Potential of Solar Energy Contribution in Queensland

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Abstract
The analysis aims at identifying the potential of solar energy, grid-connected photovoltaic (PV) and solar thermal, contributing covering day-time peak demands in Queensland (Qld) Australia. Given the high demand for air-conditioning and industrial activities, this study shows the ability of solar energy to satisfy those diurnal demands achieving a moderate load profile and improved economics at lower energy cost. Further more, the solar energy being located on site offers the advantage of avoiding transmission losses and voltage drops throughout the network. Life-time energy cost calculations for solar equipment indicate the ability of the solar system to provide competitive prices to cover demand peaks. The research incorporates grid-connected photovoltaic and evacuated tube solar water heaters in order to cover electrical and thermal loads respectively. The results quantify the power able to be waived by using solar systems in Qld.

Keywords:

Solar Energy, Electrical Energy Generation and Distribution, Evacuated Tubes Solar Water Heaters, Peak Demand, Photovoltaic, Solar Water Heaters,

Introduction

Electricity resources and infrastructure, a backbone of the contemporary human societies and economy, is currently undergoing major stresses due to constantly increased demand. Evident indications for those stresses are extreme peaks translated into high pikes in electrical energy prices. **Figure 1** shows a typical day energy price and demand in Queensland as reported by the Australian Energy Market Operator AEMO (2009). Main reasons for such piking demand can be easily referred back to increased energy consumption in several sectors implying full reliance on electricity in most to all of domestic usages, commercial activities and services.

According to the Energy Users association Australia (EUAA) in report EUAA (2005) pp10, rises in electricity prices are expected to occur due to continuously increased demand, reduced competition (merges and market power) and the need for major investments required for additional supply side infrastructure especially to meet rapidly growing peak demands. It states further, electricity consumers pay significant (and largely unseen) price for building sufficient electricity generation and networks to meet the short peaks in electricity demand, which can occur for only a relatively small number of hours a year. EUAA (2005) reports further on pp16: more than 5% of the network infrastructure is only used for 0.2% of the time and this under-utilised capital investment in the network is paid for by all consumers, whether they ever use it or not, due to the nature of retail energy contrasts and networks charges.

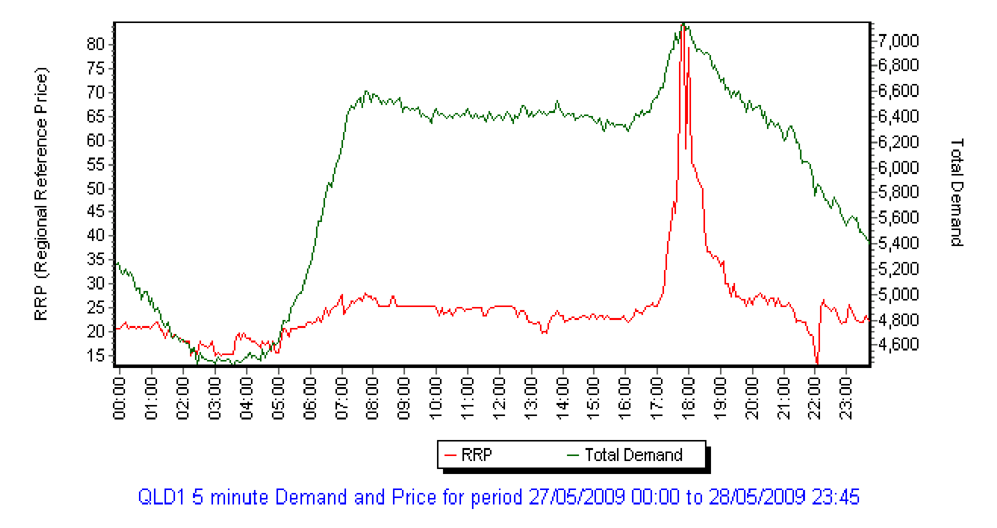


Figure 1 Demand and Price of Electricity for period 27/- 28/05/2009 in Queensland as reported by the Australian Energy Market Operator AEMO (2009).

Peak demands in Queensland, while recently slightly improving, likely due to implementing Demand Side Response DSR measures, yet still evidently manifesting in peculiar peak prices as shown in **Figure 2** extracted from Australian Energy Market Operator AEMO (2009).

