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Optimum Sizing and Techno-Economic & Environmental Analysis of Renewable Energy Sources Integration into a Micro-Grid for a University: A Case study

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Abstract

Renewable energy sources have been gradually used as energy sources: either grid supported or stand-alone systems in recent years. Hybrid energy systems comprising of Renewable energies are preferred to supply power at different locations due to their stochastic behavior and efficient utilization. In this paper, the optimal design and sizing of the renewable energy resources like solar panels and wind turbine connected to the grid is considered and studied. The optimal sizing and their economic feasibility is addressed for Victoria University at the St Albans campus in Melbourne using HOMER.

Key words: *Optimal sizing, Economic analysis, renewable energy, HOMER*

1. Introduction

World energy demand has been estimated to be greater than 800EJ by 2050. For this estimation, with the present scenario of escalating oil prices when considered, renewable energy could promise to be an alternate option as an energy resource [1]. Alternately, the global concern towards pollution and global warming has supported this cause. In recent years, there has been much technical advancement in renewable energy systems (RES) including the storage units. Many countries have been striving to reach their renewable energy target towards the global energy contribution; Australia being one among them.

Australia is the world's 9th largest energy producer using coal and the largest exporter of uranium [2]. In its share of renewable energy generation, Australia's renewable energy contribution is far too minimal for the abundance of natural resources it possesses. Despite the fact of the volatility of the conventional energy market, this cheaper environmentally unfriendly energy has been dominant in the energy market. Although several studies conducted on Australia being 100% renewable have given negative results [3, 4]. However, pondering renewable energy being a part of the modern grid has equally been dealt with [5-10].Designing and optimizing a micro-grid and analyzing their economic and environmental impacts have been the template of this study. Similar studies have been conducted using Solar cells or Photo-voltaic (PV), wind turbines, fuel cells (used either as an energy source or as a storage unit) for isolated villages, islands, wind farms, resorts [5, 8, 11-17]. The current study is aiming at integrating renewable energy like PV and wind turbine connected to the grid with battery storage for Victoria University located at the St Albans campus in Melbourne, Australia. A similar study has been conducted for this university for a grid connected system in [18]. The location map is shown in Figure 1.

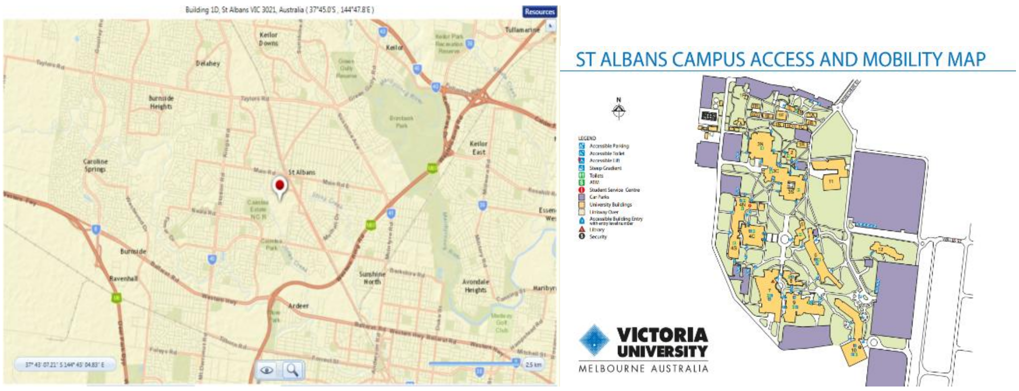

Figure 1 Victoria University St Albans location map from Google and campus access map

To design and optimize any micro-grid, it is significant to understand and study the load requirement of the desired location. This crucial step during the design of a micro-grid should not terminate in underestimating or overestimating the consumption, either of which could result in unmet load or oversized setup respectively. Various methods have been used to optimize a micro-grid including genetic algorithm and swarm optimization techniques. However, many software have been used in such studies like MATLAB/SIMULINK, HOMER etc [19]. The aforementioned problem has been studied here using HOMER (Hybrid Optimization using Multiple energy sources) software which designs and optimizes the setup with least Net Present Cost (NPC) of the system [20]. The study conducted also includes the environmental impact of the designed system by analyzing the amount of harmful gases they emit to the environment.

