Solar Power Supply to Mitigate the Diurnal and Seasonal Electricity Demand in Victoria

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ABSTRACT

This study aims at estimating the effect of solar power supply on the diurnal and seasonal electricity demand of the state of Victoria in Australia. There have been studies on the mitigating effect of solar power on the diurnal peak demand of electricity. Many of them are based on upscaling the net energy demand for a typical single house adopting grid-connected Photovoltaic (PV) technology. This work takes a different approach: it compares half-hourly solar power yield with Victoria's electricity demand over time; it focuses on centralised solar power generators (big PV or solar thermal generators) rather than distributed PV on house roofs; and it considers the impact of the solar power supply on the state-wide demand of electricity rather than on the individual home demand. The Australian Government has selected in May 2010 eight electricity generation and construction companies to participate in feasibility studies for centralised solar photovoltaic and solar thermal technologies to generate up to 150-250 MW electricity power. This adds timeliness and relevance to the study.

In the study we assume a future scenario that Victoria's solar power generators are able to supply up to 4500MW electrical maximum in day time, and that Victoria's base load demand (day and night) is supplied by conventional base load generators. We then match the Victorian daytime demand profile with the corresponding instant solar power supply profile. At anytime the outstanding demand will be supplied by other peak load and intermediate load generators; and the leftover solar energy will be stored away. The study provides a qualitative analysis of the impact of such arrangements on the peak demands and prices. The analysis demonstrates that matching the daytime demand profile with the corresponding instant solar power supply profile may help reducing peak demands and their prices. Further discussions argue that, when the cost of solar energy generation is not cheap enough to compete with fossil fuel generators, such arrangement can be achieved by delivering solar power as a non-scheduled energy source.

The study is based on a solar power generation model in CSIRO's NEMSIM electricity demand model (Grozev et al. 2005) and AEMO's electricity demand data of Victoria (AEMO 2010)

Keywords – Peak demand, solar power supply, bid stack, smart grid

Introduction

ABARE (2010) reports that Australia's solar power generation has a very low uptake base, but is expected to grow at an average annual rate of 17% from 2007 to 2030. Currently solar power generation in Australia is almost entirely sourced from distributed photovoltaic (PV) installations, but interest in centralised solar technology systems for large scale electricity generation (both solar thermal and PV) is increasing. In May 2010, the Australian Government (2010) selected eight electricity generation and construction companies to participate in feasibility studies for centralised solar photovoltaic and solar thermal technologies to generate up to 150-250 MW electricity power each.

The strength of solar technology is that it generates electricity while producing very low levels of greenhouse-gas emission. It is a key technology for mitigating climate change (IEA 2010a). However, a full implementation of solar energy technology is not easy. It requires R&D efforts, planning and policy development to increase the market penetration of solar technology for electricity generation. And the market acceptance requires a holistic uptake of smart grid technologies, power storage and further improvements in high quality product components along the manufacturing supply chain (IEA 2010b).

This study aims at estimating the effect of solar power supply on the diurnal and seasonal electricity demand of the state of Victoria in Australia. There have been studies on the mitigating effect of solar power on the diurnal peak demand of electricity, e.g. Kamel (2009). However many of them are based on upscaling the net energy demand for a typical single house adopting grid-connected PV technology. This work takes a different approach: it compares half-hourly solar power yield with Victoria's electricity demand over time; it focuses on centralised solar power generators (big PV or solar thermal generators) rather than distributed PV on house roofs; and it considers the impact of the solar power supply on the state-wide demand of electricity rather than on the individual home demand.

The demand and supply profiles in Victoria

Demand for electricity in Victoria grows as investment and population rise. It is further pushed along in short term events such as heat spells and bush fires. The times for peak demand of electricity are hot days, and during daylight hours. During these times the electricity distributor has to buy electricity from every power generator available, including the much more expensive electricity from diesel generators. Fig. 1 shows the Victorian electricity demands and prices of the year 2009 (AEMO 2010). During the hot summer time in early 2009, high temperature caused simultaneously high electricity demand and network system failures in a short span of time. As a result the electricity prices shot up for hours in a shot span of a few days time.

