Characterising the Effect of High Penetration Solar Intermittency on Australian Electricity Networks

Dr Saad Sayeef  |  Research Scientist
20 April 2012
Problem

• Solar installations are uncontrolled generating systems

Solar power generated on a sunny day

Solar power generated on a cloudy day
Problem

- Solar installations are uncontrolled generating systems

Variable output of HP-IG

Large variations in energy supply

Significant potential network impacts
Objective of study

• To summarise and assess worldwide research on solar intermittency

• To understand the differences between wind and solar intermittency

• To characterise the impact of solar intermittency on Australian electricity networks

• To understand the variability of solar power plants, both PV and CST sources, in order to support the rapid development of high-penetration solar power in the electric power system
## Intermittency Timescales

<table>
<thead>
<tr>
<th>Timescale of Intermittency</th>
<th>Potential Power System Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seconds</td>
<td>Power quality (e.g. voltage flicker)</td>
</tr>
<tr>
<td>Minutes</td>
<td>Regulation reserves</td>
</tr>
<tr>
<td>Minutes to hours</td>
<td>Load following</td>
</tr>
<tr>
<td>Hours to days</td>
<td>Unit commitment</td>
</tr>
</tbody>
</table>
Section 1: Effects of intermittent generation
Solar farm output variations

- Power output of a 4.6MW PV system in Arizona on a partly cloudy day – 10-second resolution

Source: [http://www.megawattsf.com/gridstorage/gridstorage.htm](http://www.megawattsf.com/gridstorage/gridstorage.htm)
Net load variability – hourly changes

• 25% penetration (relative to total annual load energy) – 1 year

Net load variability – different load levels

• 33% penetration of wind and solar

1st decile: load 90% - 100% of peak load (top 10% of peak load hours)
10th decile: loads up to 10% of peak load

Increase of 47% in s.d. of net load variability in 10th decile

Net load variability – by time of day

Section 2: Impacts of intermittent generation
Functions of generation operations that could be impacted are:

- Load frequency control
- Load following
- Ramping rate – fast ramp rates make voltage and frequency regulation difficult
- Unloadable generation: down-ramping vs. up-ramping
- Operating reserve
Rapid net load variations

Cloud activity – high frequency 1-sec sampling in Massachusetts showing the kind of ramp rates possible in PV output

53 residential properties and 28 PV installations

Network Impacts

• Wind: ERCOT – declare emergency – abrupt loss of 1,200 MW of wind energy – 26\textsuperscript{th} February 2008
  
  • Occurred over a 3-hour period where overall electricity loads were increasing and stability of power grid was threatened – potential of causing rolling blackout

• Network: European power grid failure in 2006 due to power imbalance and blackout in Italy in 2003 – in both cases Germany belonged to an exporting network – frequency increased to above 50.2 Hz
HP-IG Impacts on Peak and Minimum Load

CAISO study: Impact of increased PV generation on Net Load
- Small impact on peak load, larger impact on minimum load

Original Net Load data from July 2007

CAISO study: Impact of increased PV generation on Fuel mix – 30% PV penetration

- Californian fuel mix
- US fuel mix

**Impacts on Fuel Mix – Daily Dispatch**

US Western Interconnection Study: Impact of increased PV generation on Dispatch profiles – 1-hour resolution

- Dispatch profile with 25% solar

Impact of increased PV penetration on voltage regulation

- Actual solar irradiance and load data were used to simulate 20% PV penetration
- Study performed on a simple distribution system on partly cloudy days
- 1-minute sampling rate
- No flicker problems (sampling rate too low?)
- Significant increase in the number of transformer tap changes

