows [43]:

$$\begin{aligned} &\mathrm{Min} f_i(X),\ i = 1,2,3\ldots \\ &s.t. \begin{cases} G(X) = 0 \\ H(X) \le 0 \\ X \in \Omega \end{cases} \end{aligned} \tag{9}$$

where:

X is the variable;
$f_i(X)$ is the objective function;
$G(X)$ and $H(X)$ are constraint functions;
Ω represents the space of possible solutions.

This optimization model helps to determine an ideal system configuration that satisfies the desired constraints and meets the load demand while eliminating non-viable parameters.

In HOMER, MG design models are selected according to the value of the economic cost optimization function (C_{NPC}) in the following equation [44]:

$$C_{NPC} = \frac{C_{Annual,Total}}{CRF(J, R_{project})} \tag{10}$$

where:

$C_{Annual,Total}$ represents the annual cost
$R_{project}$ represents the life of the project
J represents the annual interest

CRF is the annual return on capital calculated by the equation:

$$CRF = \frac{J(1+J)^N}{(1+J)^N - 1} \tag{11}$$

where N is the number of years

The energy cost (*COE*) is calculated according to the following equation:

$$COE = \frac{C_{Annual,Total}}{E_{primary} + E_{def} + E_{grid,sell}} \tag{12}$$

where:

$E_{primary}$: Energy supplied to the base load
E_{def}: Energy supplied to slow loads
$E_{grid,\ sell}$: Energy sold to the grid

In this process, HOMER simulates a variety of system configurations, eliminating non-viable configurations. Possible solutions are those that satisfy the desired constraints. Possible configurations are sorted by lowest net current cost (C_{NPC}) and lowest energy cost (*COE*). The goal of the optimization problem is to analyze decision variables that can be controlled by the user to select the best configuration for the desired load.

4. An Application for Designing Isolation Microgrid in Con Dao Island, Vietnam

Con Dao is an isolated island located off the coast of South Vietnam. Having a total area of 76 km^2 and more than 10,000 inhabitants, Con Dao is oriented to become one of the national tourism sites of Vietnam. The island attracts 400,000 tourists every year [45]. The forecast electricity demand in Con Dao by 2030 is 33.3 MW. However, the current power supply is only about 11.8 MW [46]. Therefore, it is necessary to propose studies to design a grid system such as a microgrid to meet the future electricity demand for the island. This is also an opportunity to develop renewable-based microgrids in Vietnam [47]. The location of Con Dao island in relation to a Vietnam map is shown in Figure 5.

