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Phoebe Heywood

Historical Market Trends of Distributed Photovoltaic Inverters in Australia

Phoebe Heywood[1], Navid Haghdadi[2,3], Anna Bruce[1,3], Iain MacGill[2,3], Naomi Stringer[1,3]

[1]*School of Photovoltaic and Renewable Energy Engineering, UNSW Sydney*
[2]*School of Electrical Engineering and Telecommunications, UNSW Sydney*
[3]*Centre for Energy and Environmental Markets, UNSW Sydney*
Email: p.heywood@unsw.edu.au

Abstract

Some two million distributed PV systems have been installed on rooftops across Australia over the past decade but there is surprisingly little data available about inverter market trends and therefore their potential behaviour and impact on the grid. This paper seeks to remedy this gap with regard to inverter specifications including rated AC power, DC-AC ratio, number of phases and manufacturer. We utilise data on each PV system installation collected by the Clean Energy Regulator, and made available to the Australian PV Institute, combined with the specifications of 1597 individual inverter models. We consider changes in system design and sizing over time, and by State and distribution network service provider. Our analysis highlights that as the price of PV panels and balance of systems components has fallen, there has been a shift towards installations with a higher AC output. However, this is bounded by AC inverter limits set by distribution network businesses, and inverters rated at 5kW now command the largest market share. We also see a strong trend in DC to AC ratio; where inverters were overwhelmingly sized larger or equal to array rated capacity in 2011, whereas roughly 80% of systems installed in 2018 had a smaller rated AC output than the rated DC output of the array. These changes have implications for the operational characteristics of distributed PV and hence the challenges and opportunities they pose for grid integration.

1. Introduction

The Australian Photovoltaic (PV) market has evolved over the past ten years, experiencing a tremendous deployment rate in both the small scale distributed and large utility scale sectors. The total capacity of installed PV systems has increased from the order of 100MW to 13GW in just the past ten years (APVI, 2019) and is expected to rise to possibly more than 40GW according to the Australian Energy Market Operator (AEMO, 2019a). As of June 2019, more than half of the current PV capacity is comprised of around 2.15 million small scale rooftop installations (APVI, 2019). The extraordinarily distributed nature of this source of power, compared to all other electricity generation types, has raised a set of opportunities and challenges (Passey, et al., 2011). One of the most important implications of such distributed and hence diverse installation conditions is the lack of visibility, comprehensive understanding of behaviour, or control over the fleet (AEMO, 2019b). Therefore, given the significant and growing contribution of distributed PV systems in Australia's national electricity market, understanding their characteristics is crucial for security and reliability of Australia's energy system. Methods developed to understand and manage Australia's world-leading distributed PV fleet are also likely to be of interest to other countries facing high distributed PV penetrations.

Aggregate installation data of distributed PV systems by postcode is published by the Clean Energy Regulator (CER), the Australian Government agency tasked with the administration of the Renewable Energy Target (CER, 2019a). Using this data, the historical trend of PV system installations, including the number and DC capacity installed in different Australian geographical locations has been analysed by different institutions (APVI, 2019, AEC, 2019, Sunwiz, 2019). System level data including size, postcode and installation date is also provided to the Australian PV Institute

(APVI, 2019) through disclosure agreements with the Australian Renewable Energy Agency (ARENA). The APVI publishes a set of customisable charts that can be used to view status and monthly trends of capacity and number of PV installations by postcode, LGA or State, broken down by PV (DC) system size category. Distribution Network Service Providers (DNSPs) also collect a range of information about the distributed PV systems connecting to their network, however in many cases, this is limited to the AC (inverter) rating, and does not include information about the DC (PV array) capacity. Moreover, as of December 2019, all PV systems will need to register in a newly implemented database of distributed energy resources (AEMO, 2019c). A review of DNSP grid connection requirements was also published by Noone (2013). However, this review is now outdated and to date there has not been a published study that provides detailed information about inverter market trends in Australia. This paper therefore presents analysis of trends in the characteristics of inverters installed in Australia from 2011 to 2019, using data provided by ARENA to the APVI Solar Mapping Platform (APVI, 2019), combined with specification data of 1597 of the individual inverter models. The analysis investigates market trends in inverter sizes and models, and the impact of connection requirements in place at various times in different Australian States or DNSP regions, on the inverter size, DC to AC ratio, single or three phase connection, and the popularity of different inverter brands and models.

The results of this study may be useful to a range of stakeholders, including PV installers, inverter manufacturers, distribution network service providers, retailers and other third parties acting on behalf of consumers, that are seeking to better understand deployment trends and the implications of inverter connection requirements. The inverter fleet characteristics are also of increasing interest at the power system level, including to the Australia Market System Operator given the potential system security impacts of many highly distributed generators (AEMO, 2019b). For instance, previous work by AEMO has used information regarding inverter type to estimate the possible behaviour of PV during frequency disturbances (AEMO, 2016), and in future a more detailed understanding of the fleet including the number of three phase systems may form an important input to modelling tools such as composite load modelling.

The following sections of this paper present the steps taken and the findings of this analysis. Section 2 discusses the data used and a summary of the supporting databases. Section 3 then covers the method and the key incentives and regulations, followed by results in Section 4. Finally, Section 5 provides a summary of the key implications of these findings and Section 6 concludes the study.

2. Data

2.1. Data Sources

The data on inverter deployment used in this study was collected by the CER from installers and system owners during the registration of Small-scale Technology Certificates (STCs) under the Small-scale Renewable Energy Scheme (SRES) (CER, 2019a). ARENA has provided this database to the APVI to produce the tools on the APVI Solar Mapping platform (APVI, 2019). The data provided by APVI is used widely by industry and has also been used for a number of research projects (Haghdadi et al 2015a, Stringer et al 2019, Haghdadi et al 2015b). The data contains specifics on every distributed PV system under 100kW installed in Australia since 2001 that has created certificates, including the date installed, postcode, locality, DC system size, module brand and model, and inverter manufacturer, series and number.

