



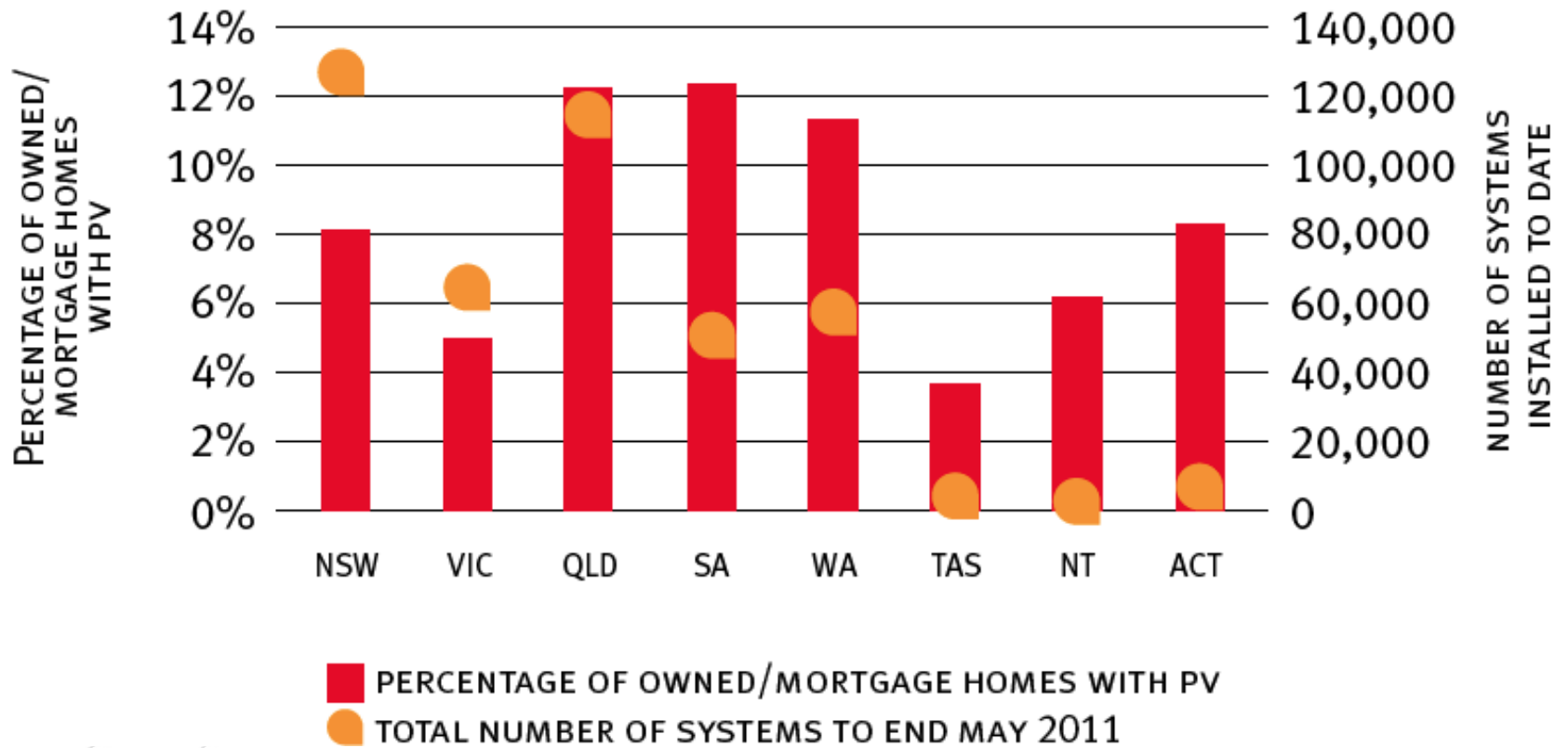
High PV Penetration in Electricity Grids

Australian Case Studies:
Alice Springs (with NT Power & Water Corporation)
Carnarvon (with Horizon Power)

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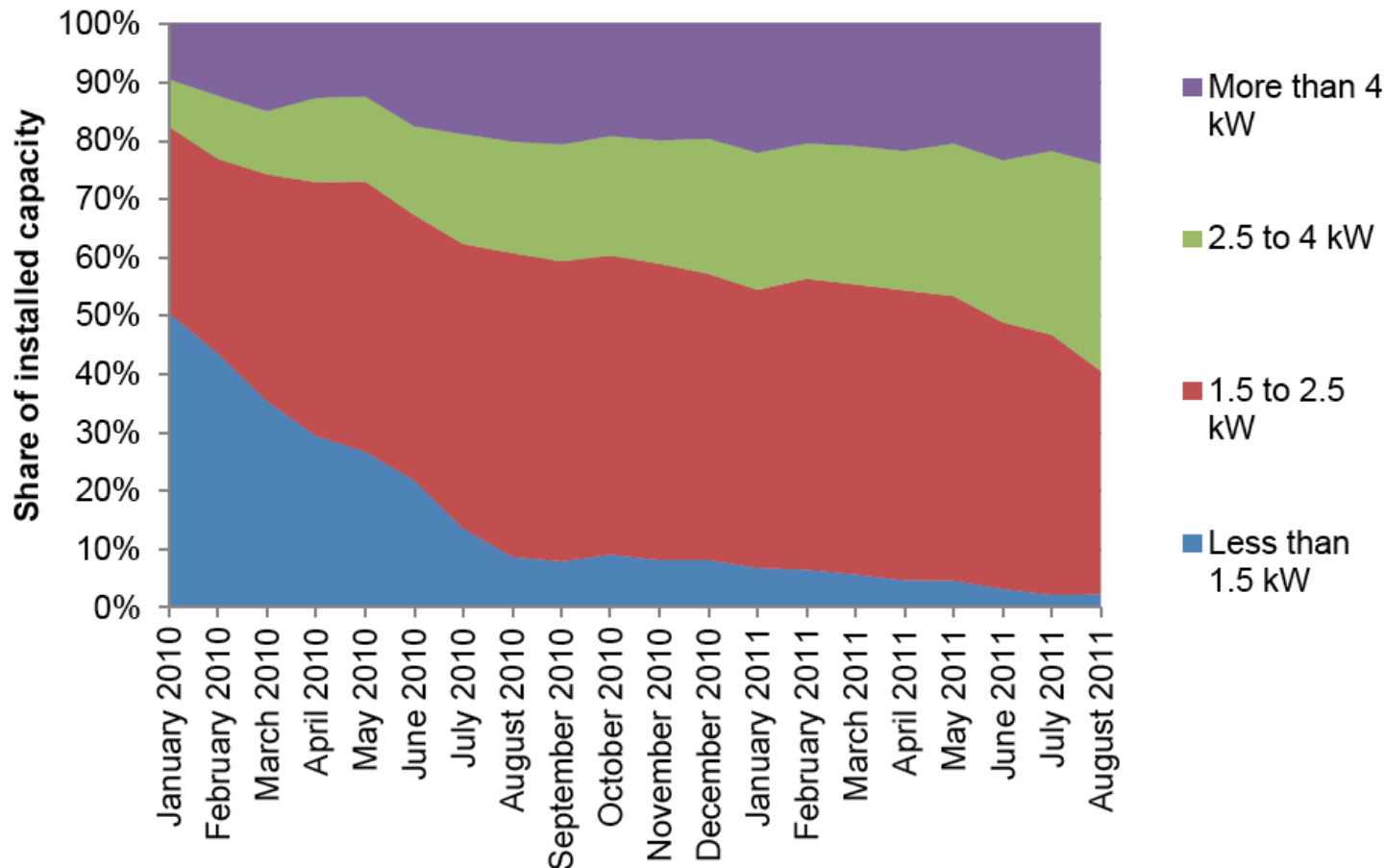
Figure 6 Proportion of owned/mortgaged dwellings with PV