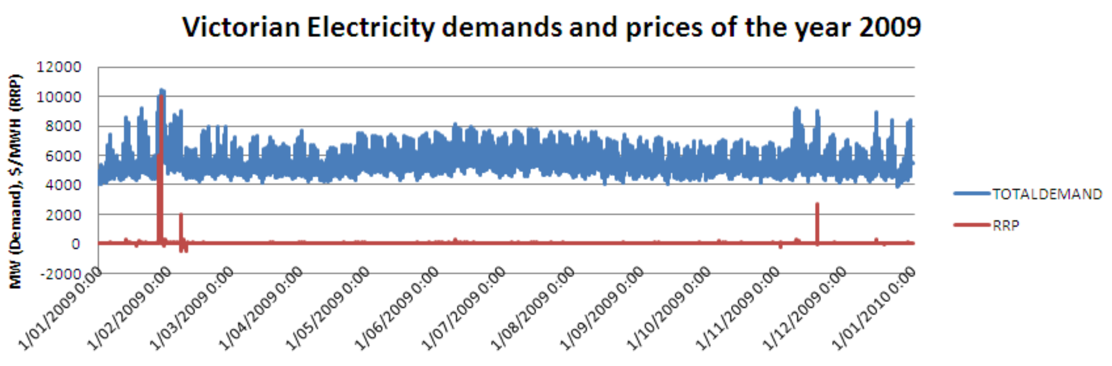


Fig. 1: Victorian electricity demands (MW) and Regional Reference Prices (RRP in $/MWh) of the year 2009.

Fig. 2 shows the daily demand of a summer and winter day in Victoria. A summer day has a peak demand at about the hour of 4:00pm; whereas in a winter day, there are morning and evening peaks which coincide with the usage pattern of households. The same diagram illustrates the three different types of supply: base load power, intermediate load power and peak load power.

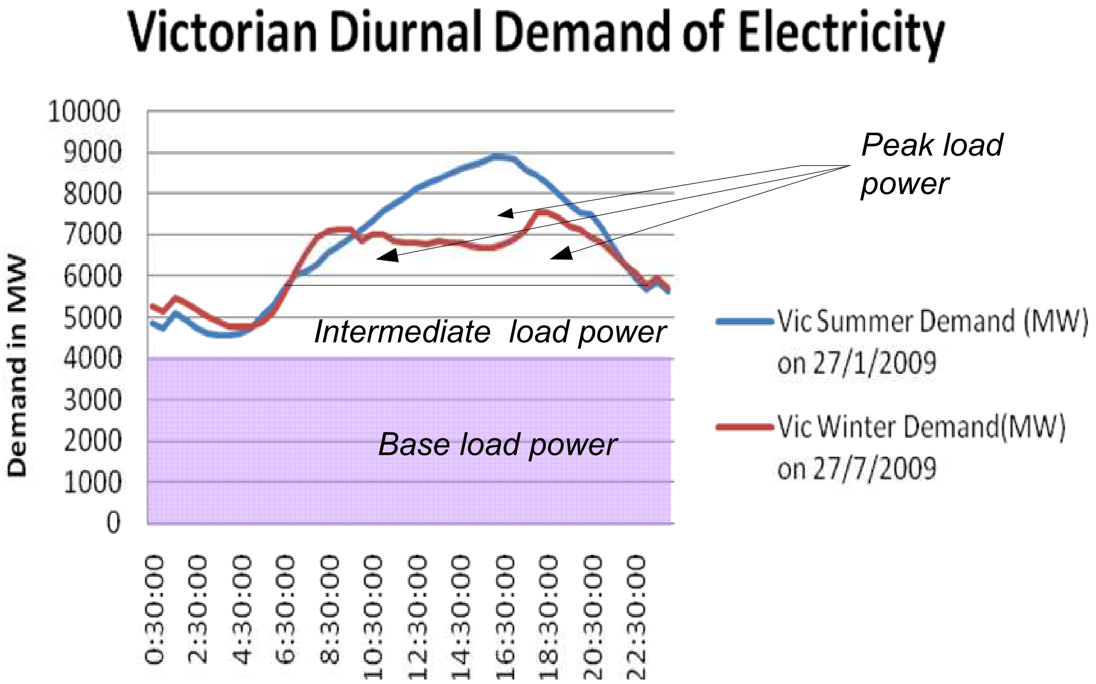


Fig. 2 Daily power demand and supply in typical summer and winter weekdays.

Base load power plants produce continuous, reliable and efficient power at low cost. They take a long time to start up and may not be efficient at less than full output. Base load plants run all times through the year except in the times for scheduled and non-scheduled maintenance. They are excellent candidates for long term agreements to provide stable power at attractive prices. Base load power plants include coal facilities. Geothermal and hydro plants can be used as base load using renewable energy sources.