A number of entries in the dataset were unsuitable for this analysis and were removed. For instance, prior to mid-2011 inverter data was not mandatory and hence many systems did not report their inverter make or brand, and so were unable to be analysed in this study. The analysis in this paper is thus only targeting ‘known’ systems installed after mid-2011, which is equivalent to 79.1% of the total installed number of PV systems in Australia as of June 2019, or 90.1% of the installed DC panel capacity. Other entries removed included those with obvious errors in inverter input and those with DC-AC ratios with a value greater than 2.

Due to potential commercial sensitivity, this research does not identify specific brands, but nevertheless aims to provide as much useful information as possible about inverter deployment trends, particularly to assist the integration of growing distributed PV penetrations. The data used for this paper was accessed at the end of June 2019, however PV system owners are given 1 year to submit their installation to the CER, and so the data for the first half of 2019 is not complete.

Specifications of the inverters installed, most importantly the rated power output, number of phases and the local distribution network service provider (DNSP) were also matched to the inverter installation data. Two databases were used to find the rated power output for each inverter brand and model, namely the California Energy Commission database used by NREL's System Advisor Model (Blair et al, 2018) and the Australian CEC (Clean Energy Council) approved inverter list (available from CER, 2019b). Combining these and adding additional data from the manufacturers' datasheets for specific inverter models allowed 91% of known inverters to be matched with their AC rated power and further analysed. Note that in the following analysis the rated power has been rounded to the nearest hundred Watts. The phase connections for each inverter make were taken from manufacturers datasheets and 82% of systems were able to be matched, excluding those with micro inverters. To identify the DNSP for each installation, the average latitude and longitude for each postcode was matched to a geospatial database of DNSP boundaries sourced from the Australian Renewable Energy Mapping Infrastructure (AREMI) (ARENA, 2019a). Additional information for postcodes in the NT and WA was found online. The DNSP for 97.6% of postcodes were able to be identified using this method.

3. Methodology

Since the SRES database provided by ARENA is populated, in many cases manually, with data input by installers or owners, there are significant variations in how the data are input. The database was carefully inspected and processed to minimise the impact of variation, for instance in the level of detail in reporting the model, formatting, abbreviations and variations in spelling used to report inverter brand name and model number. The inverter size, number of inverters per system, rated AC power output and DNSP were then identified using the above-mentioned databases. With this done, the DC to AC ratio could be calculated by dividing the installed system array size by the rated power output of the inverter. The trend of each parameter over time was then graphed such that this can be compared to known events that may have impacted the market, such as policy changes in FiTs, allocation of STCs under the SRES and, more importantly for inverters, changes in connection requirements and regulation such as the updated AS4777.

Policy mechanisms that have had significant impacts on PV installation trends include the Solar Bonus Schemes in New South Wales and Queensland, which closed in May 2011 and July 2012 respectively, and the STC Multiplier that determined the number of STCs that new installations are eligible to create (APVI, 2019). The 5x STC multiplier ended July 2011, 3x multiplier in July 2012 and 2x multiplier in December 2012, with a 6-month transition period to the end of June 2013. Changes associated with other State FiT schemes had more minor impacts. In terms of regulatory changes during this period, AS4777.2 came into force in October 2016 following a 12-month transition period. This standard covers the requirements for grid connection of energy systems via inverters. AS4777.1 was published in October 2016, with a transition period of 6 months, such that it came into effect on the 30th of March 2017 (GSES, 2017). The standard states that "unless specifically stated by the electricity distributor, the rating limit for a single-phase IES in an individual installation shall be equal to 5kVA" (AS4777.1, 2016). The original standard, introduced in 2005, applied to single phase systems up to 10kVA and 3 phase systems up to 200kVA. Prior to this a limit for single phase connection of inverters was not set.

Many Australian DNSPs have set alternative requirements on automatic approvals for PV system connection within their areas. The best available published inverter limits for each DNSP is given in Table 1, along with the limits as they were in 2013, reported by Noone (2013) and the date of change where available.

Table 1. Historical and current limits on new PV system connections for each DNSP

State	Company	Historical limits (Noone, 2013)	Date changed	Current limits	Notes and Source document
ACT	ActewAGL	10 kW single phase, 200kW three phase		5 kW single phase	
NSW	AusGrid	10 kW per phase	N/A	10 kVA per phase	Secondary systems requirements for embedded generators (Ausgrid, 2018)
	Endeavour	5 kW single phase, 30 kW three phase	N/A	5 kW single phase, 30 kW three phase	Panels limited to 8 kW for single phase. (Endeavour Energy, 2019)
	Essential Energy	10 kW	July-13	3 kW rural, 5 kW urban single phase	Connecting to the network information pack (Essential, 2019)
NT	Power and Water Corporation	4.5 kW residential, 30 kVA for 3 phase commercial	June-17	5 kVA single phase, 7 kVA three phase	Systems within the given limits may export. Larger systems of up to 10kVA single phase and 30kVA three phase may be installed with a zero-export limit (Power and Water Corporation, 2019)
QLD	Energex	10 kW	May-17	5 kVA single phase, 15 kVA three phase	Connection standard for Micro Embedded Generating Units (0-≤30kVA) (ENERGEX and Ergon Energy, 2017)
	Ergon	5 kW	N/A	5 kVA single phase, 15 kVA three phase	Connection standard for Micro Embedded Generating Units (0-≤30kVA) (ENERGEX and Ergon Energy, 2017)
SA	SA Power Networks	10 kW	Dec-17	10 kW single phase, 30 kW three phase	Export limits set in May-19 to 5kW and 15kW respectively. Technical Standard TS129 (SA Power Networks, 2019)
TAS	TasNetworks	10 kW single phase, 30 kW three phase	N/A	10 kW single phase, 30 kW three phase	Requirements for Connecting Micro Embedded Generating Systems to the TasNetworks Distribution Network (TasNetworks, 2017)
VIC	AusNet	4.6 kW single phase, 5 kW three phase		10 kW per phase	Export limited to 5kW per phase (AusNet Services, 2019)
	CitiPower	10 kW per phase		5 kW single phase, 30 kW three phase	CitiPower & Powercor website (CitiPower and Powercor Australia, 2019)
	Jemena	10 kW per phase	N/A	10 kW single phase, 30 kW three phase	Jemena website (Jemena, 2019)
	United Energy	10 kVA per phase	N/A	10 kW single phase, 30 kW three phase	UE Embedded generation network access standards (United Energy, 2017)
WA	Horizon Power	10 kW per phase	N/A	10 kVA single phase, 30 kVA three phase	Horizon Power website (Horizon Power, 2019)
	Western Power	5 kVA single phase, 30 kVA three phase		10 kW single phase, 30 kW three phase	Network Integration Guideline for Inverter Embedded Generation (Western Power, 2019)

