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Prospects of Solar Energy in Australia

GM Shafiullah[1], Amanullah M. T. Oo[2], Dennis Jarvis[3], ABM Shawkat Ali[3], Peter Wolfs[4]
[1, 2] Faculty of Sciences, Engineering & Health, CQUniversity
[3] School of Computing Sciences, Faculty of Arts, Business, Informatics & Education, CQUniversity
[4] Faculty of Science and Engineering, Curtin University of Technology
[1]Email:g.shafiullah@cqu.edu.au

Abstract — **Today, more than 80% of energy is produced from fossil fuels that pollute the air and surrounding environments each and every day, creating global warming. Therefore it is time to think about alternative sources of energy to build a climate friendly environment. In contrast to fossil fuels, renewable energy offers alternative sources of energy which are in general pollution free, unlimited, and environmentally sustainable. This paper presents a feasibility study undertaken to investigate the prospects of solar energy for the climate similar to Australia so as to further investigate the impacts of renewable energy sources in existing and future smart power systems. The monthly average global solar radiation has been collected for twenty-one locations in Australia from the National Aeronautics and Space Administration (NASA). Hybrid Optimisation Model for Electric Renewable (HOMER), and Renewable-energy and Energy-efficient Technologies (RETScreen) computer tools were used to perform comparative analysis of solar energy with diesel and hybrid systems. Initially, total net present cost (NPC), cost of energy (COE) and the renewable fraction (RF) were measured as performances metrics to compare the performances of different systems. For better optimisation, the model has been refined with a sensitivity analysis which explores performance variations due to solar irradiation and electricity prices. Finally, a statistical analysis was conducted to select the best potential places in Australia that produce maximum solar energy.**

Keywords—Renewable Energy, HOMER, RETScreen, Performances Metrics, Sensitivity Analysis.

I. INTRODUCTION

The advantages of renewable energy sources are enormous as they are free from greenhouse gas emissions which impact on global warming, and can in principle meet the world's total energy demand. Renewable energy is starting to be used as the panacea for solving the climate change problems. Currently, renewable energy sources fulfill 15 percent to 20 percent of the world's total energy demand. However, to get a climate friendly environment for the future, economic sacrifices will be required with high upfront capital costs of the move to much higher levels of renewable energy sources [1-3]. Renewable energy sources such as wind or solar are weather-driven, and therefore non-scheduled as these sources depend on wind flow or solar activity respectively [3-5]. Solar energy is one of the most promising renewable energy sources which is free from greenhouse gas emissions, and that encourages interest worldwide. Small scale photovoltaic technology is cost-effective in providing electricity in rural or remote areas, in particular in countries like Australia [6].

Australia's abundance of coal has helped to keep energy prices low; thus, more than three-quarters of the country's electricity is generated by coal-burning plants. However, Australia's reliance on coal-fired power gives it one of the world's highest per-capita greenhouse gas emission rates. Therefore, it is necessary to reinvigorate the Australian environment policy to bring a higher percentage of renewable energy sources into the energy mix to build a climate friendly environment for the future. A primary national goal of Australia is to increase the use of renewable energy from present levels to 20 percent or even 25 percent of total electrical supply [1].

Substantial research, planning and development are required for increased integration of renewable energy sources with the current power transmission and distribution network. Therefore, at the beginning of the 21st Century, the Government authorities, the utility companies and the research communities are working together to develop an intelligent grid system that can effectively integrates renewable energy sources with the grid. This will reduces overall greenhouse gas emissions with better demand management and encourages energy efficiency, improves reliability, and manages power more efficiently and effectively [1, 7-8].

In Australia, the Intelligent Grid Program [8] was launched on 19 August 2008, being established under the CSIRO's Energy Transformed Flagship, and focuses on the national need to reduce greenhouse gas emissions [1]. The Townsville Solar City Project administered by the Australian Government and Ergon Energy (a local Queensland based distribution utility organisation) has conducted 742 residential and commercial assessments, and installed 1445 smart meters, 160kW of solar panels and eight advanced energy storage systems [1]. Ergon Energy is also working on analysing the impacts of high photovoltaic (PV) penetration on the grid. Western Power (a local Western Australia based transmission and distribution utility organisation) has also implemented a Solar City program which includes a PV saturation trial to test the impact of distributed generation on the network. The Australian Government's Solar Cities program has helped many distributors to understand the impact of inverter connected renewable distributed generation (DG) [1, 4].

