Review of Cost Optimization of Electricity Supply by Using HOMER and a Case Study for a Big Commercial Customer in Brazilian Amazon Area

Abdulrahim Hamed S. Alghamdi,
Carlos Henrique Marciano Rodrigues Castro, and Ramon Zamora(✉)

Electrical and Electronic Engineering Department,
Auckland University of Technology, Auckland, New Zealand
{wgs0484,mtr0836}@autuni.ac.nz, ramon.zamora@aut.ac.nz

Abstract. Renewable energy utilization for electricity supply has increased significantly. Technology maturity, cost reduction, and environmental friendliness are significant factors that encourage this increase. The expansion of distributed generation is increasing significantly due to the concern of many householders and entrepreneurs in minimizing the energy costs at residential and commercial properties due to the high significance of the energy costs at total expenses of most families and business. This study focuses on exploring optimization process of energy costs of a grid-connected hybrid PhotoVoltaic (PV)/Battery/Grid. The profile of a big commercial load located in Brazilian Amazon area is used as an optimization example. The system performance and optimization results are verified by using Hybrid Optimization of Multiple Energy Resources (HOMER).

Keywords: HOMER software · Energy management
Energy cost optimization

1 Introduction

Solar systems applications in smart grids and hybrid systems are recognized all over the world as a financially and technologically viable solution for electricity supply. Solar applications have increased 53% per year in the US over the last five years, and 60% per year globally [1]. The growth of distributed generation, mainly leaded by the number of installed solar systems, results in great challenge and more complexity for traditional grids and utilities [2]. Smart grid systems has an important role to support the growth of renewable energy sources, promising reliability, security, resiliency and efficiency for the electric grid [3].

Residential, commercial and industrial applications of solar energy are set to increase even more once the technology is already well established. While solar energy is more environmentally friendly and sustainable, as well as promising for remote areas, investment in a solar system is dependent on the financial viability compared to other energy sources. Solar energy price is governed by the costs of equipment and

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installation. The equipment price links to the technical specifications; the higher the capability, the higher the cost. Consequently, the equipment cost will have a significant impact on the decision to develop a hybrid system using solar energy. By investing in hybrid systems, commercial businesses can control their energy prices and even freeze their energy costs for future years at current prices. After all, such businesses as supermarkets have free space on their roofs to install large solar panels and energy storage systems.

To guarantee minimal investment costs to supply a specific load profile, optimization methods are required to effectively design hybrid systems on smart grids. HOMER is an optimization method capable to model and simulate a considerable number of system combinations, in order to achieve the best technical and economical results for the studied system.

This study considers an economic and technical approach of optimization model for hybrid solar energy for commercial businesses in order to reduce the cost of energy. By proposing an optimal energy cost, entrepreneurs have reason to invest in hybrid renewable energy. This paper will demonstrate the benefits of HOMER software usage in power generation and optimization of energy systems. A literature review of how HOMER helped in optimizing different systems to produce a better system in terms of power generation and economic aspects is also included. As a study case, the load profile of a big commercial load in Brazilian Amazon area is analysed for a PV/Battery/Grid system by using HOMER.

2 Overview of HOMER Optimization

In this section, HOMER software will be introduced. Then, different type of power systems from several case studies in different countries will be reviewed. The case studies are stand-alone PV system and hybrid renewable energy systems with and without grid connection. The typical standalone system consists of one of Renewable Energy Sources (RES) and involves a storage system, and the hybrid system contains either more than one RES or include a conventional source of energy and storage system with or without grid connection.