4. Results

4.1. Inverter rated capacity trends

Figure 1 displays the installed capacity of the 25 most popular inverter sizes over time. Each size category contains inverters ± 50W of the specified rated power output to capture small variations around these key inverter sizes. This data includes the majority of inverter capacity installed over the analysis period, the remaining inverters are included in the ‘other’ category. Changes in the proportions of inverters installed of different sizes can be seen over the period of the analysis. We can also identify significant events that influenced the market by observing the months in which installed capacity peaks and/or declines rapidly. The spike in July 2012 can be partially attributed to the closure of the Solar Bonus Scheme in QLD, as discussed in methodology, as well as the changes in STC multipliers under the SRES. Prior to his date,1.5-3kW systems were popular (in 2011 and 2012). There is a clear trend away from the smaller inverters after July 2012 towards 4.6 and 5kW inverters, particularly. An inverter capacity of 5kW has emerged as the most popular, especially since the start of 2016, when the new AS4777 standards were released and most DNSPs updated their limits to allow systems with inverters up to 5kW to be installed with automatic approval. This trend is mirrored across nearly all DNSP areas. By 2018, 55% of new installations included a 5kW inverter.

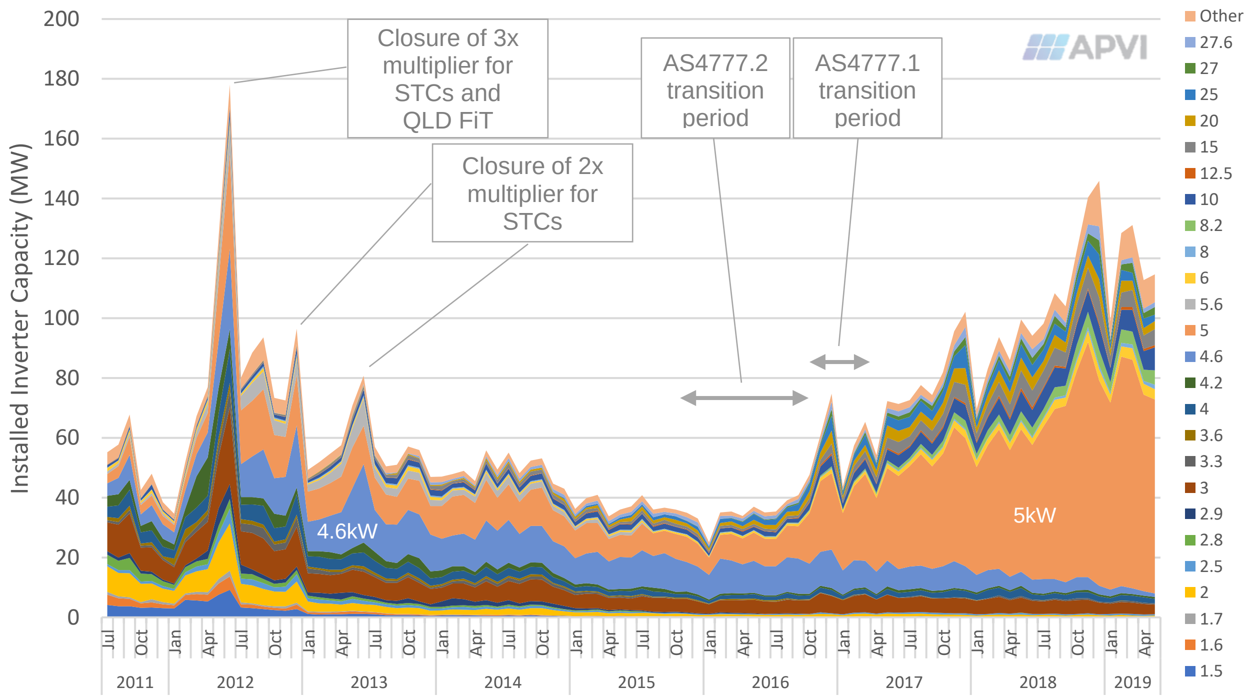

Figure 1: Total identified inverter capacity installed in each month, broken down into the 25 unique sizes (in kW) with the highest capacities.

For comparison, Figure 2 indicates the number of inverters installed in each month. Here all inverters that could be identified are included in the analysis (91% of known inverters), binned into rated power output ranges. From this analysis we can see an increase in the number of microinverters installed in early 2019, by count making up 35% of individual purchases however due to their small size this only makes up 2.4% of the installed capacity.

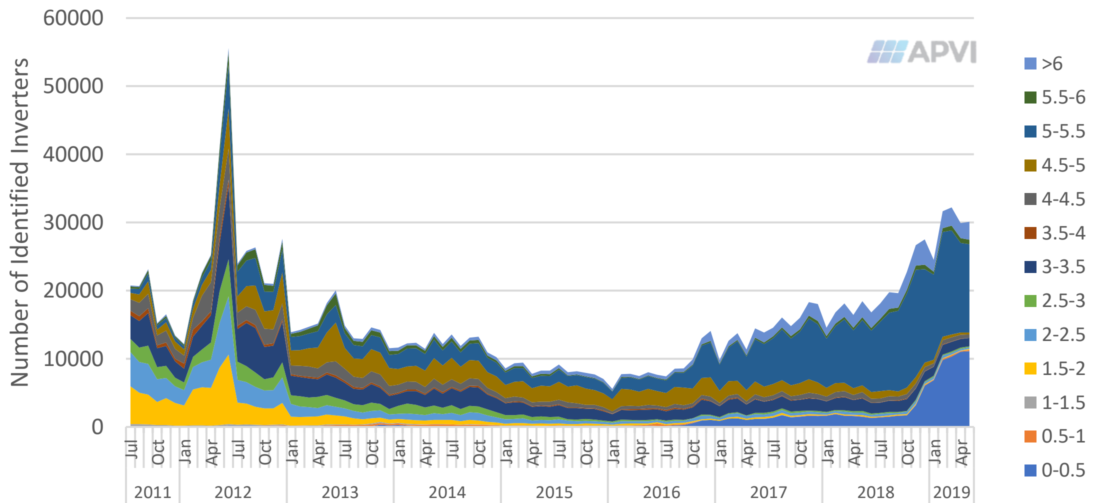

Figure 2: Total number of matched inverters installed in each month, by rated output in kW