Electricity demand fluctuates over the hours of a day, and there are weekly and seasonal variations. To meet the changing demand for power, peak load and intermediate load power plants come into play.

Peak load power plants specialise in providing power during peak system demand periods. They can be started up quickly and vary the output amount in minutes. Peak plants typically operate 10-15% of the time and are smaller in capacity than base load plants. They are expensive to run, given the amount of electricity they produce and the cost of fuel to power them. However they are less expensive to build because of their relatively small sizes. Peak plants are most often run on natural gas, but some are on light oil.

Intermediate load plants fill the gap between the base load and peak load plants. They run typically 30-60% of the time. Their costs of construction are considered to be higher than peak load plants but lower than base load plants.

Solar energy can be considered as an intermediate or sometimes peak load power source. It is intermittent in nature as its output fluctuates with weather patterns. It may not be suitable for use as a constant base load power. With suitable backup systems, solar power can be called in to dispatch intermediate or peak load power to reduce the demand for fossil fuels (Cordaro 2008).

High electricity demand events

Fig. 3 shows the daily peak demand for the few days 27-30 January 2009 when extreme heat occurred in Victoria just before the deadly Black Saturday Bushfire 7 February, 2009. NEM regions, in particular South Australia, Victoria and Tasmania, saw significant energy spot price fluctuations from trading interval 13:00hrs on 28 January

2009 to trading interval 18:00hrs on 30 January 2009. On 29 January, RRP spiked to the max allowable amount at the time of $10000.

The main contributor to the high energy prices in Victoria was high temperatures in excess of 40˚C in Melbourne between 28 and 31January 2009. This drove the demand to a record maximum of 10,494MW in Victoria on 29 January 2009 when temperatures peaked above 43˚C. The energy price in Victoria was manually set to $10000/MWh from 12:40hrs to 15:20hrs on 29 January 2009 when a Lack Of Resource (LOR) 3 condition was declared and instructions for load shedding were issued. This initial shedding of load in Victoria was large enough to relieve the shortage of supply. On 30 January 2009, an LOR 3 condition was again declared in Victoria. The energy prices in Victoria were capped at $300/MWh during the Administered Price Period on the day (AEMO 2009). Between dispatch interval 17:45hrs and 17:55hrs on 30 January 2009, the Victorian energy price collapsed to the administered price floor of -$300/MWh when 1200MW of load was shed from the western side of Melbourne.

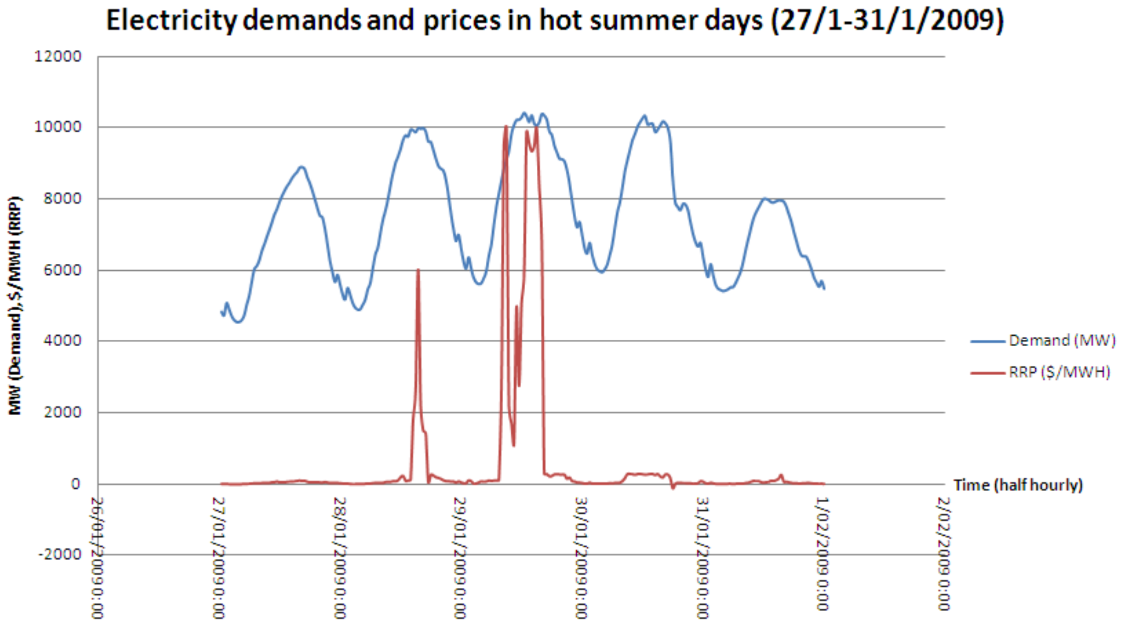


Fig. 3: Demand and peak demand prices in three hot summer days in Victoria in 2009.