2.1 HOMER Software

The Hybrid Optimization of Multiple Energy Resources (HOMER) microgrid software was developed by the U.S. National Renewable Energy Laboratory (NERL) to aid in designing microgrid systems as well as to ease comparing different sources of power generation for a wide-range applications [4, 5]. In addition, HOMER assists in building techno-economic and reliable systems which can include renewable and non-renewable energy sources, storage systems and load management [4]. It is used by more than 120,000 users in more than 190 countries. HOMER facilitates the users to compare many different design options in regards to their technical and economic aspects [5]. Moreover, it helps in considering any changes in the inputs of the modelled systems. HOMER provides users with the ability to include off-grid and grid-connected systems to supply different loads, and also contains various combination of wind turbine, PhotoVoltaic (PV), small hydro, biomass power, batteries, fuel cells and hydrogen storage.

There is a challenge of designing and analysing microgrid systems because of a number of available options and the uncertain key parameters. Renewable energy sources add the complexity due to their intermittency and availability. HOMER was designed to overcome these difficulties. HOMER performs three tasks which are simulation, optimization and sensitivity analysis.

In the simulation task, HOMER test the performance of the designed systems each hour of the year in order to find its technical feasibility and life-cycle cost. In the next stage (optimization), HOMER searches for the best fit system from many different simulations of different systems considering the constraints given by the users at the lowest life-cycle cost. Lastly, the sensitivity analysis in HOMER does consider multiple optimizations considering any change in the inputs to have a better understanding of the effects of any uncertainty in the modelled systems.

2.2 Review of Standalone Solar Energy Systems

A standalone PhotoVoltaic (PV) system consists of PV module, a storage system, controller, inverter and a load as shown in Fig. 1. This standalone solar energy system has been increasingly used in developed and developing countries [6]. A review of a case study with various options of single renewable source and hybrid systems is discussed in [7]. The load tested in that study is 50 rural households (24.4 MWh/year), and HOMER software was used to assess the systems. The standalone system consisting of PV/Battery is selected as the most cost-effective system for the location (Iran). The analysis results show the Cost of Energy (COE) of $0.247/kWh–without allowing power supply shortage–and Net Present Cost (NPC) of $120,738.00. In another study in India, different power generation combinations were tested and found that 150 W PV/60 Ah Battery system is the most economical system for 219 kWh/year load [8]. The COE is $0.258/kWh without subsidy. With subsidy, it becomes

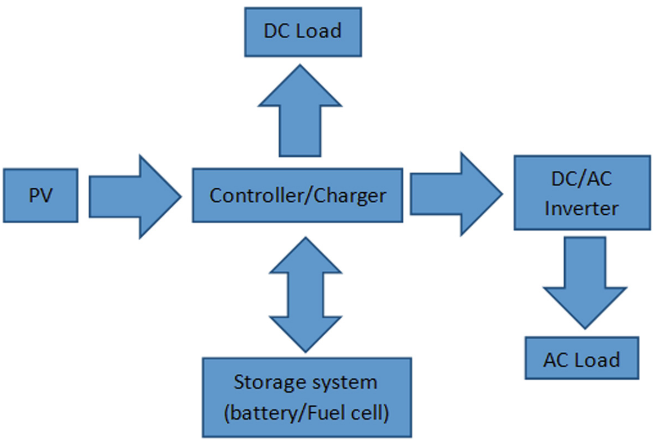

Fig. 1. The general structure of standalone PV system [6].

$0.145/kWh and the system is more economic. With subsidy by 50%, the solar system is more viable at distance greater than 6.08 km as the grid system costs more. Nevertheless, without the subsidy, the solar system is still more cost effective than the grid when the distance is 8.64 km or more. In a rural area in south of Iraq, a health clinic load of 11.534 MWh/year was analysed by HOMER [9]. In this study, a standalone 6 kW PV, 3 kW inverter and 80 batteries (225 Ah and 6 V) was selected as the most economic system with COE of 0.238 US$/kWh.

2.3 Review of Hybrid Renewable Energy Systems Involving Solar Energy

A Hybrid Renewable Energy System (HRES) consists of more than one RES with or without Conventional Energy Sources (CES), grid connection, controller, converter/inverter and a storage system. The general structure of HRES involving solar energy (PV) is shown in Fig. 2.

