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# A STANDALONE HYBRID POWER SYSTEM FOR THE OUTBACK COMMUNITY OF OODNADATTA IN SOUTH AUSTRALIA

**Abstract:** Hybrid electrical power systems consisting of a combination fossil fuels powered generators and renewable energy sources in standalone grid-off configurations are gaining prominence in remote communities where grid extension are difficult and often very costly. This paper focuses on the design of a hybrid power system in an outback community of South Australia – Oodnadatta. An optimal standalone hybrid power system comprising photovoltaics, diesel and propane is proposed with the lowest levelised Cost of Electricity (COE) with at least 10% solar contribution. The proposed hybrid system is designed with the HOMER software utilising average daily solar radiation values for the years 2007-2009 and estimated power consumption data. The existing conventional power system in Oodnadatta is also modelled to compare and contrast with the proposed hybrid system to assess its impact on COE and greenhouse gas emissions.

## 1. Introduction

Countries around the world have been making commitments to renewable energy. For instance, China has just announced a target of 15% of renewable energy generation by 2020 [1]. This compares with 20% of the renewable energy generation commitment by the Australian Government within the same time span [2]. As the renewable energy sources are relatively unreliable due to changing operational conditions, such as wind speed, solar irradiation, hydro flow and tidal force; it makes sense to integrate them with other energy sources to create systems less prone to the variations in the renewable sources of energy in nature.

This paper examines and discusses details of a design for a hybrid power supply for an off-grid outback community in Australia, which currently depends on conventional generators driven by internal combustion engine prime movers. It is proposed to augment the existing system by the integration of solar panels, to create a *hybrid power supply* system.

## 2. Power generation in remote communities in South Australia

The South Australian Government's Remote Areas Energy Supplies (RAES) scheme [3], a part of the national Renewable Remote Power Generation Program [4], was intended to provide electricity consumers in remote off-grid communities with safe, reliable and affordable electricity supplies. Small to medium domestic customers (up to 8,000kWh/yr) paid no more than 10% above the on-grid regulated contract tariff. This has changed with new tariffs introduced on 7 March 2011, which in some cases almost doubled the electricity bills [5].

In South Australia, over 16 million kWh of electricity is generated annually through the RAES, which supplies approximately 2,600 customers in 13 remote communities. Only one of these communities, Parachilna, has a hybrid power supply system using solar energy, with the rest relying on a combination of diesel and propane powered generators [3].

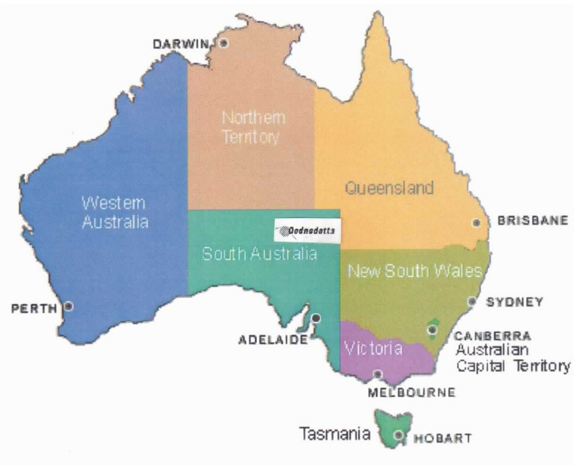


*Figure 1. Location of Oodnadatta in South Australia [3]*

## 3. Oodnadatta

Oodnadatta is a remote community in South Australia (SA), located some 1,011km north of Adelaide – the State capital (Figure 1). The distances in the state are vast: SA's total surface area of 983,483 km$^2$ is more than that of Germany and France combined!

Oodnadatta has a population of 277, of which 103 are indigenous Australians. The power supply in Oodnadatta is unreliable with several blackouts of more than 24 hours duration a year [7]. Integrating renewable technologies with conventional generators promises to reduce the costs associated with standalone systems as well as increasing reliability [8].
Oodnadatta receives about 5.83–6.67kWh/m$^2$ of solar radiation per annum, with a mean daily global solar radiation of 6.29kWh/m$^2$ per annum on a horizontal surface. When a solar module is tilted at 37.6° the radiation increases to 6.74kWh/m$^2$ [9]. The Australian Standard AS 4509.2 recommends an optimal tilt of 'latitude + 10°' for latitudes within the range of 25° – 45°. Oodnadatta has a latitude of 27.6°.
The sunshine duration in Oodnadatta, another parameter of solar potential, is comparable to that in Egypt and Saudi Arabia, the two countries with the greatest solar potential in the world. The mean daily sunshine hours in these countries are 11 hours and 8.9 hours respectively [10], [11], compared with Oodnadatta's 9.6 hours per day (Figure 2. [12]).