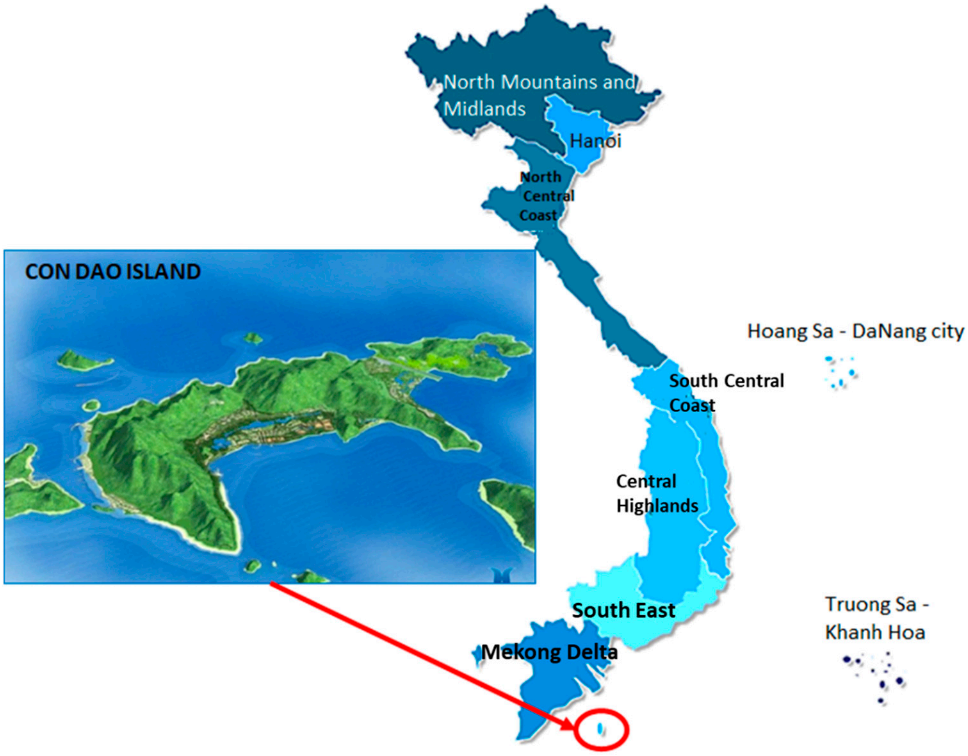


Figure 5. Con Dao island in Vietnam.

4.1. Application

This section presents a simulated grid design for a small area in Con Dao island, Vietnam, where the main power grid cannot be connected. The case study illustrates is an approach towards a better environment for remote areas by taking advantage of renewable energy resources, specifically solar energy.

The MG is designed to include a solar power system as the main source of generation, in addition to a battery to store excess energy from the solar generator and supply electricity to meet the load during non-sunny periods. Diesel generators are also considered to provide electricity at specific hours of the year. Based on the available data and economic feasibility, HOMER is applied to analyze scenarios and then propose the most suitable and cost-competitive power system for designers. The designed microgrid components are shown in Figure 6.

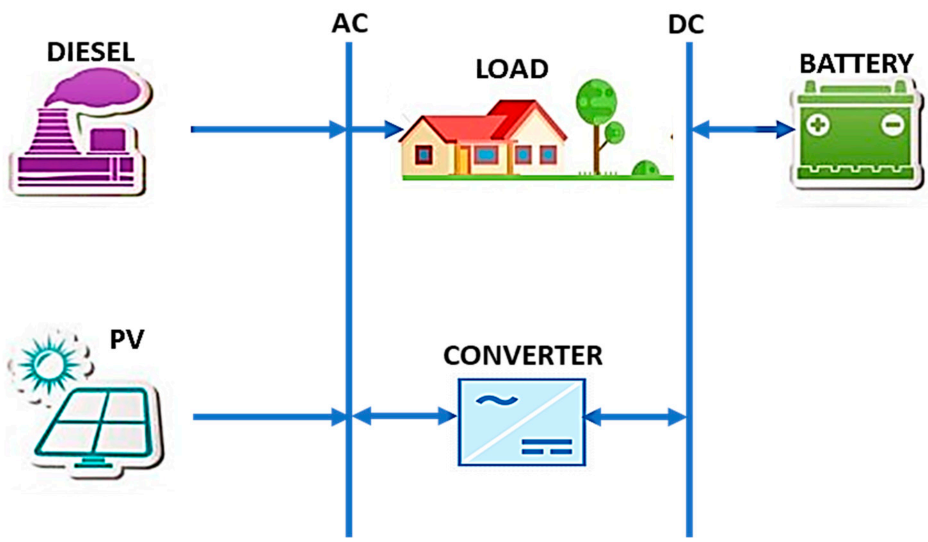


Figure 6. Designed microgrid components.

- Daily estimations of energy usage: The daily energy capacity in the considered area is about 623 kWh, the peak load capacity of the day is about 60 kW. The graph of load profiles is shown in Figure 7.