Source: 2006 Census Data, SHCP/PVRP data, REC Registry Analysis



PV System Size trends

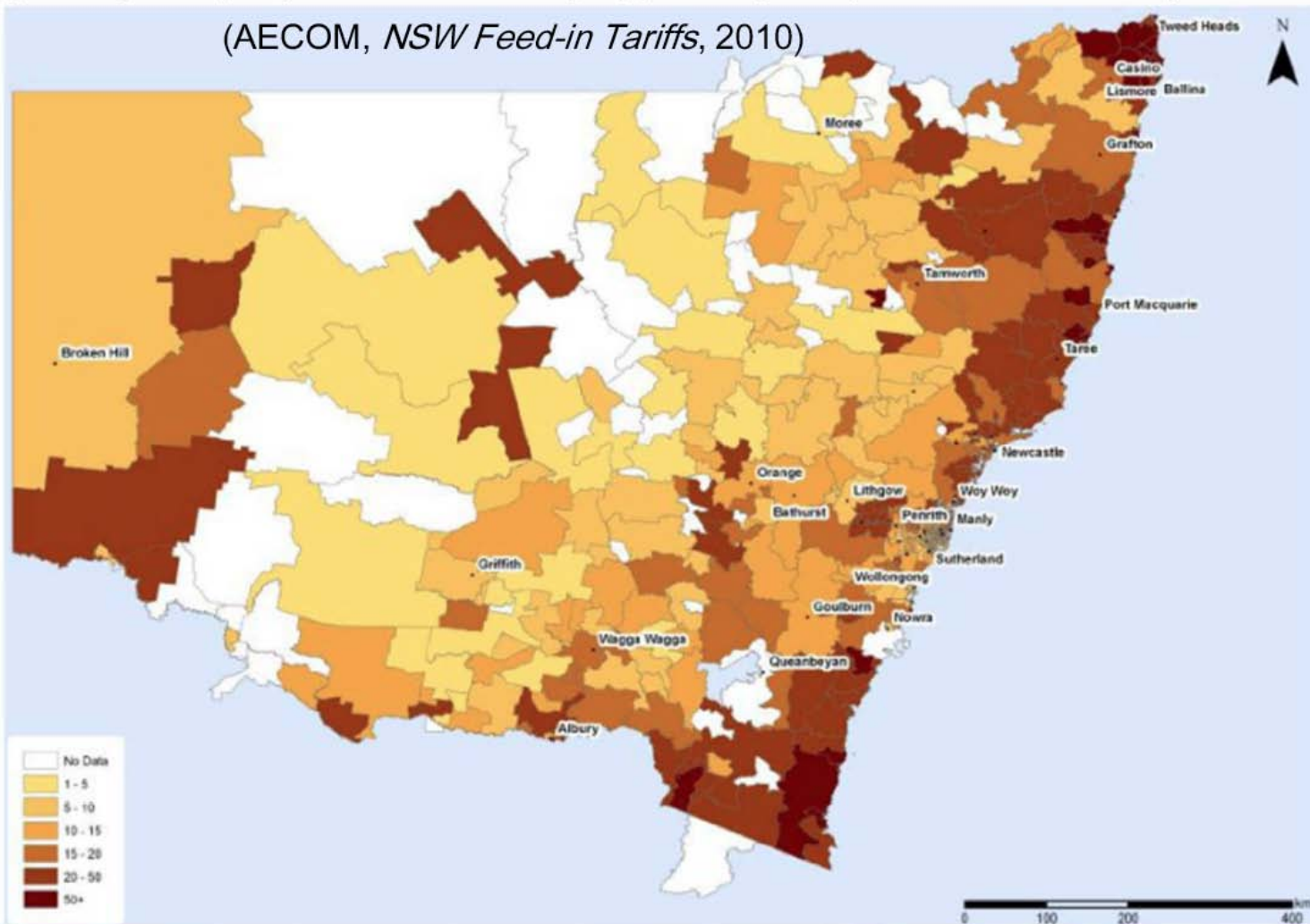
Figure 12 PV system size trends – January 2010 to August 2011



Some High Penetrations Emerging

Figure 5: Systems per 1,000 "suitable" dwellings by postcode, NSW (data as at end June 2010)

(AECOM, *NSW Feed-in Tariffs*, 2010)



... growing issues

Solar dream gets caught in gridlock

Peter Hall

THE solar power revolution is in danger of stalling, with the State Government admitting the electricity grid is failing to cope with its green vision.

Energy Minister Stephen Robertson confirmed new applications for rooftop solar systems were being rejected in areas where Queensland's high uptake threatened the safety and reliability of its network.

Thousands of homeowners hoping for promised power savings of up to \$540 via a 1.5kW system are in limbo, with those wanting larger systems even being asked to pay more than \$20,000 to help cover local upgrades.

Energex said the state's electricity network since the 1950s had been designed to deliver power from the station to the home and the voltage now heading "the other way" was causing a huge dilemma.

more than 107,000 Queensland households have jumped at the Solar Bonus Scheme, launched in 2008, exporting 72.5 million kW hours back to the grid.

However, unless significant, costly upgrades are completed, many who might want to add solar panels in the future may not be able to.

Energex is warning Queenslanders considering installing solar to make applications well before entering a contract with an installer in case they are not able to proceed.

Spokesman Mike Swanston told *The Courier-Mail* about 600 local distribution transformer zones on the Gold Coast, Brisbane Valley and Sunshine Coast had reached saturation.

Mr Swanston said, at this stage, only a handful of applications had been "rejected outright", but he confirmed that 30 per cent saturation was the "trigger" for applications to be

being examined closely." Mudgeeraba resident Andries Kaden was stunned when his application for a 10kW system was knocked back.

Mr Kaden was told there were enough solar systems in the area and the transformer would have to be upgraded for him to install one.

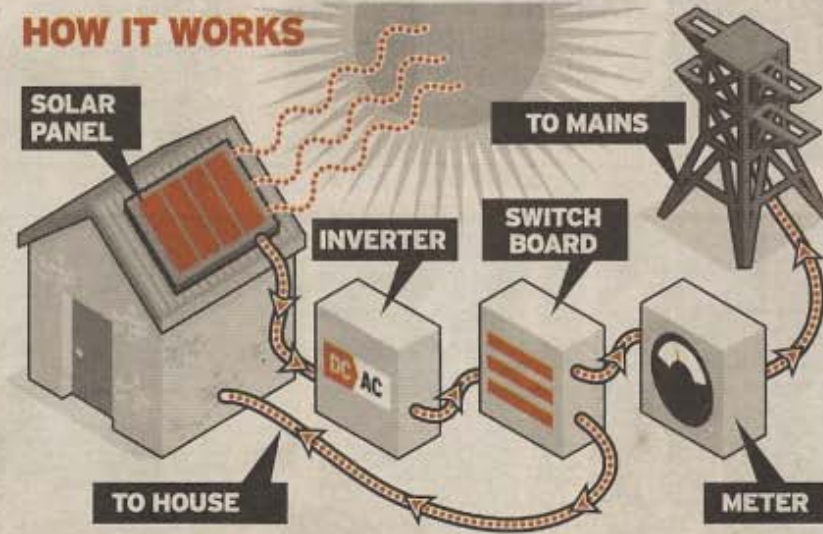
"Energex told me if I wanted to proceed I would have to pay between \$20,000 and \$30,000 for an upgrade," he said.

