# Impact of Renewable Energy in the Future Smart Power System

G. Shafiullah, A. Oo, D. Jarvis, A. Ali, P. Wolfs

***Abstract*— Current power systems create environmental impacts due to utilisation of fossil fuels, especially coal, as carbon dioxide is emitted into the atmosphere. In contrast to fossil fuels, renewable energy offers alternative sources of energy which are in general pollution free, technologically effective and environmentally sustainable. There is an increased interest in renewable energy, particularly solar and wind energy, which provides electricity without giving rise to carbon dioxide emissions. This paper presents a feasibility study undertaken to investigate the availability and usefulness of renewable energy sources in Central Queensland of Australia so as to further investigate the impacts of renewable energy sources in existing and future smart power system. The daily mean global solar irradiance and three hourly mean wind speed have been collected from the Rockhampton Aero Weather Station, Queensland, Australia for this study. Hybrid Optimization Model for Electric Renewable (HOMER), a computer model developed by National Renewable Energy Laboratory (NREL) has been used to perform comparative analysis of solar and wind energy with diesel and hybrid systems. Initially total net present cost (NPC), cost of energy (COE) and the renewable fraction (RF) have been measured as performances metrics to compare the performances of different systems. Finally for better optimisation, the model has been refined with sensitivity analysis which explores performance variations due to wind speed, solar irradiation and diesel fuel prices. From the simulation, it is shown that there are a number of factors that impact the integration and performance of renewable energy sources to the power systems.

***Keywords*—Renewable Energy, Smart Grid, HOMER, Performances Metrics, Sensitivity Analysis.

## 1. INTRODUCTION

A recent issue of increasing public focus is the need for robust, sustainable and climate friendly power transmission and distribution systems that are intelligent, reliable and green. From the existing electricity grid it is not possible to provide adequate services addressing energy efficiency, reliability and security, or the deployment of clean renewable energy at the scale needed to meet the clean-energy demand for a new century. There are a number of challenges in integrating renewable energy sources with the existing power systems. 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 Governments, the utility companies and the research communities are working together to develop an intelligent grid system, now commonly known as the Smart Grid that reduces overall greenhouse gas emissions with demand management and encourages energy efficiency, improves reliability, and manages power more efficiently and effectively [1-3].

The Center for American Progress provides a concept called a clean-electricity or clean energy "pipeline" which produces large scale renewable electricity; deliver electricity nationwide on a new high capacity grid; manages all power generation and distribution with new sophisticated information technology methods; allows consumers to contribute energy to the grid [2]. In April 2003, the Department of Energy (DOE), USA declared its 'Grid 2030' mission, the vision of which was: *Grid 2030 energizes a competitive North American Market place for electricity. It connects everyone to abundant, affordable, clean, efficient and reliable electric power anytime, anywhere. It provides the best and most secure electric services available in the world* [4]. To fulfill this vision, Electrical Power Research Institute's (EPRI's) IntelligridSM has under-taken an initiatives to develop the technical foundation for a smart power grid that links electricity systems with communication and computer technology to achieve tremendous gains in reliability and customer services [5]. Figure 1 shows a schematic diagram of EPRI's Intelligrid model.

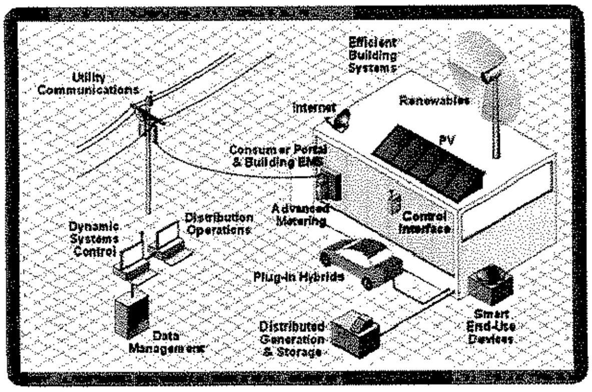


Figure 1 A typical scenario of EPRI's Intelligrid Model [5]