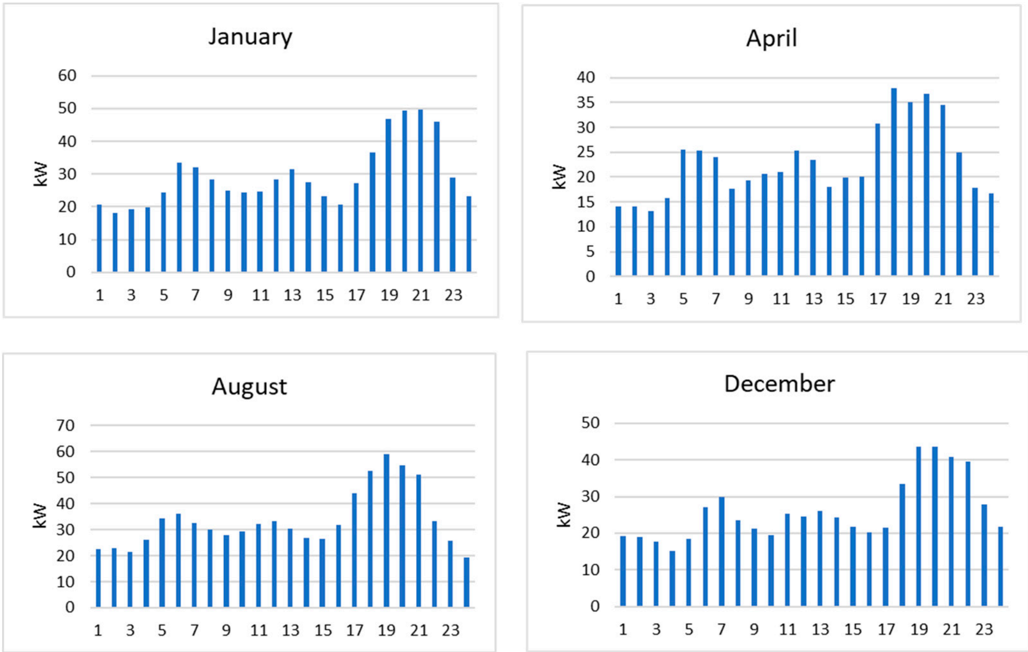


Figure 7. The 24 h load profile of four typical months in the year.

The daily load estimates of a household's energy consumption in the considered area are shown in Table 1.

Table 1. The daily load data of households.

Load	Number of Units	Consumption Energy (Watts)	Time (Hours)	Total Energy (Wh)
Domestic Lighting	3	30	12	75,600
Fans	2	40	10	56,000
Refrigeration	1	100	14	98,000
Television	1	400	12	336,000
Radio	1	22	12	18,480
Other loads	1	40	14	39,200
		Total		623,280

- The model of diesel generator: The simulated diesel generator has a fixed capacity of 40 kW. The capital cost of the generator is is USA 8000, its replacement cost is USD 15,000, and it has a lifetime of 15,000 h [48]. The model will run with different scenarios with and without a diesel generator to check if it is necessary to install this generator in the MG. The model of the generator is shown in Figure 8.
- Model of PV system: The power output of the solar system is estimated based on the size of PV system, in addition to the temperature and solar energy data at the considered location. The solar irradiance, temperature, and clearness index at Con Dao island were imported from National Renewable Energy Laboratory (NREL) resources [49]. Figure 9 shows the monthly average solar irradiance and clearness index for Con Dao.

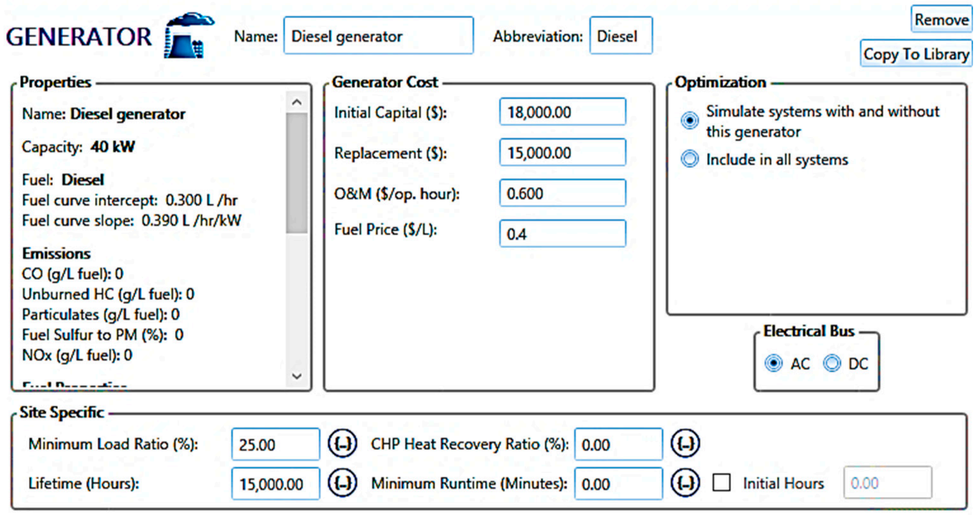


Figure 8. Diesel generator model.

