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Small Scale Domestic Rooftop Solar Photovoltaic Systems

Technical Note 10
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Endeavour Energy

University of Wollongong

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1. Executive Summary

This Technical Note examines small scale domestic rooftop solar PV systems and more specifically, the subset known as grid connect systems. A description of the components, including construction and operating characteristics, which constitute a solar PV generating source, namely solar panels and the grid-connect inverter is given. The level of solar resources in Australia and the pros and cons of solar PV systems are discussed. A review of the Australian standards concerning connection of PV generation is presented. Finally, the Technical Note examines some of the potential engineering difficulties associated with the connection of large numbers of solar PV sources. These potential difficulties include deterioration of network power quality levels, interference with protection schemes and stability problems.

2. Introduction

Strong community sentiment with respect to mitigation of climate change, desires to reduce electricity costs and various government climate change abatement incentives, including generous feed-in tariffs, have led to an exponential increase in the number of small scale (less than 10 kW) solar photovoltaic (PV) systems being connected to electricity distribution networks.

Traditional electricity distribution systems have been designed and built to distribute power from large generation plants to end-users. This arrangement is known as centralised generation. Connection of large numbers of small generating sources, one example of which is solar PV, is known as distributed generation (DG). DG represents a significant change in the power distribution paradigm and has presented some foreseen and unforeseen technical difficulties. Domestic rooftop solar PV systems are generally small, with generation capacities in the range of 1.5 – 5 kW. This Technical Note specifically applies to systems under 10 kW rating for single-phase and 30 kW rating for three-phase applications.

3. Grid-Connected Solar PV Installations

In NSW, the main driver of increased domestic rooftop solar PV system uptake was the Solar Bonus Scheme Act which came into force on 1st January 2010. Under this scheme a solar feed-in tariff of 60 cents per kilowatt hour was guaranteed for seven years. This scheme led to exponential growth in applications for connection of rooftop PV systems to the electricity network as illustrated in Figure 1 which shows the number of applications received per month for one NSW electricity distributor. Such high levels of take-up were not anticipated when the scheme was designed and implemented.

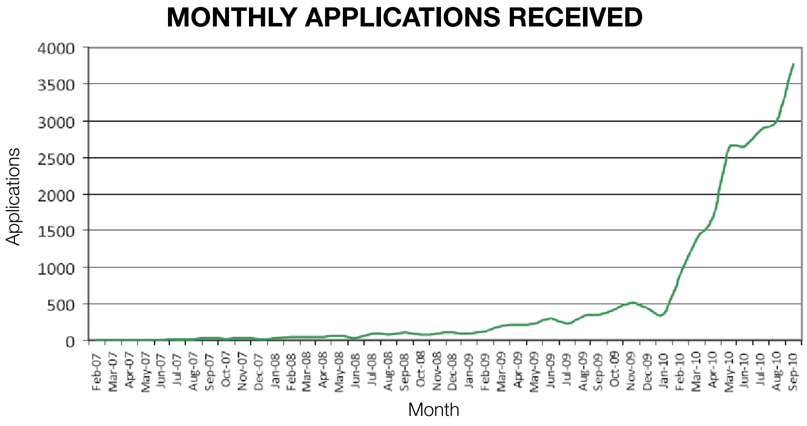

Figure 1: Monthly Rooftop Solar Connection Applications for one NSW Electricity Distributor [1]

Other Australian states with generous feed-in tariffs have seen similar trends in grid-connected solar PV system connection applications and installations. This is especially the case in Queensland and Western Australia; two states with vast solar resources. The report "PV in Australia 2010" [2] prepared by the Australian PV Association details the number of grid-connect solar PV systems as of 2010. Figure 2 sourced from this report clearly shows the exponential increase in grid-connected systems over the last two years.

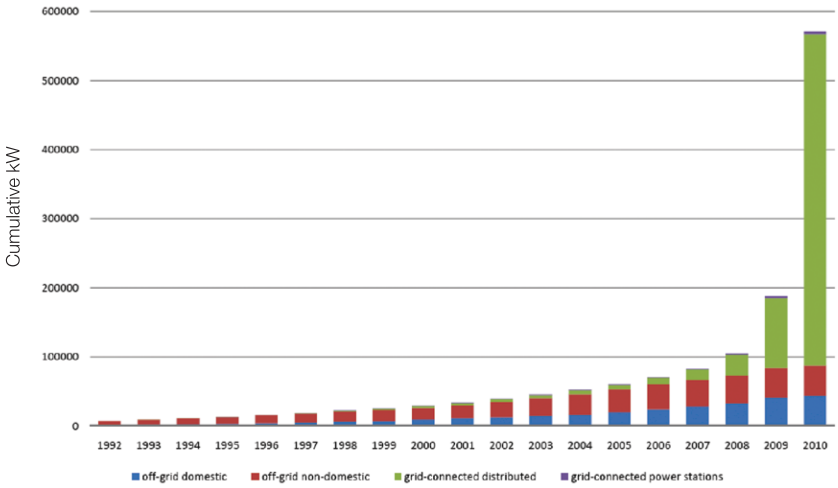

Figure 2: Cumulative Solar PV Installations 1992 – 2010 [2]

4. Basic Composition of a Solar Photovoltaic System

The basic solar photovoltaic (PV) system is comprised of two main components; the solar panels, consisting of a number of solar cells, which convert sunlight to electricity and a power conditioning device known as an inverter which acts as the interface between the solar panels and the load. The inverter transforms the direct current (DC) generated by the solar panels into alternating current (AC) compatible with the requirements of the load.