"I couldn't believe it because we have all been told to grab this, but it's not possible. You had better get in quick if you want solar is all I can say.

"I fought this all the way to the minister and they have since said I can have the system but I am a guinea pig to see if the network can handle it."

Mr Robertson advised Mr Kaden he was to be part of a trial "to see if the electricity network can operate at higher penetration levels".

HOW IT WORKS



THE PLUS SIDE

- Photovoltaic cells (PV) generate DC electricity when exposed to sunlight.
- The DC electricity is fed into a solar inverter which converts it to 240V 50Hz AC electricity for use in the home
- Surplus electricity is fed back into the main grid
- The value of the surplus power is credited to the household electricity account at 44¢ for every kW. On a 1.5kW system this can mean a credit of up to \$540 a year

THE PROBLEMS

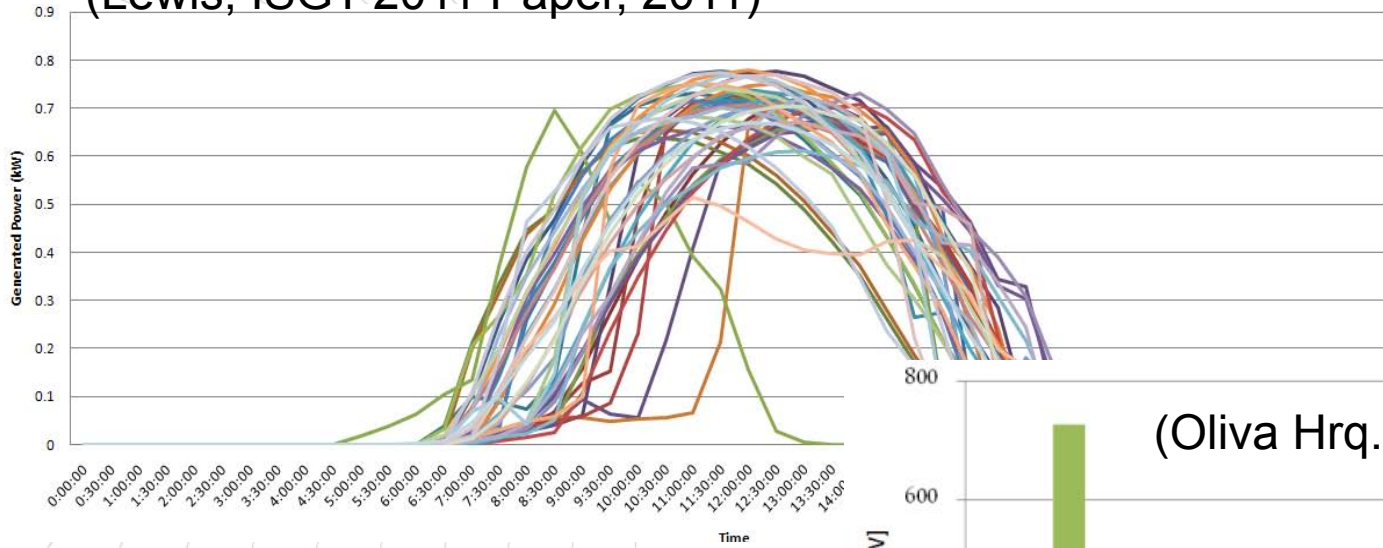
- Since the 1950s, the state's electricity network has been designed to deliver power from power stations to homes and businesses. The grid is unable to cope with the amount of power now heading the other way
- 600 Queensland local distribution zones - of about 50 homes each - already have hit saturation point. Areas include the Gold Coast, Sunshine Coast and Brisbane Valley

PV High Penetration Technical Issues

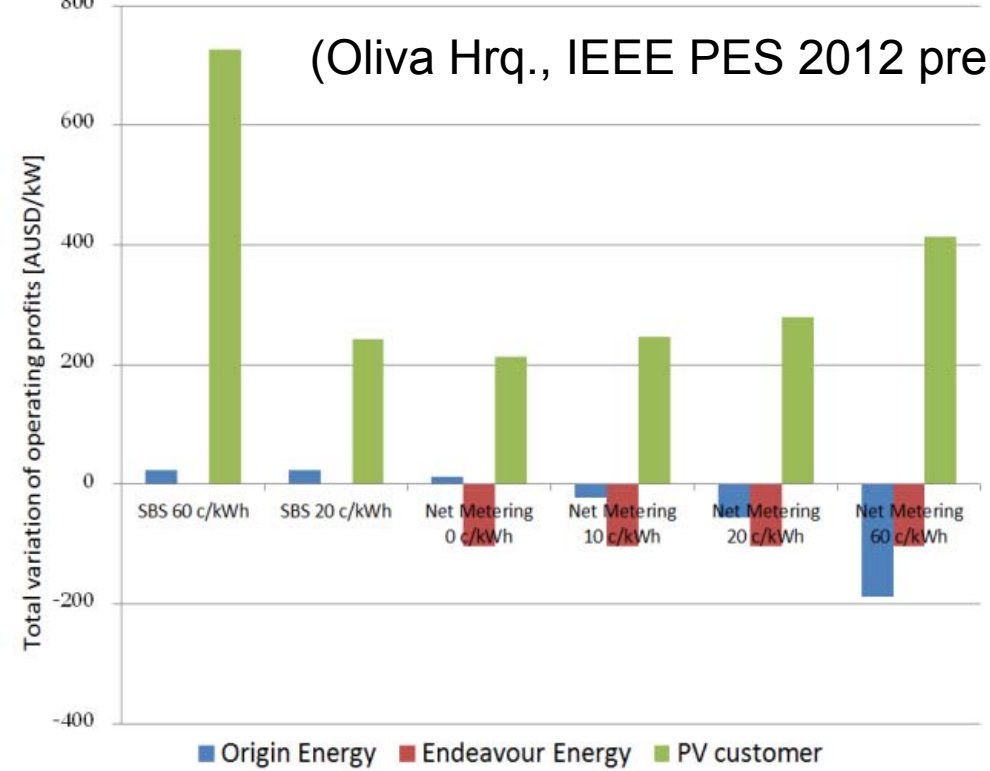
- Summary:
 - Voltage rise/reverse power flow
 - Phase imbalance
 - Grid voltage fluctuations/frequency changes
 - PV power output fluctuations
 - Power quality (short term fluctuations)
 - Reserve generation requirements (longer term fluctuations)
 - Power factor decrease
 - Harmonics
 - Fault behaviour