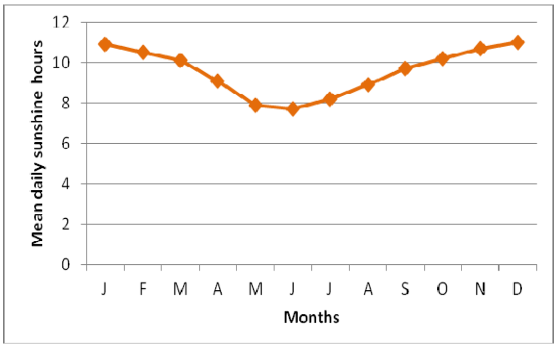


*Figure 2. Mean daily sunshine hours in Oodnadatta from 1951 – 1985*

In the load profile (Figure 3), it can be seen that the overnight demand is less than 100kW and gradually increases to 160kW by 8am [13]. Power consumption rises steadily over the next couple of hours and reaches a high of 250kW by 1pm. The increasing consumption is due to commercial and work related activities. Power demand reaches a peak of 287kW in the evening when most people have dinner.

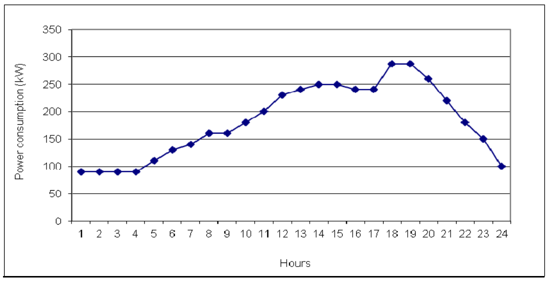


*Figure 3. Load profile for Oodnadatta*

## 4. Power system design

The proposed augmented system proposed for adoption in Oodnadatta was designed using the HOMER software [11]. HOMER performs three tasks: simulation, optimisation and sensitivity analysis. At simulation stage, HOMER investigates the performance of a particular power system configuration for each hour of the year to determine its technical feasibility and lifecycle cost. The lifecycle cost is the optimisation criterion.
HOMER has been used for modelling both the existing power system and the proposed hybrid power system for Oodnadatta.

### 4.1 Conventional power system

The existing power system in Oodnadatta consists of one 240kW LPG (propane) generator and two 185 kW diesel generators – One of the two diesel generators is kept in reserve. A model of the system, illustrated in Figure 4, depicts the system as modelled by HOMER. Notably, HOMER models a conventional power system as a parallel configuration.
Modelling takes into account technical specifications of the generators: size, operating reserve, lifetime, economic parameters, capital cost, replacement cost, operation and maintenance (O&M) and fuel costs.
The total net present cost (NPC) of the existing power system over the lifetime (25 years) is roughly AUD 5.1million. The bulk of the cost, around 92%, is the result of purchasing fuel. The NPC for Generator 1 and Generator 3 are 18% and 82% of the total NPC of the system, respectively. Generator 3 incurs significantly greater costs because it operates throughout the whole year (8760 hours) compared with Generator 1 which operates for only 3650 hours in a year.

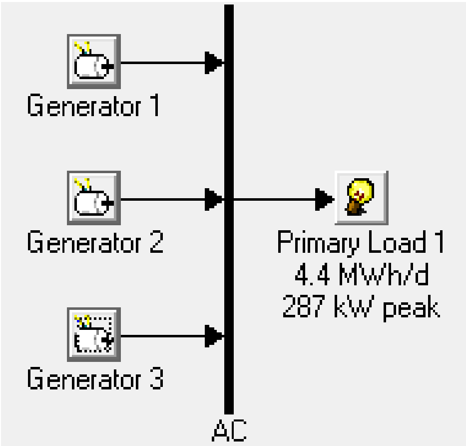


*Figure 4. Parallel configuration of the existing power system in Oodnadatta*

### 4.2 Hybrid power system

Figure 5 shows the model of the proposed hybrid power system integrating a PV array/inverter with the existing conventional power system. Here, the hybrid system has a parallel, DC coupling configuration, in contrast with the conventional power system which is also depicted in a parallel configuration but with an AC coupling.