There are two main configurations for solar PV systems; with and without energy storage. PV systems with storage elements (most typically batteries) allow power generated when solar resources are available to be stored for later use. Systems of this type are often used in remote areas where other means of supply are not available. In such systems, the DC generated by the solar panel is used to charge the energy storage elements. This stored energy may then be utilised in one of two ways; AC or DC distribution. If AC power is required, an inverter is used to transform the DC supplied by the batteries to AC. In some cases, DC distribution is preferred to conversion to AC power as it reduces losses. In these applications, the DC power supplied by the batteries is directly supplied to specially designed DC loads. For PV systems without energy storage, power is only available from the PV system when the sun is shining. One subset of these systems is those known as grid-connected or grid-tied systems. For these systems, the electricity grid is the load. It is these systems that are the main focus of this Technical Note.

5. About Photovoltaic Solar Cells

Each solar PV panel comprises a number of smaller elements known as solar cells. These solar cells form the basic building blocks of solar panels and are added together until the desired solar panel specification is reached. A solar cell is a semi-conductor device which has much in common with diodes and transistors. The solid state physics which explains the operation of solar cells is beyond the scope of this Technical Note. However, in simple terms, solar cells use the properties of semi-conductor devices to exploit the solar photovoltaic effect and generate electricity. Detailed explanations of solar cell physics can be found in any good textbook on solar PV systems.

There are two main commercial solar cell manufacturing technologies currently used. These are crystalline silicon cells and thin film cells. Each of these technologies is discussed in detail below.

5.1. Construction of Solar Panels

Solar panels are made up of a number of solar modules connected together in order to achieve the desired panel shape and power ratings. Solar modules consist of a number of solar cells. The overall solar panel has the same characteristic behaviour as the cells and modules which constitute it. Commercially available solar panels range in rated power from around 2 W up to 300 W with maximum voltages of approximately 12 V – 35 V DC. A number of solar panels connected together is known as an array. Figure 3 shows the photovoltaic hardware hierarchy.

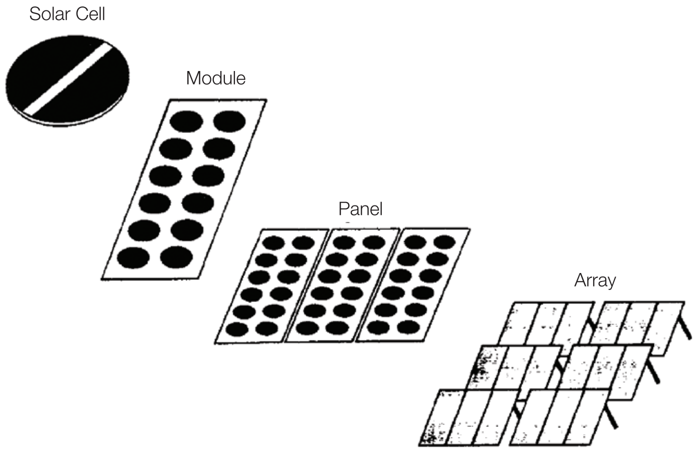

Figure 3: Solar Photovoltaic Hardware Hierarchy [3]

5.2. Crystalline Silicon Cells

Crystalline silicon cell technology is very mature, having been around since the 1950s. The first application for crystalline solar cells was power production for space craft. Over time, solar cells have developed and are now used for more mundane terrestrial power generation. There are two main types of crystalline solar cells; single crystal (or monocrystalline) and multicrystalline. The process of manufacturing crystalline solar cells involves melting and purifying silicon in a crucible. For the monocrystalline cell a seed crystal is then used to slowly draw a single-crystal cylindrical ingot. For the multicrystalline cell, instead of drawing single crystals, the molten silicon is directly cast into ingots. Monocrystalline cells are more efficient than multicrystalline cells, however, they are considerably more expensive, energy intensive and slower to manufacture and a considerable amount of silicon is lost through having to cut the cylindrical ingot into squares or rectangles to form solar modules (panels).

5.3. Thin Film Cells

Manufacture of thin film cells involves depositing photovoltaic materials directly onto suitable substrate materials. Although thin film solar cells are currently less efficient than crystalline cells, manufacturing requires significantly less materials and as such thin film cells are less expensive per unit watt generated. Four main types of commercially viable thin film cells currently exist. These are thin film silicon (e.g. amorphous silicon), copper indium diselenide, cadmium telluride and gallium arsenide. A full explanation of the chemical composition and manufacturing of the aforementioned thin film cells is beyond the scope of this Technical Note. Thin film cells are gaining popularity due to their lower manufacturing costs and ease of installation due to flexibility and lighter weight.

5.4. Solar Cell Efficiencies

The theoretical maximum efficiency for a crystalline silicon solar cell is 29% [4]. In laboratory environments, cell efficiencies of approximately 25% have been achieved [5]. The efficiency of commercially available solar panels is considerably lower than the levels achieved in the laboratory. The most efficient commercially available panels have efficiencies of approximately 15%. At present, commercially available thin film solar panels are considerably less efficient than crystalline silicon panels. Commercially available thin film panel efficiencies are currently limited to approximately 9% [6].

5.5. Solar Cell Electrical Output Characteristics

The basic I-V (current-voltage) characteristic curve of a solar cell is shown in Figure 4. As can be seen, the solar cell basically acts as a constant current source up to a given output voltage after which current magnitude falls away rapidly. There is a single point on the curve (labelled as P_{max} in Figure 4) which corresponds to the combination of voltage and current magnitudes which result in the maximum power being delivered by the solar cell.

