NSMP
National Smart Metering Program

Business Requirements Work Stream

Function 10
Power Factor Measurement

Version number:	Version 1.1
Status:	Final
Author:	Dr Martin Gill
Date published:	2nd March 2011
File name:	NSMP Power Factor Measurement v1.1.doc

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1 Document Control

1.1 Version Control

Version	Date	Description	Amended by
0.1	22/06/2009	First Draft	Dr Martin Gill
0.2	6/7/2009	Added appliance recognition	Dr Martin Gill
0.3	31/7/2009	Review by Dr John Ward (CSIRO)	Dr Martin Gill
0.4	5/9/2009	Added reference to AEMO Service Level Requirement	Dr Martin Gill
0.5	1/10/2009	Added explanation of need for lead and lag	Dr Martin Gill
0.6	2/11/2009	Added NEM Pool and typographical corrections	Dr Martin Gill
0.7	18/6/2010	Added discussion points after BRWG 10/11 Feb 2010 and included new inverters offering onsite PF correction	Dr Martin Gill
1.0	25/1/2011	A number of clarifications of the final recommended functionality	Dr Martin Gill
1.1	2/3/2011	Clarification of performance levels	Dr Martin Gill

1.2 Approval

Authorised by	Signature	Date
NSSC Program Director		4/3/11

1.3 References

The following documents are referred to in this document.

Document Name	Version
NSMP Smart Metering Infrastructure Minimum Functional Specification	Version 1.1
National Electricity Rules Chapter 7 Metering	Version 26
Cost Benefit Analysis of Smart Metering and Direct Load Control: Phase 1 Overview Report	17th September 2007
AS 62053.23 Electricity metering equipment (ac)— Part 23: Static meters for reactive energy (classes 2 and 3)	2006

Document Name	Version
Service Level Requirements Metering Data Collection, Processing and Transfer Services for Metering Installation Types 1 - 4	4 November 2008
IEC61000-4-30 Electromagnetic Compatibility Part 4-30: Testing and measurement techniques – Power quality measurement methods	Edition 2.0 2008-10
NSMP Interval Data Channels	Version 1.0
ActewAGL Guidelines for Grid Connected Photovoltaic Installations	Draft Feb 2009
Australian Standard AS4777 Grid connection of energy systems via inverters Part 2: Inverter requirements	AS 4777.2—2005

1.4 Disclaimer

This discussion paper was produced by Dr Martin Gill of KEMA Consulting in order to assist the Business Requirements Working Group (BRWG) in the development of the Smart Metering Infrastructure Minimum Functionality Specification. This paper has not been vetted or endorsed by the BRWG or the National Stakeholder Steering Committee (NSSC).

2 Introduction

2.1 Background

The MCE cost benefit analysis recommended that meters should be capable of power factor measurement (this was included as function 10). Power factor is a useful indicator of the efficiency of the distribution network. While Power factor measurement was a recommended function in the National Economic Research Association (NERA) Phase 1 cost benefit analysis, it is noted that NERA only assumed that 5% of the three phase meters would include the collection of reactive energy measurement.

This paper will firstly describe power factor and the means of measuring it before going on to discuss the required functionality for power factor measurement in the meter. The Smart Metering Infrastructure Functionality Specification (SMI F.S.) has chosen to implement power factor measurement using the measurement of reactive energy flows. The measurement of reactive energy flows supports the calculation of power factor.

2.2 Why is Power Factor Important?

Power Factor is a means of measuring how efficiency customer loads are using power being supplied from the network. When the load is efficiently using the power, network losses are minimised. The less efficiently the load uses the delivered power, the more power that the distribution network must supply and the greater the chance the load will adversely affect the distribution network. Poor power factor results in increased distribution network losses and potentially system voltage instability.

In the past poor power factor was generated by large electric motors and was associated with large industrial consumers. For these types of loads, power factor is a good measure of the *extra* impact that the load has on the electricity network. Indeed some customer contracts provide incentives for these large customers to correct the power factor of their loads.

Modern appliances in common use throughout domestic homes also contribute to poor power factor. These include motors in air-conditioners and refrigerators. From personal experience Dr Gill undertook the measurement of the power factor of domestic fridges, finding that they exhibited a typical power factor of 0.65 (and some as bad as 0.45). Some modern electronic products, especially those utilising switch mode power supplies, also cause substantial harmonics – that is distortion of the alternating current waveform. Like a poor power factor, this distortion results in network losses (leading to overheating of infrastructure) and disruptions to network voltages.