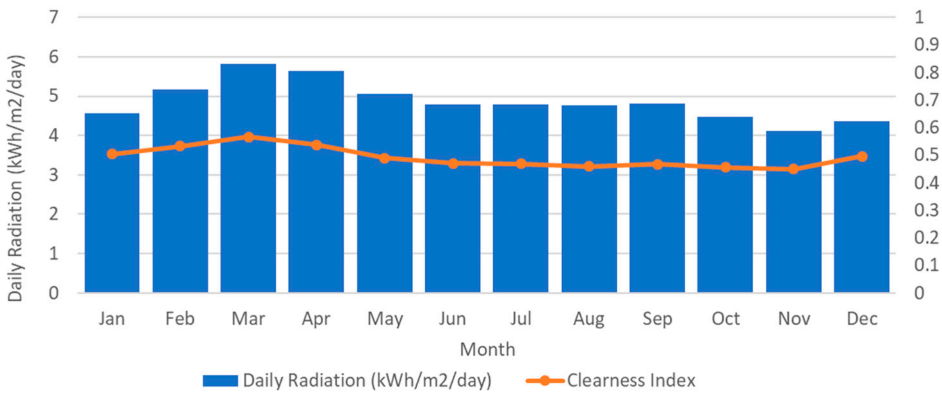


Figure 9. The average solar irradiance and clearness data for 12 months.

The solar power generation system is designed to find the optimal power capacity using HOMER Optimizer. The system has a 25 year lifetime, the capital cost is about USD 75,000, and the replacement cost is USA 20,000 [50]. The model of the PV system is shown in Figure 10.

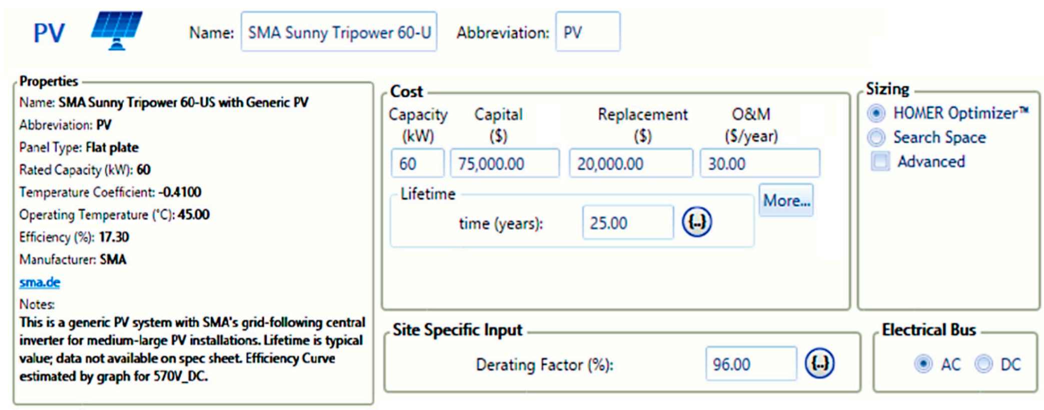


Figure 10. PV system model.

- Model of the battery: The battery is used to store excess energy from the PV system at peak times and then supply electricity to the load when the system is out of power. The battery is modelled using vanadium redox flow battery specifications with a 40 kWh capacity. The capital cost is USD 15,000, replacement cost is USD 15,000, and the lifetime of the battery is 7 years [51,52]. The model of the battery is designed to find the optimal amount of battery for the system. The model is shown in Figure 11.