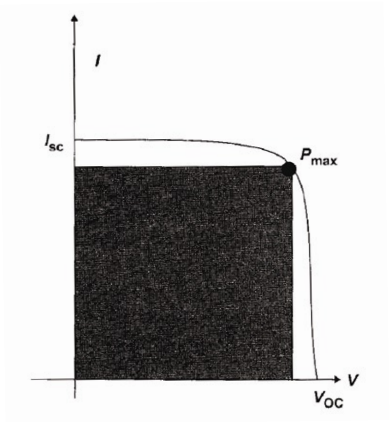

Figure 4: Solar Cell Basic I-V Curve [5]

6. Factors Affecting Solar Cell Output

Three main factors impact on the output of solar PV cells. These are:

- Operating temperature
- Sun intensity
- Sun angle

6.1. Operating Temperature Effect

With increasing ambient temperature, the operating temperature of the solar cell will increase. As cell temperature increases, output current increases while output voltage decreases. However, the change in current is not nearly as great as the change in voltage leading to an overall decrease in output power. The voltage decrease of a typical silicon solar cell is 2.3mV/°C [5]. Figure 5 demonstrates the impact of cell operating temperature on the

I-V characteristics of a solar cell. Since a solar module is made up of a number of cells connected in series the output voltage decrease due to temperature rise may become significant. Figure 6 shows the I-V characteristics of a commercially available solar module which contains 32 individual cells [7].

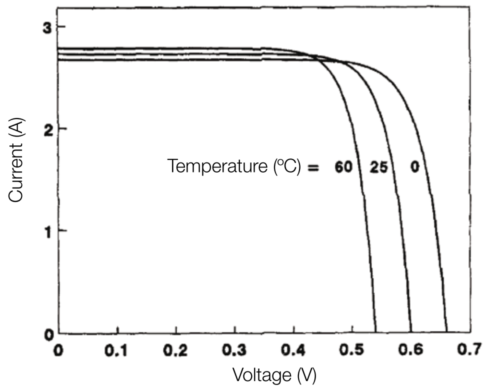

Figure 5: Theoretical Impact of Cell Operating Temperature on Output [5]

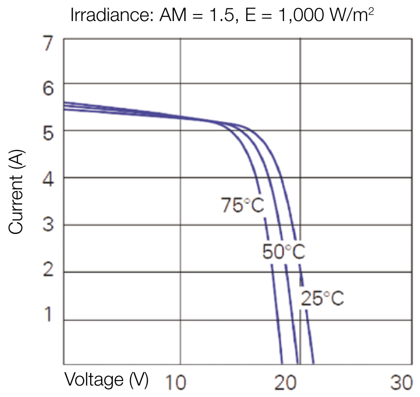

Figure 6: Impact of Cell Operating Temperature on Output of a Commercially Available Solar Panel [7]

6.2. Solar Intensity (Irradiance) Effect

Solar irradiance is the amount of solar energy that arrives at a specific area at a specific time. The short circuit current (i.e. maximum current) generated by a solar cell or module is directly proportional to the solar irradiance with short circuit current level increasing as irradiance increases. The output voltage is also dependent on irradiance and increases slightly as irradiance increases. The change in voltage is negligible compared to the change in current and is generally ignored in practical applications. Figure 7 illustrates the I-V dependence of a solar cell on solar irradiance while Figure 8 shows the I-V dependence on irradiance for a commercially available solar module.

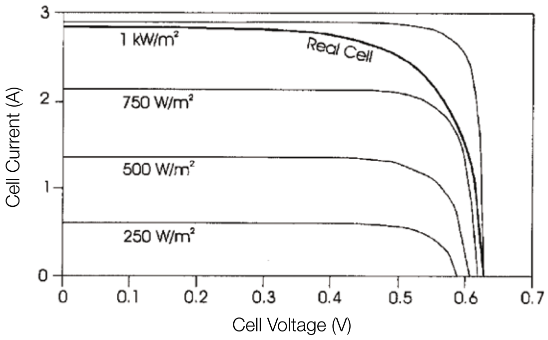

Figure 7: Theoretical Impact of Irradiance on Solar Cell Output [3]

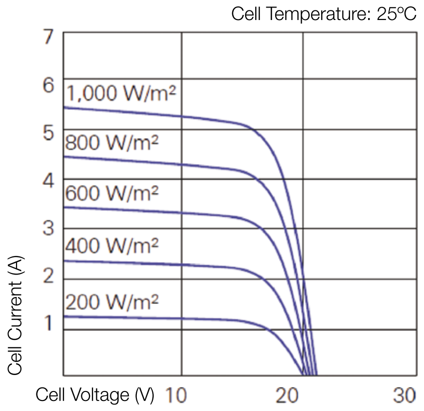

Figure 8: Impact of Irradiance on Output of a Commercially available Solar Panel [7]

6.3. Sun Angle Effect

The cell output current is given by the equation $I = I_o \mathrm{Cos}\,\theta$ where I_o is the current with normal sun and θ is the angle of the incidence of sunlight. According to this equation the optimum sun angle is 0 degrees i.e. sun shining directly down on the cell. Figure 9 illustrates the impact of sun angle on cell output current. However, the transit of the sun through the sky means that stationary solar arrays (i.e. without sun tracking systems) cannot maintain an incidence angle of 0 degrees. As such, a compromise must be made when solar panels are installed in order to achieve the best possible power output. Further information related to this topic is provided in Section 8, which describes practical solar system installation.

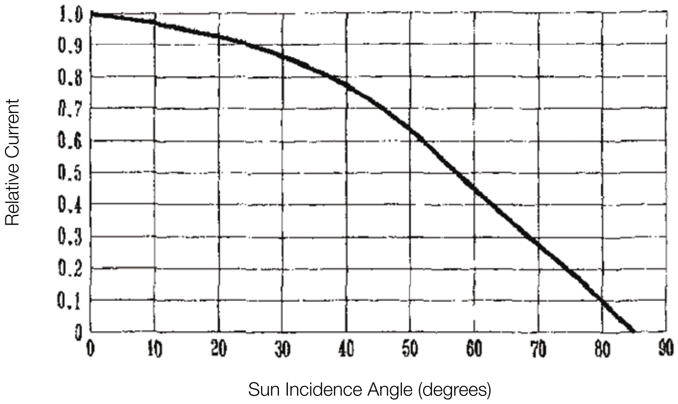

Figure 9: Impact of Sun Incidence Angle on Solar Cell Output [8]

7. Pros and Cons of PV Systems

The table below lists some of the advantages and disadvantages of solar PV systems.

