Solar Energy to Mitigate Electrical Diurnal Peak Demand in Queensland

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Abstract

This research is handling the contribution photovoltaic (PV) and solar water heaters (SWH) might offer to mitigate peak electrical demands in Queensland. Given, heavy electricity peak demands manifested in strong electricity price fluctuations, with a range from \$20/MWh to more than \$2000/MWh for short period, it is generally accepted that electricity peak demand must be satisfied at a particularly elevated energy cost. High demand in Queensland for air-conditioning and industrial activities makes solar energy contribution not only viable, but also economical. Besides covering demand peaks, the solar system – being located on site – offers the advantage of avoiding transmission losses and voltage drops throughout the network. Life-time cost calculations for solar kWh indicate the ability of the solar system to provide competitive prices to cover demand peaks. The project incorporates a 1kW (peak-power) grid-connected photovoltaic and a 1.37m^2 (collector area) -120Litre (storage tank) evacuated tube solar water heater SWH unit. 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, 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 peak demands translated into high spikes in electrical energy prices. Main reasons for those spikes can be easily referred back to increased energy demand in several sectors implying full reliance on electricity in most to all of human needs especially in domestic usages. **Figure 1** shows a typical day energy price and demand in Queensland and **Figure 2 and 3**; show average reference and peak price of electricity in Queensland 2008-09; data extracted from the Australian Energy Market Operator AEMO (2009).

EUAA (2005) pp16 is describing electricity consumers pay significant (and largely unseen) price for building sufficient electricity generation and networks to meet the short demand peaks, which can occur for only a relatively small number of hours a year. 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 and networks charges.

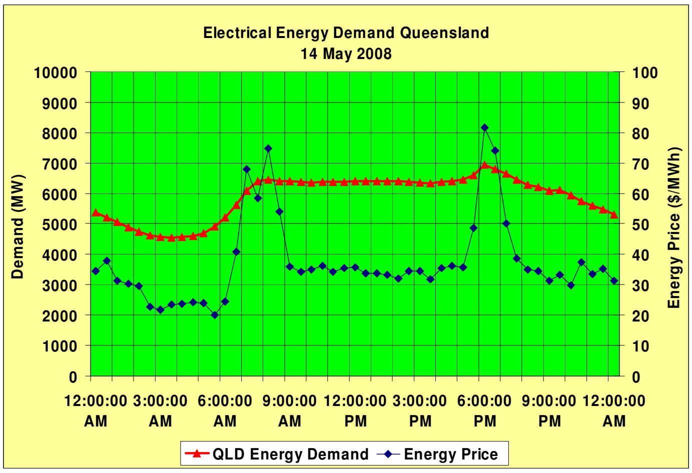


Figure 1 Demand and Price of Electricity for Queensland on14 May 2009; data extracted from the Australian Energy Market Operator AEMO (2009).

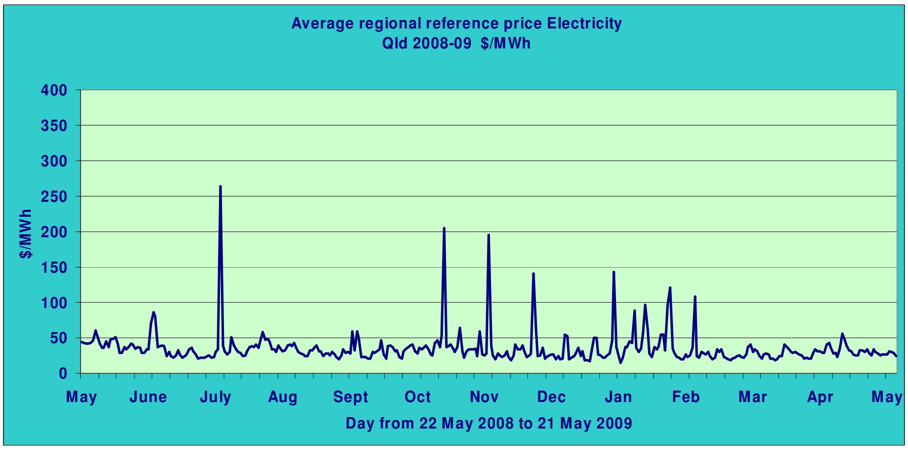


Figure 2 Fluctuation of Average regional reference price in Queensland, source: The Australian Energy Market Operator AEMO (2009)