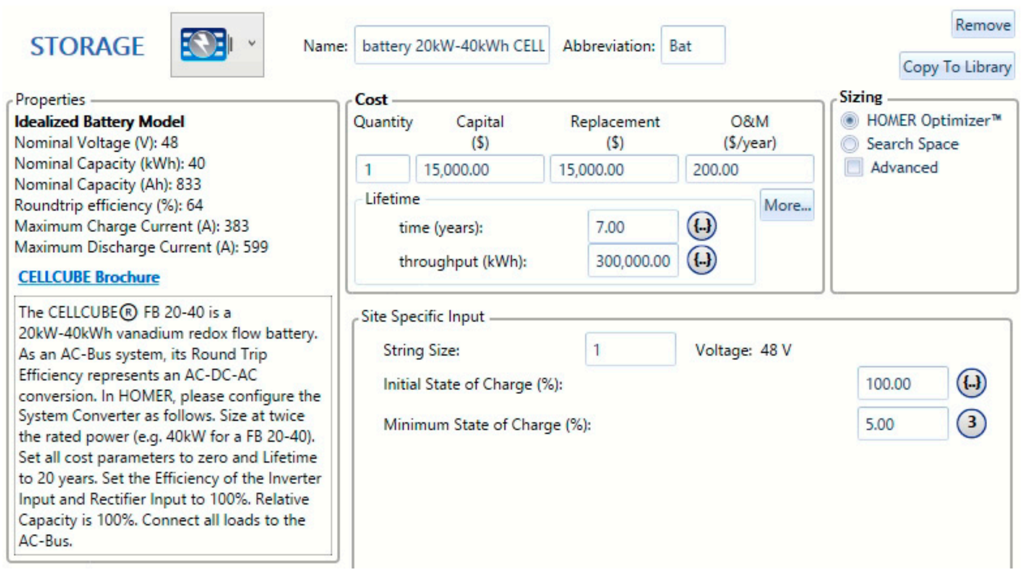


Figure 11. Battery model.

- Converter model: Converters are used to convert DC to AC and vice versa. The size of the inverter represents the amount of electrical power received from the AC system to be converted to DC power. The capital cost and replacement cost of the converter are the same, i.e., USD 2800 [53]. Its lifespan is 20 years. The model is shown in Figure 12.

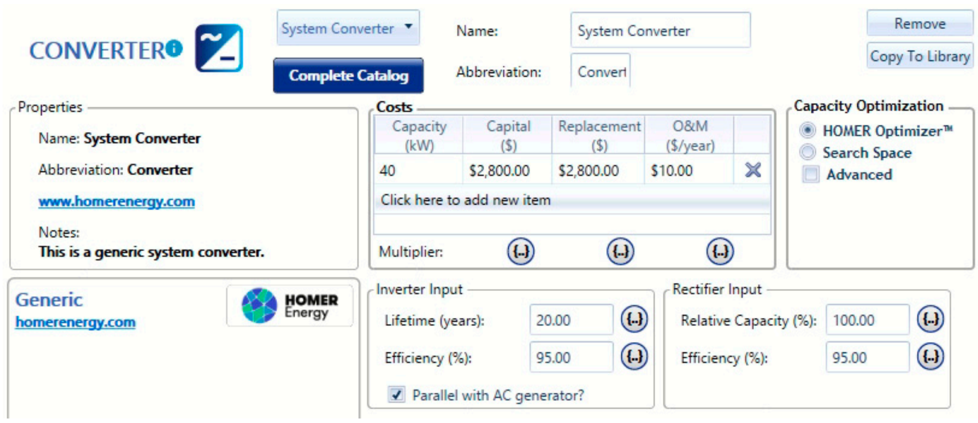


Figure 12. Converter model.

4.2. Results Analysis

The goal of this design problem is to optimize the average energy cost over 25 years. HOMER will analyze different scenarios based on the load demand and the given information of the considered system. The total cost of the project and the monthly electric production of each generator are shown in Figures 13 and 14.

The selected model consists of a 40 kW diesel generator, a 67.5 kW solar power system, one 20–40 kWh battery, and a 22.2 kW power converter. The total optimal system cost was USD 677,663, less than the total cost of designing a basic system consisting of only a diesel generator and a battery. However, the initial cost of the selected system is USD 118,886 higher compared to the base system initial capital cost of USD 33,184 due to the high cost of the PV system.