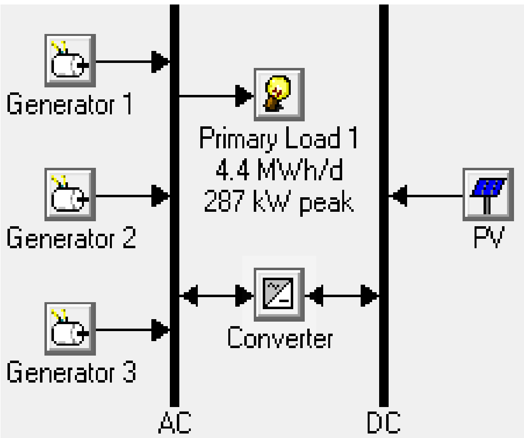


*Figure 5. Proposed addition of a PV module to the conventional power system*

Effects of photovoltaic (PV) system penetration on diesel (Figure 6) and propane (Figure 7) consumption and on levelised cost of electricity (COE) (Figure 8) were simulated to find the optimal PV penetration, which was determined at 14%.

Modelling the hybrid power system in HOMER required solar resource data, temperature data for a one year period as well as the technical specifications and cost data for the PV array and inverter. These data were required in addition to the data used to model the conventional power system.

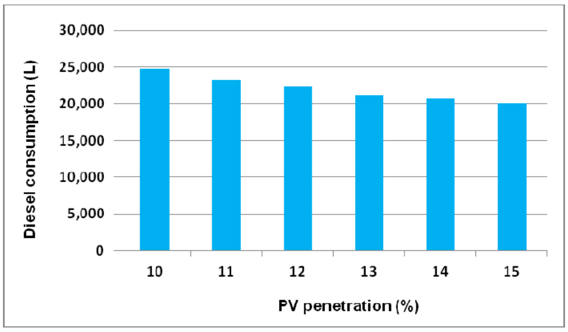


*Figure 6. Effect of PV penetration on the diesel consumption*

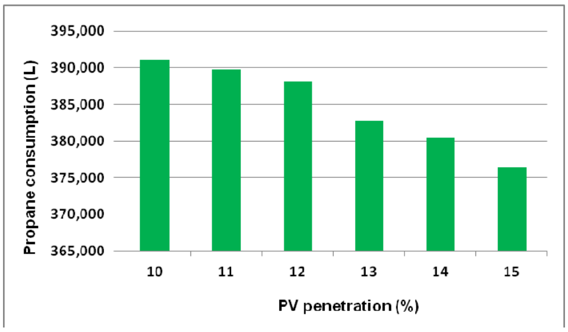


*Figure 7. Effect of PV penetration on the propane consumption*

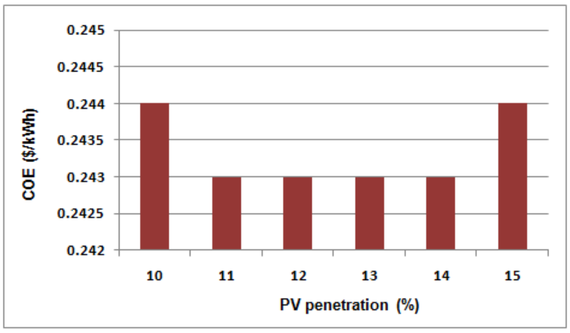


*Figure 8. Relationship between the COE and PV penetration*

Simulation results of the hybrid power system with the 95kW PV array and the 84kW inverter are shown in Table 1.

#### 4.2.1 Energy generation

The PV array produces 225MWh of energy per year, which is equivalent to 14% of the total energy produced by the hybrid power system. The energy contribution of Generator 1 is 8%.