2. System Description

The RES designed for this study considers the total cost of the system which includes the total capital cost and the maintenance cost. The architecture of this system consists of PV arrays, wind turbine, controller, batteries and grid support. To minimize the cost of the system and meet the load demand, HOMER defines a few terminologies which are deciding factors for the suggested model. They are expressed as follows:

- Net Present Cost (NPC): Net Present Cost determines the profitability of the project, which is the total net present value of the component subtracted by the (income) profit it incurs for the complete lifetime of the project.

  $$NPC=\sum ((Total\ Cash\ flow / (1+Interest\ rate)^{(Project\ Life\ time)}) - Initial\ Investment \quad (1)$$

- Annualized cost of the system (ACS): Annualized cost is that cost of the set up when factored equally over the entire lifetime of the project considered

  $$ACS= (Cost\ of\ the\ Project \times Discount\ rate) / (1-(1+Discount\ rate)^{-Project\ life\ time}) \quad (2)$$

- Levelised Cost of Energy (COE): It is the average cost of useful electrical energy produced by the system. To calculate the levelised cost of energy, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total electric load served, using the following equation:

  $$COE = (Total\ annual\ electricity\ production) / (Load\ Served\ by\ the\ system) \quad (3)$$

- Renewable Energy penetration (REP): It is the amount of renewable energy that serves the load annually

  $$REP= (Power\ produced\ from\ renewable\ energy) / (Total\ electrical\ load\ served) \quad (4)$$

To design and optimize the RES, it is necessary to identify the sensitive variables along with evaluating their electricity load profile, solar irradiation and wind energy which are introduced in the following section

2.1 Solar Radiation Data & Wind Energy

The solar radiation data and wind speed data has been analyzed from the National Renewable Energy Laboratory (NREL) data for St. Albans, Melbourne. This data is used to design the RES to integrate into a micro-grid to meet the load demand. Figure 2 shows the average solar radiation at the given place is 4.13kWh/m^2/day. Clearness index for the same location was used to design the micro-grid setup using HOMER

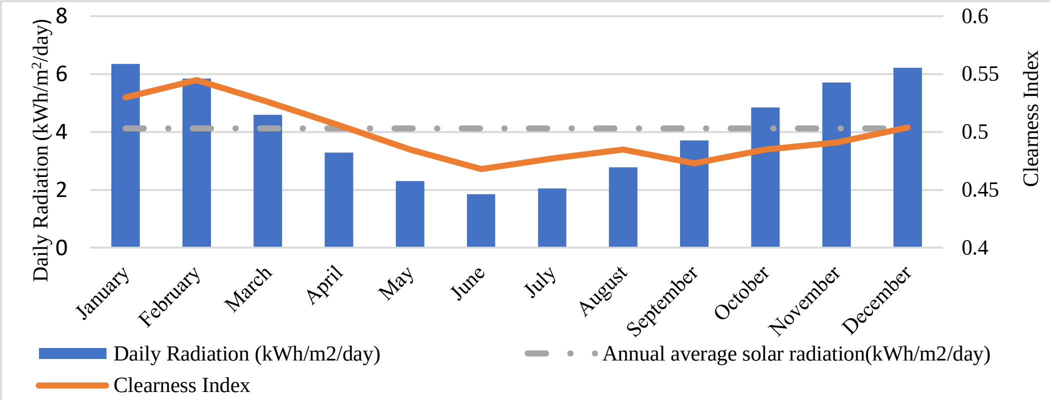

Figure 2 Daily Solar Radiation and Clearness Index for the desired location

The wind resource data has been analyzed from NASA Surface meteorology for the desired location which provides monthly averaged values of wind speed at 50m above the Earth's surface over a period of 10 years (July 1983 –June 1993). Figure 3 shows the wind distribution at the desired location with an average wind speed of 4.53m/s.

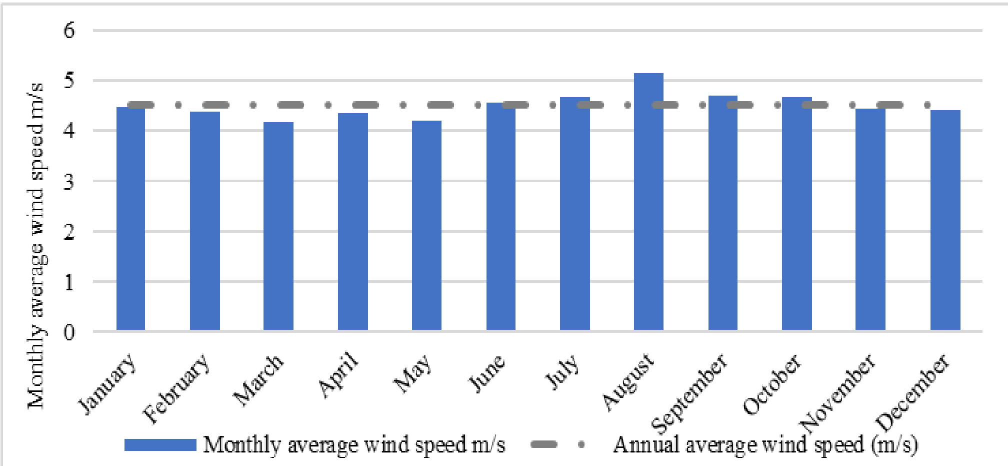

Figure 3 Average Wind speed for a year at desired location.