PV technical issues + value very context dependent

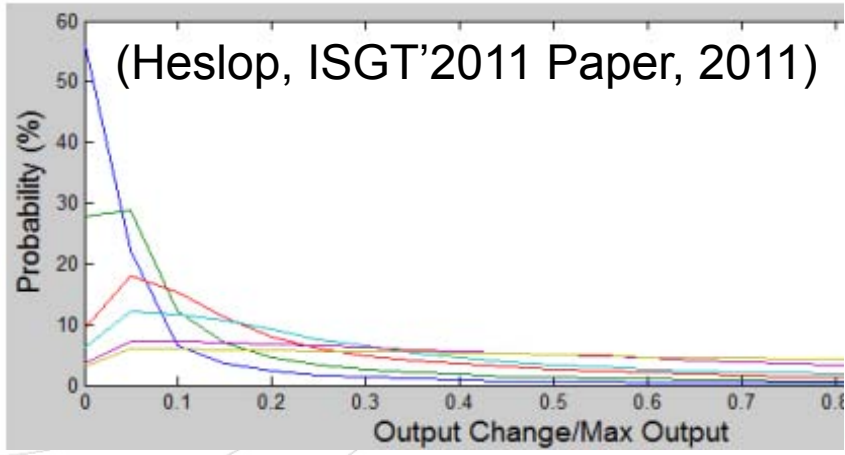
(Lewis, ISGT'2011 Paper, 2011)



(Oliva Hrç., IEEE PES 2012 prelim.)



(Heslop, ISGT'2011 Paper, 2011)



IEA PVPS Task 14 participation

- 14 Countries... with more coming



- Australian participation through APVA with ASI funding support for international collaboration
- Australian contributions to date from Partners including APVA, CEEM – SPVRE – EE&T UNSW, CSIRO, NT Power and Water Corporation, Horizon Power, CAT Projects

High Penetration PV Definition by Task 14

- High penetration situation exists if additional efforts are (would be) necessary to integrate the (planned) PV generation in an optimum manner.

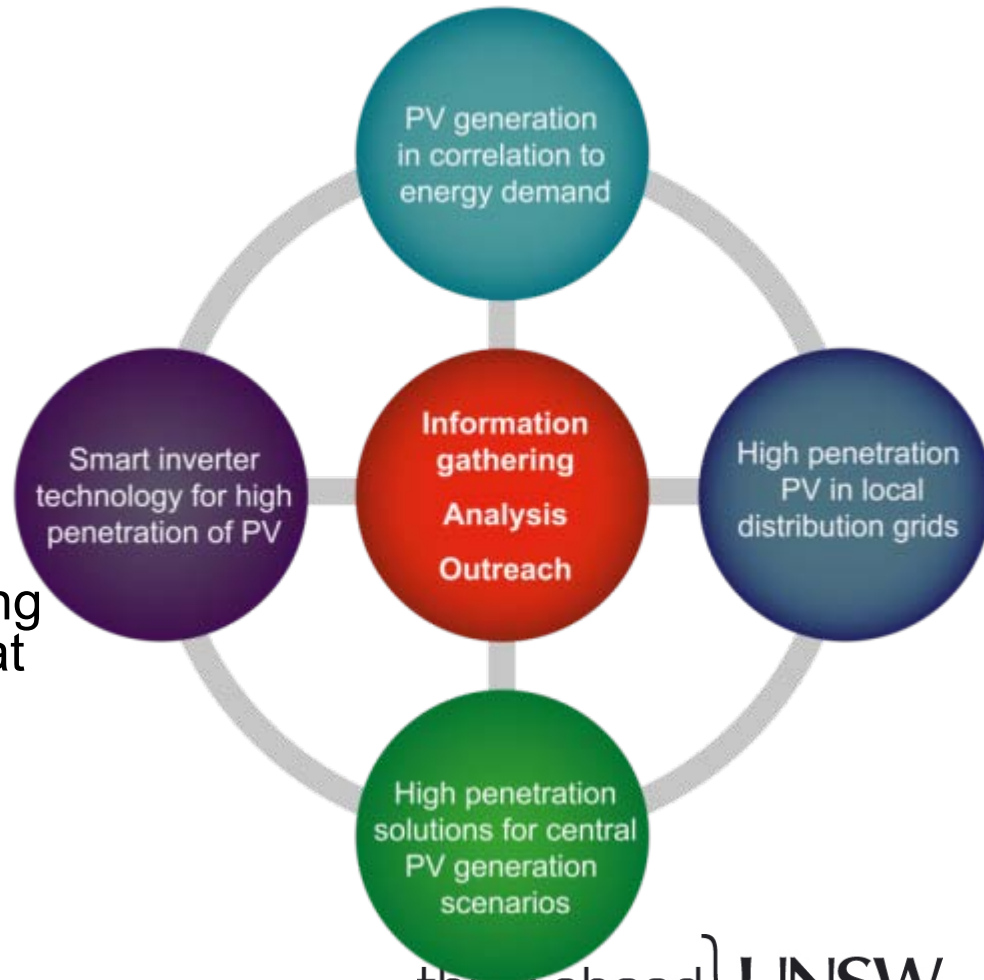
Overall Goal of this international collaboration

- **Promote the use of grid connected PV** as an important source in electric power systems also on a high penetration level where additional efforts may be necessary to integrate the dispersed generators in an optimum manner.
- **Develop and verify mainly technical requirements for PV and electric power systems** to allow for high penetrations of PV systems interconnected with the grid
- Discuss the **active role of PV systems related to energy management and system control** of electricity grids
- **Reduce the technical barriers to achieve high penetrations** of distributed renewable energy systems on the electric power system

IEA PVPS - Task 14

Organization and structure

- PV generation in correlation to energy demand focusing on consumer behavior to be better linked to the generation profile
- The effects on PV generation to the local grid as well as to the general electricity system
- Smart inverter technology dealing with requirements for inverters at high PV penetration
- Convincing case studies, Best practice examples



- **Subtask 1: PV generation in correlation to energy demand**
 - 1.1: Prediction Tools
 - 1.2: Network driven demand side management
 - 1.3: Handling temporal fluctuations
- **Subtask 2: High penetration PV in local distribution grids**
 - 2.1 Review of State-of-the-Art
 - 2.2 Optimized Reactive Power Balancing
 - 2.3 Optimized Active Power Control Strategies
 - 2.4 Change from Distribution to Supply Grids and Dynamic Studies
- **Subtask 3: High penetration solutions for central PV generation scenarios**
 - 3.1: System-wide PV generation analysis and forecast
 - 3.2: Power system operation planning with PV integration
 - 3.3: Power system augmentation planning with PV integration
- **Subtask 4: Smart inverter technology for high penetration of PV**
 - 4.1: Opportunities for Smart PV inverters in High-Penetration scenarios
 - 4.2: Technical capabilities and Inverter Topologies
 - 4.3: Remote control and communication for Smart Inverters

Australia – potential lessons + contributions

- Many common challenges
 - Australia a low overall PV penetration by comparison with some other countries
 - Lessons from those countries with high PV penetrations and (at least somewhat) similar lines
- Some particular Australian challenges relevant to particular task members in some contexts
 - Virtually all installed PV is small single-phase systems connected to LV network
 - Long weak rural feeders
 - Diesel mini-grids

Some Potential Australian High PV Case Studies

- Alice Springs Solar City
 - Regional (50MW) grid with gas-fired generation and 3MW of PV,
 - *Case study now completed in partnership with NT Power & Water Corp*
- Carnarvon
 - *Case Study now complete in partnership with Horizon Power*
- Townsville Solar City
 - PV with major demand management initiative
- Urban contexts
 - Some preliminary analysis for Solar Cities Blacktown
 - *Other emerging opportunities*
- High PV mini diesel grids