PROS	CONS
Simple – there are no moving parts, no water is required, no regular maintenance is required.	**Variability** – no generation during the evening. Shading from clouds, trees, etc. dramatically reduces output. Power is also unable to be scheduled.
Modular – capacity can be easily increased through the addition of extra panels and inverter capacity.	**Cost** – still higher per kWh than coal and gas.
Long Life – panels typically have a 25 year lifespan. Inverter lifespan is around 10 years.	**Area** – relatively large area needed to generate relatively small amount of power due to low cell efficiencies.
Short Lead Time – systems can be installed very quickly.	**Power Quality Issues** – including steady state voltage rise.
Renewable – effectively infinite energy source.	**Polysilicon** – may become rare or expensive as demand increases.

Table 1: Pros and Cons of Rooftop Solar Photovoltaic Systems

8. Practical Aspects of Solar Installations in Australia

Most regions of Australia have significant solar resources and, as such, solar systems will generally perform well in Australian conditions. Figure 10 shows an annual solar insolation plot for the world. It can be seen that parts of Australia have some of the largest insolation levels of anywhere in the world. High solar insolation levels combined with large areas of open space make Australia an ideal location for generation of solar electricity.

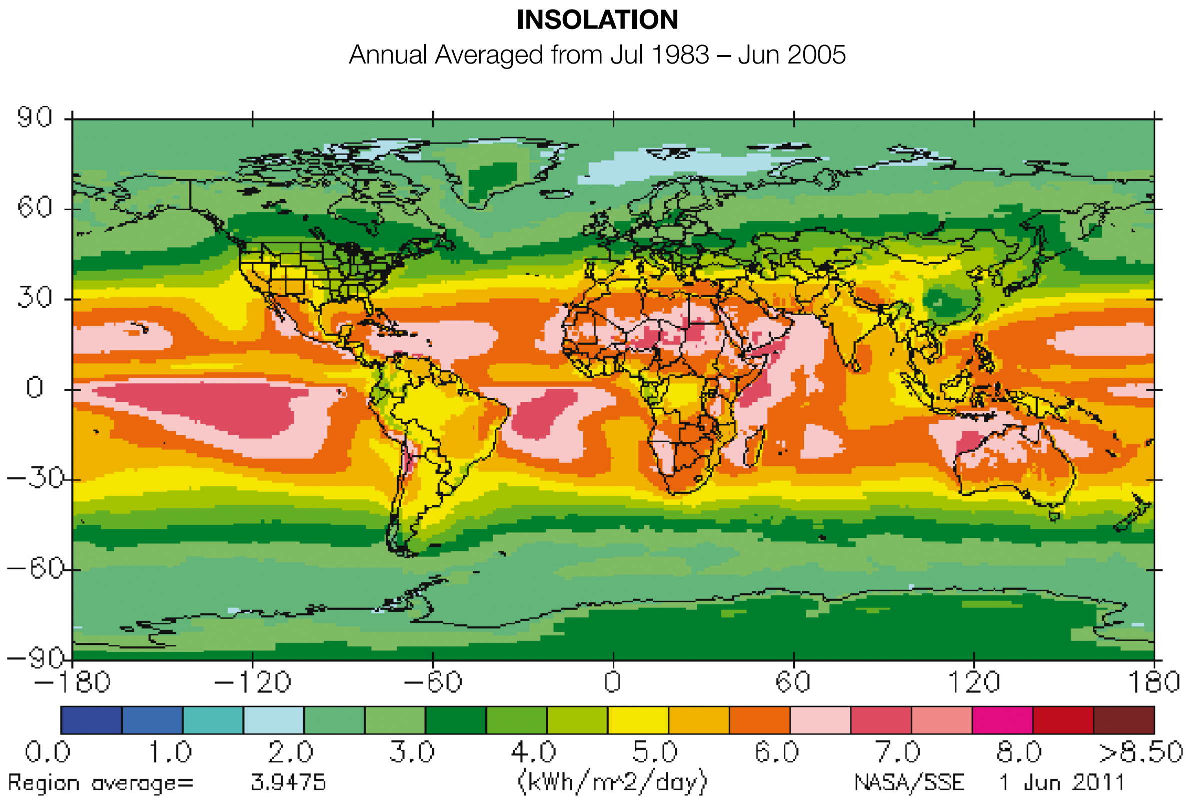

Figure 10: World Annual Solar Insolation [9]

In spite of the fact that solar resources are generally abundant in Australia, a number of installation factors may have a significant impact on solar PV system output. As detailed in Section 6, solar irradiance and sun angle have a significant impact on solar system output. Systems should be installed to avoid areas of shading which will significantly decrease output. Transits of clouds through the sky along with overcast conditions will also impact on solar PV system output. Dirt on panels can also compromise performance; however, if panels are installed at the correct tilt angle rainwater should clean panels.

Section 6.3 showed that the angle of incidence of sunlight striking the solar module has an important impact on solar system performance. The majority of small solar PV systems will be mounted in a fixed location (i.e. will have no sun tracking capability). The transit of the sun across the sky and the different position of the sun in the sky across the seasons mean that it is impossible to obtain the maximum theoretical power output from a solar array installed in a fixed position. As such, for a fixed installation, an optimum installation orientation and tilt angle needs to be determined to obtain the maximum possible output power. For Australian conditions, solar modules should be installed to face north for optimum electricity production. The optimum tilt angle for a fixed array in Australia is 32 degrees [10], however, angles anywhere between 20 degrees and 40 degrees will generally result in performances of approximately 90% of optimal.