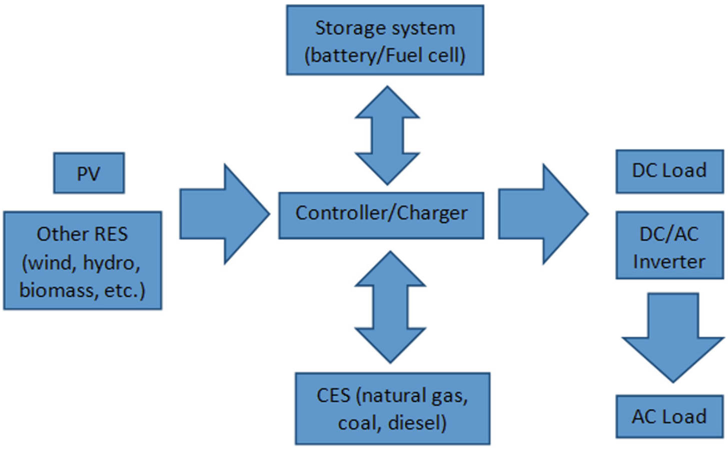

Fig. 2. The general structure of HRES involving solar energy (PV) [10].

In India, AC home appliances were used as a load for power generation analysis with the energy consumption of 1.825 MWh/year [10]. The output of this analysis was that the most cost-effective system is the hybrid system of PV, wind turbine and Vision 6FM 200D with the values of 2 kW, 1 kW and 12 V, 200 Ah battery, respectively, with COE of $1.232/kWh. Another example of HRES with CES involvement, a 2 kW PV, 4 kW diesel generator and 2 Surrette 6CS25P battery (6 V, 1156 Ah) were selected to be the optimal solution for the load of 17.52 MWh/year in remote area of Jordan [11]. The COE of that system was $0.297/kWh. In Saudi Arabia, a study analysis were done using HOMER for six different systems consisting of solar, wind, converter, battery banks, fuel cells, electrolyser and hydrogen tank for different cities and some chosen international cities [12]. The analysis results in the most economical hybrid system involving RES which consists of PV array, wind turbine, converter and battery storage bank with the values of 2 kW, 3 kW, 2 kW and 7 banks respectively for Yanbu city in Saudi Arabia. The COE was $0.609/kWh. This study was done for a typical house with an average load demand of 14 kWh/day.

3 Optimization Model Using HOMER

To demonstrate the usage and effectiveness of HOMER optimization method, it will be used to analyse a load profile of a commercial building located in Brazil.

In hybrid systems, the optimal size of each system component is a complex task and involves several variables. The optimal size of hybrid systems will lead to a good relation between performance and cost. It has been shown that optimally designed hybrid systems have been found to be cost effective and reliable [13].

As optimization model, a load profile of a Brazilian commercial building was used in this research. The hybrid system is modelled as a PV/battery/grid connected system. The optimization process is focused on identifying and proposing the optimal PV/battery system size that simultaneously result in lower grid energy dependency and lower energy prices.

In this system, the optimization objective is to minimize the Levelized Cost of Energy (LCOE). To evaluate the optimal size for the proposed system, different configurations from various component size options of the solar installation are analysed. After adding the system inputs, such as load profile, monthly solar radiation, annual real interest rate and a range of equipment sizes, HOMER starts an hourly simulation for every possible system configuration, computing the power from the grid, PV array and batteries. Once the simulation is ended, HOMER sorts feasible combinations for the system in order to increase the net present cost and minimize the cost of energy.

3.1 System Description

The studied system is located in the city of Tucuruí, state of Pará – Brazil, located at 3°45’53.0”S, 49°40’16.0”W. The system is based on a commercial property with a public of 2.000 customers per day on average. The load is basically composed of motors and compressors from many refrigerators, as well as lighting. Additionally, the daily operation hours is Monday – Sunday from 8 am to 8 pm.