Fig. 4 shows the 5-minute bid stack of the Victorian generators during the days 28-31 January 2009 (AEMO 2009). The chart displays the total capacity of electricity available during the peak demand period. The chart shows that there were times when Victoria's maximum capacity of electricity generation was reached.

In electricity grids, the demand for electricity is highly concentrated to the top 1 percent of hours (1 year = 8760 hours). According to Faruqui et al. (2007), in most part of the U.S., the top 1 % accounts for roughly 8-12% of the peak demand. In the Canadian province of Ontario, of 8,760 hours in all of 2006, peak electricity demand in the province only surpassed 25000 megawatts for 32 hours (0.37% of the total hours in a year). We currently do not have the corresponding Australian figures, but believe that the demand for electricity is also highly concentrated to the top 1 percent of hours.

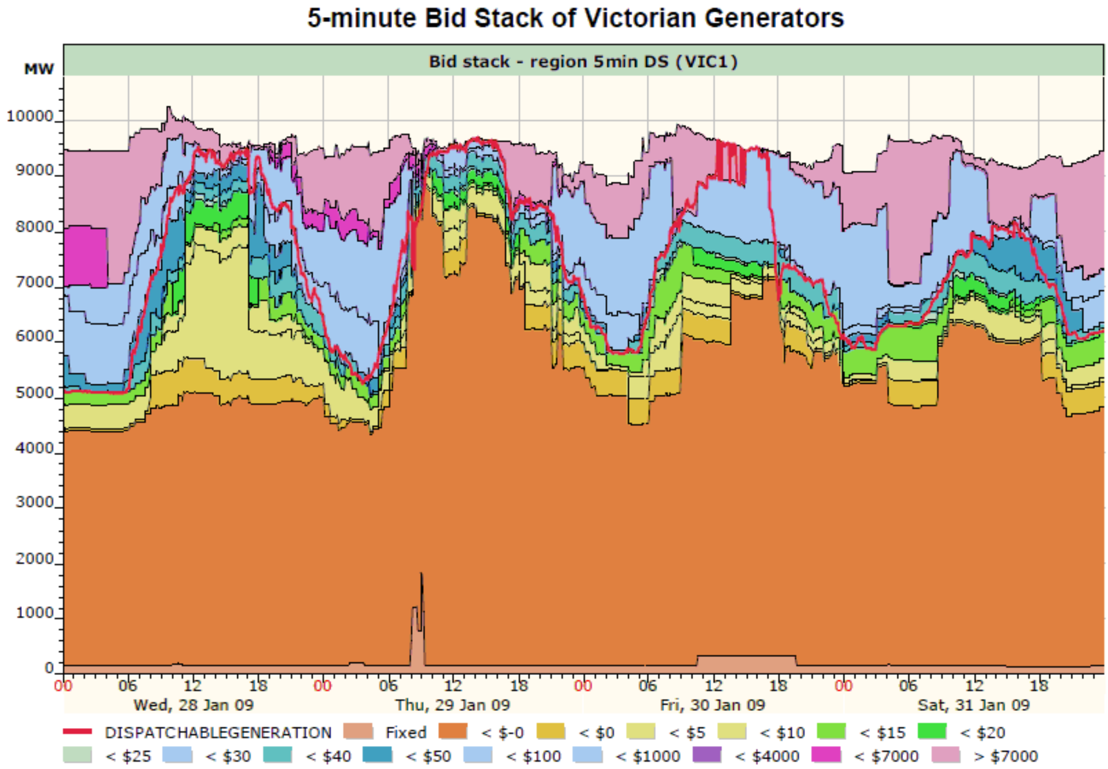


Fig. 4:5-minute bid stack and dispatch of Victorian generators on 28-31 January 2009 (AEMO 2009).

Matching demand profile with solar power generation profile

Currently the uptake of centralised solar technology is only at its embryonic stage. The major reason is the cost and the technology is not yet mature for industrial production. However, the cost of solar power relative to fossil fuel based technology will decrease over time because of (a) government incentive of developing renewable source of energy (carbon tax etc.), and (b) technological advancement of solar power. The Australian weather is generally hot, dry and sunny. In the longer term solar power will play a critical part of renewable energy supply.