However, since the data seem to have been collected till June 1993, to understand the wind speed over recent years was also considered from Bureau of Meteorology, Australian Government. The site details closest to the university were found out to be Melbourne airport (lat 37.67°S, long 144.83°E) and the mean 9am wind speed statistics from 1970 to 2010 was 5.28m/s. It is noted that the data measured was at an elevation of 113m. To use the above information in the simulation the wind speed was evaluated for 50m (similar to NASA surface meteorology data) using Power law of wind profile given by equation (5).

$$u/u_r=(z/z_r)^{\alpha} \quad (5)$$

where u is the wind speed at a height z and u_r is the known wind speed at a reference height. From equation (5), the wind speed at a height of 50m using the data measured from Bureau of Meteorology, is measured as 4.708m/s with the power law exponent factor (α) to be 0.14.

2.2 Electrical Load analysis

The Electric power consumption of the university was studied using their electricity bill procured for one year. The average electricity consumption is 11091.27kWh/d. Inflation period, discount rate, lifetime of the project, feed in tariffs, electricity price were considered as the sensitive variables or the boundary conditions in the analysis are shown in Table 1.

Table 1 Sensitive Variables used as boundary conditions in simulation.

Inflation Rate	3.5%
Discount Rate	6.7%
	25 years
Sell-back Price	$0.03/kWh
	$0.113/kWh
Electricity Price	$0.226512/kWh

3. HOMER Simulation Model

The simulated model shown in Figure 4 considers integration of Solar cells or PV and wind turbine, batteries into the grid. Wind energy and solar energy complement each other as distributed energy resources in the micro-grid. The intent to use a grid supported system instead of a stand-alone system is its resilience and the fact that the presence of only battery as a storage would escalate the cost of the setup which is already high due to the presence of wind turbine. Supplementing the above criteria, excess of power generation from RES be fed into the grid to acquire an additional profit in the form of energy sell back as feed-in tariffs (FiTs). Additional storage batteries would compensate in terms of grid failure or the stored renewable energy can be used in times when the cost of energy from the grid is high. The presence of converter in the system is to converts DC source output from PV to AC.

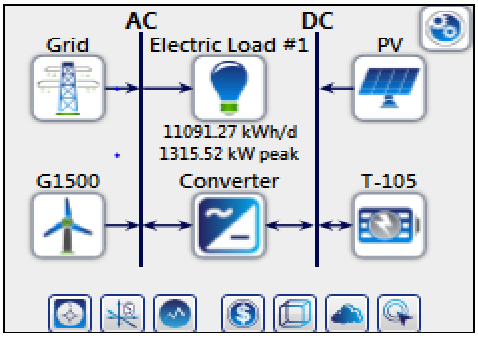

Figure 4 Schematic diagram of the micro-grid considered

HOMER simulated the size of the system to be integrated to the grid to meet the load demand of the university, the details of the cost of the system are provided in Table 2.

Table 2 Component details considered in the analysis.

Component	***Details***	***Capital Cost ($)***	***Operational & Maintenance cost ($/year)***
PV (1kW)	Generic flat plate	680	10
Converter	Generic system converter	240	-
Trojan 1.52kWh battery	Deep cycle-flooded battery	300	10
Generic 1.5MW Wind turbine (G1500)	Rated capacity 1500kW, hub height 80m	3,900,000	39,000

4. Results & discussion

The setup for simulation considers PV and Wind turbines as RES along with Trojan batteries connected to the grid. HOMER simulates a set of values having least NPC, considering the sensitive variables, and optimizing the size of the system. When the current Discount rate of 6.7% and current inflation rate of 3.5% and a sell back of $0.03/kWh and 0.113/kWh was considered [21 , 22, 23], HOMER optimized the size of the RES having least NPC, the results are shown in Table 3. HOMER modelled the size of the RES according to the measured load. 3200kW of PV. A single 1.5MW wind turbine scaled for different wind speeds integrated into a grid through converters ranging from 1146kW to 5922kW. The lifetime for the project was 25 years. The smallest architecture for the RES is about 3026kW PV and one 1.5MW wind turbine with 31 Trojan 105 battery connected to the grid through converter of about 1672kW with a wind speeds 4.708m/s and project lifetime of 25 years and sell back price of 0.03$/kWh.