*Table 1. Summary of the energy produced by each component of the hybrid power system in Oodnadatta*

| **Energy consumption** | **MWh/yr** |
|---|---|
| AC primary load | 1596 |
| **Energy production** | **MWh/yr** |
| PV array (95kW) | 225 |
| Generator 1 (185kW) | 91 |
| Generator 2 (185kW) | 0 |
| Generator 3 (240kW) | 1290 |
| Total energy produced | 1606 |

This is a 5% reduction in energy produced by the generator when compared with that in the conventional power system. The output of Generator 3 has also decreased. When part of the conventional power system, its output comprised 87% of the total energy produced while in the hybrid power system it produces 80% of the total energy.

Integrating the PV array with the conventional power system in Oodnadatta has reduced the operating hours of Generator 1 by 55% to 1644 hours/yr, leading to the same percentage reduction of its fuel consumption. The operating hours of Generator 3 have remained at 8760 hours per year; with fuel consumption reduced by 7%.

### 4.2.2 Economic Analysis

The cost of purchase of 538 PV modules and cost of their installation along with the inverter are a major component of the capital cost, constituting some 91% of the total cost. Considering replacement as well as operation and maintenance (O&M) costs the overall cost of the hybrid system has now increased beyond that of the hybrid system and the conventional system (13 % compared with 5 %).

A large proportion of the costs incurred are due to Generator 3. On the other hand, Generators 1 and 3 require less fuel to operate which has reduced the fuel cost by 16%. However, it still comprises a considerable share (78%) of the total net present cost (NPC), which decreased from AUD 5 million (conventional power system) to AUD 4.9 million (hybrid system).

The conventional power system has a total NPC of AUD 5,049,962 with a COE of AUD 0.247/kWh. These costs are incurred if the diesel and propane prices are AUD 1.45/litre and AUD 0.72/litre, respectively. Any increase in the prices will increase the COE. The increasing propane price has a significant impact on the COE compared with that of diesel. On average, a 5% hike in the propane and diesel prices increases the COE by 5% and 0.6%, respectively.

The total NPC over the lifetime of the hybrid power system is AUD 4,962,743. The COE is 0.243 (AUD/kWh), which is a 1.6% reduction from 0.247 (AUD/kWh). Increasing prices of diesel and propane also increase the COE. The rate of increase of the COE is about the same both for the conventional and hybrid power systems. Details of the influence of the fuel prices on COE are shown in Figures 7 and 8.

### 4.2.3 Annualised costs

The annualised operating costs of the hybrid power system are summarised in Table 2. Similar trends are observed between the total NPC and the annualised operating cost.

*Table 2. Components of annualised cost of hybrid power system*

| Component | Capital (AUD) | Replacement (AUD) | O & M (AUD) | Fuel (AUD) | Salvage (AUD) | Total (AUD) |
|---|---|---|---|---|---|---|
| PV array | 45,206 | 0 | 1,140 | 0 | 0 | 46,346 |
| Generator 1 | 0 | 1,590 | 937 | 29,988 | -477 | 32,039 |
| Generator 2 | 0 | 0 | 0 | 0 | -492 | -492 |
| Generator 3 | 0 | 22,421 | 4,993 | 273,914 | -51 | 301,278 |
| Inverter | 4,633 | 4,031 | 924 | 0 | -540 | 9,048 |
| System | 49,839 | 28,042 | 7,994 | 303,903 | -1,559 | 388,219 |

For instance, replacement cost and the O & M costs increase by 5% and 13% respectively when the PV array is integrated with the conventional power system. Furthermore, the fuel cost constitutes the bulk (78%) of the annualised operating cost.

### 4.2.4 Sensitivity analysis

Sensitivity analysis was performed to investigate the effect of the increasing diesel and propane prices on the COE.

Figure 7 depicts changes in the COE as the diesel price is increased (propane price is assumed constant at AUD 0.72/litre). The increasing diesel price has only a slight impact on the COE, for instance, an AUD 0.05 rise in the price increases the COE by 0.6%. This is due to the reduced operating hours of Generator 1.