Kaiser and Aditya [9] developed a model using the HOMER simulation tool to find out the best technically viable renewable based energy system for the consumers located in Saint Martin Island, Bangladesh. Experimental results showed that it will be better to create a PV-wind minigrid combination system for 50 homes instead of installing single home systems.

Setiawan et al. [10] presented a design scenario for supplying electricity and fulfilling the clean water demand in remote areas by utilising renewable energy sources and a diesel generator with a reverse osmosis desalination plant as a deferrable load. It was shown that this hybrid power system is more efficient compared to a stand-alone system both economically and environmentally.

A techno-economic feasibility analysis has been done for a 500 kW grid connected solar photovoltaic system using HOMER and RETScreen software by Islam et al. [11]. From the experiments, it was found that the per unit electricity production cost is competitive compared to a grid-connected system.

This paper investigates the usefulness and availability of solar energy in the Australian context. In particular, a feasibility study has been undertaken to investigate the availability of solar energy considering pollution, production cost and cost of energy. For experimental analysis, twenty-one weather stations have been selected to collect solar radiation. This study also explores the most feasible places in Australia for solar energy production. This paper is organised as follows: Section II discusses the evaluation of the model; Section III presents the experimental setup to build a hybrid renewable energy system; results and discussions are described in Section IV; and Section V concludes the article with future directions.

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II. Model Evaluation

A renewable energy hybrid model has been developed using HOMER [12] and RETScreen [13] to explore the feasibility and availability of solar energy in the Australia. This section sets out the necessary data collection procedure, simulation software details and the ranking algorithm used in this study to develop the hybrid model.

2.1 Data Collection

Data have been collected for the twenty-one locations of Australia from NASA, Surface meteorology and solar energy (SSE) [15]. NASA's SSE data set is formulated monthly averaged data from 24 years of data. To synthesise data by HOMER, it is necessary to enter twelve average monthly values of either solar radiation or clearness index and HOMER builds a set of 8760 solar radiation values. Three locations have been selected from each State considering mean solar radiation, i.e., location with maximum, average and minimum solar radiation for experimental analysis.

2.2 Simulation Software

HOMER version 2.68 [12] has been used in this study to investigate the feasibility and cost analysis study of renewable energy sources. HOMER models a power system's physical behaviour and its life-cycle cost which allows the modeller to compare many design options based on their technical and economical merits. It can evaluate design options both for off-grid and grid-connected power systems for remote, stand-alone and distributed generation applications [12, 15].

RETScreen, developed by the Ministry of Natural Resources, Canada, is a leading clean-energy decision making software. Comprehensive analytical tools are integrated with a five step standard analysis including energy analysis, cost analysis, emission analysis, financial analysis, and sensitivity/risk analysis [13].

2.3 Performance Metrics

In this paper NPC, RF and COE have been considered as performance metrics to evaluate and compares different systems. The total NPC of a system is the present value of all the costs that it incurs over its lifetime, minus the present value of all the revenue that it earns over its lifetime. Costs include capital costs, replacement costs, Operation and Maintenance (O&M) costs, fuel costs, emissions penalties, and the costs of buying power from the grid [12, 15]. On the other hand, COE is the average cost per KWh of electricity. To calculate the COE, HOMER divides the annualised cost of producing electricity (the total annualised cost minus the cost of serving the thermal load) by the total useful electric energy production. The NPC is a more trustworthy number than the COE, therefore in this analysis NPC has counted as the primary metrics.

The renewable fraction is the portion of the system's total energy production originating from renewable power sources. HOMER calculates the renewable fraction by dividing the total annual renewable power production (the energy produced by the PV array, wind turbines, hydro turbine, and biogas-fuelled generators) by the total energy production [12, 15].

2.4 Ranking Algorithm

Finally, to select the most feasible and economically viable locations in Australia, a statistical analysis has been conducted using the results of performance metrics for different locations. The ranking performance has been estimated for each given location based on NPC, COE and RF to select the most feasible locations for solar energy. The best performing location on each of these measures is assigned the rank of 1 and the worst is ranked 0. Thus, the rank of the *j*th algorithm as in equation 1 on the *i*th dataset is calculated as stated in [16]:

$$R_{ij} = 1 - \frac{e_{ij} - \max(e_i)}{\min(e_i) - \max(e_i)} \qquad (1)$$

where e_{ij} is the percentage of correct classification for the *j*th algorithm on dataset *i*, and e_i is a vector accuracy for dataset *i*. A detailed comparison of performance can be evaluated from this equation.