4.2. DC to AC ratio trends

The DC to AC ratio in this analysis refers to the ratio between the rated peak power output of the PV array and the rated AC power output of the inverter. A ratio greater than 1 refers to a system where the inverter rated output is smaller than the array rated output.

Figure 3 illustrates the percentage (by number) of PV systems installed such that the DC-AC ratio is less than 1, indicated by the grey shading. Above and below the grey line, each inverter rated power range is shown twice, to indicate the percentage installed with a DC-AC ratio <1 (below the line) and DC-AC ratio ≥1 (above the line). Since 2010 there is a clear shift in popularity from DC-AC ratios less than 1 to greater than or equal to 1. In 2010, 76.8% of installed systems had a ratio less than 1, however by 2019 this had decreased to only 11.7%, with the remaining 88.3% of systems having a DC-AC ratio greater than or equal to 1.

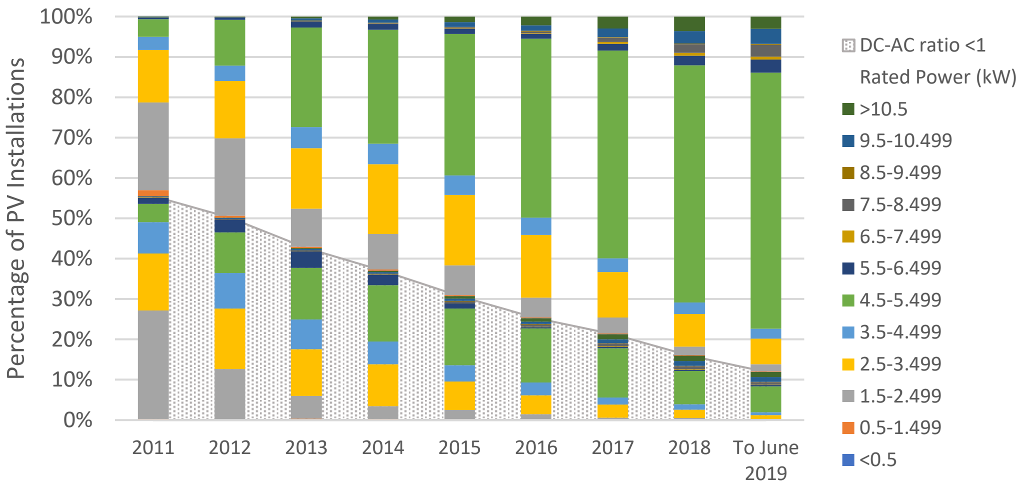

Figure 3: Percentage of systems with inverters in each power output range, separated into DC to AC ratio ≥ 1 or < 1, which is indicated by the shading. Each power value is shown twice, indicating what proportion is installed in each configuration

Figure 5 give greater detail as to the number of systems installed with a specific DC to AC ratio. We can see that the most popular ratio overall is 1, however the number of systems with this ratio has been dropping off since late 2015. The number of systems installed with ratios between 1.2 and 1.4 have been growing exponentially since start of 2016. The modal ratio in the first half of 2019 is 1.32, which is the maximum ratio allowed by the CEC in their design guidelines (CEC, 2013), and must be adhered to for the system to be eligible for STC's. With the most popular inverter size of 5kW, this corresponds to a 6.6kW system, which is also the most popular PV system capacity installed (APVI, 2019). This suggests that as prices decrease customers are trying to maximise their system size while still remaining within the limits for automatic approval set by network service providers. This AC-DC ratio will cause curtailment of the PV output on the inverter maximum power limit and therefore has implications for the variability and generation profile of these systems. Since PV systems must reduce their real power output when operating in volt-var mode at maximum inverter power output, this trend also raises concerns around limited inverter headroom for providing services such as volt-var response.

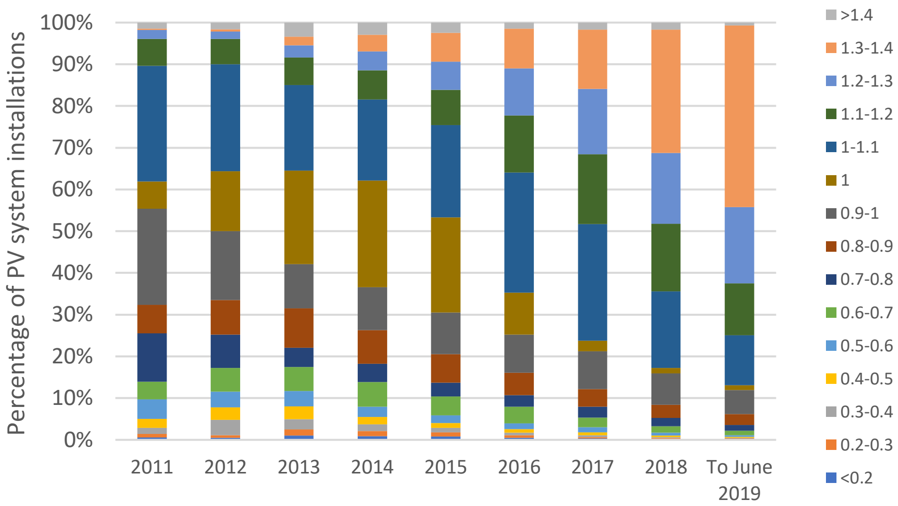

Figure 4: Relative proportion of systems installed with each DC-AC ratio in each year. Note that bands include the lower bound but not the upper bound, and that 1 includes ratios between 0.995 and 1.005