The system characteristics are detailed bellow:

- Daily consumption: 2,550.23 kWh/day
- Monthly consumption: 79,057.13 kWh/month
- Grid Energy Price: $0.28/kWh
- Power Factor: 0.87
- Maximum demand: 180.43 kW
- Roof top area: 3,600.00 m^2

3.1.1 Load Profile and Solar Irradiation

The load profile in Fig. 3 shows the daily load profile of the studied system. The daily average demand is 2,550.23 kWh/day with a peak demand of 180.01 kW. The monthly average solar Global Horizontal Irradiance (GHI) data for the location of 3°45’53.0”S, 49°40’16.0”W is shown in Fig. 4. The annual average solar GHI is 5.01 kWh/m^2/day.

According to the graphs above, the load profile presents a high correlation with solar irradiation hours. As a result, the load profile will also correlate with solar energy production, which represents a great opportunity for economical savings.

Fig. 3. System daily load profile.

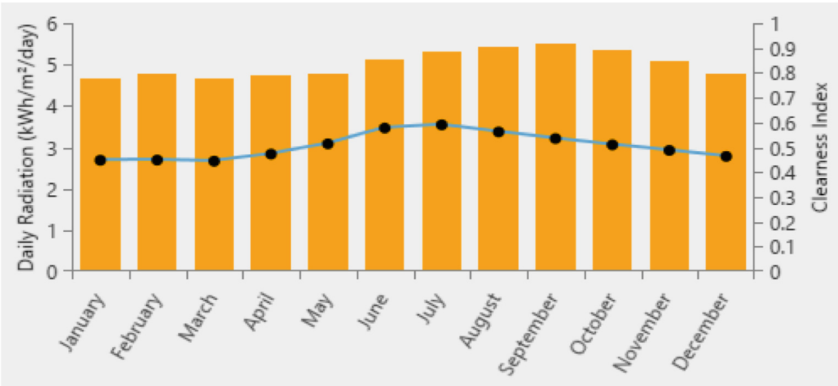

Fig. 4. Tucuruí solar irradiation.

3.1.2 PV Panels

The PV panels generate DC electricity from the sunlight exposure. The panels tilted at an angle of 0° due North with slope of 3.75° and the derating factor is 80%. The PV panels have a capital and replacement costs of 888.889 \$/kW with lifetime of 20 years for the system. This price is of a JA Solar 315 W Silver Poly Pallet consisting of 23 PV modules [14]. The technical specifications for this PV panels are shown in Table 1.

The output power of the PV array is expressed by (1) based on [15].

$$P_{PV} = Y_{PV} f_{PV} \left[\frac{\bar{G}_T}{\bar{G}_{T,STC}} \right] \tag{1}$$

where:

Y_{PV} is the rated capacity of the PV array under Standard Test Conditions (STC) [kW],
f_{PV} is the PV derating factor [%],
$\bar{G}_T$ is the solar radiation incident on the PV array in the current time step [kW/m^2],
$\bar{G}_{T,STC}$ is the incident radiation at STC [1 kW/m^2].

The above equation neglects the temperature effect. However, if the effect of the temperature is considered, then the above equation is modified as in (2).

$$P_{PV} = Y_{PV} f_{PV} \left[\frac{\bar{G}_T}{\bar{G}_{T,STC}} \right] \left[1 + \alpha_P \left(T_c - T_{c,STC} \right) \right] \tag{2}$$

where:

α_P is the temperature coefficient of power [%/°C],
T_c is the PV cell temperature in the current time step [°C],
$T_{c,STC}$ is the PV cell temperature under STC [25 °C].

Table 1. Technical specifications for the PV module.