Solar City locations



Case study process – stakeholder engagement

- System questionnaire
 - collect and collate high-level information on:
 - the electricity supply system;
 - photovoltaic systems connected to the network;
 - general experiences being encountered with high levels of PV penetration on the network;
 - specific experiences being encountered with high levels of PV penetration on the network;
 - use the questionnaire as a basis for discussion with key stakeholders, and to identify specific high PV penetration areas/ issues to focus on in more detail.”
- Possible feeder level surveys
- Site visits, stakeholder meetings

Alice Springs Case Study

- Alice Springs Solar City
 - Regional (50MW) grid with gas-fired generation and 3MW of PV,
 - *Case study now completed in partnership with PowerWater*



Centre for Energy and
Environmental Markets

PowerWater



Alice Springs

A Case Study of Increasing Levels of PV Penetration
in an Electricity Supply System

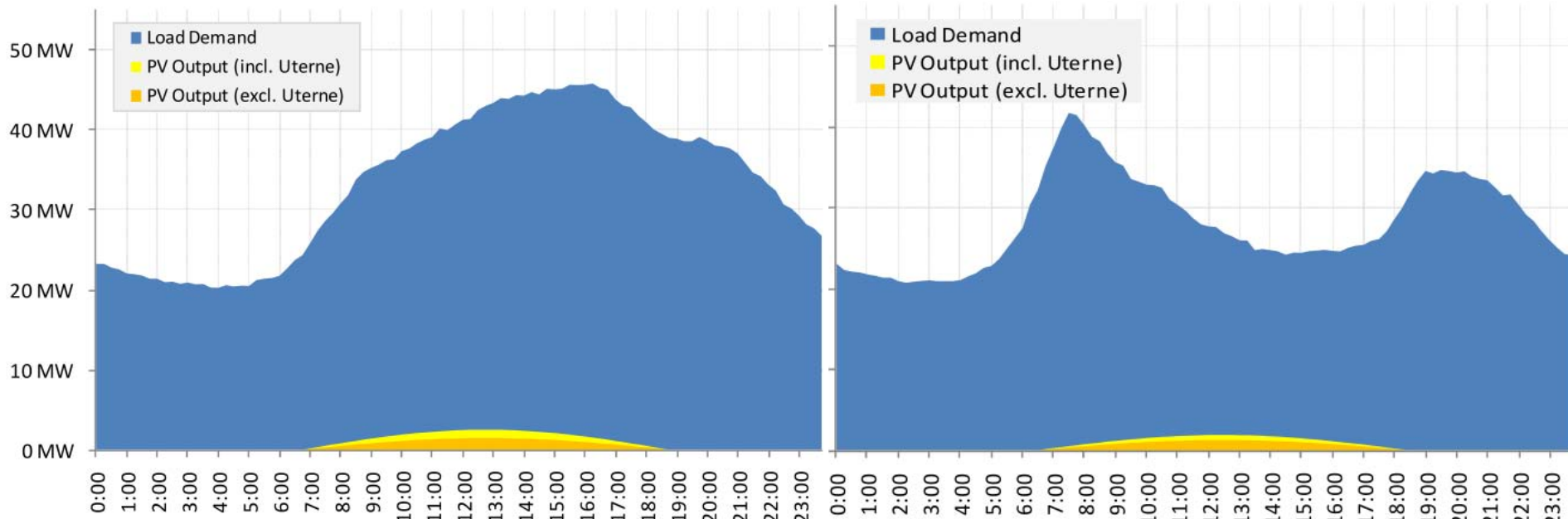
June 2011

think ahead } UNSW
THE UNIVERSITY OF NEW SOUTH WALES

Typical Summer & winter profiles

PV Penetration Measure	PV Measure	Value	System Measure	Value	% PV Pen.
PV Capacity Penetration (%)	Installed Nominal PV Capacity	3.1 MW	Peak Load	55 MW	5.6%
PV Peak Power Penetration - Summer (%)	Est. Summer Midday PV Peak Power	2.6 MW	Ave. Summer Midday Load Demand	40 MW	6.5%
PV Peak Power Penetration - Winter (%)	Est. Winter Midday PV Peak Power	2.2 MW	Ave. Winter Midday Load Demand	26 MW	8.3%
PV Annual Energy Penetration (%)	Est. Annual PV Energy Generated	5.7 GWh	Annual Gross System Load	230 GWh	2.5%

Measures of expected levels of PV penetration at the system level (i.e. with Uterne 1MW system)



Specific network issues

Feeder rating	10 MW
PV system capacity on feeder	1 MW
PV capacity penetration	10%
Indicative load on feeder	3 MW
Indicative PV peak power/load penetration	33%

Indicative figures for Alice network feeder with highest PV penetration (Uterne)

Distribution transformer rating	300 kW
PV capacity on transformer	34 kW
PV capacity penetration	11%
# Customers supplied	110
Est. average midday demand per customer	1 kW
Est. average midday load on transformer	110 kW
Indicative maximum PV power/load ratio	~31%