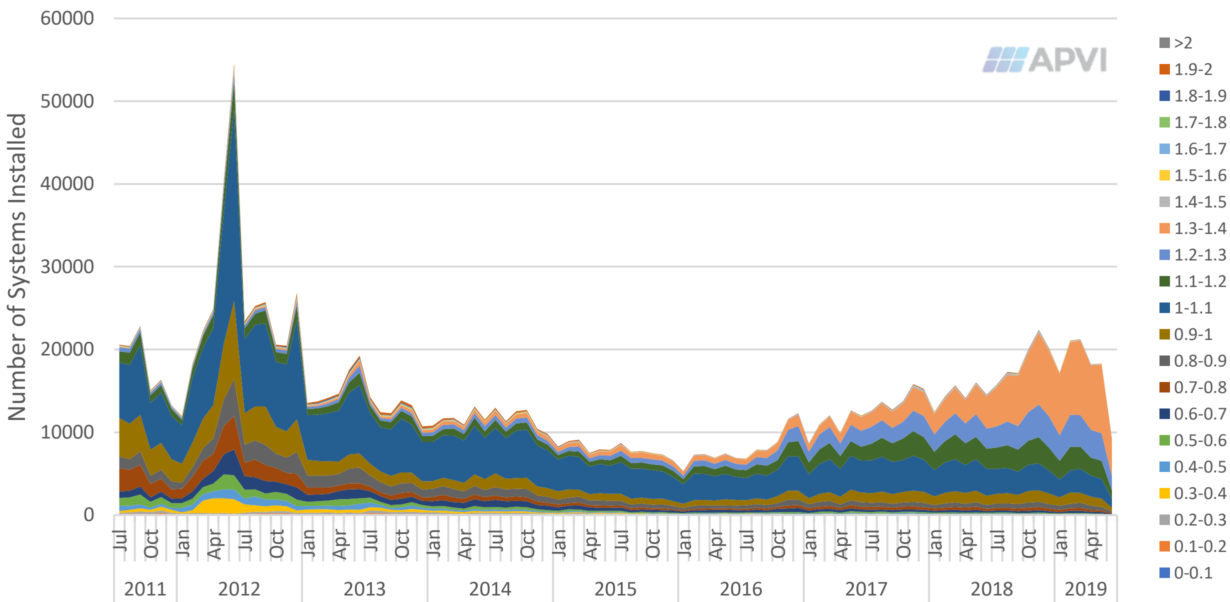

Figure 5: Area graph indicating the number of systems installed in each month, broken down by DC to AC ratio

4.3. System phase configuration trends

Distributed PV systems can be connected in either single phase or three-phase configuration, which is often required by the DNSP according to the type of existing grid connection as well as the inverter size. The number of connection phases for most inverters in the database was determined from the manufacturers' datasheets. Due to the limits set by each DNSP on the maximum PV system allowed under each connection type, we would expect systems under 5kW to be single phase and systems over 10kW to be connected to 3 phases. Systems in between may be connected to either depending on the local limits. Figure 6 shows the difference in the inverter capacity installed with each connection type over time. Initially three-phase systems were rare, likely due to the price gap and the stronger deployment of smaller systems at the time. The proportion has slowly increased over time, with the biggest change noticeable in the fourth quarter of 2016, around the time that AS4777 was updated, specifying a maximum of 5kVA for an inverter single phase connection unless set otherwise by the DNSP. This may have led to three-phase systems gaining a much stronger share of the market in the last 3 years.

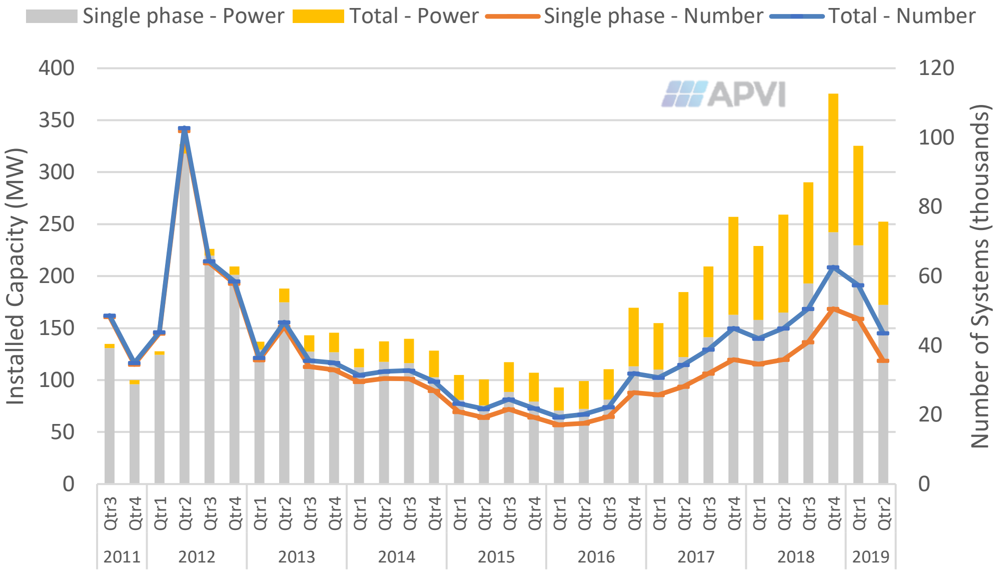

Figure 6: Installed capacity and number of analysed inverters over the last 10 years, separated by number of inverter output phases. Note that the blue line indicates the sum of single and three-phase systems, such that three-phase by number is the difference between the blue and orange lines.

Figure 7 displays this data separated into the top 10 most commonly installed inverter sizes in each DNSP. The installations vary between DNSPs but are much more similar within each state or territory. We can see that 5kW is the most commonly installed inverter in every distribution network area, and also the inverter size where three phase systems start to appear. In every DNSP apart from Western Power, 4.6kW is the second most installed inverter capacity, likely since it is just below the limit, and some inverter makes that are listed at 5kW actually have a rated output of 4.6kW. 3kW inverters are also popular, particularly in rural areas (Essential and Powercor) where there may be additional limits set for high impedance lines and in areas which had higher early uptakes when smaller systems were more popular.