Utilities employ power factor correction to compensate for .poor customer loads. On a larger scale, AEMO dispatches reactive power as an ancillary service to help control power factor and voltage throughout the electrical network.

For all these reasons the measurement of power factor is valuable to distribution businesses.

2.2.1 Non-technical example of Power Factor[1]

Power factor is a rather abstract concept, so in order to provide a simple explanation we consider trying to push a train along railway tracks. In this case the further the train moves for a given effort the more efficiently we are using the available power:

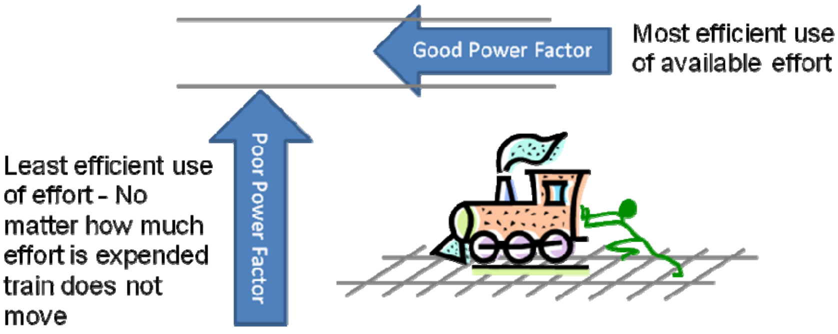

Figure 1: Example of Good and Poor Power Factor

Good Power Factor:
Pushing the train in the direction of the tracks is the most efficient use of the available effort. The train will move the greatest distance for the available amount of energy.

Poor Power Factor:
When the person pushing is at an angle to the tracks, the effect of their effort decreases. The greater the angle the less effective their effort becomes. In the extreme (as shown) when attempting to push the train sideways (at 90°to the tracks) the train will not move no matter how much power is applied.

The electrical equivalents of the two directions shown in Figure 1 are active power) (measured in watts) is the force applied in the direction of the tracks and reactive power (measured in vars) is the force applied at right angles to the tracks.

Just like the train example the delivery of power via the distribution network is achieved most efficiently when the majority of the force applied is the direction of the tracks. For those who are interested the direction of the tracks is specified by the voltage waveform and it is the angle of the current waveform relative to the voltage waveform that determines the power factor. Section 0 presents the mathematical equations associated with the measurement of the relevant quantities.

2.3 How is Power Factor Measurement Currently Used?

Currently the measurement of reactive energy flows is mainly undertaken on high voltage feeders. This allows the network to apply power factor correction at the system level. This use is presented in section 2.10).

On the low voltage network reactive energy measurements and the resulting power factor tariffs are only applied to a minority of customers (the majority of which are large industrial sites). Negotiated energy contracts between these large customers and the FRMP or LNSP may include the measurement of power factor. The normal contract takes the form of a penalty payment when the customer uses large loads at poor power factor[2].

[1] The author acknowledges the suggested example came from Dr John Ward of the CSIRO
[2] These measurements are often more complex than the simple half-hourly interval energy data capture specified in the SMI F.S. For example some meters are required to store the Power Factor measured at the moment of maximum demand.

This is also reflected in the metering types described in 'Chapter 7 of the National Electricity Rules', reactive energy measurement (and the calculation of power factor) is only specified for meter types 1 to 3. These meter types are used for large (industrial) energy users. Small customer meters (type 4 and below) are not required to measure reactive energy (the introduction of electronic meters often supports its inclusion at minimal incremental cost. This will be discussed in below).

2.4 Why Measure Reactive Energy?

Meters do not measure power factor directly, instead they generally[3] measure active and reactive energy, which can be used to calculate the power factor. This is shown in the following diagram:

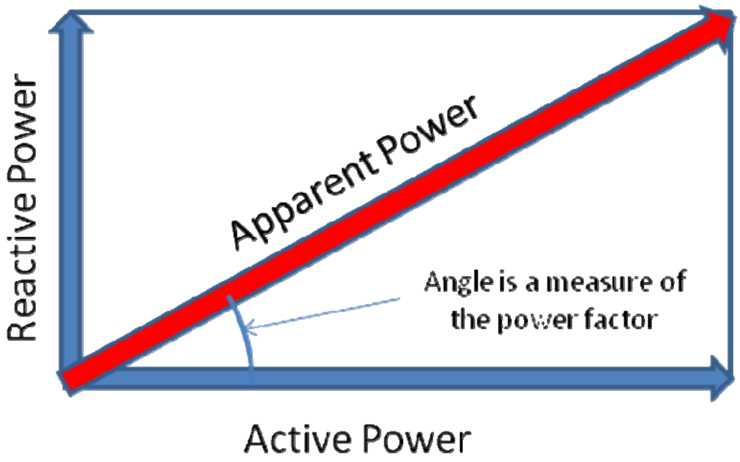

Figure 2: Active, Reactive and Apparent Power

From the train example shown in Figure 1, the apparent power is analogous to how hard you are pushing the train. This can be broken down into how hard you are pushing the train in the direction of the tracks (active power) and how much of the power is "wasted" attempting to push the train sideways (reactive power).

Power Factor is defined as the ratio of active power to the apparent power. The number varies from 1 (the available power is being used very efficiently) to 0 (the power is being used very inefficiently).

As discussed meters do not measure power factor directly, instead it is a calculated value. Early three phase electro-mechanical meters could be used to measure reactive energy. By deliberately changing the voltage wiring. The simple change meant that instead of the meter measuring active energy it could measure reactive energy. The industry has grown comfortable with the use of reactive energy measurement, indeed there is an Australian Standard covering the measurement of reactive energy, allowing devices to be delivered having been tested to a certified standard.

To highlight the advantages offered by recording reactive energy rather than power factor we extend the simple train pushing example given earlier. If we wish to determine the total power available from a team of people attempting to push the train, we need to do a vector (directional) sum of all their individual contributions. This is easily achieved by breaking the effort from each person into a component in the direction of the train and a component at right angles to the train. A simple arithmetic sum can then be used across the team to compute the combined effect. This is shown in the following figure which computes the combined power factor from three individual measurements.

[3] Section 0 presents a range of measurement methods

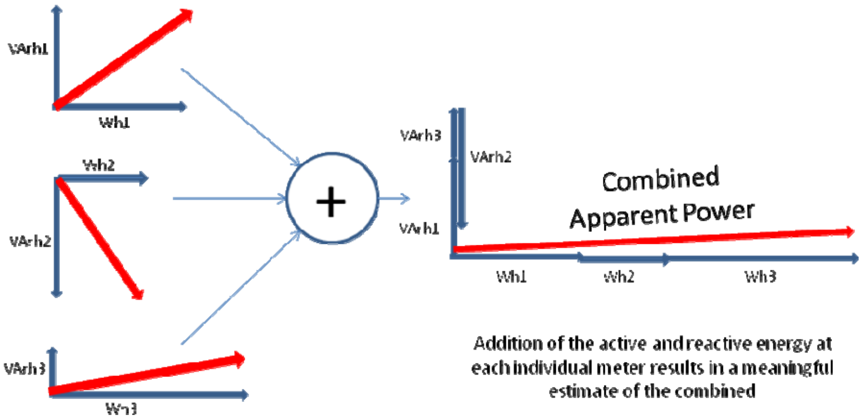

Figure 3: Summation of individual Meter Active and Reactive Energy

Figure 3 shows that reactive energy can be either positive or negative. This is analogous to active energy, indeed the SMI F.S. specifies separate values for imported and exported active energy flows. Reactive energy can also be imported or exported from the National Electricity Market (pool). Once again referring to Figure 3, VArh1 and VArh3 are exported while VArh2 is imported, the net energy VArh1+VArh2+VArh3 is shown as exported. The definition of Imported and Exported reactive energy is contained in the separate briefing paper 'NSMP Interval Data Channels'.

For those who are interested Pythagorus's theorem can be used to calculate the power factor in fFigure 3 as:

$$Power\ Factor = \frac{\sum^{All\ Meters} Wh}{\sqrt{\sum^{All\ Meters} Wh^2 + \sum^{All\ Meters} VArh^2}}$$

2.5 The case For Measuring Apparent Energy

Put as simply as possible, there is no standard definition for reactive energy measurement with many different implementations providing reactive energy measurement. While each method would pass the Australian standard for reactive energy measurement, each would give a slightly different answer in the presence of harmonics. This partially explains why the accuracy of reactive energy measurement is only listed as 2 or 3%, compared to active energy which for a high accuracy meter can be as low as 0.2%.