<table>
<thead>
<tr>
<th>Date (d/m/y)</th>
<th>w/o PV &amp; 1 min. delay</th>
<th>w/o PV &amp; 5 min. delay</th>
<th>with PV &amp; 1 min. delay</th>
<th>with PV &amp; 5 min. delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/7/2010</td>
<td>20</td>
<td>14</td>
<td>92</td>
<td>34</td>
</tr>
<tr>
<td>12/7/2010</td>
<td>10</td>
<td>8</td>
<td>42</td>
<td>24</td>
</tr>
<tr>
<td>13/7/2010</td>
<td>10</td>
<td>6</td>
<td>26</td>
<td>20</td>
</tr>
<tr>
<td>Total</td>
<td>40</td>
<td>28</td>
<td>160</td>
<td>78</td>
</tr>
</tbody>
</table>

Integration Cost Impacts - Wind

Penetration level vs. cost

For successful integration of large amounts of intermittent generation:

• Accurate forecasting is essential

• Increasing system flexibility is required
  • Balancing the generation portfolio
  • Introducing more flexible conventional generation
  • Redesigning the power system to enable the handling of reverse power flow from distributed PV

• Reducing net load variability – decreasing required system flexibility – is needed
  • Energy storage
  • Load control
  • Increased control and communication
  • Ability to curtail intermittent generation
  • Spatial diversity of the resource
But there is a world of difference...

- Different penetration limit levels, different network topologies, different economics, different weather conditions, different generation sources, different market dynamics, different quality of service, different expectations, different differences....

- Differences in maximum penetration level - reported reasons include:
  - Ramp rates of conventional generation
  - Reverse power swings
  - Frequency control capability
  - Voltage regulation capability
  - Differences in types of grid and penetration context:
    - Distribution system penetration vs. central generation penetration

- Maximum penetration level is highly situation-dependent and varies widely
One example...

Different penetration limit levels as reported by different sources:

<table>
<thead>
<tr>
<th>Maximum PV Penetration Level</th>
<th>Cause of the Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>Ramp rates of mainline generators. PV in central-station mode.</td>
</tr>
<tr>
<td>15%</td>
<td>Reverse power swings during cloud transients. PV in distributed mode.</td>
</tr>
<tr>
<td>No limit found</td>
<td>Harmonics.</td>
</tr>
<tr>
<td>&gt; 37%</td>
<td>No problems caused by clouds, harmonics, or unacceptable responses to fast transients were found at 37% penetration. Experimental + theoretical study.</td>
</tr>
<tr>
<td>Varied from 1.3% to 36%</td>
<td>Unacceptable unscheduled tie-line flows. The variation is caused by the geographical extent of the PV (1.3% for central-station PV). Results particular to the studied utility because of the specific mix of thermal generation technologies in use.</td>
</tr>
<tr>
<td>10%</td>
<td>Frequency control versus break-even costs.</td>
</tr>
<tr>
<td>Equal to minimum load on feeder</td>
<td>Voltage rise. Assumes no LTCs in the MV/LV transformer banks.</td>
</tr>
<tr>
<td>&lt; 40%</td>
<td>Primarily voltage regulation, especially unacceptably low voltages during false trips, and malfunctions of SVRs.</td>
</tr>
<tr>
<td>5%</td>
<td>This is the level at which minimum distribution system losses occurred. This level could be nearly doubled if inverters were equipped with voltage regulation capability.</td>
</tr>
<tr>
<td>33% or ≥ 50%</td>
<td>Voltage rise. The lower penetration limit of 33% is imposed by a very strict reading of the voltage limits in the applicable standard, but the excursion beyond that voltage limit at 50% penetration was extremely small.</td>
</tr>
</tbody>
</table>
Section 3: Project Activities
Industry workshop

Aim: To understand issues being faced due to intermittency and concerns that Australian industry players hold.