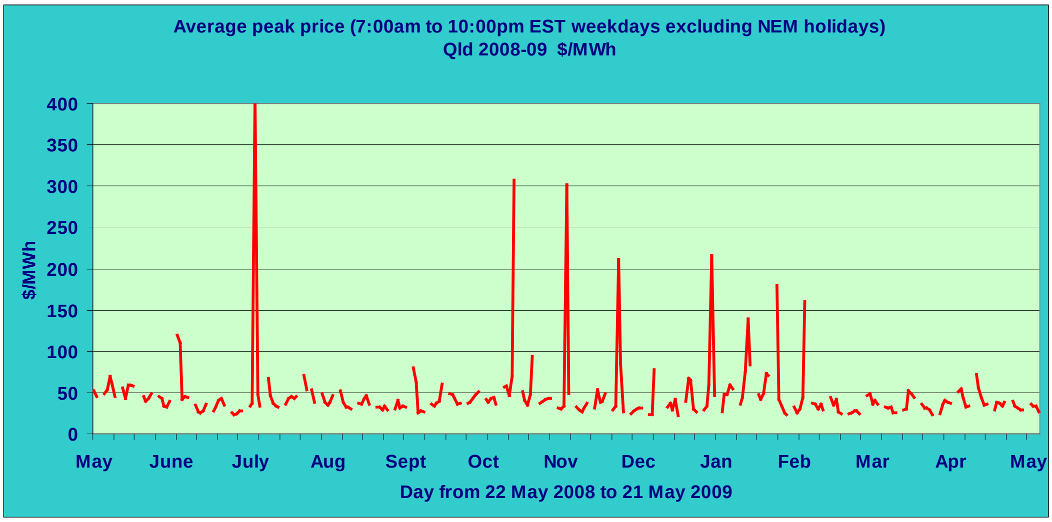


Figure 2 Fluctuation of Average regional peak price in Queensland, source Australian Energy Market Operator AEMO (2009).

Obviously, those stresses might be encountered by implementing well known energy-handling methods such as raising public awareness about the issue, demand side response DSR measures, utilization of diverse and on-site available renewable energy sources such as solar or wind energy, energy efficiency measures etc. A range of policy measures have been introduced to support the take-up and development of all renewable energy sources in Australia. Under a national Renewable Energy Target (RET), the government will require that 20 per cent of power generation comes from renewable energy sources as in RET (2009) pp. 5. In a report on National Energy Policy-Framework 2030 strategic directions paper the RET guarantees a market for renewable energy based on electricity generation using a mechanism of tradable renewable energy certificates. The government is also supporting renewable energy development through initiatives that complement the RET scheme by encouraging research, demonstration and commercialisation of renewable energy products.

Grid-connected photovoltaic generators can effectively provide users with adequate electricity at solar day times, while at night and solar-weak times the user is withdrawing electricity from the common distribution grid. Mills (2008) reported on photovoltaic power systems effective load carrying capacity (ELCC) as the amount of electricity PV can reliably supply as a proportion of its maximum output power. ELCC for PV is estimated to be 50-60% in Queensland. Mills (2008) reports further on economic impacts of PV embedded generation and residential air conditioning on electricity infrastructure, that I kW of air conditioning is estimated to impose a cost of $1,627 in infrastructure impacts, while 1 kW of PV is estimated to provide a benefit of $750 when installed in residential areas with an evening peak and $1,500 when installed in commercial and industrial areas with a mid-afternoon peak.

A danger persists in cases when using grid-connected photovoltaic systems, the valuable electrical energy generated from photovoltaic panels at efficiency around 15 % is likely to be utilized at end-user's side for heating purposes. In such cases, the use of solar energy gets totally out of a sustainable context. Therefore, it is strongly recommended, to consistently engage photovoltaic with solar water heating systems in order to cover thermal loads, to make photovoltaic systems devoted just to cover essential electrical loads like TV, lightings or computers.

Methodology

This research is analysing the contribution photovoltaic (PV) and solar water heaters (SWH) might offer to mitigate peak electrical demands. Those technologies can only achieve effective contribution with conscious electric energy users realizing the importance of a renewable-energy-assisted electrical system.