Further analysis not presented here showed that across NSW, there is an increasing number of larger three phase systems, which is also seen in the CBD DNSPs in Victoria (Citipower, Jemena and United Energy). This may be in part influenced by installations in the commercial and industrial buildings market. Across all Australia, the Northern Territory has the highest proportion of capacity with three phase systems at 34%, followed by New South Wales at 30%. The national total is 22%.

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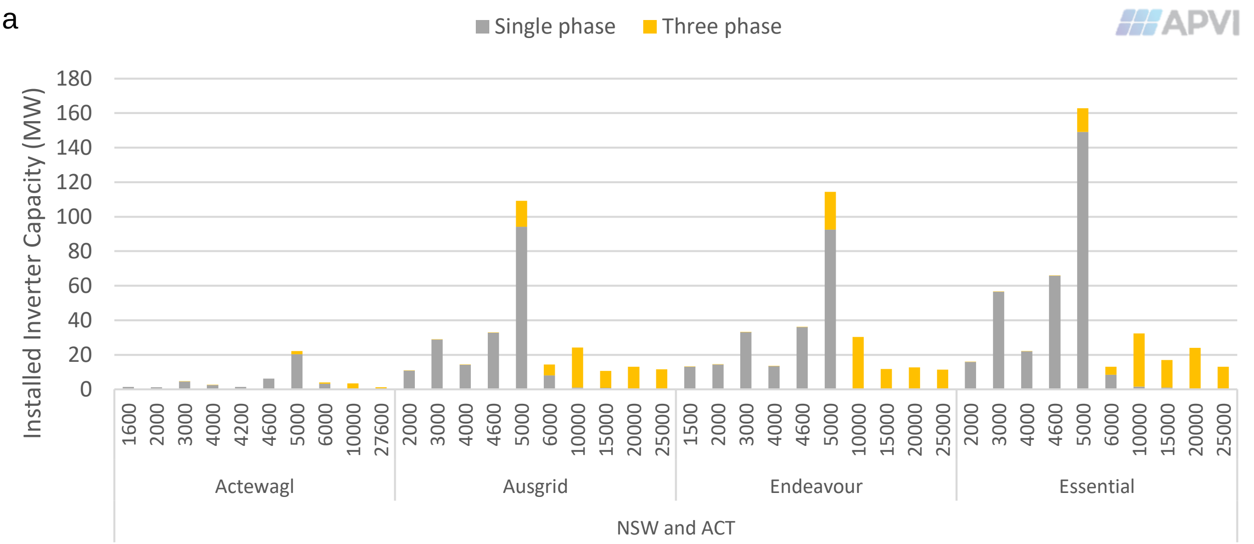
Single phase
Three phase
APVI
Installed Inverter Capacity (MW)
0 20 40 60 80 100 120 140 160 180
1600 2000 3000 4000 4200 4600 5000 6000 10000 27600
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Actewagl
Ausgrid
Endeavour
Essential
NSW and ACT