Indicative figures for distribution transformer with highest PV per

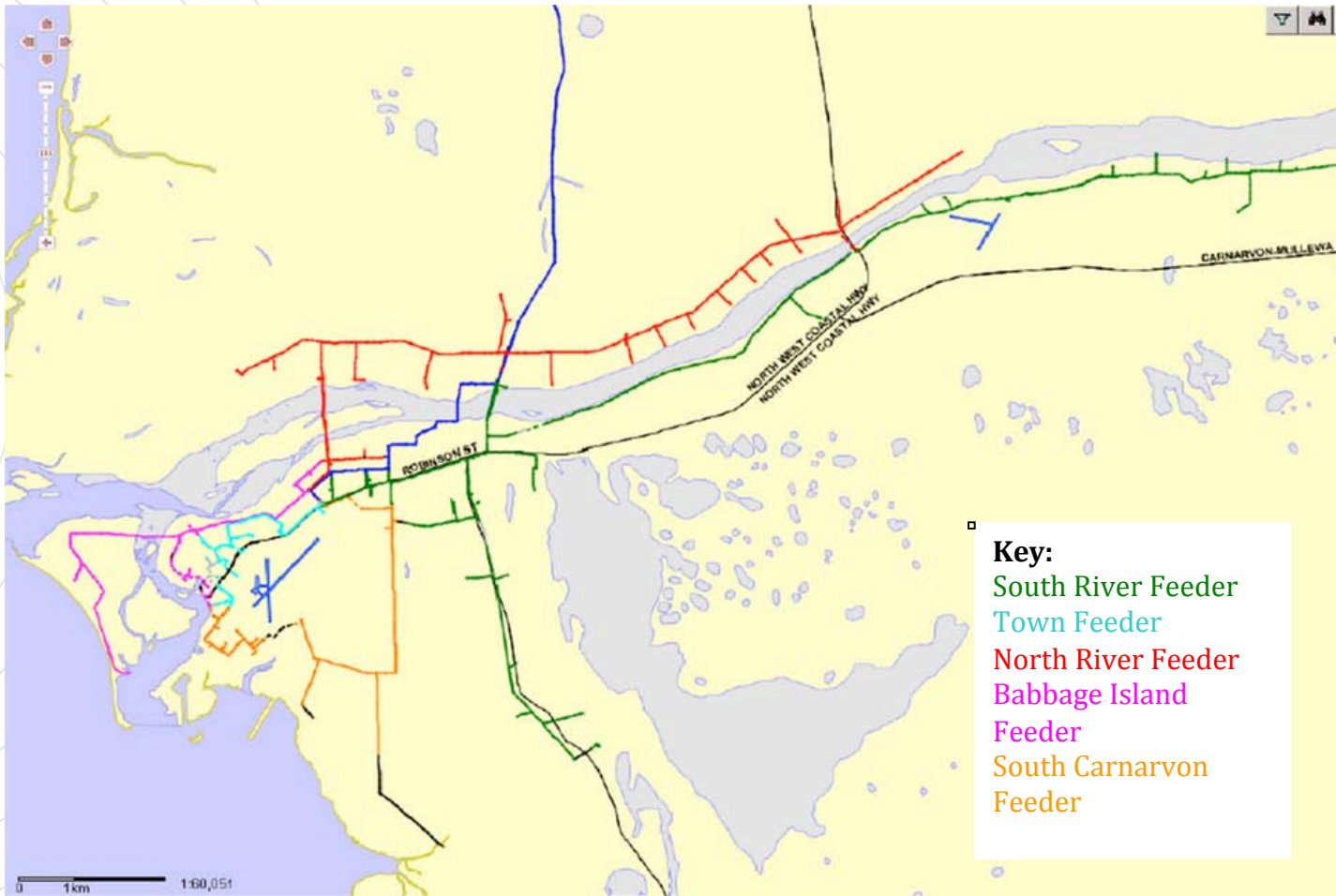


PV Penetration Experience/Issue	Comment/Status
Significant tripping of PV systems during system frequency drop events.	<p>Previously experienced during certain system low frequency events. Steps have been taken by P&W to address this by changing inverter low-frequency trip requirements (i.e. reduced to 46Hz). This issue has been resolved for connection of future PV systems but not yet fully resolved for existing PV systems on the network. There has been no significant impact on network operation.</p> <p>Raises a related issue concerning the ability or otherwise of utilities to confirm and change settings for existing inverters.</p>
Small PV fluctuations on system net load profile due to clouds.	Recently observed (order of close to 1MW over period of minutes). No material impact on network operation as yet. To be monitored by P&W.
LV distribution system voltage management.	Presently no problems with LV system voltage due to PV penetration. However P&W has initiated a project to more closely investigate potential LV system voltage effects on a section of the network with high PV system penetration.
Reactive power management.	Presently no problems with reactive power management due to PV systems. However the general issue is currently being assessed/reviewed by P&W. Consideration is being given to larger systems (e.g. 100kW+) providing reactive power support.
<p>Other potential PV penetration effects:</p> <ul style="list-style-type: none"> • Reverse power flow • Network fault protection • PV system islanding • Harmonic injection 	<ul style="list-style-type: none"> ⇒ Not presently an issue. ⇒ Currently no issues due to PV systems. ⇒ Not experienced. ⇒ Not considered an issue (from PV systems).

Canarvon Case Study

- Isolated 11.5MW gas/diesel grid
- 1.1MW of PV capacity installed
- *Case study with Horizon Power*





Canarvon case study

PV Penetration Measure	% PV Pen.
PV Capacity Penetration (%)	9%
PV Peak Power Penetration - Summer (%)	13%
PV Peak Power Penetration - Winter (%)	13%
PV Annual Energy Penetration (%)	4.3%

% of Feeder Cap
8%
3%
3%
2%
2%

PV Capacity as a % of Transformer Capacity
70.29%
63.49%
52.60%
47.62%
40.00%
32.38%
30.12%
28.91%
28.50%
21.32%
17.35%
15.05%
15.00%
11.72%
10.20%

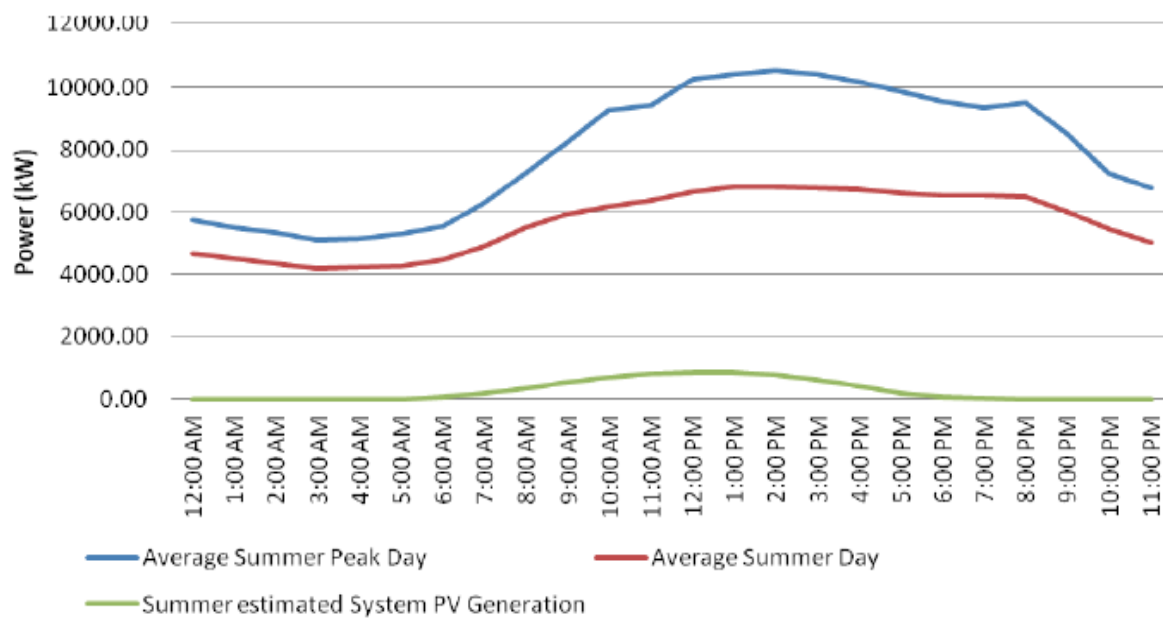


Figure 6: Carnarvon average peak day and average load profile in summer over the period 2006-2011 with estimated aggregate PV system output