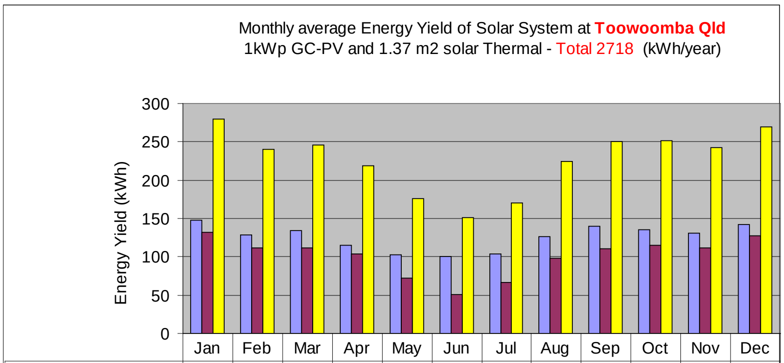
The research incorporates 1 kWp grid-connected photovoltaic and a 1.37 m^2 (aperture area) 120 litre-tank evacuated tube solar water heater to cover electrical and thermal loads respectively. As previously reported in other publications Fouad Kamel (2001), Fouad Kamel (2002;) and Fouad Kamel (2005) ETC-SWH systems can best be suited to provide thermal energy at quite elevated efficiency of 50–60 % at relatively high temperatures 80 – 90 °C . Life-time system cost analysis is used to demonstrate the ability of such a system to produce energy at competitive price and void large parts of electrical diurnal peak demands.

The study illustrates further the importance of the plant capacity factor (PCF) showing how that electrical generators operating at a PCF less than the unity (less than 8760 hour/year) are as a matter of fact producing quite expensive energy. With the solar energy replacing those generators at diurnal peaks it improves the economic performance of the entire system. Further on, the solar systems, being operated on or close to premises, are avoiding transmission and distributions cost and infrastructure.

Net Present Value, benefits and system life-cycle analysis

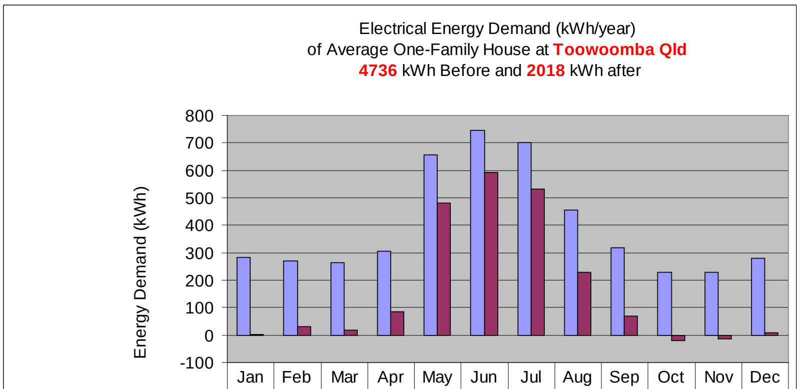
In a life-cycle analysis the study illustrates economic performance of a domestic solar system consisting of a 1 kW peak grid-connected photovoltaic (GC-PV) system feeding-in user's electrical loads and exporting excess electricity to the grid in addition to an evacuated tube collector (ETC) solar water heating system (SWH) covering hot water demand at the premises. Savings from the generated photovoltaic electricity and from the thermal energy produced by the SWH in kWh are deducted from total consumer energy demand and accounted to pay back the solar system. The small ETC 20-tube unit has a 1.37m^2 total aperture collector area fitted to a 120 litre water tank.

The study is based on operational data at Toowoomba Queensland at an average solar irradiation of 2008 kWh/m^{2}year. **Figure 3** shows the average monthly energy yield of the combined solar system. Impact of the installed combined solar system on energy consumption of an average domestic user is shown in **figure 4**.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GC-PV-ac (kWh)	147.2	128.3	134.3	115.0	102.6	100.0	103.3	125.9	140.0	135.6	131.2	142.0
Solar Thermal (kWh)	132.3	111.4	111.3	103.5	72.72	51.06	66.77	98.23	110.1	115.4	111.5	127.3
Total (kWh)	279.5	239.7	245.6	218.5	175.4	151.0	170.1	224.1	250.1	251.0	242.7	269.3

Figure 3. Average monthly Energy yield of the combined solar system.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand Before (kWh)	282	271	265	305	655	745	702	454	319	230	229	279
Demand After (kWh)	2	31	19	87	480	594	532	230	69	-21	-14	10

Figure 4. Electric energy savings from the PV-SWH combined solar system.