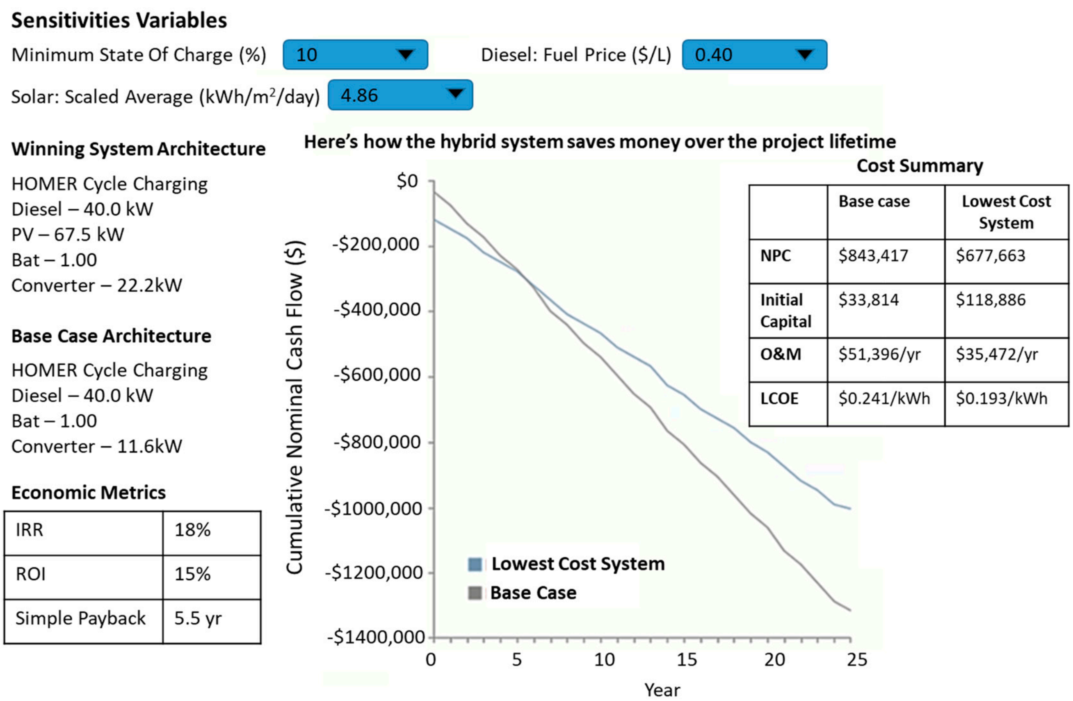


Figure 13. Model evaluation.

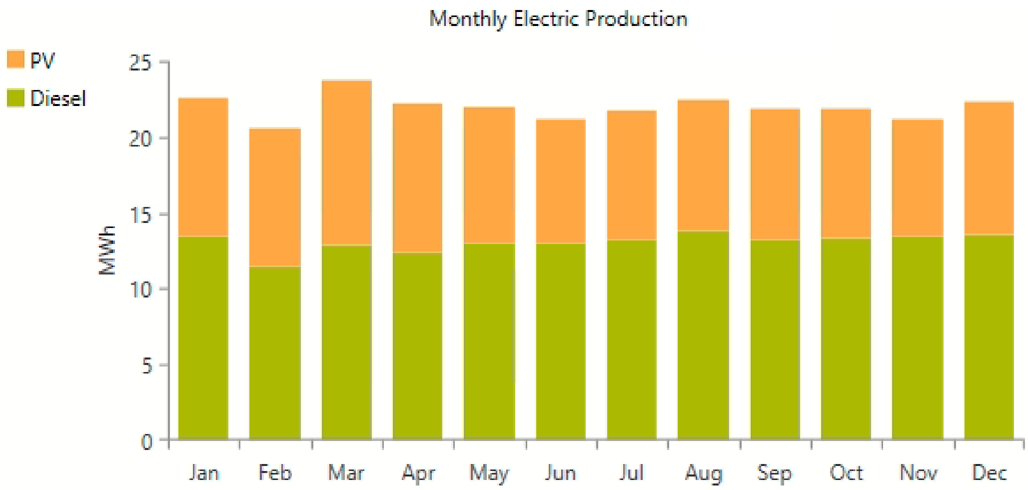
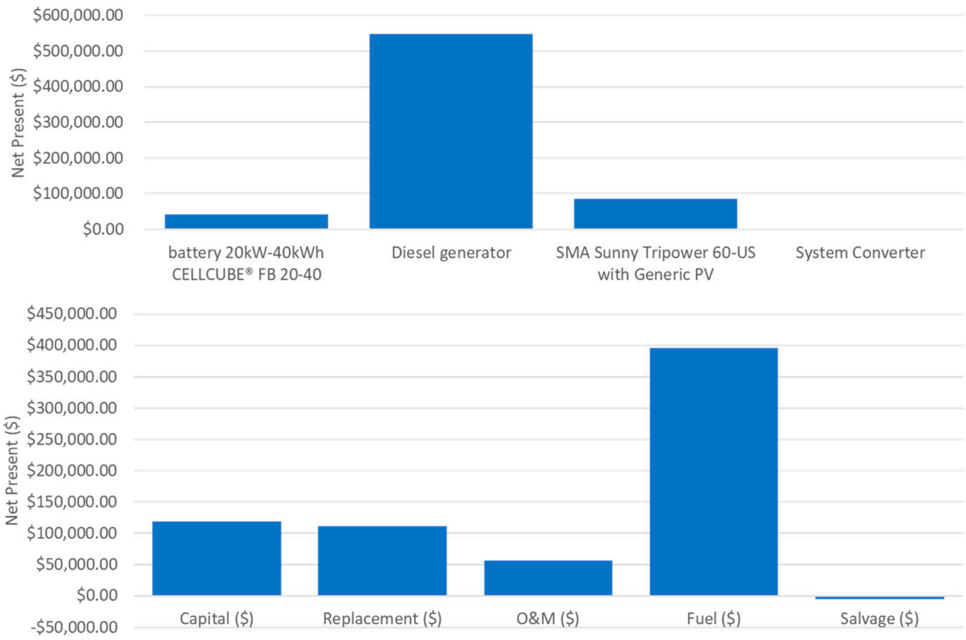