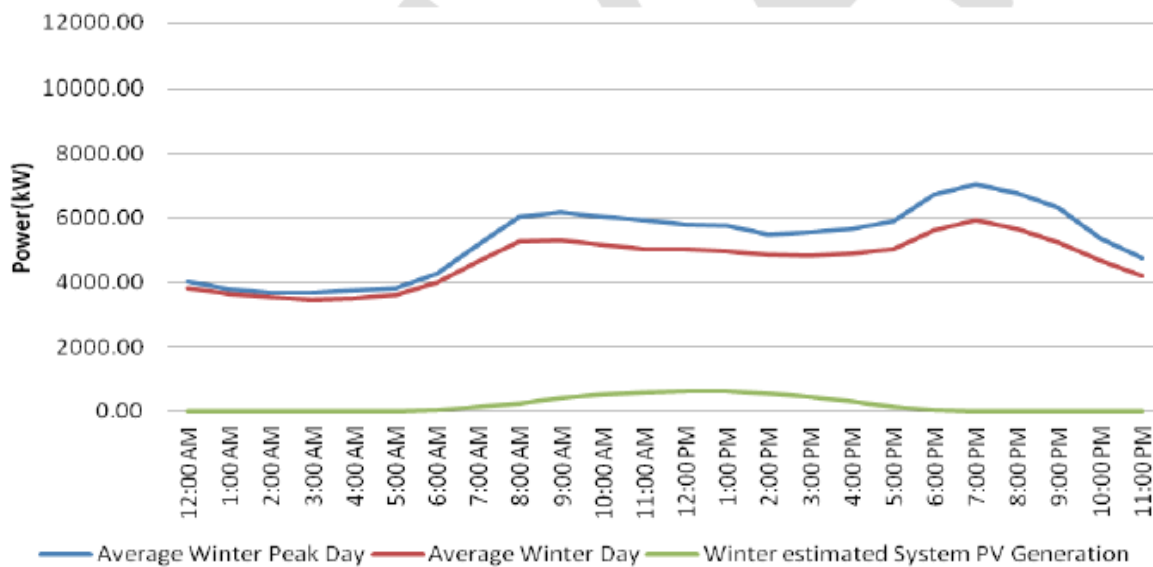
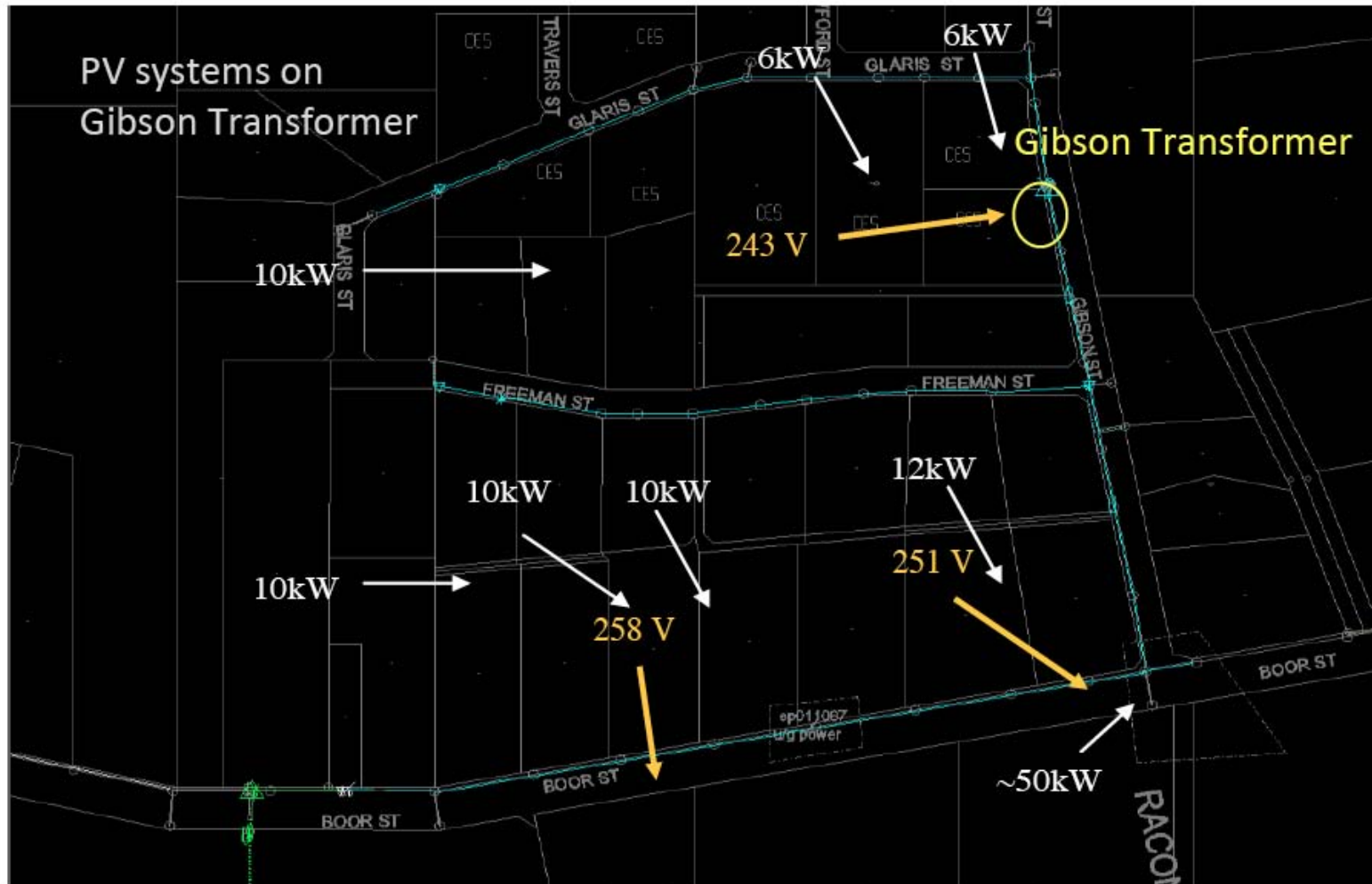


Figure 7: Carnarvon average peak day and average load profile in winter over the period 2006-2011 with estimated aggregate PV system output⁸