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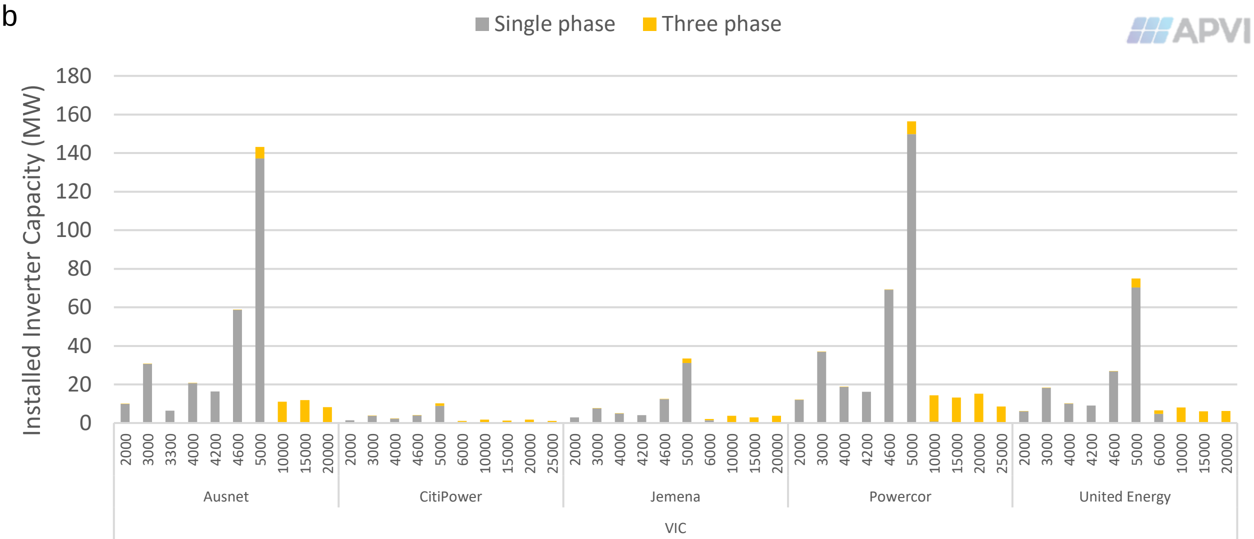
Single phase
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Installed Inverter Capacity (MW)
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CitiPower
Jemena
Powercor
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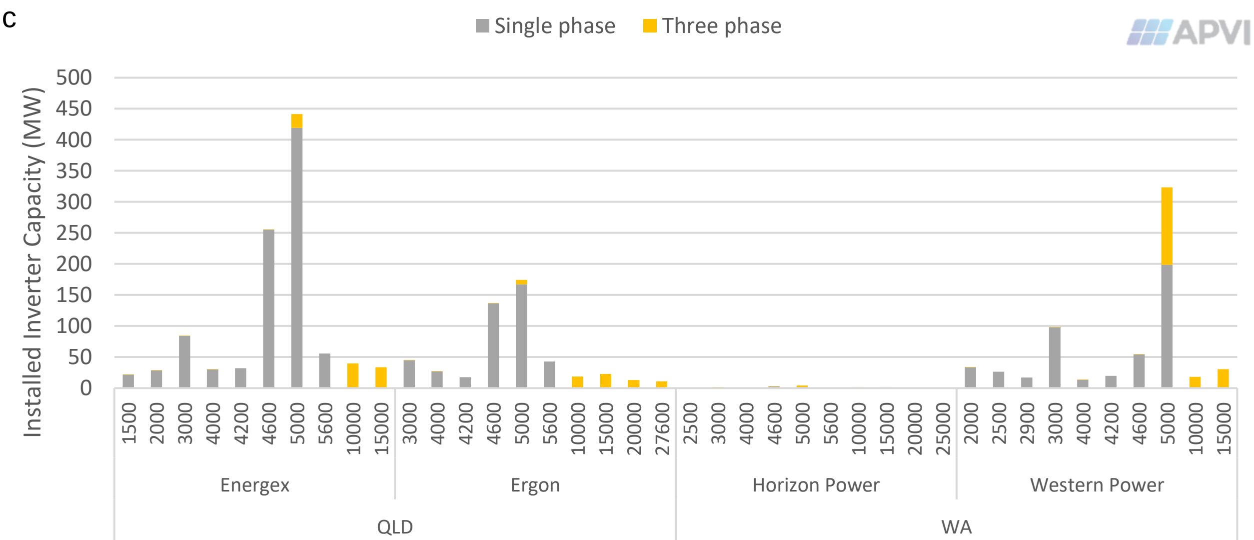
Single phase
Three phase
APVI
Installed Inverter Capacity (MW)
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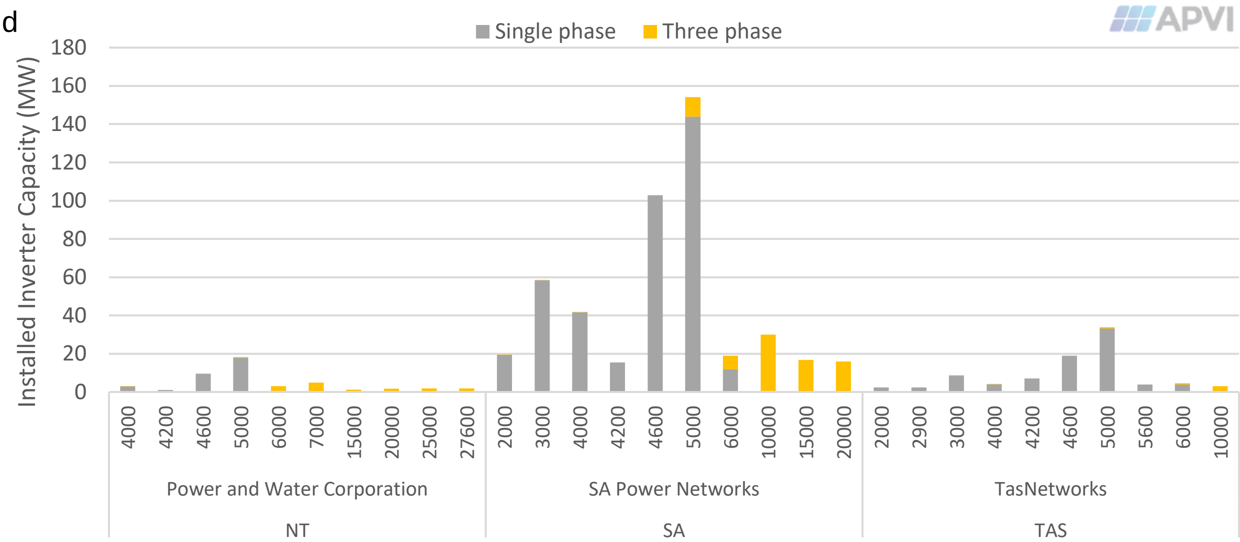

Figure 7: Capacity of matched inverters installed across each of the top 10 most installed inverter ratings in Watts (± 50W) in each DNSP, separated by number of phases. Chart a displays the data for NSW and the ACT, b covers VIC, c is QLD and WA and d contains NT, SA and TAS.

4.4. Inverter brands

There has been considerable development of the market for distributed PV inverters in Australia and internationally over the last 9 years, including changes in product requirements according to standards and consumer demand, and there have been significant changes to market share. Figures 8 and 9 show the relative sizes of the Australian inverter market held by each of the most popular 20 companies, quantified by installed capacity and number of inverters installed respectively. Note that brand names are not included, and the colours are not consistent between charts. Looking at Figure 8, we can see that about half of the brands that were most popular in 2011 have remained in the market, and with a largely unchanged share in terms of capacity. However, there is also an apparent shift in the market between pre- and post- 2015, which is potentially due to the new AS4777.2 coming into effect, but may have also been impacted by changes in price, marketing and agreements between manufacturers/distributors and installers. A number of brands that were initially very popular disappeared from the market around this time, some of which are as a result of being de-listed from the CEC Approved Inverter list. Two brands that historically held a small proportion have emerged as the most installed in 2018. The differences between these two figures can be partly attributed to the variation in popular inverter sizes over time, and the recent increase in sales of micro-inverters, which have an impact on the number installed but each contribute only a small amount to the capacity installed.