8.1. Power Output from PV Systems

The table below is reproduced from the Clean Energy Council Consumer Guide to Buying Household Solar Panels [11]. It shows the average daily production of a number of PV system sizes for various cities across Australia.

AVERAGE DAILY PRODUCTION					
City	**1 kW System**	**1.5 kW System**	**2.0 kW System**	**3.0 kW System**	**4.0 kW System**
Adelaide	4.2 kWh	6.3 kWh	8.4 kWh	12.6 kWh	16.8 kWh
Alice Springs	5.0 kWh	7.5 kWh	10.0 kWh	15.0 kWh	20.0 kWh
Brisbane	4.2 kWh	6.3 kWh	8.4 kWh	12.6 kWh	16.8 kWh
Cairns	4.2 kWh	6.3 kWh	8.4 kWh	12.6 kWh	16.8 kWh
Canberra	4.3 kWh	6.45 kWh	8.6 kWh	12.9 kWh	17.2 kWh
Darwin	4.4 kWh	6.6 kWh	8.8 kWh	13.2 kWh	17.6 kWh
Hobart	3.5 kWh	5.25 kWh	7.0 kWh	10.5 kWh	14.0 kWh
Melbourne	3.6 kWh	5.4 kWh	7.2 kWh	10.8 kWh	14.4 kWh
Perth	4.4 kWh	6.6 kWh	8.8 kWh	13.2 kWh	17.6 kWh
Sydney	3.9 kWh	5.85 kWh	7.8 kWh	11.7 kWh	15.6 kWh

Table 2: Average Daily Production for Solar Photovoltaic Systems located in Various Australian Cities [11]

9. Solar PV Inverters

As discussed in Section 4, the power generated by solar PV panels is DC. In order to integrate this DC power with the AC grid a device is needed to transform DC into AC of correct frequency. Such a device is called an inverter. Inverters are power electronic systems which convert DC to AC through complex high frequency switching algorithms. The basic circuit diagram of an inverter is shown in Figure 11. In the case of a grid connect inverter, the load is the electricity grid.

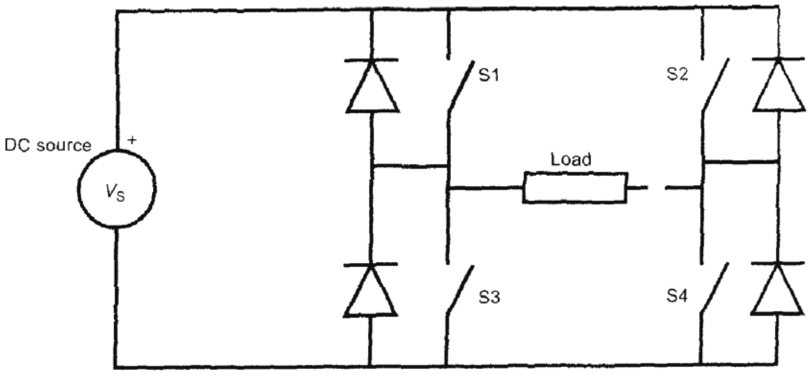

Figure 11: Basic Circuit Diagram of an Inverter [5]

There are two main inverter designs that are used in solar PV system applications. Both types have the same basic layout. The difference between them is that one design includes an isolation transformer between the inverter output and the load. Modern inverters rarely incorporate this isolation transformer as it makes the inverter units very heavy and increases losses.

Figure 4 in Section 5.5 showed that there is one point on the solar I-V curve which corresponds to the maximum power output of the solar cell. This point depends on the environment in which the cell is operating e.g. temperature and irradiance level. Maximum Power Point Tracking (MPPT) incorporates an electronic control system and is included in most modern grid connected inverters. The MPPT system is capable of varying the solar system output voltage and current to ensure that the maximum power is exported from the source under all operating conditions. In modern inverters, MPPT is accomplished through the use of DC-DC converters.

9.1. AS 4777

All PV inverters with ratings up to 10 kVA single-phase or 30 kVA three-phase used in Australia must comply with AS 4777 [12], the Australian standard for grid connection of energy systems via inverters, for both installation and operation. The AS 4777 standard is comprised of three parts; Part 1 specifies installation requirements (e.g. switchboard labelling, circuit breaker configuration) and is of little interest here, Part 2 specifies inverter requirements and Part 3 specifies grid protection requirements. This standard is currently under review and the new version may have a revised format. A summary of the contents of Part 2 and Part 3 of the standard as they stand at present is given below.

9.1.1. AS 4777 Part 2 – Inverter Requirements

As stated, Part 2 of AS 4777 specifies inverter requirements. This part of the standard specifies power quality requirements for inverters. A summary of the most important requirements of this part of the standard is given below.

9.1.1.1. Power factor Requirements

The power factor of the inverter when considered as a load from the perspective of the grid should be maintained in the range 0.8 leading to 0.95 lagging for output levels ranging from 20% to 100% of rating. Most inverters are configured to supply only active power and as such operate at unity power factor.

9.1.1.2. Harmonic Current Requirements

The inverter output harmonic current limits are shown in Tables 1 and 2 of the standard for odd and even harmonics respectively. These tables are reproduced below in Table 3.