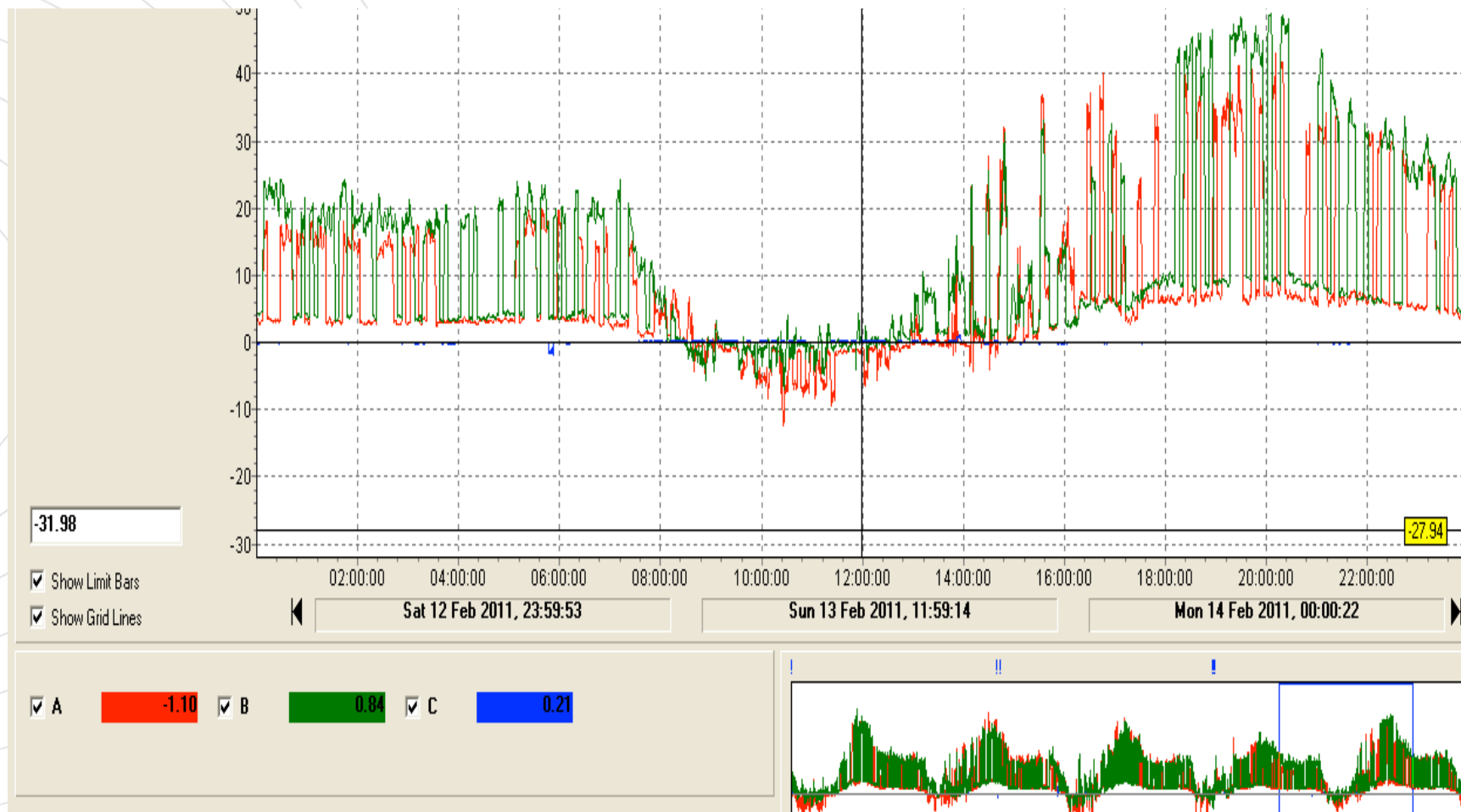
Voltage Rise/Phase Imbalance

A range of solutions:

- Manual tap changing
- Phase change
- Voltage regulation
- Upgrade feeder/ mains



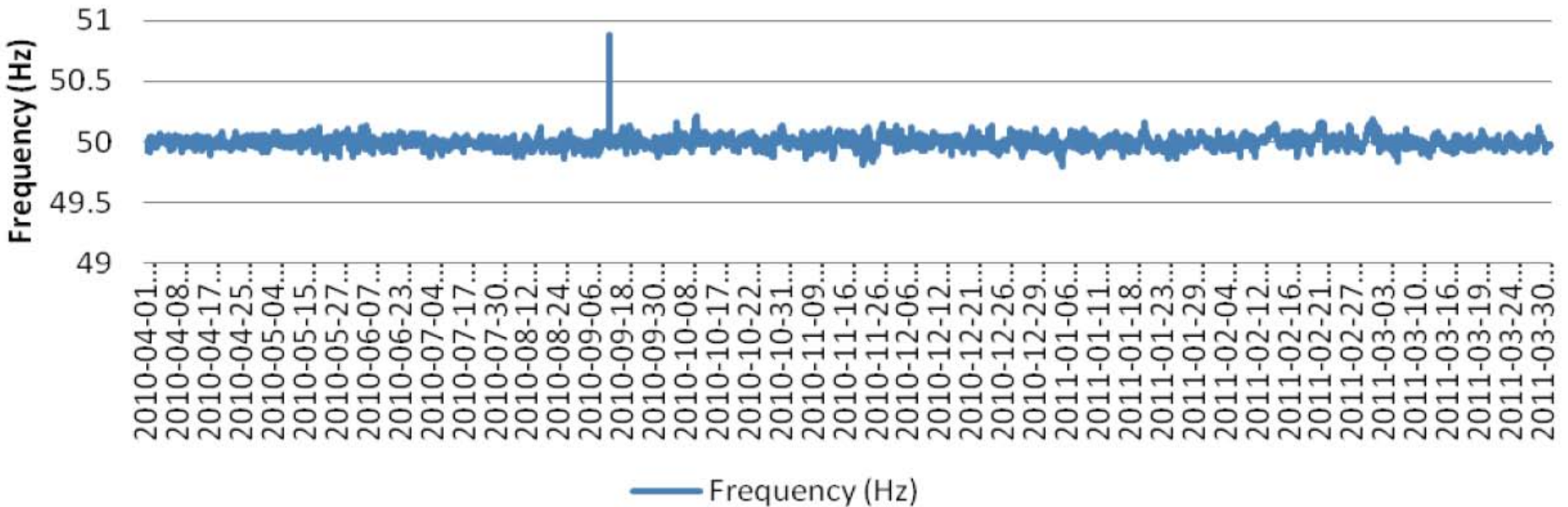
Reverse Power Flow/Reactive Power



System Stability – Cloud Effects

- Cloud Shear
 - Impacts of aggregated systems unknown
 - Time resolution of load data seen by generators insufficient
 - Work being undertaken to predict fluctuations & dynamically adjust spinning reserve
- Solutions
 - Frequency (& voltage) ride through

System Stability – Inverter Protection



- Spinning reserve n-1 – allows loss of largest generator
- Management options:
 - Spread inverter islanding setpoints
 - Controllable loads
 - Larger PV systems monitored and controlled by utility

Inverter Protection Settings

LV Parameter	Min	Max
AS4777 Voltage	200-230V	230-270V
Horizon Power Voltage	225.6V	254.4V
Default SMA Voltage protection set points in Australia	200V	270V
AS4777 Frequency	45-50Hz	50-55Hz
Horizon Power Frequency¹⁶	47.5Hz	52Hz
Default SMA frequency protection set points in Australia	45Hz	55Hz

Table 11: Allowable voltage and frequency ranges as per AS4777 and Horizon Power connection guidelines. Note that an installer can modify the default inverter protection set points.

Fuel Savings & CO₂ abatement

Fuel Type	Volume used per annum for load (kUnits)	Volume offset by PV systems (kUnits)	Carbon Dioxide produced by load requirements (tonnes)	Carbon dioxide offset by PV systems (tonnes)
Diesel	1,561	51	7,369	242
Gas	10,146	308	19,506	591

Power System Planning Strategies

- PV forecasts could be more sophisticated
- Monitoring (of large systems)
- Utility control (e.g. Horizon 300kWp planned system)
 - Can control output
 - Reactive power support
 - Fault ride through
- Potential
 - Dynamic spinning reserve strategy
 - Can regulations be interpreted differently?

Wider objectives for case studies

- Engaging key stakeholders for appropriately facilitating high PV penetrations
- An emphasis on successful innovation to accommodate PV
- Case studies of
 - Key issues arising from high PV penetrations in a range of Australian contexts
 - successful management of these high PV penetrations
 - Identification of future issues and options that support more proactive management in emerging high PV penetrations

Case Study Conclusions

- More work needed to understand cause of issues identified, if and how PV contributes to these
- Best ways of addressing problems
- Experience with wind has tested and in some cases driven changes to industry arrangements
- Rules related to high penetration PV may need reinterpretation/revision:
 - Redundancy, spinning reserve requirements as penetration of intermittent RE increases
 - Voltage and frequency settings of grid connected inverters should be wider (AS4777 now being revised, low voltage ride through)
- Active management of PV and loads
- Significant level of DM can facilitate further penetration increases
- *What arrangements will we 'choose' for disruptive technologies like PV, or (past) air-conditioning, or (possible future) eg. Electric Vehicles*