The SmartGrids European Technology Platform [6] vision is that Europe's electricity network must be flexible (fulfilling customer needs); accessible (access to all network users, particularly for renewable energy sources and high efficiency local generation with low carbon emission); reliable (assuring security and quality of supply); and economic (cost and energy efficient management). However, country like Australia, due to its availability of coal to produce cheap energy, is lack behind compared to

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USA and European in an attempt to integrate renewable energy sources and building smart grid infrastructure. Australia's reliance on coal-fired power gives it one of the world's highest per-capita greenhouse gas emission rates [1-3, 7]. Therefore, it is necessary to reinvigorate the Australian economy by building new generation, transmission and distribution systems for efficient use of low-carbon electricity. 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 administrated 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. Ergon Energy is also working on analysing the impacts of high photovoltaic's (PV) penetration on the grid. Western Power's (a local Western Australia based transmission and distribution utility organisation) Solar City program includes a PV saturation trial to test the impact of distributed generation on the network. The Solar cities program has helped many distributors to understand the impact of inverter connected renewable distributed generation (DG). This analysis included smart meters that collect bi-directional data to capture how much power the distributed generator is feeding back to the grid [1, 9].

Wind generation is one of the fastest growing and cost effective resources among different renewable energy sources. In addition to solar and wind, bio-gas and geothermal are also useful renewable energy sources that can play a key role in reducing carbon emissions [9]. As the penetration [10] of renewable energy continues to increase, it is time to rethink to develop a sustainable, green power system which is capable to integrate the various renewable energy sources. Fortunately an operational smart grid has the potential to mitigate some of the difficulties encountered by renewable energy generation. 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. The use of smarter grid operations allows for greater penetration of variable energy sources through more flexible management of the system. Integration studies are continuing to improve performance, though there are still a few existing challenges [11-12].

Zoulias and Lymberopoulos [13] investigated a techno-economic analysis of the integration of hydrogen energy technologies in renewable energy-based stand-alone power systems using HOMER simulation tool. The experimental result shows that the replacement of fossil fuel based gensets with hydrogen technologies is technically feasible and economically favourable compared to the PV-diesel system as long as a 50% reduction on the cost of electrolysers and a 40% reduction on the cost of hydrogen tanks are made.
Kaiser and Aditya [14] developed a model using 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 PV-wind minigrid combination system for 50 homes instead of single home system.

Setiawan et al. [15] presented a design scenario for supplying electricity and fulfil 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. HOMER has been used to find the optimum configuration for a hybrid power system. It has shown that this hybrid power system is more efficient compared to stand-alone system both economically and environmentally.

This paper investigates the impacts and integration of renewable energy sources with power system, analysing the benefits and outcomes for a typical Australian power network. In particular a feasibility study have been undertaken to investigate the necessity of solar and wind power considering pollution, production cost and cost of energy. This paper is organised as follows: Section II discusses the evaluation of the model. Section III presents experimental setup to build a hybrid renewable energy system. Results and discussions are described in Section IV. Section V concludes the article with future directions.

## 2. Model Evaluation

A renewable energy hybrid model has been developed using HOMER to explore the impacts of renewable energy sources on the modern power grid. This section presented necessary data collection procedure and the simulation software used in this study to develop the hybrid model with the measured performance metrics.

### *2.1 Data Collection*

Data have been collected from the Australia Bureau of Meteorology [16] for the location of Rockhampton and position of the Rockhampton Aero Weather Station (-23.3753$^0$, 150.4775$^0$, 10.4m). Daily mean solar radiation data and three hourly mean wind speed data have been collected from the year of 2007 as shown in Table 1 and 2 respectively as a sample data. Data have been collected using a real time automatic system with performing quality checking.