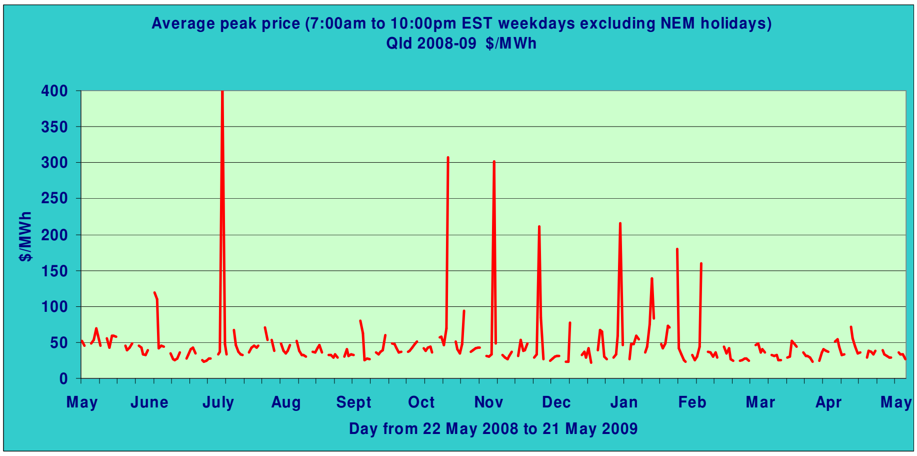


Figure 3 Fluctuation of Average regional peak price in Queensland, source: The Australian Energy Market Operator AEMO (2009).

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 reported in RET (2009) pp. 5 and in pp.6 “Australia has committed to reducing greenhouse gas emissions by 60 per cent from 2000 levels by 2050 and to meeting a medium-term national target to reduce emissions by between 5 per cent and 15 per cent below 2000 levels by the end of 2020”.

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

Solar energy technologies used

The research incorporates 1 kWp grid-connected photovoltaic and a 1.37 m^2 (aperture area) 120 litre-tank evacuated tube collector (ETC) solar water heater for supplying user’s electrical and thermal loads respectively. The small ETC 20-tube unit has a 1.37m^2 total aperture collector area fitted to a 120 litre water tank.

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. And in Mills (2008) reported 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.

Solar Water Heating systems are efficiently capable of providing economically and environmentally viable and sustainable thermal energy. For the purpose of this research Evacuated-Tube Collector (ETC) Solar Water Heaters (SWH) are chosen to tackle thermal loads for domestic and industrial applications. As previously reported in other publications Kamel (2001), Kamel (2002;) and Kamel (2005) ETC-SWH systems can be best suited to provide thermal energy at quite elevated efficiency of 50–60 % at relatively high temperatures 80 – 90 °C .

Why combining photovoltaic systems with solar water heaters?

Basic energy knowledge is indicating that whenever thermal energy is needed the best is to be provided directly from a prime energy source, e.g. thermal solar. In such cases reasonable conversion efficiency e.g. 30-60% could be achieved.

Electricity on the other side is considered a high-grade and expensive energy source because, when produced from fossil fuels for example, it is usually accomplished at an end efficiency of around 30%, and then it get transmitted and distributed at a further 80% to reach the user at a final efficiency of 30 x 80 % ≅ 24 %. This means it has already lost at least 76 % of the original value to reach the user in electric form instead of the thermal form. Now to transform it back again into heat at the best efficiency of 50-60 % makes the final transforming efficiency from heat back to heat of 24 x 50 % = 12.5 %. This means, throwing away around 87.5 % of the prime energy source such as petrol or coal. In other terms, the well economically and environmentally expensive oil get used at 12.5 % usage while 87.5 % get thrown away in form of thermal waste, just heating the already suffering environment.

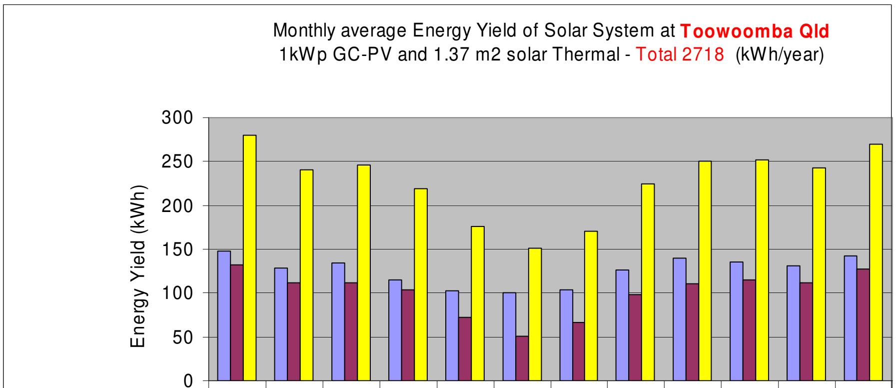
A danger persists in cases when using grid-connected photovoltaic systems, that the valuable electrical energy generated from photovoltaic panels at efficiency around 15 % is likely to be utilized at end-user's side for heating purposes. In such cases, the use of solar energy gets totally out of a sustainable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