Module type	P_{mp} (W)	V_{mp} (V)	I_{mp} (A)	V_{oc} (V)	I_{sc} (A)	Area (m^2)	Price ($)
JAP6-72-315/4BB	315	37.19	8.47	45.95	8.98	1.94	280.00
23 panels	7245	855.37	194.81	1056.85	206.54	44.58	6440.00

3.1.3 Battery and Inverter

For the battery model, in charging mode, HOMER executes three different limits in order to calculate the maximum charge power for the battery. These three limits come from the kinetic storage model, the maximum charge rate of the storage and lastly the storage's maximum charge current. Therefore, HOMER equates the maximum storage charge power to the least of these three values of the previous limits with the assumption of each applies after charging losses and is shown in (3).

$$P_{batt,cmax} = \frac{MIN\left(P_{batt,cmax,kbm}, P_{batt,cmax,mcr}, P_{batt,cmax,mcc}\right)}{\eta_{batt,c}} \tag{3}$$

where:

$P_{batt,cmax,kbm}$ is the maximum amount of power that can be absorbed by the two-tank system (kinetic storage model),

$P_{batt,cmax,mcr}$ is the maximum amount of the storage charge power regarding the maximum charge rate of the storage,
$P_{batt,cmax,mcc}$ is the maximum amount of storage charge power regarding the maximum charge current of the storage.

Table 2. Technical specification for the battery.

Model	Nominal capacity (Ah)	Voltage (V)	Minimum charge (%)	Price ($)
CR-430 (16#)	860	48	20	5544.00

All these three different maximum powers are calculated based on different equations and can be found in [15]. The technical specifications for the battery are shown in Table 2 [16]. This price is for 16 batteries of this model.

As the PV panels produces DC electricity, an inverter is required in order to supply AC loads. The selected inverter for this system has a capital and replacement cost of 73.573 $/kW with minimal lifetime of 12 and up to 25 years, as well as efficiency of 98%.

4 Results and Discussion

For this commercial building, a grid-connected PV system with battery banks was simulated to find whether or not the system is feasible to lower the LCOE. The modelled system is shown in Fig. 5.

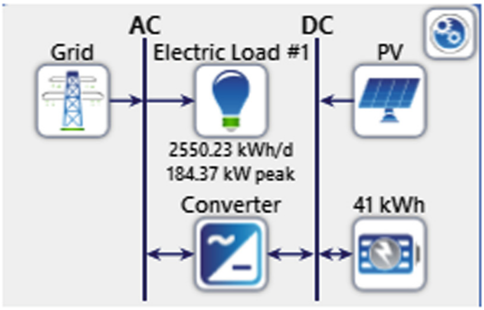

Fig. 5. Grid-connected PV system.

4.1 Optimization Results

As can be seen from Fig. 6, the optimization results in having 463 kW of PV array, 100 kW converter and 1600 batteries. The dispatch strategy that was used for this system is called load following (LF) which means that when the generator operates, it produces only enough power to meet the primary electrical load for the system.

Therefore, other loads and lower priority loads such as charging batteries and deferrable loads are left to the RES [15].

In Fig. 7, the costs of each component of the system and the total costs are shown. The total initial capital cost is $973,312.91, NPC is $2,506,631.00 and LCOE is $0.2004/kWh. Nevertheless, the high cost is due to the number of batteries used in the system. Even though the battery costs a lot and increases the overall cost of the system, the LCOE of the system is still lower than the COE of the grid price which is $0.28/kWh.

Architecture									Cost				System
					PV (kW)	41 kWh	Grid (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($)	Initial capital ($)	Ren Frac (%)
					463	1,600	999,999	100	LF	$0.200	$2.51M	$118,609	$973,313	63

Fig. 6. Optimization result of the system.

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
CR-430	$554,400.00	$0.00	$206,840.25	$0.00	$0.00	$761,240.25
Grid	$0.00	$0.00	$1,262,667.69	$0.00	$0.00	$1,262,667.69
JA Solar 315W PV	$411,555.61	$0.00	$59,854.43	$0.00	$0.00	$471,410.04
System Converter	$7,357.30	$5,571.58	$0.00	$0.00	($1,615.62)	$11,313.26
System	$973,312.91	$5,571.58	$1,529,362.37	$0.00	($1,615.62)	$2,506,631.24

Total NPC:	$2,506,631.00
Levelized COE:	$0.2004
Operating Cost:	$118,608.90

Fig. 7. The cost of each component and overall cost of the system.