Table 3 Architecture details of optimized model by HOMER

Sell-back Price ($/kWh)	***Wind Speed Scaled Average (m/s)***	***PV (kW)***	***1.5MW Wind Turbine***	***Grid (kW)***	***Trojan 105 Battery***	***Converter (kW)***
0.03	4.518	3229	1	999999	5	1892
0.03	4.708428	3026	1	999999	31	1672
0.113	4.518	11092	1	999999	47	5922
0.113	4.708428	11092	1	999999	47	5922

The above architecture of the RES from Table 3 has NPC ranging between $11.4M and -$2.67M. The renewable energy penetration for these systems ranging from 83.7% to 94.9% is shown in Table 4. The unmet load from renewable energy of less than 16% is bought from the grid, while the excess of renewable energy being sold using the RES for a year converts to a profit or revenue.

Comparing the results of Table 3 and Table 4, it is observed that there are two architectures of RES with a project lifetime of 25 years and FiTs of 0.113$/kWh, size of PV and converter is 11092kW and 5922kW respectively with 47Trojan batteries. The size of the HRES is similar , renewable energy penetration varies between 94.6% and 94.9% with wind speed 4.518m/s and 4.708m/s respectively these two HRES have the grid purchase and selling of energy around 4% and 8% respectively. This is the main reason behind the COE, NPC and initial investment is negative value as the revenue exceeds the costs. The other two architectures with sell back period of 0.03$/kWh has smaller renewable energy penetration of about 84% compared to the system discussed earlier. This smaller value ids due to the smaller value of FiTs though the system architecture is bigger of about 3229kW and 3026kw of PV with 2 and 31 batteries connected to the converter of 1892kW and 1772 kW respectively for wind speed of 4.519m/s and 4.798m/s. The NPC and COE about $11M and 0.009$/kWh respectively. These two models have smaller energy sold (less than 5%) while the energy purchased is about 15%.

Table 4 Energy and economics details of the optimized model

COE ($)	***NPC ($)***	***Operating cost ($)***	***Initial capital ($)***	***Renewable Energy Fraction (%)***	***Internal Rate of return (%)***	***Simple Payback period (yr)***
0.0983	11.7M	297372	6.55M	83.7	8.3	9.66
0.0974	11.4M	290467	6.37M	83.9	8.8	9.32
-0.00802	-2.14M	-871436	12.9M	94.6	13.7	6.87
-0.00986	-2.67M	-901791	12.9M	94.9	13.8	6.77

The Internal rate of return and simple payback period was considered as the method used to choose the best HRES. It is observed that the HRES with FiTs of 0.113$/kWh and wind velocity 4.708m/s to be the economically viable option. This system has the smallest payback period of 6.77ys with a maximum rate of return 13.8% compared to the rest of the HRES models. When monthly average electric production is considered for the above discussed RES, PV and Wind turbine contributed the major share of energy to reach the load demand. The maximum energy produced by the RES are during the months when solar energy radiation and wind energy are at their maximum. Table 5 summarizes the annual energy production details of the micro-grid sources considered. 83.4% of energy contribution is by PV and 12.2% of energy production is from Generic 1.5MW wind turbine. Total Grid purchase of about 4.5% is noted. The contribution of grid energy is mainly when the PV and wind turbine is not able to meet the load requirement when there is not enough sunlight or wind.

Table 5 Annual energy production details of the micro-grid sources considered

Energy Production	***kWh/yr***	***Percentage***
Generic flat plate PV	14,838,685	83.4
Generic 1.5 MW Wind Turbine	2,165,316	12.2
Grid Purchases	795,407	4.47
Total	17,799,407	100

Table 6 discusses the toxic gas emissions of the winning system. The data shows it illustrates the net toxic gas of carbon dioxide being maximum compared to Sulphur dioxide and Nitrogen dioxide with negative emissions indicating excess of energy being fed to the grid.

Table 6 Toxic gas emissions of the model considered

GHG emissions	***kg/year***
Carbon Dioxide	-6,855,083
Carbon Monoxide	0
Unburned Hydrocarbons	0
Particulate Matter	0
Sulfur Dioxide	-29,720
Nitrogen Oxides	-14,535

5. Conclusion

In this project, RES like generic flat plate solar PV, wind turbine, storage batteries were optimally sized according to the sensitive values. HOMER presented a list of values according to the least NPC. However, with the present condition of discount rate, sell back price for 25years was considered. NPC of -$2.67M resulted with 95% of renewable energy penetration. The negative emission of Carbon dioxide explains the fact that the energy sold is greater than the energy purchased through the grid. This system proves to be environmental friendly when the toxic gas emissions are considered. Return on investment and simple payback period were used as the important factors to decide the financial viability of the HRES. FiTs and the wind speed were the most important factors that reflect on the economics of HRES from the results. An increase in the FiTs by 10c/kWh has shown an increase of nearly double the energy penetration into the grid from the HRES. Exploring the benefits of FiTs and other Government aided policy for renewable energy adoption would be considered in our future work.

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