Economic analysis

The analysis describes the economic performance of a domestic solar energy system consisting of photovoltaic and a solar water heating devices in a life-cycle analysis. 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 study is based on operational data at Toowoomba Queensland at an average solar irradiation of 2008 kWh/m^{2}year. **Figure 4** 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 5**. The contribution made by the PV system added to that of the solar thermal system results in the total reduction in the energy demand from the utility grid.

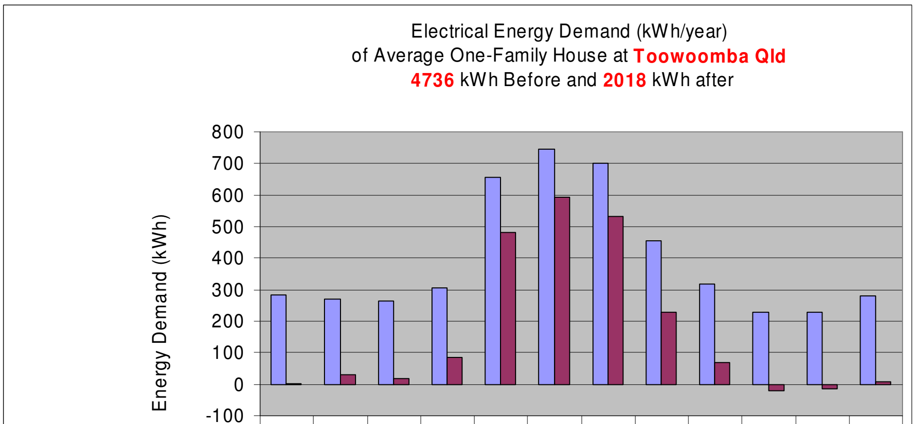
Figure 5 shows that such a simple solar system is able to strongly reduce electrical energy consumption of an average domestic user. The system is even able, in solar-rich months, to totally eliminate electrical withdrawal from the utility grid and rather to export excess energy to the electrical supplier.

Lifecycle analysis has been used here as described by Doane (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. Break-even conditions are satisfied when the system capital investment is exactly met by the savings or benefits generated over system lifetime.



	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 4 Average monthly Energy yield of the GC-PV-SWH 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 5 Electric energy savings from the GC-PV-SWH combined solar system.

Market-available system 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.

Figures 6 show breakeven conditions of the solar system under three different conditions: 1) the photovoltaic grid connected unit alone, 2) the solar system GC-PV and SWH combined, and 3) the solar water heater system alone. The analysis shows 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. More details on such analysis are reported by Kamel (2001), Kamel (2002) and Kamel (2003).

The analysis demonstrates e.g. that the PV-SWH system at present market conditions is able to produce energy at actual competitive prices of 20, 14, 10 and 8 cent/kWh at 15, 20, 25 and 30 years life-time respectively. This corresponds to 200, 140, 100 and 80 $/MWh. Comparing those solar energy cost with AEMO electricity prices on **Figures 1, 2 and 3** indicate the system is already now able to economically cover peak loads (at peak prices) at competitive prices. Furthermore, systems bought today shall produce energy at a constant price to the end of their life, while electricity prices are constantly rising. Saving electrical transmission and distribution losses happening on the conventional network and offering more energy supply security, solar energy is thus representing convincing option to cover peak diurnal demands.

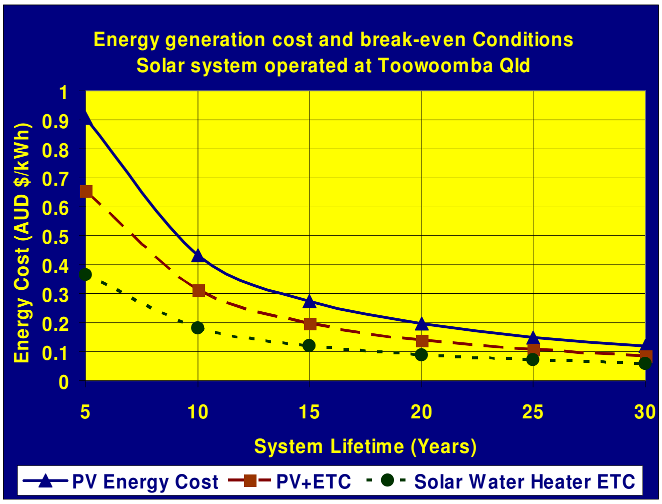


Figure 6 Energy generation cost and break-even conditions of the 1 kW GC-PV system and the evacuated tube SWH system.