Two rationales make the supply of solar power worthwhile. First, solar energy is a type of renewable energy source, the use of which helps reducing fossil fuel burning. Second, the bulk of human social and economic activities happen in daylight time, and as a result of this, the solar power supply profile roughly matches the electricity demand profile in daylight time.

In the research of this paper, we hypothesise that by matching demand profile with solar power generation profile, the outstanding peak demand will be reduced; lack of resource will be less likely to occur; and the electricity bidding prices are less likely to spike.

Let us assume a future scenario (Fig. 5) that the base load, up to 4500MW, is supplied by conventional power plants at both day and night times, and that the solar power plants are big enough to generate 4500 MW for the day light time only.

The theoretical estimation of solar power output in Fig. 5 is devoid of any atmospheric influence. This is a good approximation for a dry and sunny area like Mildura in Victoria. As a rule of thumb, 1km^2 of PVs or heliostats can generate about 100MW electrical (MWe) of electricity power; so 4500 MWe of solar powers will take up about 45km^2 of PV or heliostats. As shown in the figure, solar power supplies about two third of the daylight demand. The oustanding demand (vertically shaded sections in Fig. 5) will be met with other peak load and/or intermediate load supplies.

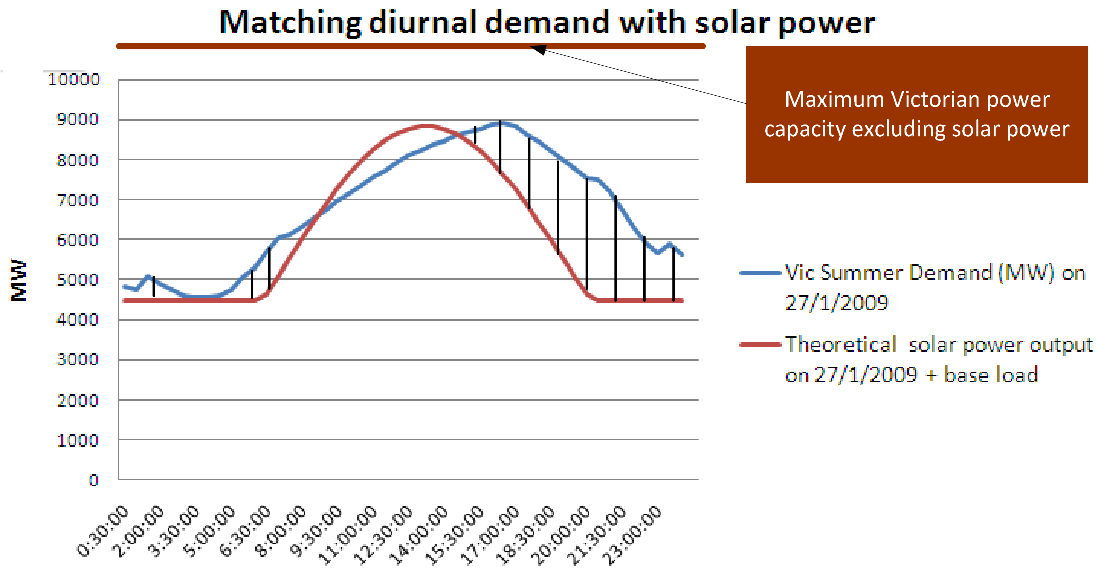


Fig. 5: Matching diurnal demand with solar power.

We also assume that the introduction of solar power in Victoria has not reduced Victoria's maximum power capacity excluding solar power. The assumption is reasonable as the operaion of the national electricity market is based on the assumption that all power generators are competing with each other in a market competition environment.

Without the supply of solar power, the summer time daily peak demand (i.e. the peak of the blue curve in Fig. 5 at 16:30, ~9000 MV) is very close to Victoria's maximum capacity ~11000 MV. This may create a competition for limited power supply. The competation can be further amplified if some generator systems and/or connectors fail due to high temperature.

With the supply of solar power, the outstanding demand (vertically shaded sections in Fig. 5) is much less than the maximum capacity of Victorian power system, excluding the solar power . As a result, the competition for limited power supply is expected to be less severe than the supply network without solar power. And it is less likely to have price spikes.