- Industry workshop on the effects of renewable generation intermittency conducted in April 2011
- Follow-up survey was also conducted
Australian context – Unique aspects

- Large Coverage Area
- Low Average Population Density
- Areas of High Population Density
- High impedance network compared with Europe
- Large number of long 'skinny' feeders
- Low levels of interconnection
- Network subject to Australian usage, weather and environmental conditions*
- Market Dynamics
Characterisation of Intermittency Timescales and Ramp Rates

• 10 months data recorded collected from the Desert Knowledge Australia Solar Centre (DKASC)

• 10-second resolution

• Located in Alice Springs, Central Australia

• Range of commercialised solar power technologies in a number of different configurations

• Total rating of 196kW
Irradiance and Output Power of PV plant

26th May, 2011

Graph showing irradiance and output power over the course of a day.
PV output power ramp events – 10 seconds

10-second ramp events

• **Ramp up:**
  • 120 occurrences of 6kW/s or more
  • Increase in power of at least 31% in 10 seconds

• **Ramp down:**
  • 302 occurrences of 6kW/s or more
  • 7 events between 13 and 14kW/s (66-71% drop in power)
• Ramp up:
  • 1344 occurrences of 2kW/s or more
  • Increase in output power of at least 51% in 50 seconds

• Ramp down:
  • 1515 occurrences of 2kW/s or more
  • 54 events of over 3kW/s (>77% drop in power in 50 seconds)
Overview of DKASC power ramp events
PV output power ramp events – 22kW PV

5-second ramp events

- **Ramp up:**
  - 54 occurrences of 0.9kW/s or more
  - Increase in output power of at least 20.5% in 5 seconds

- **Ramp down:**
  - 10 occurrences of 1.3kW/s or more
  - Decrease in power output of at least 6.5 kW (>30% drop in power in 5 secs)
PV output power ramp events – 1.22MW PV

- **Ramp up:**
  - 10 occurrences of 12kW/s or more
  - Increase in output power of at least 720kW (59%) in 1 minute

- **Ramp down:**
  - 11 occurrences of 12kW/s or more
  - Decrease in power output of at least 720 kW (>59%) drop in power in 1 minute
Model developed – Irradiance to PV output power

• Power curve smoother than irradiance curve

• PV plant power output can be described as the signal output of a low-pass filter.

• Input: incident irradiance

• First order filter whose pole value is a function of the PV plant area
PV output power estimate

PV Output Power - Actual vs. Predicted

Actual PV Output | Predicted PV Output

PV Output Power (kW)

Date/Time

06:00 12:00 18:00

07:00 09:00 11:00 13:00 15:00 17:00 19:00
Network effects model – Low penetration

Low PV penetration and weak grid

Low PV penetration and strong grid
Network effects model – High penetration

High PV penetration and strong grid

High PV penetration and weak grid
Section 4: Summary of key findings
Summary of key findings

• Large-scale uptake of solar generation is highly dependent on mitigating the effects of intermittency

• Existing research has conflicting outcomes, suffers from a lack of quality data and consequently often overemphasises anecdotal evidence

• There is considerable intermittency in the existing electricity system

• The effect of solar intermittency is not uniform
  • Context specific and needs to be considered case-by-case
Summary of key findings

• Solar intermittency can be managed. Possible mechanisms that can be employed include:
  • Using short-term energy storage
  • Strengthening the electricity network
  • Controlling loads in response to network requirements
  • Deploying additional ancillary services
  • Curtailing the output of renewable generators

• Accurate solar forecasting is essential to plan and manage intermittency

• Australia is unique
Section 5: What next?
Further work required

Research and demonstration work is required in Australia

• Development of models representing solar behaviour and net load – to quantify performance and economic impacts on regulation and load following

• Determination of required flexibility of conventional generation to manage variability introduced by HP-IG

• Simulations to determine impact of HP-IG on power quality at distribution level

• Investigations into how flexibility can be introduced (or variability mitigated) into networks – e.g. Energy storage and load participation

• Collection of high-resolution temporal and spatial solar and electrical data
The Full Report will be available in June 2012
Thank you

Energy Transformed Flagship
Dr Saad Sayeef
Research Scientist

+61 2 4960 6131
saad.sayeef@csiro.au
www.csiro.au