Figure 4 shows that such a simple solar system is able to strongly reduce electrical energy consumption of an average domestic user. The system is even able, in solar-rich months, to totally eliminate electrical withdrawal from the utility grid and rather to export excess energy to the electrical supplier.

Lifecycle analysis has been used here as described by Doane J.W. (1976) and by Mierzejewski (1998) to evaluate the payback time of the solar system. In this technique cost and benefits for each operational year are projected and then discounted back to the year of installation to obtain the "net present value NPV". Usually, as described by BOER (1978), the payback time is computed as the time at which first cost and annual expenses with compounded interest equal the total savings of energy cost with compounded interest. In the following the Net Present Value of Lifetime System Cost and Benefit will be calculated and compared. A lifecycle cost of zero represents a "break-even" investment, i.e. the system capital cost is exactly met by the savings or benefits generated over its lifetime.

Valid system initial capital cost has been used for this analysis as AUD$8,000 for the 1 kW peak grid-connected PV system and AUD$2,500 for the 1.37 m^2 120 litre tank evacuated tube solar heater. Following assumptions have been made to calculate the Net Present Value of Lifetime System Cost and Benefit: Interest rate 7% p.a., lifetime of the system 5-30 years, marginal tax bracket 0 % (no governmental subsidies), savings escalator 0.10, i.e. 10% p.a., operation, maintenance and insurance first year = 0.2% of invested capital and operation, maintenance and insurance increase = 5%/year.

Figure 5 show breakeven conditions, where the system is paying back the investment at a certain energy cost and system operating time. At market energy prices below that level the expected benefits are lower than the system cost and consequently, on just immediate economic considerations, the system might not be justified. At higher energy prices the economic benefits generated are higher than the incurred cost i.e. the system is paying back itself before the expected lifetime. The solar system at present market prices is able to produce energy at actual competitive prices. At 20 years life-time, for example, the system is producing energy at 15 cent/kWh equal $150/MWh. Comparing this cost with those in **Figure 2** indicate the system is already now able to economically cover peak loads (at peak prices); taking into account solar systems bought today shall produce energy at a constant price to the end of their life, while electricity prices are constantly rising. Solar systems, on the other hand, are saving electrical transmission and distribution costs and losses on the network.

Economic analysis and Plant Capacity Factor

The plant capacity factor (PCF) or the so also called utilization factor of a power plant is, by definition, the relation between the yearly electrical energy generated by the plant and the electrical energy generated in case the plant operates at its rated power for a full year time, Brinkmam (1980). The factor has a direct influence on the energy cost as can be deduced from the following equations of the fixed charge method according toDe-Meo (1978), Leonard (1977), Chobotov (1978) and Clorefeine (1980):

$$c_E = c_{tr}\ FCR / (T_o\ PCF) + c_{op} \qquad (1)$$

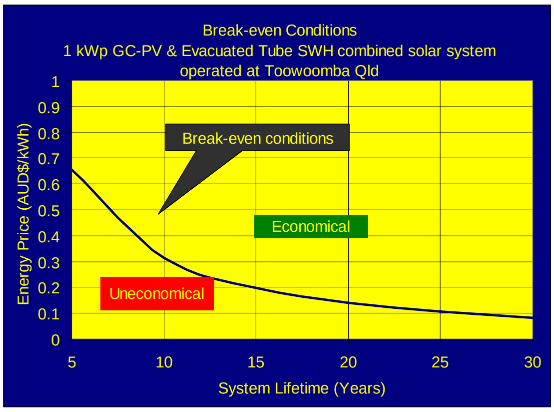


Figure 5. Break-even conditions of the 1 kW GC-PV operating alongside a 1.37m^2/120 Litre evacuated tube SWH system.

where c_E is the cost of energy generation, c_{tr} the cost of the installed power including taxes during the installation period, FCR fixed charge rate of the capital, normally 15…18% a year according to Leonard (1977) and Leonard (1978). T_o =8760 the hours per year, PCF plant capacity factor and c_{op} the operation and maintenance cost of the plant. For plants operating 24 hour/day, 7 days a week, i.e. 8760 hour/year PCF is a unity, which produces the least possible energy cost. For power stations operating for any less than 8760 hour/year the PCF will respectively be lower (below unity) what drives the cost of the produced energy to be accordingly higher.