The above analysis is based on a theoretical solar power output. The argument will be strengthened by simulation results based on a solar power generator model and realistic solar irradiance data.

NEMSIM's solar power estimation model

This paper uses the solar power estimation model in CSIRO's NEMSIM simulation program (Grozev et al. 2005) to estimate solar power generation at half-hourly steps (Fig. 6). The aim of the model is to produce a time series of solar intensity (irradiance) received for each solar power generator site that has reasonable intra-day variability. The time series of solar energy received are then converted into electricity generated by the power generator so that the effect of solar power on the market can be realistically investigated. The model can be used together with electricity demand, gas demand and hydro generation inflows to model various energy efficiency options. Currently we do not have any solar datasets derived from climate change models; instead we consider only historical solar time series that will give us a realistic inter-day variability.

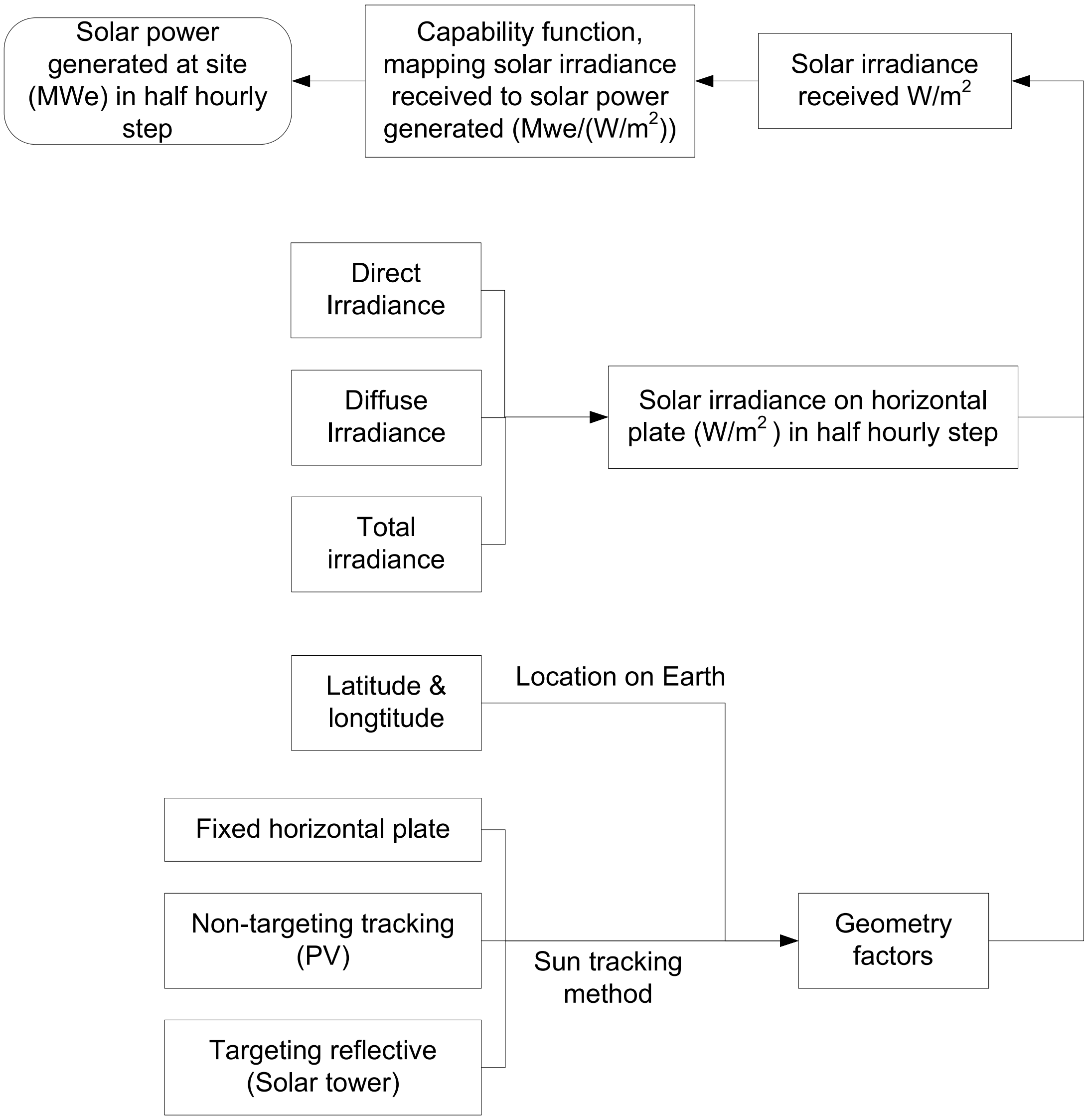


Fig.6: Parameterisation of NEMSIM's solar power generation model. Arrows show the direction of information flow.