Figure 14. Monthly electric production of the generators.

As shown in Figure 14, the PV system contributes 40.6% of annual electric production, at 106,881 kWh per year, whereas diesel provides 59.4% of annual electric production, at 156,638 kWh per year. It can be observed that the diesel generator is the main generator of the system. The PV size had to increase to 67.5 kW and the battery size had to decrease to 22.2 kW to match with the model specifications. This means that the pre-sizing of the PV system and the battery is not suitable for the design load. HOMER redesigned the system to give the most feasible configuration with lowest cost. The detailed calculation results are also clearly analyzed in Figure 15.

It can be seen that the cost analysis helps the designer to clearly see which components in the system involve the highest investment costs and the sources of these costs. Based on the data in Figure 15, it can be seen that although diesel contributes only 60% of the energy to the system, the amount of investment needed for this generator is equal to 80.9% of the total cost. Most of the cost is associated with fuel, accounting for 72.12%; the replacement cost accounts for 15.32%; and the remainder is the initial investment and maintenance costs. In the future, it will be possible to consider increasing the size of the renewable energy power system to reduce the cost of using diesel generators, considering additional criteria for reducing emissions into the environment, towards the development of a clean and sustainable energy system.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
battery 20kW-40kWh CELLCUBE® FB 20-40	$15,000.00	$26,900.85	$3,150.48	$0.00	($2,457.38)	$42,593.95
Diesel generator	$18,000.00	$84,039.15	$53,655.81	$395,681.54	($3,086.74)	$548,289.76
SMA Sunny Tripower 60-US with Generic PV	$84,335.59	$0.00	$531.40	$0.00	$0.00	$84,866.99
System Converter	$1,550.80	$718.52	$87.25	$0.00	($444.60)	$1,911.96
System	$118,886.39	$111,658.52	$57,424.93	$395,681.54	($5,988.72)	$677,662.65

Figure 15. Cost analysis of the designed model by system component and cost type.

5. Discussion

The above result is not the only system proposed; based on changes in fuel price, the minimum stage of charge in the battery, and the amount of solar radiation, other solutions were proposed by the software. The details of the results are presented in Table 2.

Depending on the individual evaluation criteria of the investors, the designer can choose the solution that suits their needs and financial ability. Sensitivity parameters are not limited to those given in Table 2, but can also consider the capacity of the solar power system, the number of batteries, the lifetime of the devices, etc. The greater the number of sensitivity parameters given, the more solutions are offered to choose from.

Table 2 shows that, the larger the capacity of the PV system, the higher the investment costs, because the cost of the PV system is still high. However, as a result of the ongoing rapid decline in the cost of renewable energy electrical appliances, this will no longer be a concern in the future. Scenario 14 focuses on developing a solar power system with a total cost of USD 2.8 M; the scenario also requires 26 batteries to support the solar power generation system. Scenario 13 focuses on developing a diesel generator and battery system with a total cost of USD 843,417. However, scenario number 13 is not recommended for development because, due to its location in an isolated area, transporting oil fuel for diesel generators will be very expensive, and is thus not yet possible. Moreover, the price of fuel oil will increase in the future due to its increasing scarcity. The problem of environmental pollution is also an important factor affecting the decision of whether to use diesel generators. Furthermore, as a result of the current rapid decrease in the cost of renewable energy electrical equipment, investment costs for renewable energy generation systems will not be a concern in the future.