TABLE 1
ODD HARMONIC CURRENT LIMITS

Odd harmonic order number	Limit for each individual odd harmonic based on percentage of fundamental
3, 5, 7 & 9	4%
11, 13 & 15	2%
17, 19 & 21	1.5%
23, 25, 27, 29, 31 & 33	0.6%

TABLE 2
EVEN HARMONIC CURRENT LIMITS

Even harmonic order number	Limit for each individual even harmonic based on percentage of fundamental
2, 4, 6 & 8	1%
10 – 32	0.5%

Note: The harmonic limits in Tables 1 and 2 are based on those in IEEE 929-2000 *IEEE Recommended Practice for Utility Interface of Photovoltiac (PV) Systems*.

Table 3: AS 4777 Harmonic Current Limits for Inverters [12]

9.1.1.3. Voltage Fluctuations and Flicker Requirements

Inverters must comply with the flicker limits as specified in AS/NZS 61000.3.3 (for inverters rated less than 16 A per phase) or AS/NZS 61000.3.5 (for inverters rated greater than 16 A per phase).

9.1.1.4. Other Requirements

Part 2 of the standard also specifies limits for impulse protection, transient voltages and direct current injection. It should be noted that there are no specific overvoltage limits explicitly defined in Part 2 of AS 4777. Rather, the issue of overvoltage is dealt with under anti-islanding protection in Part 3 of the standard and is discussed in Section 9.1.2.1.

9.1.2. AS 4777 Part 3 - Grid Protection Requirements

Part 3 of AS 4777 specifies grid protection requirements. This part of the standard specifies the conditions under which an inverter must disconnect from the grid and specifies performance requirements for the equipment or other mechanisms which are used to accomplish this disconnection. The standard states that the inverter must disconnect from the grid:

- If supply from the grid is disrupted;
- If the grid goes outside present parameters (voltage and frequency limits);
- To prevent islanding.

Part 3 of the standard also describes the mechanisms by which inverters may re-connect to the grid after a disconnection.

9.1.2.1. Voltage and Frequency Limits

According to AS 4777, if the voltage at the inverter terminals is below 200 V or above 270 V for a single-phase system or below 350 V or above 470 V for a three-phase system the inverter must disconnect from the grid. Further, if the frequency of the grid measured at the inverter terminals falls below 45 Hz or exceeds 55 Hz the inverter must disconnect. In all cases disconnection must be take place within two seconds.

9.1.2.2. Islanding

Islanding refers to generation independent of the wider electricity grid or continued operation when the grid is not available (e.g. due to an outage caused by a fault). AS 4777 specifies that inverters must disconnect from the grid if the grid voltage is lost. The process employed to perform this disconnection is known as anti-islanding protection. Anti-islanding protection is important in order to protect grid equipment and personnel working on the grid. In most instances, if the grid supply is lost, loading levels will be much higher than distributed generation (DG) source capacity, and individual DG generators (e.g. solar PV systems) would disconnect due to influences related to lack of capacity (e.g. over/under voltage or over/under frequency conditions). However, in areas of very high DG penetration, DG capacity may be similar to or exceed loading levels. In such cases, if DG sources do not disconnect during faults, there is potential for the source to feed the fault leading to further damage of grid equipment and hazards associated therewith (e.g. fires). Further, personnel working to clear faults and restore power may be exposed to hazardous voltages due to generating sources of which they were not aware of.
AS 4777 specifies the minimum timeframes for inverters to disconnect from the grid if the grid is lost.

10. Power Quality Issues Related to Solar PV Systems

Potential power quality issues related to high penetration of solar PV systems include increases in harmonic levels, deterioration in power factor and voltage rise.

10.1. Harmonic Distortion

Depending on the design of the inverter, there is potential for solar PV inverters to inject harmonic currents into the electricity network leading to increased harmonic voltage distortion. Square wave and quasi-sine wave inverters which have highly distorted output current waveforms are well known sources of harmonic distortion. However, the harmonic current output of modern inverters complying with AS 4777 is limited by the standard. Further, many modern inverters generally supply current waveforms which are nearly sinusoidal. As such, harmonic distortion due to modern inverters is expected to be negligible and to date there is little evidence of harmonic levels rising due to the influence of high solar PV inverter penetration.

One area of concern with respect to harmonic distortion that has arisen recently is the contribution of inverters to what would be considered very high frequency harmonics. In order to produce a high quality output waveform, inverter systems switch at high frequencies (20 kHz or more). Harmonic voltages due to these switching frequencies have been detected in distribution networks. The magnitude of these switching frequency harmonics and their impact on the distribution network is an area of ongoing research.

10.2. Power Factor

As detailed in Section 9.1.1.1, AS 4777 requires inverters to operate at a high power factor. Further, most modern inverters operate at unity power factor. As such, the inverter itself does not constitute a problematic load with regard to power factor. However, one side effect of inverters operating at unity power factor is that solar PV systems may reduce power factor at distribution transformers. This is due to the fact that active load current is generated locally by the inverters while the upstream grid must supply all reactive load current. This results in a higher proportion of reactive to active load currents passing through distribution transformer resulting in reduction of the power factor at the transformer. However, this in itself does not present any operational problems for the network. In fact, local generation of active current reduces network losses as power does not need to be transported as far. Figure 12 illustrates graphically the mechanism by which power factor may be reduced at distribution transformers due to the interaction of PV systems.