The solar system covering peak diurnal demand

This work presents a simulation of electrical demand of the 14th May 2008 in Queensland (**Figure 1**) with solar energy covering diurnal peaks above a base load of 4100 MW (for the year 2008). Base load is left to be covered by conventional power stations operating throughout the year at a capacity factor of unity providing best economic operating conditions at least possible energy price. A graph of the simulation is presented in **Figure 7**.

Discussion

A look at the AEMO peak demand prices in **Figure 3** shows an average of around AUD $40/MWh (4 ¢/kWh) wholesale price (transmission and distribution cost not yet included); peaks at times are exceeding AUD $400/MWh (40 ¢/kWh). Historical reports are indicating energy prices incidents of as high as AUD $6,622/MWh (¢660/kWh) NEMMCO (2008). The solar system in consideration shows ability to provide energy price at end-user premises of ¢14/kWh ($140/MWh) (**Figure 6)** for 20 years life-time. This provides evidence that solar systems composed of photovoltaic grid-connected and solar water heating units are today already able to cover diurnal peak demands, particularly those above the base-load. Base load is left to be covered by low-cost power plants throughout the year, since those are producing the most economic operation.

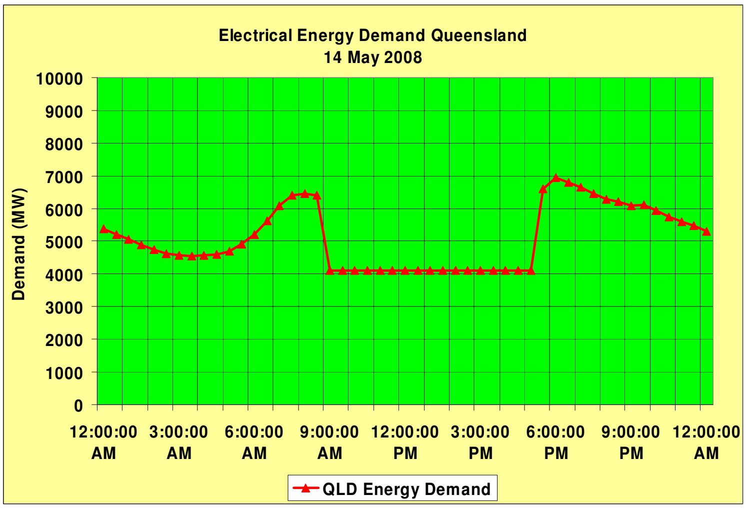
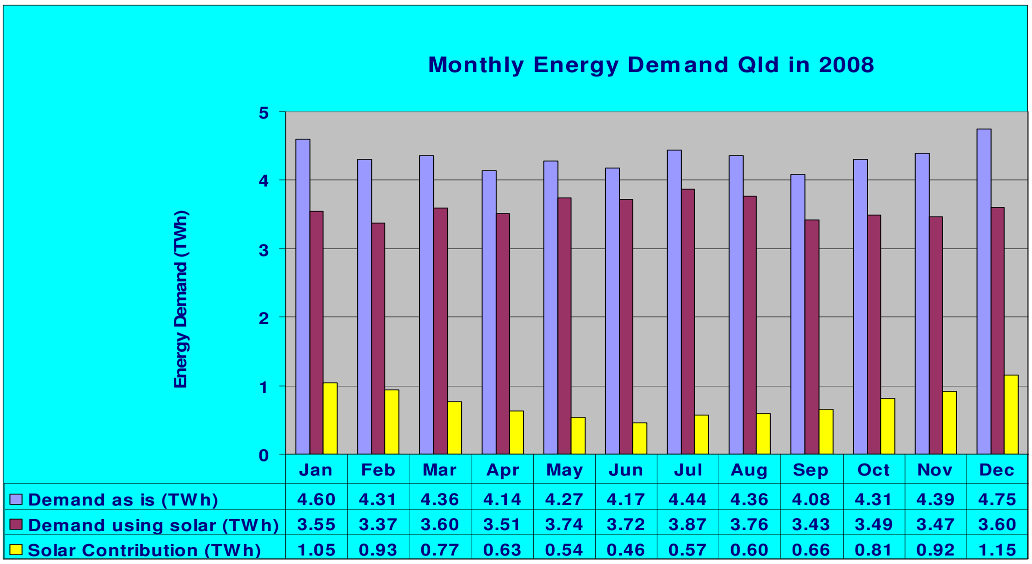


Figure 7 Implementation of solar systems to cover peak demands in all Queensland.