Table 2. Proposed solutions based on sensitivity parameters.

	Minimum State of Charge (%)	Diesel Fuel Price ($/L)	Solar Scaled Average (kWh/m^2/day)	PV (kW)	Diesel (kW)	Battery	Converter (kW)	NPC ($)
1	10	0.4	2	98.72	40	1	21.76	768,245.80
2	20	0.4	2	92.74	40	1	34.72	773,242.80
3	5	0.4	2	97.10	40	1	23.52	767,418.70
4	10	0.4	4.863	67.47	40	1	22.15	677,662.60
5	20	0.4	4.863	100.88	40	1	27.60	691,798.60
6	5	0.4	4.863	68.74	40	1	22.17	677,201.00
7	10	0.6	2	118.47	40	1	22.78	980,418.10
8	20	0.6	2	116.65	40	1	21.79	981,539.30
9	5	0.6	2	117.69	40	1	22.26	979,611.20
10	10	0.6	4.863	76.87	40	1	22.50	872,892.50
11	20	0.6	4.863	79.43	40	1	21.81	873,540.50
12	5	0.6	4.863	79.91	40	1	22.06	872,801.60
13	System with only diesel generator			0	40	1	11.6	843,417.00
14	System with only PV			1330	0	26	172	2.8 M

HOMER gives the designer system parameters that are updated regularly, so the results are often close to reality. Users can use sample parameters from the software or easily import parameters they design themselves. From the obtained calculation results, it can be seen that HOMER is an efficient and easy-to-use optimization tool, significantly reducing the calculation time for the designer. By properly planning the location and capacity of power generation, an MG can make full use of renewable resources, satisfy load demand, meet special economic requirements, and provide environmental benefits. However, HOMER does not include voltage, frequency, losses, or power flow calculation functions, so the designer is not yet able to evaluate the stability of the designed system in operation.

Vietnam has been making efforts to develop microgrid models. However, current projects tend to focus on introducing technologies rather than operating models, and the benefits of microgrids are also being underestimated. From a technical perspective, Vietnam needs to focus on developing advanced MG control systems and solutions to enhance energy system management for MG, maximizing profits from renewable energy sources, and reducing transmission and distribution burden on the main grid.

6. Conclusions

In this paper, a procedure is proposed to design microgrid systems. The main contributions of this paper are providing an overview of the microgrid and proposing a flexible procedure to design an isolated microgrid using the HOMER model. The proposed procedure was applied to design an isolated microgrid for Con Dao island in Vietnam. The pre-sizing system was redesigned to have the lowest cost with the most feasible configuration. The total cost of the selected model, including a 67.5 kW PV system, a 40 kW diesel generator, and a battery, was only USD 677,663, which was USD 165,754 less than the base system. In addition, 13 other models were also offered, based on sensitivity parameters, to provide more choices for designers. The analyses and method presented in this paper can be used as a guideline in the design and implementation of isolated hybrid microgrids in Vietnam, and is applicable to similar isolated areas around the world. These hybrid microgrids will provide efficient, low-cost, and clean energy, and increase reliability and resiliency of the microgrid in isolated areas. In future work, the method will be developed to not only be applied on remote islands, but also in areas where electricity supply is already safely available. Research can also be extended to develop a design model for a network of interconnected microgrids.

Author Contributions: Conceptualization, Q.T.T.; methodology, Q.T.T.; software, Q.T.T.; validation, Q.T.T.; writing—original draft preparation, Q.T.T.; writing—review and editing, Q.T.T., K.D., S.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Acknowledgments: The authors wish to thank the Institute of Energy Science (IES), and Vietnam Academy of Science and Technology (VAST) for their support to the research activity of Projects: "Design and installation of a grid connected microgrid 100 kW photovoltaic system and study solutions for developing solar generation in Vietnam to 2030, taking into account greenhouse gas emission reduction". Code NDT.80.ITA/20.

Conflicts of Interest: The authors declare no conflict of interest.

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