Table 1 Weekly Solar Radiation

| Day | Radiation (kWh/m$^2$/day) |
|---|---|
| Day 1 | 6.400000 |
| Day 2 | 5.838889 |
| Day 3 | 7.377778 |
| Day 4 | 6.872222 |
| Day 5 | 8.366667 |
| Day 6 | 6.036111 |
| Day 7 | 8.372222 |

Table2 Daily Wind Speed

| Hour/Time | Speed(m/s) |
|---|---|
| 00:00 | 2.758133 |
| 03:00 | 6.639949 |
| 06:00 | 5.720571 |
| 09:00 | 10.47069 |
| 12:00 | 8.478704 |
| 15:00 | 9.398081 |
| 18:00 | 5.720571 |
| 21:00 | 6.639949 |

### *2.2 Simulation Software*

HOMER version 2.68 [17] 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. Inputs to Homer contain load data, renewable source data such as photovoltaic, wind turbines, system components specification and cost, and various information of optimisation. It simulates thousands of system configurations, optimises for lifecycle cost and generates results of sensitivity analyses on most of the inputs. It repeats the optimisation process for each value of the input, so it is possible to examine the effects of changes in the value on the results [17-19].

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, O&M costs, fuel costs, emissions penalties, and the costs of buying power from the grid. Revenues include salvage value and grid sales revenue [16-17].

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 [16-17].

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.

## 3. Hybrid Renewable Energy System

To investigate the strategic impacts of renewable energy in the smart power system in this paper, a model has been developed and simulate with HOMER to identify the operational characteristics of different renewable energy sources with the existing power grid. This paper also calculates the cost of different hybrid systems and compares their performances based on performance metrics such as NPC, RF and COE. Simulation, optimisation and cost analysis of the model has been performed and final recommendation has been made. In this study solar and wind energy have been connected with a Grid-connected system and designed a PV/Wind/Grid hybrid system. This hybrid system consists of an electric load, renewable energy sources (Solar and Wind) and other system components such as, PV, Wind turbines, Converter, Grid.

### *3.1 Electric Load*

A typical load system has been considered for this analysis considering Australian average monthly load demand. Daily load demand has illustrated in Figure 2 in which 13:00 to 16:00 time period has been observed as peak demand. The electric load has a seasonal variation in December, January and February as peak months due to summer while March to June requires fewer loads due to winter which is shown in Figure 3. The annual average of the electric load is 200 kWh/day and the annual peak load is 27 kW of the data collected for this study.

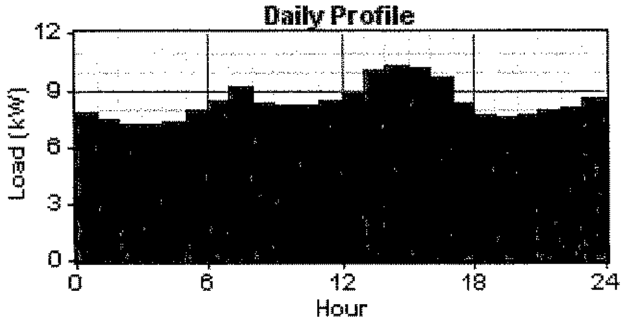


Figure 2: Daily load profile

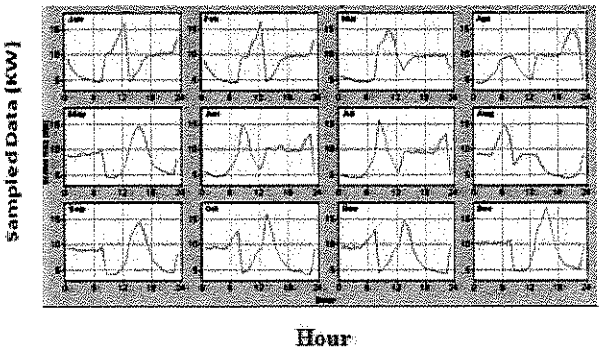


Figure 3: Monthly load variations

### *3.2 Renewable Energy Sources*

#### *3.2.1 Solar Energy*

Daily solar radiation data were imported in HOMER to calculate daily radiation and monthly average values of clearness index. Figure 4 illustrates that solar radiation is high between October to December. The average annual clearness index is 0.568 and the average daily radiation is 5.68. Figure 4 demonstrates the daily radiation in kWh/m$^2$ per day and the clearness index curve over the period of the whole year. Considering the radiation variation, the sensitivity analysis is done with four values around the mean radiation.