Figure 6 shows the impact of the plant capacity factor on the cost of the produced energy. The calculation is made here on the basis of the cost of the installed power ctr = \$1000/kW, capital fixed charge rate FCR = 0.17 and the operation and maintenance cost of the plant c_{op} = \$0.02/kWh. It is evident that a power plant operated at low plant capacity factor e.g. PCF = 0.1 (this is 2.4 hour/day) will be producing energy \$150/MWh, while if operated continuously for 24 hour it will produce energy at a cost of \$25/MWh.

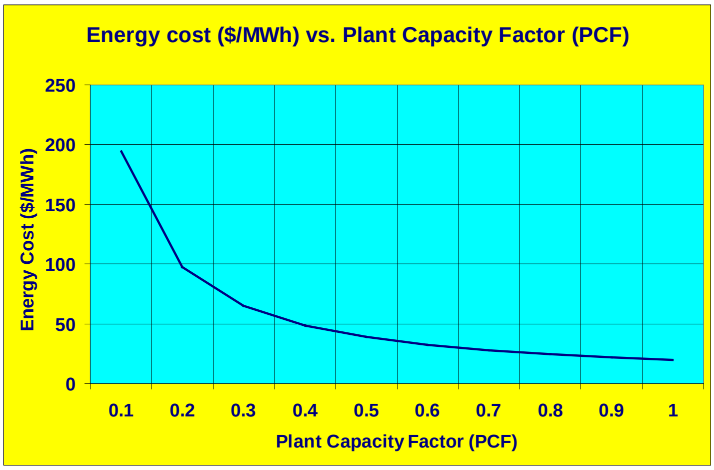


Figure 6 Impact of the plant capacity factor on the cost of the produced energy.

As typical daily load curves are in continuous changing, such as that in **Figure 7**, the generating capacity needs to cope with those changes. From a supply point of view, the ideal daily load curve would be a horizontal straight line, representing 8760 hour/year, as a power plant would be then operated at a plant capacity factor of unity.

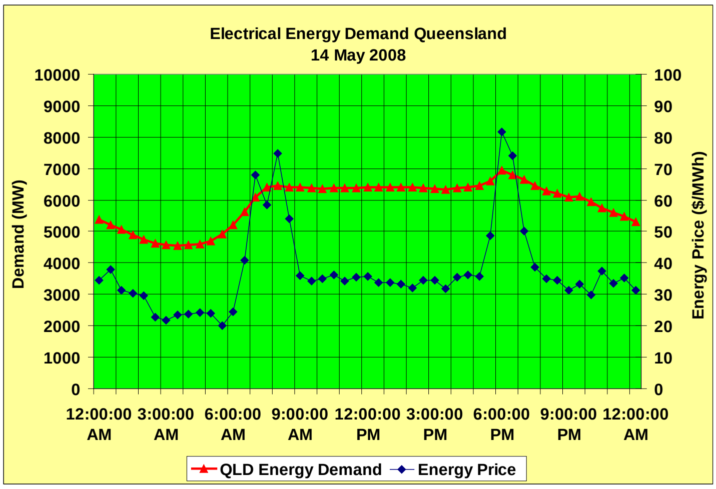


Figure 7 Typical daily load curves and fluctuating energy prices.

The solar system covering peak diurnal demand

The implementation of solar systems to cover electrical peak demands in all Queensland is simulated and represented in **Figure 8**. While the solar system is ought to be covering the diurnal peak, the base load of 4100 MW (of the year 2008) is left to be covered by base-load power stations. Those are operating whole year through at a capacity factor of 1 and are providing best operating conditions.