III. Hybrid Energy Model

A hybrid energy model has been developed using HOMER to identify the cost of different hybrid systems, and compares their performances based on performance metrics such as NPC, COE and RF. Simulation, optimisation and sensitivity analysis of the models have been performed and final recommendation made. In this study, solar energy has been connected with a Grid-connected system and designed a PV/Grid hybrid system. This hybrid system consists of an electric load, solar energy and other system components such as PV, Converter, and Grid.

2.5 Electric Load

A typical load system has been considered for this analysis considering Australian average monthly load demand. The electric load has a seasonal variation, with December, January and February as peak months due to summer, while March to June requires lower loads due to winter. The annual average of the electric load is 100 kWh/day and the annual peak load is 14 kW from the data collected for this study.

2.6 Solar Energy

Monthly average solar radiation data were imported in HOMER to calculate daily radiation and monthly average values of clearness index. Considering the radiation variation, the sensitivity analysis is done with four values around the mean radiation.

3.3 System Components

The major components of the grid-connected hybrid system are PV panels, batteries and a power converter. For economic analysis, number of units to be used, capital, replacement and O&M costs, and operating hours have been defined in HOMER in order to simulate the system.

A. Photovoltaic

For an optimum solution, the installation cost for a 1.0 kW stand-alone PV array is assumed as AU$4500 and O&M cost is considered practically zero [18]. Sizes of the photovoltaic arrays are varied from 1 to 4 kW.

B. Power Converter

A converter is required to convert AC-DC or DC-AC. The installation costs for a 1.0kW converter is AU$800, replacement cost is AU$700 and O&M cost is considered practically zero [17].

C. Grid

Figure 1 shows the proposed hybrid system developed with HOMER. This proposed system is a grid-connected system in which the grid acts as a backup power component. The grid is activated to supply electricity when there is not enough renewable energy to meet the load [18].

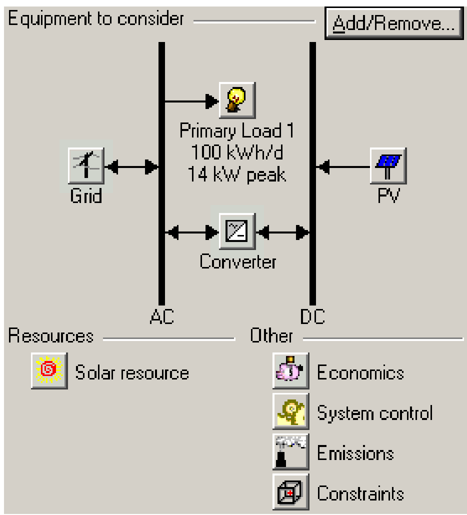


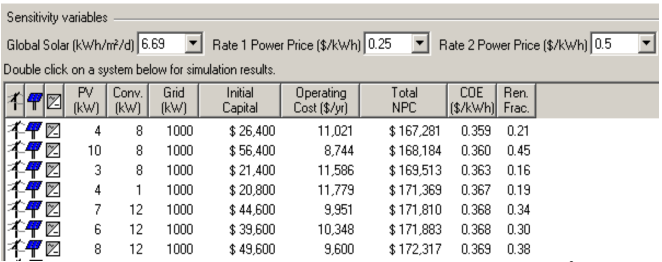
Figure 1: Hybrid renewable energy system with HOMER

IV. Results and Discussions

To evaluate the performances of different hybrid systems in this study, optimal systems and the sensitivity analysis have been measured using HOMER simulation tools. For experiments, twenty-one weather stations have been selected with three from each States of Australia. Three locations have been considered from each of the State of Australia based on solar radiation of those particular locations; for experimental flexibility and to get better accuracy, the three locations were selected with maximum, average and minimum solar radiation for individual States. Performance metrics NPC, COE and RF have been measured for each location. Sensitivity analysis and optimisation results have given a detail scenario of individual's location whether it is economically or environmentally feasible or not in a specific meteorological condition. Considering flexibility of the experiments and load demands, electricity price is divided into three rates.