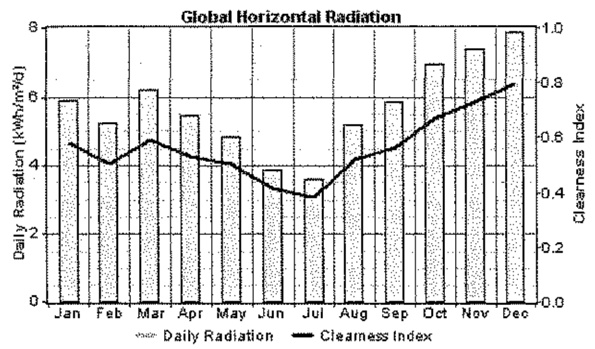


Figure 4 Daily solar radiation with clearness index

#### *3.2.2 Wind Energy*

Three hourly wind speed data (m/s) were imported in HOMER to synthesised based on weibull factor *k=1.74,* auto correlation factor=*0.901,* diurnal pattern strength=*0.0271,* and hour of peak wind speed=*22.* Figure 5 shows the monthly wind speed between 4.557 and 7.427 m/s. Wind speed also varies with seasonal condition as like solar radiation. From Figure 5 it has seen that there is a shortage of wind speed between June to August, and higher speed from October to March.

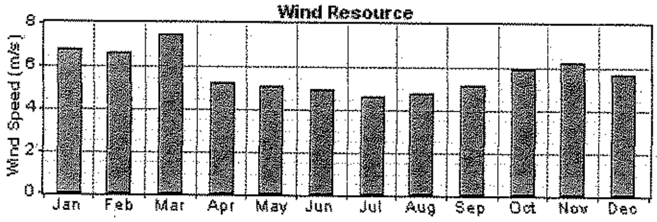


Figure 5 Monthly wind speed variations

### 3.3 *Hybrid System Components*

The major components of the grid-connected hybrid system are PV panels, Wind turbines, and a power converter. For economic analysing, number of units to be used, capital, replacement and Operation and Maintenance (O&M) cost, operating hours have defined in HOMER in order to simulate the system.

#### 3.3.1 *Photovoltaic*

The initial installation cost of photovoltaic arrays may vary from \$4.00 to \$5.00 [20]. For an optimum solution, the installation cost for a 1.0 kW stand-alone PV array is assumed \$4000 and O&M cost is considered practically zero. Sizes of the photovoltaic arrays are varied 1 to 4 kW.

#### 3.3.2 *Wind turbines*

For this study BWC Excel-R 7.5 kW DC wind turbine has been used which is manufactured by Bergey Windpower [21]. The installation, capital and O&M cost of this turbine is respectively \$17500, \$15000 and zero.

#### 3.3.3 *Power Converter*

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

#### 3.3.4 *Grid*

This proposed system is a Grid-connected system in which the Grid acts as a backup power component. The grid is activated and supply electricity when there is not enough renewable energy power to meet the load. Moreover, the grid functions as a storage system so a grid-connected system does not need any battery [22].

## 4. 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. To identify an optimal hybrid system, the PV-wind grid-connected system may be varied assuming the electricity fixed at 0.3\$/kWh. Figure 6 shows the proposed hybrid system developed with HOMER.