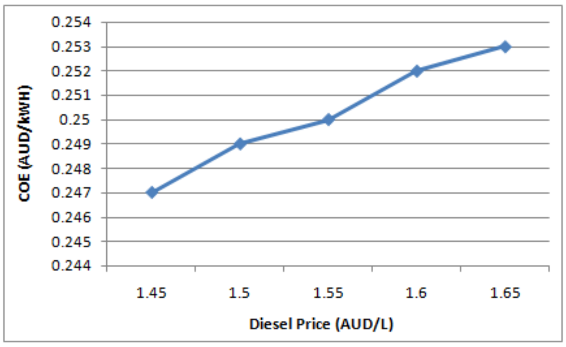


*Figure 7. Impact of diesel price on the COE*

The effect of the increasing price of propane on the COE is illustrated in Figure 8.

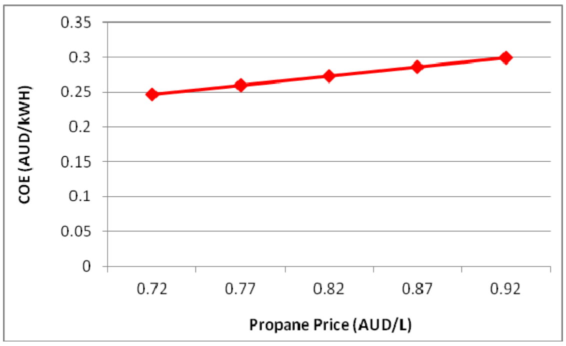


*Figure 8. Impact of the propane price on the COE*

As can be seen, the propane price has a considerable impact on the COE, largely due to the greater operating hours of Generator 3. A modest increase of AUD 0.05 in the propane price increases the COE by 5%.

Sensitivity analysis on the conventional power system produces similar results. Although the inclusion of the PV array decreases the overall COE, it has negligible impact on the rate at which the COE rises for increasing prices of diesel and propane.

### 4.2.5 Greenhouse gas emissions

The conventional power system emits 745,337 kg of carbon dioxide into the atmosphere on a yearly basis while the hybrid system emits 633,113kg/yr. This is a 15% reduction in the greenhouse gas emissions, largely due to the reduction in the fuel consumption of Generators 1 and 3. The greenhouse gas emissions of the conventional and hybrid power systems are listed in Table 3.

*Table 3. Comparison of the greenhouse gas emissions of the Conventional and Hybrid power systems*

| | **Conventional** | **Hybrid** |
|---|---|---|
| **Pollutant** | **Emissions (kg/yr)** | |
| Carbon dioxide | 745337 | 633113 |
| Carbon monoxide | 2967 | 2607 |
| Unburned hydrocarbons | 329 | 289 |
| Particulate matter | 224 | 197 |
| Sulfur dioxide | 1592 | 1360 |
| Nitrogen oxides | 26474 | 23265 |

## 5. Conlusions and recommendations

The remote town of Oodnadatta in SA consumes about 1.6GWh of energy per year. Currently the energy needs are being met by two of the three generators of a conventional power system. The 240kW propane generator operates for 8760 hours per year while the 185kW diesel generator is used for 3650 hours per annum. The third generator (185kW diesel) is for backup and is brought online only during times of excessive load demand or if one of the generators becomes unavailable due to scheduled maintenance or failure.

The power system has a total NPC of AUD 5,049,962 with a COE of 0.247AUD/kWh. These costs are incurred if the diesel and propane prices are AUD1.45/litre and AUD 0.72/litre, respectively. Any increase in the prices will increase the COE.

At this stage, the optimal solution for the proposed hybrid power system consists of a 95kW PV array (which equates to 538 modules) and an 84kW Sunny Tower inverter. The PV modules chosen for the system are 245W Trina modules. This combination produces 1,606MWh of energy per year. The solar contribution is 14% or 225MWh/yr. The two generators (240kW and 185kW) supply 86% of the energy. The 185kW generator operates for 1644 hours/yr, which is a 55% reduction in its operating hours compared to its usage in the conventional system. On the other hand, the operating hours of the 240kW generator do not change. Due to the reduced operating hours of the diesel generator, the hybrid power system consumes less fuel thus emitting 15% less carbon dioxide.

The solar radiation data collection needs to be extended over a longer period than the one used in this study, to better estimate the solar potential of the site.

Power consumption data logging has commenced in 2010 in Oodnadatta to obtain more accurate input data for modelling.

The effect of battery storage and the impact of higher levels of solar penetration (greater than 15%) also need further investigation.

## 8. References

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