5 Conclusion

This paper has provided a review of cost optimization of electricity supply by using HOMER. It discussed some examples of PV only standalone system and hybrid systems where HOMER was the tools used for analysing the technical and economic feasibilities of the systems. Then, HOMER was applied to optimize electricity supply of a big commercial building in Brazil. The optimal solution was a grid-connected PV system that produced 463 kW from PV arrays. Since the PV arrays were installed on the roof top, the installed PV size as well as the PV output power depend on the building roof area.

References

1. Torani, K., Rausser, G., Zilberman, D.: Innovation subsidies versus consumer subsidies: a real options analysis of solar energy. Energy Policy **92**, 255–269 (2016)
2. Tuballa, M.L., Abundo, M.L.: A review of the development of Smart Grid technologies. Renew. Sustain. Energy Rev. **59**, 710–725 (2016)
3. Bhalshankar,S.S., Thorat, D.C.S.: Integration of smart grid with renewable energy for energy demand management: Puducherry case study. Presented at the International Conference on Signal Processing, Communication, Power and Embedded System (SCOPES)-2016, Paralakhemundi, Odisha, India (2016)
4. HOMER Energy LLC. https://www.homerenergy.com/index.html
5. Lambert, T., Gilman, P., Lilienthal, P.: Micropower system modeling with HOMER. In: Integration of Alternative Sources of Energy, pp. 379–418 (2006)
6. Oko, C., Diemuodeke, E., Omunakwe, N., Nnamdi, E.: Design and economic analysis of a photovoltaic system-a case study. Int. J. Renew. Energy Dev. **1**, 65 (2012)
7. Askari, I.B., Ameri, M.: Techno-economic feasibility analysis of stand-alone renewable energy systems (PV/bat, Wind/bat and Hybrid PV/wind/bat) in Kerman, Iran. Energy Sour. Part B: Econ. Planning Policy **7**, 45–60 (2012)
8. Kamalapur, G., Udaykumar, R.: Electrification in rural areas of India and consideration of SHS. In: 2010 International Conference on Industrial and Information Systems (ICIIS), pp. 596–601 (2010)
9. Al-Karaghouli, A., Kazmerski, L.: Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software. Sol. Energy **84**, 710–714 (2010)
10. Dalwadi, P., Shrinet, V., Mehta, C., Shah, P.: Optimization of solar-wind hybrid system for distributed generation. In: 2011 Nirma University International Conference on Engineering (NUiCONE), pp. 1–4 (2011)
11. Nema, P., Dutta, S.: Feasibility study of 1 MW standalone hybrid energy system: for technical institutes. Low Carbon Econ. **3**, 63 (2012)
12. Al-Sharafi, A., Sahin, A.Z., Ayar, T., Yilbas, B.S.: Techno-economic analysis and optimization of solar and wind energy systems for power generation and hydrogen production in Saudi Arabia. Renew. Sustain. Energy Rev. **69**, 33–49 (2017)
13. Maleki, A., Ameri, M., Keynia, F.: Scrutiny of multifarious particle swarm optimization for finding the optimal size of a PV/wind/battery hybrid system. Renew. Energy **80**, 552–563 (2015)
14. JA Solar 315 W Silver Poly Pallet (23) of Solar Panels. https://www.wholesalesolar.com/1890060/ja-solar/solar-panels/ja-solar-315w-silver-poly-pallet-23-of-solar-panels
15. HOMER Help Manual. https://www.homerenergy.com/products/pro/docs/3.11/index.html
16. Crown 860AH 48VDC 41,280 Wh (16) Battery Bank. https://www.wholesalesolar.com/cms/crown-cr430-flooded-battery-specs-2834660653.pdf