### 4.1 *Optimization Results*

Simulation has been conducted considering different values for solar radiation, wind speed and power considering more flexibility in the experiments. The optimisation results for specific wind speed (5.67m/s), solar irradiation (5.68 kWh/m$^2$ per day), and grid electricity price (0.3\$/kWh) are illustrated in Figure 7. It is seen that, a wind based power system is economically more feasible with a minimum total net present cost (NPC) of \$ 212456 and a minimum cost of energy COE of \$0.228/kWh than the PV-wind system; however the economic performance of a PV-wind system is almost similar to the wind only system. This difference is due to the abundant of wind energy resource and the cost of wind turbine generator is less than the solar array modules. This wind and PV-wind system represents greater RF (0.64) which means the bigger proportion of renewable energy generations.

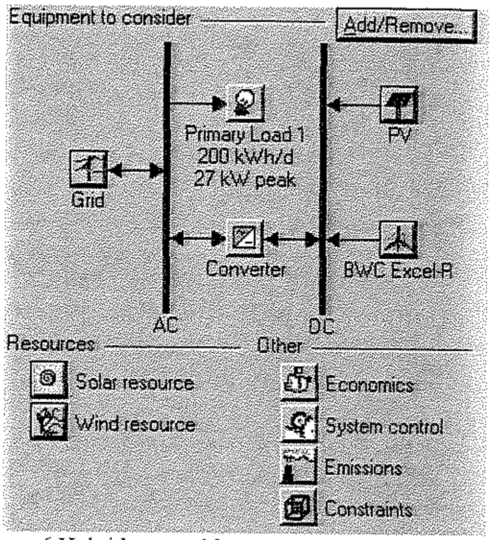


Figure 6 Hybrid renewable energy system with HOMER

Sensitivity variables
Global Solar (kWh/m²/d) 5.68 | Wind Speed (m/s) 5.67 | Rate 1 Power Price (\$/kWh) 0.3
Double clic[Solar Data Scaled Average]ation results.

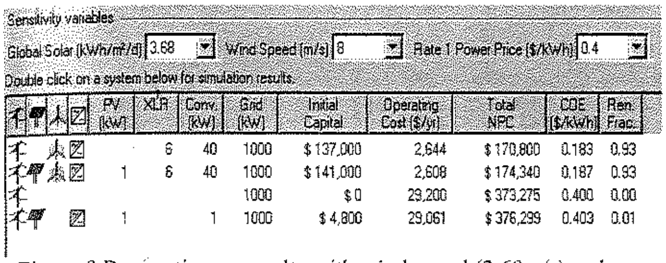
| | | | | PV (kW) | XLR | Conv. (kW) | Grid (kW) | Initial Capital | Operating Cost (\$/yr) | Total NPC | COE (\$/kWh) | Ren. Frac. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 3 | 16 | 1000 | \$ 65,300 | 11,519 | \$ 212,546 | 0.228 | 0.64 |
| | | | | 1 | 3 | 16 | 1000 | \$ 69,300 | 11,399 | \$ 215,022 | 0.230 | 0.64 |
| | | | | | | | 1000 | \$ 0 | 21,900 | \$ 279,956 | 0.300 | 0.00 |
| | | | | 1 | | 1 | 1000 | \$ 4,800 | 21,742 | \$ 282,731 | 0.303 | 0.01 |

Figure 7 Optimization results with wind speed (5.67m/s), solar irradiation (5.68 kWh/m$^2$ per day), and grid electricity price (0.3\$/kWh)

The best optimum NPC (\$174,340), COE (0.187) and RF (0.93) have achieved from the wind speed (8.0 m/s), solar irradiation (3.68 kWh/m$^2$ per day), and grid electricity price (0.4\$/kWh) shown in Figure 8. However, in this case electricity price is more than usual. Therefore, it is required to conduct further study with more and useful data. From Figure 7 and 8 it has been observed that PV-wind system or wind only system is more economical compared to the standard grid system.

From the cash flow summary in Figure 9 it has shown that in the optimised PV-wind system most of the cost is required for the grid component while least money is for the PV. Therefore it can be stated that most of the cost is due to grid component and converters while renewable energy sources requires less expenditure which is one of the most useful features of renewable energy resources. Another major advantage is this optimised PV-wind system emitted 12,061 kg carbon dioxide per year, while optimised standard grid system emitted 46,136 kg per year.