Simulation results

Figures 7 and 8 demonstrate the simulation results of matching the half-hourly demand profile with solar power generated by some solar power generators in summer and winter days. The assumptions are:

(1) Demands data are taken from Victoria electricity demand in 2009 (AEMO 2009).

(2) Solar power generators are all situated in Mildura (latitude = 34.2°S, longitude = 142.1°E) and their generation technology is centralising PV with solar azimuth tracking capacity.

(3) The maximum solar output power of the year is about 4500MW, which requires about 45 km^2 of PVs.

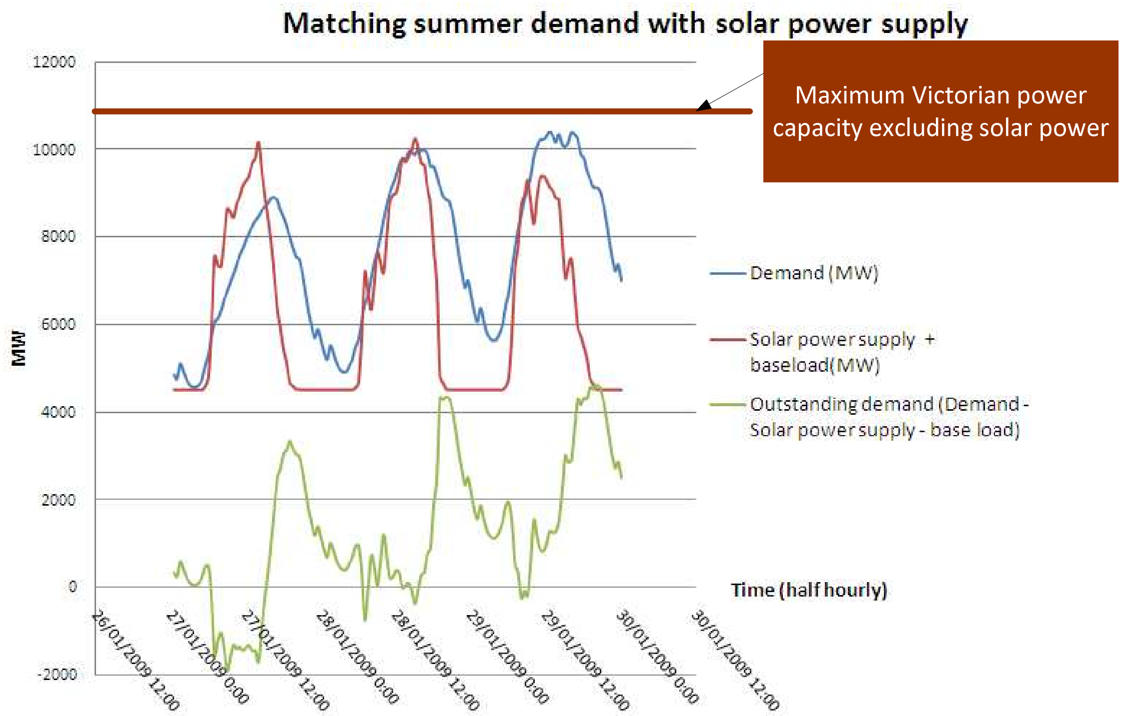
(4) The base load power (~4500MW) is supplied by conventional base load power plants for low cost and stable supply of electricity.

(5) The time step for the simulation is half hourly, running on Australian standard time with *no* adjustment for daylight saving time.

(6) Mildura's total irradiance data is taken from Australian Climate Data Bank (Walsh *et al.* 1983).

(7) All solar power generated is immediately used to bid for dispatch.

(8) Being a renewable energy source, solar power generators are regarded as intermediate load dispatch, wedging between the dispatches from base load plants and peak load plants.
(9) Outstanding solar supply after dispatch is stored away (heating up water, etc.)
(10) Outstanding demand is covered by other peak load bids.



Fig, 7: Matching daily demand with solar power in summer.