4.1 *Optimisation Results*

Simulation has been conducted considering the solar radiation collected from twenty-one locations in Australia. Maximum solar radiation for Western Australia was observed in Karratha. The optimisation results in this location for a specific solar irradiation (6.69 kWh/m^2 per day), and grid electricity price (rate 1: 0.3$/kWh, rate 2: 0.5$/kWh and rate 3: 0.4$/kWh) are illustrated in Figure 2.



Sensitivity variables

Global Solar (kWh/m²/d) 6.69 | Rate 1 Power Price ($/kWh) 0.25 | Rate 2 Power Price ($/kWh) 0.5

Double click on a system below for simulation results.

PV (kW)	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
4	8	1000	$ 26,400	11,021	$ 167,281	0.359	0.21
10	8	1000	$ 56,400	8,744	$ 168,184	0.360	0.45
3	8	1000	$ 21,400	11,586	$ 169,513	0.363	0.16
4	1	1000	$ 20,800	11,779	$ 171,369	0.367	0.19
7	12	1000	$ 44,600	9,951	$ 171,810	0.368	0.34
6	12	1000	$ 39,600	10,348	$ 171,883	0.368	0.30
8	12	1000	$ 49,600	9,600	$ 172,317	0.369	0.38

Figure 2: Optimisation results with solar irradiation (6.69 kWh/m^2 per day), and grid electricity price (rate 1, 2 and 3 are 0.3$, 0.5 and 0.4 $/kWh)

It is seen that a PV-grid based power system is economically feasible with a minimum total net present cost (NPC) of $ 167,281 and a minimum cost of energy COE of $0.359/kWh; however the contribution of renewable energy is not significant as the installation cost of the photovoltaic system is high compared to grid electricity price. The best optimum NPC ($144,340), COE (0.25) and RF (0.83) was achieved for a solar irradiation of 8 kWh/m^2 per day, and a grid average electricity price of 0.5$/kWh. However, in this case the electricity price is more than usual.

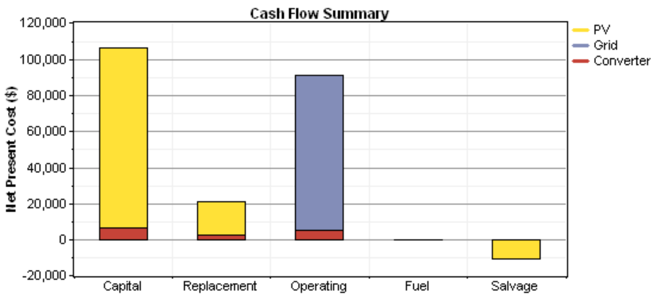


Figure 3: Cash flow summary of Alice Springs

Figure 3 shows the cash flow summary of Alice Springs weather station, Northern Territory. It indicates that, in the optimised PV-grid system, most of the capital cost is required for the PV module. However, most of the operating cost is due to grid components and converters, while renewable energy sources require less operating expenditure which is one of the most useful features of renewable energy resources. Another major advantage is that this optimised PV-grid system emitted 22,061 kg carbon dioxide per year, while an optimised standard grid system emitted 46,136 kg per year.

The monthly average electric energy production at Weipa, Queensland is represented in Figure 4. The PV module produces 36,256 kWh/year and the grid produces 20,871 kWh/year. In this system, the PV array contributed 63% and the grid contributed only 37% of the total energy production. The lowest solar radiation was observed at Macquarie Island, Tasmania. The PV output of this location is presented in Figure 5.

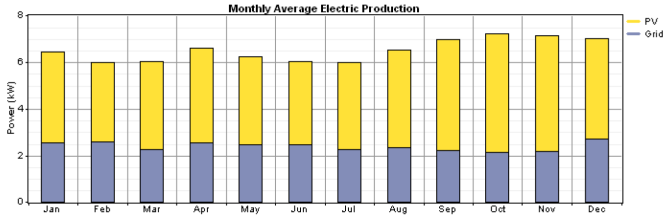


Figure 4: Monthly average electric energy production at Weipa, Queensland

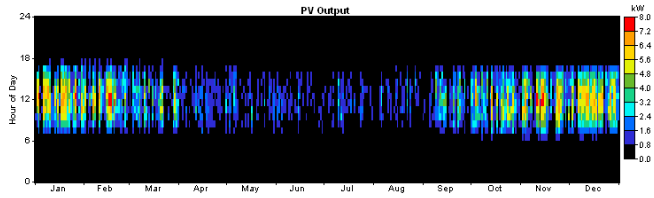


Figure 5: PV output of Macquarie Island, Tasmania

4.2 *Sensitivity Results*

Sensitivity analysis is a measure that checks the sensitivity of a model when changing the value of the parameters of the model and also changing the structure of the model. This analysis is useful to support decision making or the development of recommendations from the model. In this paper, sensitivity analysis has been undertaken to study the effects of variation in the solar radiation and to make appropriate recommendations in developing renewable energy systems. The model has been simulated based on the sensitivity variables: solar irradiation and grid electricity prices, and different NPC, COE and RF values have been observed as resultant model outputs.