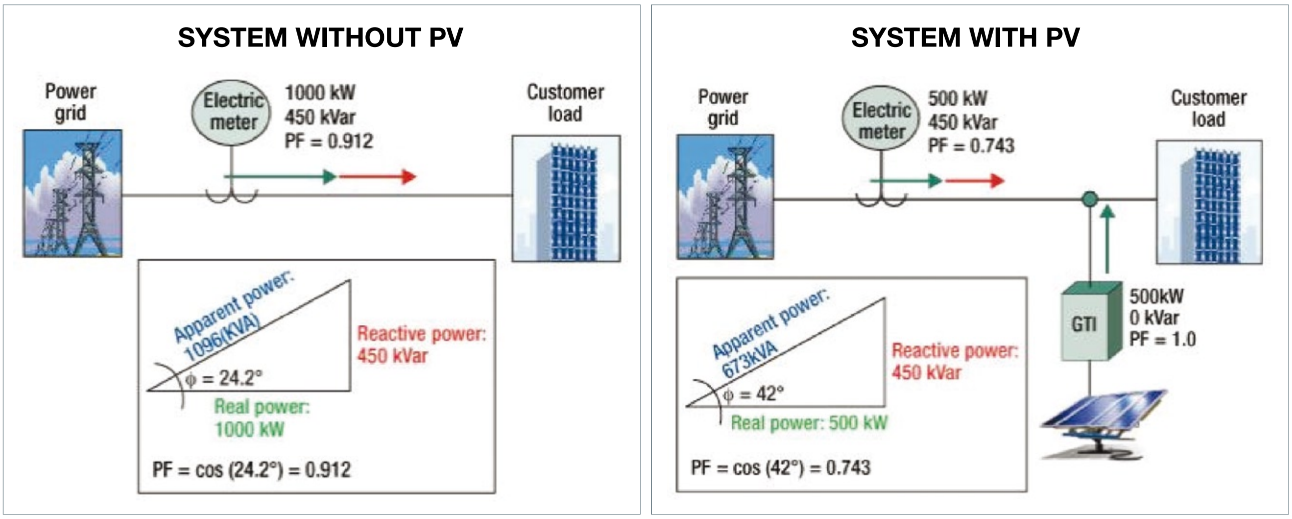

Figure 12: How PV Systems can Impact on Distribution Substation Power Factor [13]

10.3. Local Voltage Rise

To date, by far the most prevalent power quality issue related to solar PV systems has been steady state voltage rise near inverter connection points. Traditional distribution systems were designed to deliver power in one direction only. Under such a scenario, in a low voltage feeder, voltage levels were highest at the terminals of the distribution transformer and decreased along the length of the feeder due to voltage drops caused by load currents interacting with network impedances. In its simplest form, voltage rise can occur along a LV feeder due to the local generation supplying all of the current required by local loads. As such, there is little to no voltage drop along the feeder and feeder voltage levels become close to the voltage at the transformer terminals. However, the nature of inverters compounds this problem by continuing to attempt to export power regardless of the feeder voltage. In such cases, local voltage levels may exceed the voltage level at the transformer terminals. In simplified form, the concept of voltage rise due to PV generation is illustrated in Figure 13.

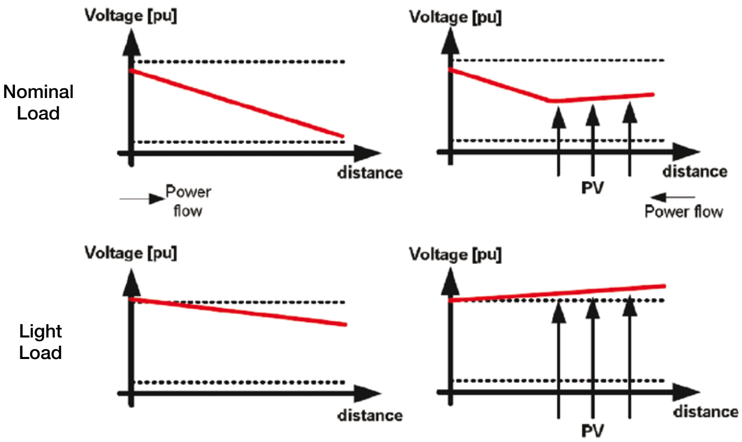

Figure 13: Simple Illustration of Voltage Rise due to PV Generation [14]

The degree of local voltage rise is directly influenced by the impedance or strength of the network. If the network to which the inverter is connected is weak (i.e. high impedance) the voltage at the inverter connection point will begin to rise. This has two potential consequences. The first impact is that once the voltage at the inverter connection point rises to the inverter pre-set overvoltage limit as prescribed in AS 4777, the inverter will disconnect from the grid. If this occurs, no power can be exported and no income can be generated from feed-in tariffs. The second issue is that if the overvoltage limit on the inverter is set too high, the connection point voltage may exceed the allowed maximum feeder voltage. Many utilities have specified that inverters should disconnect from the grid when the inverter connection point voltage exceeds 253 V. However, either by design, or other adjustment by installers, some inverters are not configured in this fashion and inverter connection point voltages of up to 270 V (maximum inverter voltage according to AS 4777 before anti-islanding protection operates) have been observed. These voltage levels are outside Australian standard voltages and will likely damage or significantly reduce the lifespan of equipment connected at or near the inverter connection point.

The problem of connection point voltage rise has been observed in the field where loading levels are low and particularly where large rated power installations are being connected to weak networks. In these cases significant investment in solar PV systems is not being recouped due to the fact that the inverters are often switching off due to operation of overvoltage protection. Figure 14, below, gives an indication of the amount of PV generation that may be installed based on a given grid impedance and pre-connection voltage (shown in box on curves) before a switch off condition of 253 V is reached. This graph clearly illustrates the impact that grid impedance has on the capability of the network to accept generation before the above voltage limit is exceeded.