The monthly average electric energy production is represented in Figure 10. Wind turbine produces 63,795 kWh/year and grid produces 35,850 kWh/year. In this system wind turbine contributed 64% and PV array contributed only 1% of the total energy production. Further analysis need to undertaken to increase the contribution of PV array modules.



Sensitivity variables

Global Solar (kWh/m²/d) 3.68 | Wind Speed (m/s) 8 | Rate 1 Power Price ($/kWh) 0.4

Double click on a system below for simulation results.

| PV (kW) | XLR | Conv. (kW) | Grid (kW) | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. |
|---|---|---|---|---|---|---|---|---|
| | 6 | 40 | 1000 | $ 137,000 | 2,644 | $ 170,800 | 0.183 | 0.93 |
| 1 | 6 | 40 | 1000 | $ 141,000 | 2,608 | $ 174,340 | 0.187 | 0.93 |
| | | | 1000 | $ 0 | 29,200 | $ 373,275 | 0.400 | 0.00 |
| 1 | | 1 | 1000 | $ 4,800 | 29,061 | $ 376,299 | 0.403 | 0.01 |

Figure 8 Best optimum results with wind speed (3.68m/s), solar irradiation (8.0 kWh/m$^2$ per day), and grid electricity price (0.4$/kWh)

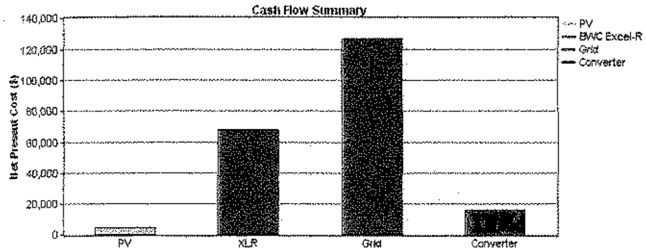



Figure 9 Cash flow summary

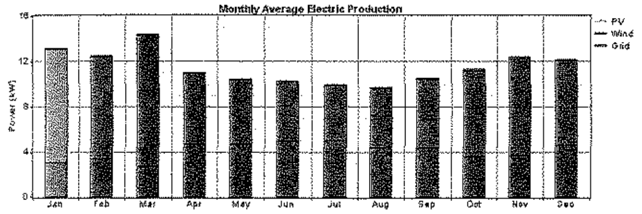



Figure 10 Monthly average electric energy production

## 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 in support decision making or the development of recommendations of the model. In this paper sensitivity analysis has been undertaken to study the effects of variation in the solar radiation and wind speed and to made appropriate recommendation in developing hybrid renewable energy system. The simulation software simulates the long-term implementation of the hybrid system based on their respective search size for the predefined sensitivity values of the components. The model has been simulated based on the three sensitivity variables: wind speed, solar irradiation and grid electricity price and different NPC, COE and RF values have been observed as a model output.

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. The sensitivity variable has been set for solar irradiation (G=3.68, 5.68, 7.68, 9.58, 10.68), wind speed (v=3.0, 4.0, 5.0, 5.67, 6.0. 7.0, 8.0), and the grid electricity price (p=0.05, 0.1, 0.2, 0.3, 0.4). A total of 175 sensitivity cases were run for each system configuration. 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 output optimal system type (OST) and surface plot were highlighted to explore the model characteristics considering solar radiation, wind speed and grid electricity price. Figure 11 shows that the PV-wind system is feasible when the grid electricity price is more than $0.3/kWh and wind speed is more than 3.0 m/s while solar radiation is fixed at 9.68 kWh/m$^2$/day. However, Grid-wind system is suitable than the grid only system if the electricity price grows up to $0.1/kWh. It happened due to availability of large amount of wind energy.