HOMER simulates all the systems in their respective predefined search spaces. Simulation is undertaken for every possible system combination and configuration for a period of one year. A total of 120 sensitivity cases were run for each of the system configurations. The simulation was carried out with an Intel Core 2 Duo CPU, 3.2 GB of RAM with Windows XP Operating System.

From the sensitivity analysis, the models were analysed to explore the model characteristics using optimal system type (OST) and surface plot options. Figure 6 represents the sensitivity results from the data collected from Tamworth, NSW weather station. It can be seen that the PV-grid system is feasible when the solar radiation is above 5.0 kWh/m^2/day and grid electricity prices are fixed at rate 1: $0.25/kWh and rate 3: $0.4/kWh. From these graphical representations, it has been concluded that a particular system would be optimal at certain sensitivity variables or conditions.

Figure 6: Sensitivity results with grid electricity prices fixed at rate 1: $0.25/kWh and rate 3: $0.4/kWh

Figure 7 shows the sensitivity results from the data collected from Macquarie Island, Tasmania, where the lowest solar radiation was observed in this study. It is seen that the PV module has no contribution in this system, and for this location a grid-only system is the most feasible solution.

Figure 7: Sensitivity results with grid electricity prices fixed at rate 1: $0.25/kWh and rate 3: $0.4/kWh

Based on the optimisation results and sensitivity analysis, it has been observed that solar energy plays a key role in this energy system for most of the States as well as locations. However, a few locations are not feasible due to weather conditions and the high upfront cost for the solar system.

4.2 Statistical Analysis

To select the most feasible place for solar plant installation, a ranking algorithm has been used in this study. Initially, from the results from HOMER, average performances have been estimated for NPC, COE and RF. Finally, a ranking performance for each model has been estimated using equation (1) to select the best feasible locations for solar energy production in Australia. From the experiments it has seen that Northern Territory is selected as ranked 1 and Tasmania is ranked 7 out of seven states in Australia. Therefore, it has been concluded that Northern Territory is the most suitable state from which it is possible to generate maximum solar energy, and Tasmania is not suitable to install a large scale solar plant. Figure 8 represents the ranking of States considering the prospects of solar energy generation in Australia. This study also explores three suitable weather stations that can generate solar energy with maximum RF and lowest NPC and COE. The three locations are Weipa in Queensland, Alice Springs in Northern Territory and Karratha in Western Australia. However, this study only focuses on renewable fraction, cost of energy, net production cost and emission. This study does not focus on transmission costs and other socio environmental factors.

Figure 8: Ranking of different States in Australia

V. Conclusions

To save the environment and overcome global warming it is a must to use a greater percentage of renewable energy even though this has a high upfront capital cost. In this paper a feasibility study has been undertaken to explore characteristics and cost analysis of a grid connected renewable energy system using HOMER simulation software. The study simulates PV-grid-connected hybrid systems in the Australian context. The optimised hybrid renewable energy system was developed considering manufacturing cost, relative efficiency which includes converter, and the PV module. Electricity prices have been considered in three rates based on daily load demand variations. The sensitivity analysis indicates that a PV-grid-connected hybrid system is feasible under specific meteorological conditions for Australia. However, agrid-connected system alone is more feasible considering only the cost of energy as coal is abundant in Australia, and it is therefore possible to produce energy with low prices which causes global warming. However, to get a climate friendly environment, Australian policy is ready to make economic sacrifices and encourage the use of renewable sources to produce energy for the future. From the experimental results it is seen that Northern Territory, which is in a hot-arid region, is the most suitable place for solar energy generation.

This study is still in its introductory stage and needs further investigations on the following areas:

- Experimental analysis with large volume of data
- Conduct same analysis for wind energy and combine them
- Analyse the impact of renewable energy sources with the smart power systems.

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