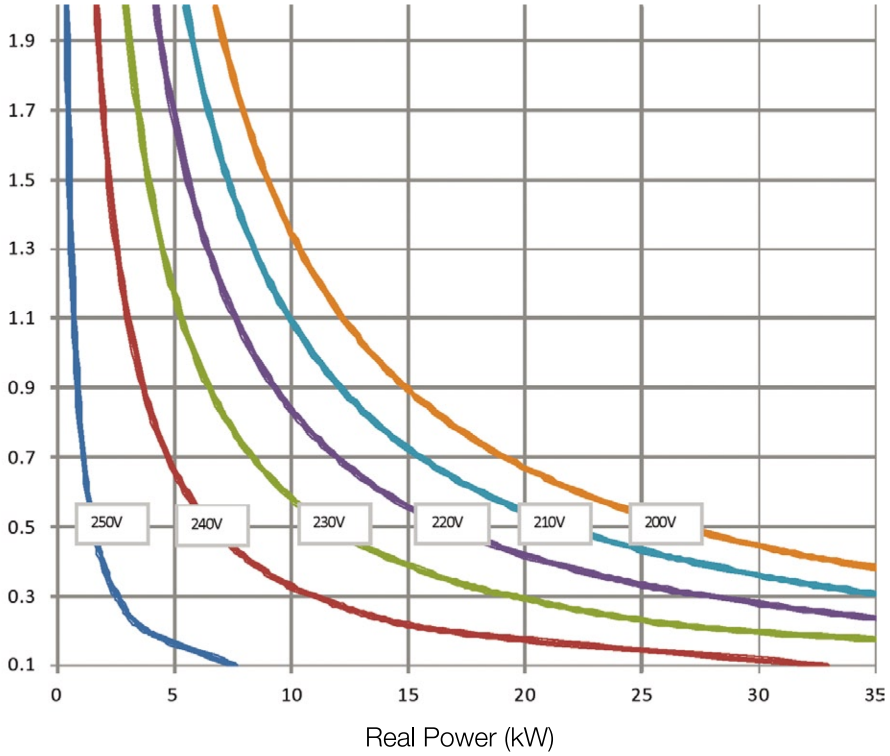

Figure 14: Graph showing PV Generation that may be Connected for a given Grid Impedance before Disconnect Voltage of 253 V is Reached

11. Other Network Issues Related to Solar PV Systems

11.1. Interference with Protection Operation

An important network issue related to high levels of solar PV system penetration is the potential to mask fault currents. Under normal network operating conditions, fault current is supplied by the upstream network and flows through upstream protection devices. Upon detection of this fault current, the protection device operates to clear the fault. Where solar PV systems are present, solar PV systems will supply a portion of the fault current. As solar inverter systems are inherently current limited, the inverter may not shut off under certain fault conditions.

The contribution of individual inverters to fault current may be small, but where penetration is high and fault current is low there is potential for the fault current supplied by the inverters to limit the fault current that flows through the upstream protection device to such an extent that it is not sufficient to cause the protection device to operate. In such a case, the solar PV systems are effectively masking the fault. This is a very dangerous situation with potential safety risk to people and the possibility of damage to equipment. Figure 15 shows diagrammatically how high penetration of solar PV systems may mask fault currents.

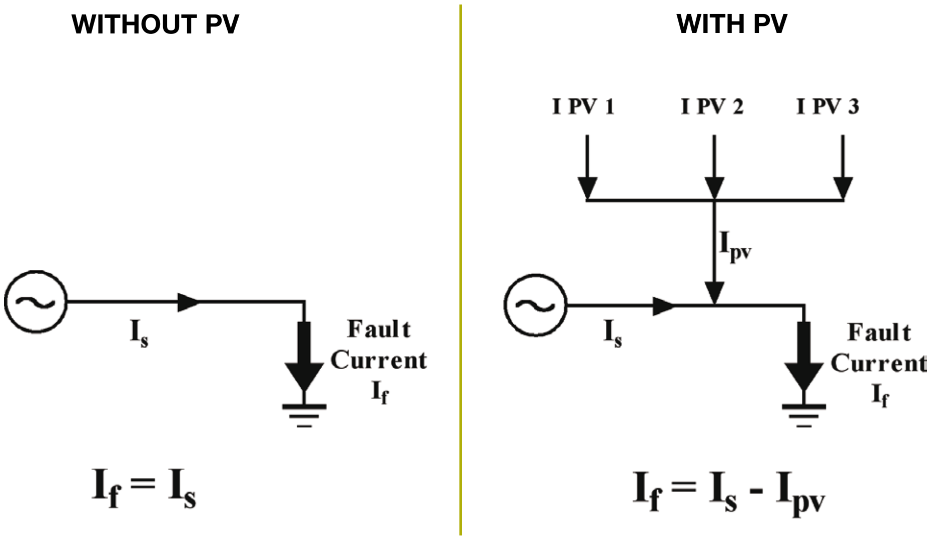

Figure 15: How High Penetration of Solar PV Systems may Reduce Fault Currents

11.2. PV Systems and Stability

Where solar PV penetration is high, a significant amount of load may be supplied by the solar generation. If the solar generation is lost, large power swings may occur. If there is insufficient generation to supply the load upon loss of solar generation, this may lead to network stability issues and potential outages. Solar generation may be lost due to a transient fault. In such case, it may be preferable for the solar PV generation to ride through the fault so that power swings are limited. However, fault ride through is not dealt within AS 4777 and, at the present time, PV systems must disconnect on detection of network faults. The impact of high penetration of solar PV systems on network stability is an area of ongoing research.

12. Conclusion

This Technical Note examined small scale rooftop solar PV systems and more specifically, the subset known as grid connect systems. A description of the components which constitute a solar PV generating source, namely solar panels and the grid-connect inverter, has been given. A brief overview was also presented on solar PV cell technology and construction along with inverter technology. Australian solar resource levels along with the pros and cons of solar PV generation have been discussed. The Australian standard concerning connection of PV systems, AS 4777, has been detailed. Finally, the Technical Note examined some of the potential engineering difficulties associated with the connection of large numbers of solar PV sources. These included deterioration of network power quality levels, interference with protection schemes and potential stability problems.

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