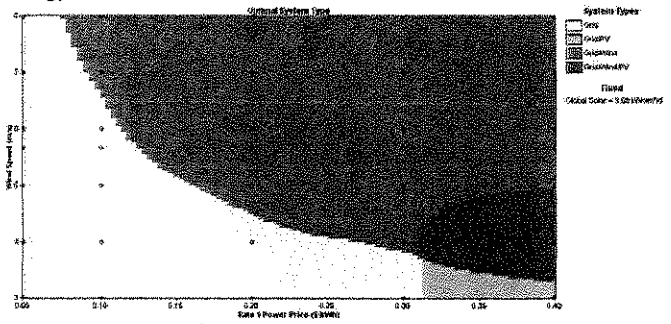


Figure 11 Sensitivity results with fixed solar radiation 9.68 kWh/m$^2$/day

Figure 12 shows a surface plot in which NPC and COE has measured in which wind speed and electricity price are variables with a fixed solar radiation of 7.68 kWh/m$^2$/day. From these graphical representations, it has concluded that a particular system would be optimal at a certain sensitivity variables or conditions.

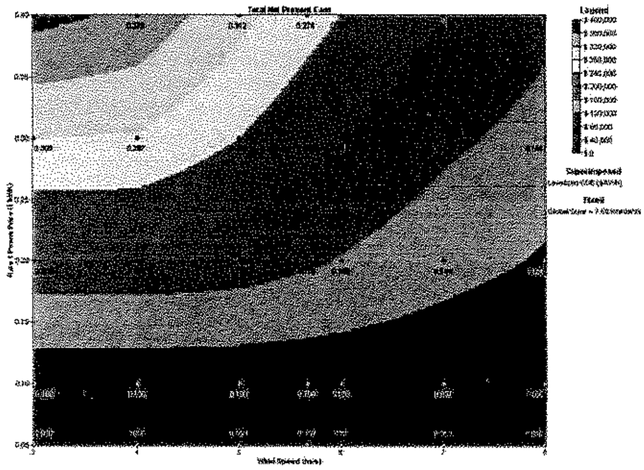


Figure 12 Sensitivity analysis with surface plot

Based on the optimisation results it has observed that wind energy plays a key role in this hybrid energy system as more than 50% of energy has produced from wind turbines while less than 5% energy has produced from solar radiation. A major reason for these results is renewable energy sources are weather-driven and possible to get wind energy 24 hours a day, 7 days a week and 365 days a year while solar energy mostly depends on sunshine, which may be 6 to 8 hours a day. Therefore the wind energy resource has more impacts on the implementation of hybrid renewable energy system for the future smart power network.

## 5. CONCLUSIONS

To investigate the impacts of renewable energy sources in smart power network, a feasibility study has been undertaken to explore the characterises, and cost analysis of grid connected hybrid renewable energy system using HOMER simulation software. The study simulates a PV-wind grid-connected hybrid system in central Queensland region. The daily solar radiation and three hourly wind speed data were collected from the Rockhampton Aero

Weather Station. In 2007, the mean solar radiation was 5.68 $kWh/m^2/day$ and wind speed was 5.67m/s. The optimized hybrid renewable energy system was developed considering manufacturing cost, and efficiency which includes a BWC excel-R wind turbine, and 1kW PV module. Experimental results show that the COE of energy of the optimized system is 0.23/kWh while the standard electricity is defined as 0.3/kWh. The sensitivity analysis indicates that PV-wind hybrid system is feasible under specific meteorological conditions in Central Queensland region, while wind-grid system is most suitable for most of the conditions. From the developed model it has clearly observed that wind energy has more impact in this hybrid system than the solar energy. However, this study is still in introductory stage and needs to be developed in different areas. Therefore further investigations are suggested on the following areas:

- Experimental analysis with large volume of data, specially focus on solar radiation
- Analyse the characteristics and availability of renewable energy sources (solar and wind).
- Analyse the impact of renewable energy sources with the smart power systems.

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