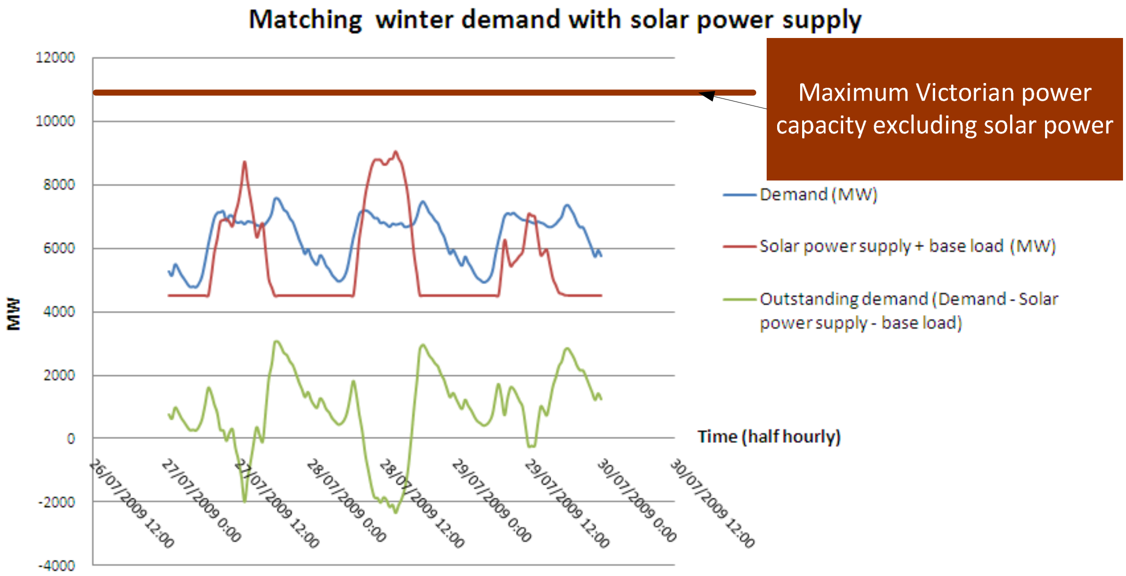
Discussions

The assumption (8) above has a significant implication on the availability of solar power in AEMO central dispatch system. Solar power is only included in the system if either (a) the cost of solar power generation has been cheap enough to compete with other ordinary types of generator, or (b) it is included as non-scheduled energy source – no bidding is necessary. If we believe that it will take a long time for solar power generation to reduce its power generation cost, we may consider the option of including the solar power system as non-scheduled energy source, not controlled through AEMO's central dispatch process.

In Figures 7 and 8 the charts in pale green colour show the outstanding demands after the total demand is partially met by the base load supply and solar power supply. The portions of the graph below the horizontal axis indicate that there is an excess of (solar power) supply, which can be used for other things (power storage, etc.) The portions of the graph above the horizontal axis shows that there is a shortage of supply; and peak load generators can be called in to bid for the demand balance.

The maximum Victorian power capacity is about 11000MW at every time step. After deducting the base load of 4500MW, the remaining Victorian capacity is 6500MW, which is well above the peak of the outstanding demand (~4500 MW in Fig.7), even in the afternoon of the hottest day of the year 2009. In contrast, in the case of having no matching of demand profile with solar power generation profile (Fig. 4), the maximum Victorian power capacity has been reached on 29 January 2009. Consequently, in the central bidding process, generation supply (6500 MW) offers more choices than the peak outstanding demand (~4500 MW) can accept. As a result, the whole electricity generation system is less stressed and the possibility of bidding price spikes is greatly reduced.

Since winter consumes less power than summer, the introduction of solar energy power in winter time can offer even more choices than the peak outstanding demand can accept.



Fig, 8: Matching daily demand with solar power in winter.

Summary and future work

This study provides a system level description of how solar power can be used to mitigate the diurnal and seasonal electricity demand in Victoria. Through analysis and simulation, we demonstrate that by matching the day time demand profile with the solar power generation profile, the peak outstanding demand is greatly reduced to below Victoria's maximum power capacity level. Consequently, more power generators are reserved for meeting the outstanding demand; the network system is less likely to fail due to lack of reserve; and the bidding prices are less likely to spike.

The limitation of this work is that it offers only a qualitative description of mitigating the diurnal and seasonal electricity demand using solar power. In the future, when data and models are further collected and developed, a quantitative model may be needed for better prediction of bidding and prices when solar power is considered as an option for electricity supply.

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BRIEF BIOGRAPHY OF PRESENTER

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