Figure 8 and 9 are showing quantitatively the amount of contribution solar systems might make by covering diurnal electrical peaks. 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 8 Possible savings achieved by solar energy covering diurnal electrical peak demand.

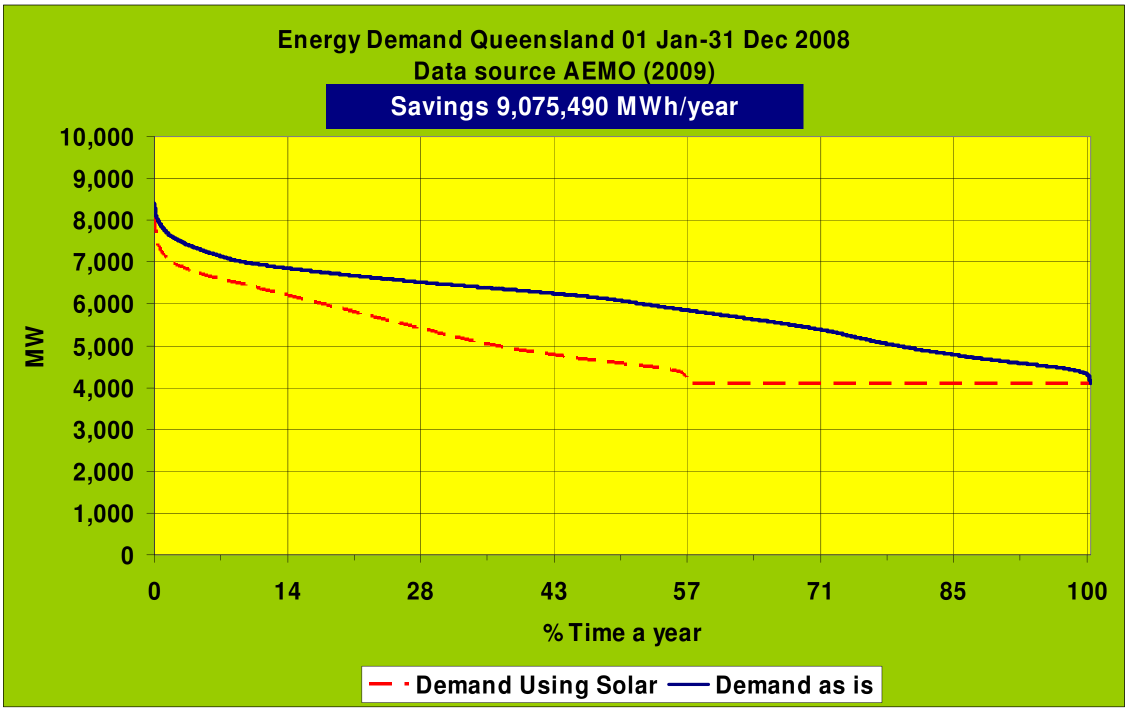


Figure 9 Solar energy contributing covering diurnal electrical peak demand in Queensland.

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 and the ability to cover diurnal electrical peak demands at competitive prices. From a total of 52.18 TWh of electricity in 2008 the solar energy is able to provide 9.07 TWh; a percentage of 17.4%. Further on the system, being installed on user's premises is saving transmission and distribution costs, besides offering a long-term energy supply security.

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Brief Biography of Presenter

Dr. Fouad Kamel is a senior lecturer at the University of Southern Queensland in Toowoomba, Faculty of Engineering and Surveying, Department of Electrical and Computer Engineering since February 2008. Graduated Diploma Engineer and PhD in photovoltaic systems from Hanover University in Germany 1984, Dr. Fouad worked as a lecturer and associate professor at the Suez Canal University in Egypt during 1985-1999. In 1999 he moved to New Zealand and worked there between 2000 and 2007 for tertiary education and research at Christchurch Polytechnic Institute of Technology and the Southern Institute of Technology. Dr. Kamel has more than 40 publications in different subjects of electrical engineering and energy. Fields of interest: Smart Grids, Renewable Energy, Photovoltaic, Wind Energy Generation, Hydrogen Production and Utilization, Fuel Cells, Wave and Tidal Energy Generation, Solar Heating Systems, Thermally activated Chillers, Engineering and Education.