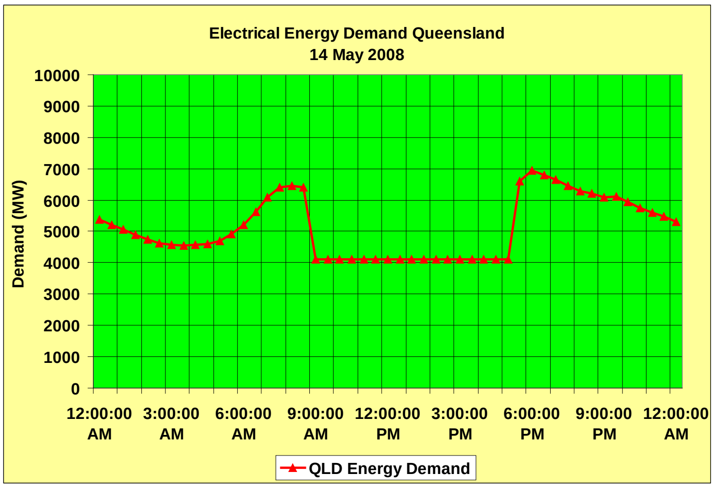
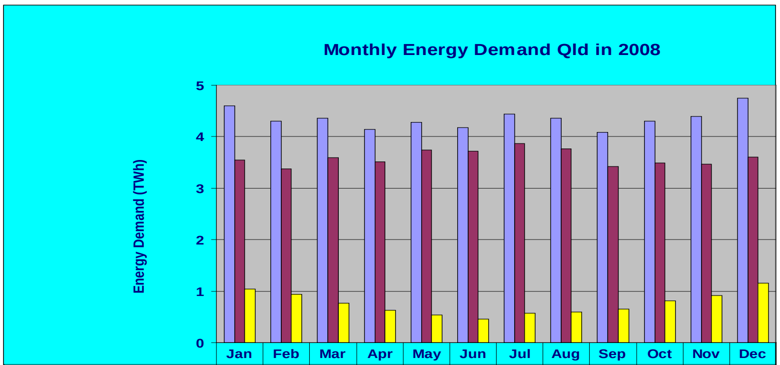


Figure 8. Implementation of solar systems to cover peak demands in all Queensland.

Figure 9 and 10 show quantitatively the amount of contribution solar systems might make by covering diurnal electrical peak demand. From a total of 52.18 TWh/year 2008 the solar energy is able to provide 9.07 TWh; a percentage of 17.4%.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand as is (TWh)	4.60	4.31	4.36	4.14	4.27	4.17	4.44	4.36	4.08	4.31	4.39	4.75
Demand using solar (TWh)	3.55	3.37	3.60	3.51	3.74	3.72	3.87	3.76	3.43	3.49	3.47	3.60
Solar Contribution (TWh)	1.05	0.93	0.77	0.63	0.54	0.46	0.57	0.60	0.66	0.81	0.92	1.15

Figure 9. Possible savings achieved by solar energy covering diurnal electrical peak demand.

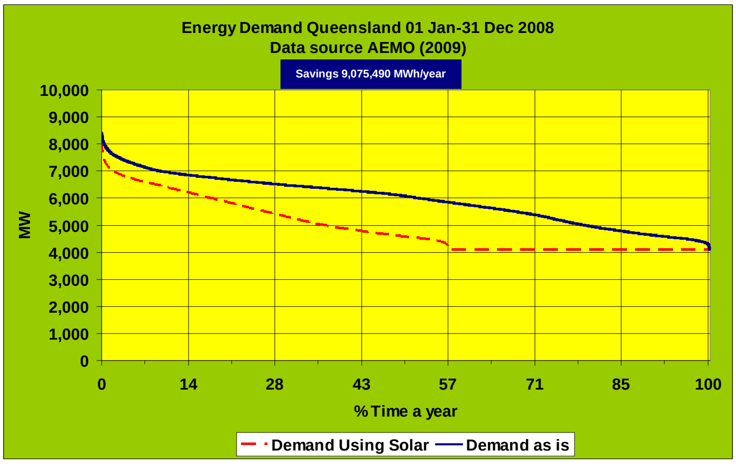


Figure 10 Solar energy contributing fully covering diurnal electrical peak demand in Queensland.

Discussion

A look at the AEMO peak demand prices in **Figure 3** show an average of AUD$30-50./MWh (3-5 ¢/kWh) wholesale price. Peaks at times are exceeding AUD$300-400/MWh (30-40 ¢/kWh). Following historical reports indicating energy prices incidents of as high as AUD$6,622/MWh ($6.6/kWh) AEMO (2009). The solar system in consideration shows an energy price of about ¢15/kWh ($150/MWh) in **Figure 5** is able to cover peaks occurring at prices of $200-400/MWh. Base load is left to be covered by low-cost power plants throughout the year, since those are producing the most economic operation.

Conclusions

The analysis presented in this paper for a combined solar installation including a grid-connected photovoltaic (GC-PV) system associated with a solar water heater shows such a system presenting realizable economic benefits. The calculations demonstrate that the system is today already providing competing energy prices able to cover diurnal peaks. Further on the system, being installed on user's premises is saving transmission and distribution costs.

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Brief Biography of Presenter

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