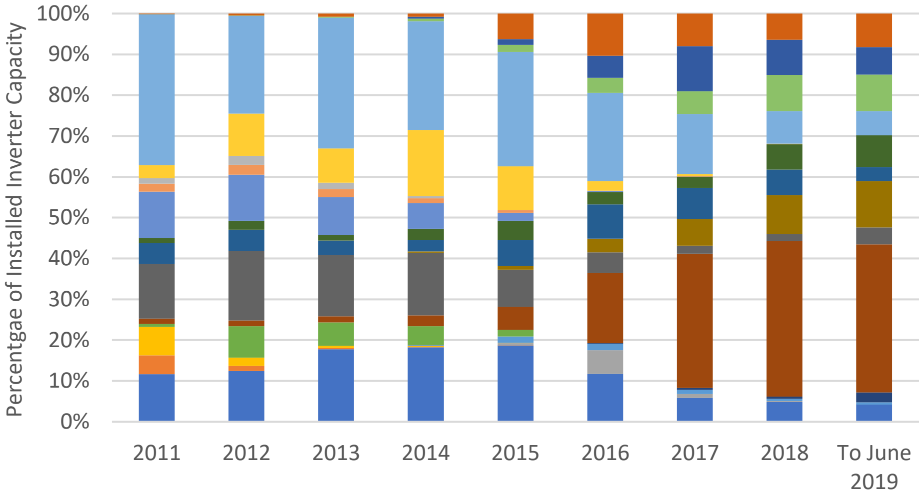

Figure 8: Proportion of the market held by each of the top 20 most installed brands (by capacity), shown by installed capacity

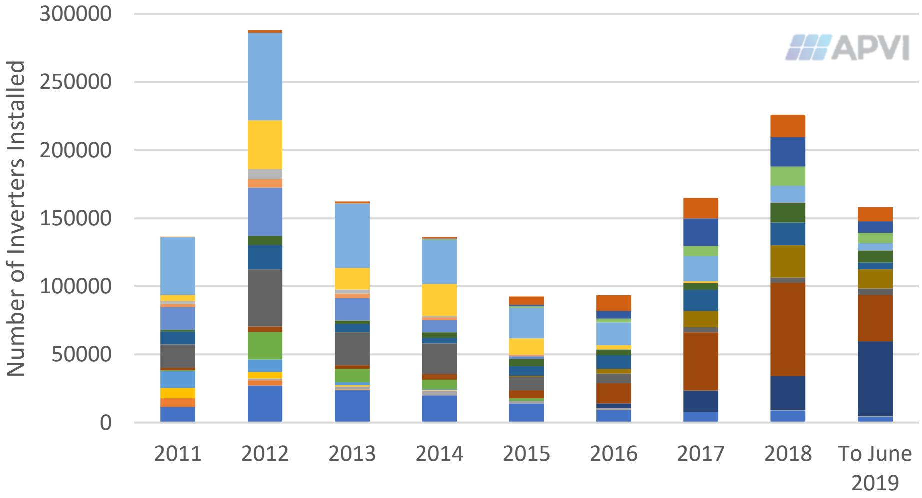

Figure 9: Number of inverters installed in each year manufactured by the top 20 most installed brands (by number of inverters installed)

5. Discussion and implications

5.1. Inverter rated capacity

Local network voltage management is widely identified as one of the key challenges for integrating high penetrations of distributed PV. Larger systems are more likely to export power to the grid and may therefore exacerbate already high voltage conditions in the LV network. This may result in increased PV tripping or operation of the V-W and V-Var response modes.

5.2. DC to AC ratio

The trend towards increased DC-AC ratios is likely due to reduced PV module costs coupled with DNSP inverter or export limits or possibly AS4777 limits on single phase inverter connection and is therefore likely to continue. A fleet of increasingly high DC-AC ratio systems is expected to increase clipping and change the overall PV generation profile shape which is important to appreciate when modelling distributed PV contribution. This has relevance to predicting minimum demand and modelling system wide impacts of distributed PV. It also is noted that trends towards higher DC-AC ratios will result in PV systems operating at maximum inverter output more frequently. At such times, operation in V-Var mode will also reduce the real power output of the inverter.

5.3. System phase configuration

In the last few years we see an increase in popularity for PV systems with three phase connections, mostly in systems with an inverter rating higher than 5kW. Three phase systems may make it easier to manage network voltage phase imbalance (compared with single phase systems). It is also important to understand the proportion of three phase systems existing in the inverter fleet because these inverters may respond differently during disturbances with system security implications.

5.4. Inverter brands

PV behaviour during disturbances is observed to vary widely by inverter model (ARENA, 2019b), so it will be increasingly important to understand which inverter brands dominate the market. It is also important to understand the fleet characteristics when considering future options for interoperability and control, which may differ significantly by brand. Finally, it is necessary to understand the diversity of the inverter fleet when designing communication and control systems, and hosting capacity methodologies and models.

6. Conclusion

Analysis of the distributed PV system data collected by the CER and provided to APVI by ARENA, and detailed matching of installation data with inverter specifications has allowed for valuable insights into the trends in the Australian inverter market over the last 10 years. The market has changed quite significantly in this time which has implications both for those involved in the PV industry and those in the broader electricity industry facing challenges of integrating high penetrations of distributed PV. A trend was observed in both array size and inverter size towards larger distributed systems. Where 2-3kW inverters made up the largest proportion of systems installed in 2011, the market is now becoming overwhelmingly dominated by single phase 5kW systems. This trend is influenced by both the newly updated AS4777 and DNSP requirements around the country. Nearly 50% of DNSPs have set 5kW as the limit for single phase systems, and others have set this as the export limit which further promotes this as the preferred size. Looking at DC to AC ratios, the trend moves away from ratios less than 1. Many inverters are now installed with a DC-AC ratio above 1 to maximise annual PV outputs while still meeting DNSP limits. The most common ratio in the first half of 2019 was 1.3, suggesting that many installations try to fit the highest number of panels that can be connected to their inverter. Three phase systems are starting to play a larger role in the distributed space especially since they are the preferred option for systems over 10kW. There are variations in the most popular brands over time, with companies moving in and out of the market. The most significant change is visible around 2015, when the new standards became enforced leading to some brands being removed from the approved list and other inverters needing upgrades in order to comply.

Overall there are observable trends in the brand, size and configuration of inverters installed in small-scale distributed systems across Australia. Many installations seem to be influenced by the financial incentives available, and an increase in number of installations occurs when these schemes are slated to close, followed by a dramatic fall. We also see that many installations choose inverter sizes that maximise capacity according to the DNSP restrictions for automatic approval and export limits, and these limits are leading to a more homogeneous market. These results improve the understanding of the Australian inverter fleet and are particularly important as inputs to modelling distributed PV behaviour and can inform their regulation PV system.

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