Modern electronic metering solutions support the direct measurement of apparent energy, or volt-amps, for which there is a standard definition (this is provided in section 0).

While specifying apparent energy measurement at the meter is technically more precise there are a number of issues which limit its usefulness.

Firstly apparent energy does not indicate if the actual power factor is leading or lagging. This information is required by the distribution business to determine how to compensate for the reactive energy flows resulting from the power factor.

Secondly in Figure 3 it was shown that it is possible to summate active and reactive energy measurements from a number of meters to arrive at the power factor for a group of meters (for example in a particular region of the distribution network). This simple addition cannot be performed if the meters measure Apparent energy.

Thirdly, while there are a number of simple methods of measuring reactive energy, the measurement of apparent energy is mathematically more demanding (referring to section 0 it involves the calculation of the square root function). As such less low cost (integrated) metering solutions offer apparent energy measurement compared to reactive energy measurement.

Finally at this stage there is no standard for testing devices for apparent energy measurement. In a response from Standards Australia: “there is no Australian Standard because there is no international standard (IEC) .The case for apparent power meters was put to the IEC committee TC 13 *Equipment For Electrical Energy Measurement And Load Control*, by an Australian delegate at their 2001 meeting. The TC 13 decision was to leave the matter on hold. TC13 seem to have no interest and there have been no further developments”.

2.6 Other Uses for Reactive Power Measurement

There is another potential benefit to the measurement of reactive power in the meter. Consumer education can be enhanced if they are able to identify energy consumption of different devices in their home. This allows consumers to be advised of specific actions they could take to improve their energy usage – for example it would allow them to compare the efficiency of their fridge against a new model or to identify high energy devices[4]

Currently the identification of individual appliance energy usage is achieved using individual appliance energy monitors. The customer must plug each appliance into a separate monitor. In addition to the cost of the individual energy monitors, there is the installation and configuration of numerous devices. Also large appliances may be installed on a separate circuit with no accessible “plug”, or the plug is behind the device (e.g. dish washers and refrigerators) meaning that many appliances may be missed. It has been reported to Dr Gill that algorithms now exist to identify individual appliances when using a single measurement (e.g. at the smart meter). These algorithms can allocate energy consumption to individual appliances avoiding the cost and complexity of individual appliance monitoring. This concept is demonstrated by the Google PowerMeter software product, which attempts to use the total household demand profile to identify the contribution from individual appliances.

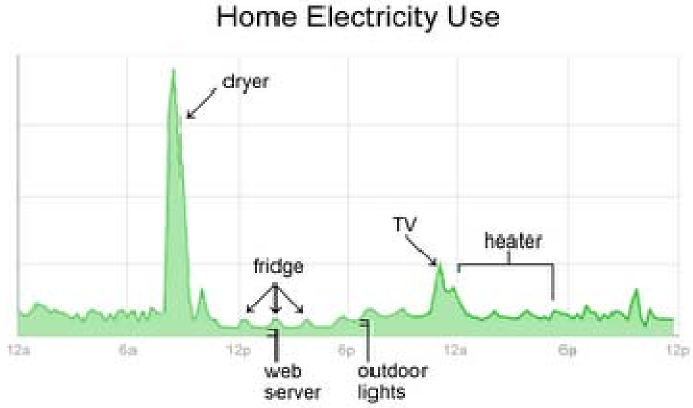

Figure 4: Google PowerMeter with Individual Appliance Identification

The identification relies on the amount of increased demand and the time over which the demand increases. In earlier work Dr Gill was attempting this identification, but found that the addition of reactive energy provided an improved means of identifying individual appliances within the home.

Finally once appliances have been identified it is possible to monitor their performance over time. As the appliance ages its efficiency may reduce (for example friction in bearings or degradation of the seals around the fridge). Tracking this degradation over time would allow systems to identify and advise customers which appliances are no longer running efficiently allowing them to rectify the situation.

[4] In one such energy audit Dr Gill found that a tropical fish tank used a similar amount of energy as a typical in ground pool.

2.7 Harmonics

This functionality was not recommended for the minimum functional specification and is included here to complete the discussion of power factor.

One of the new sources of poor power factor is harmonics. As highlighted above this is a consequence of many modern electronic devices (especially their switch mode power supplies).

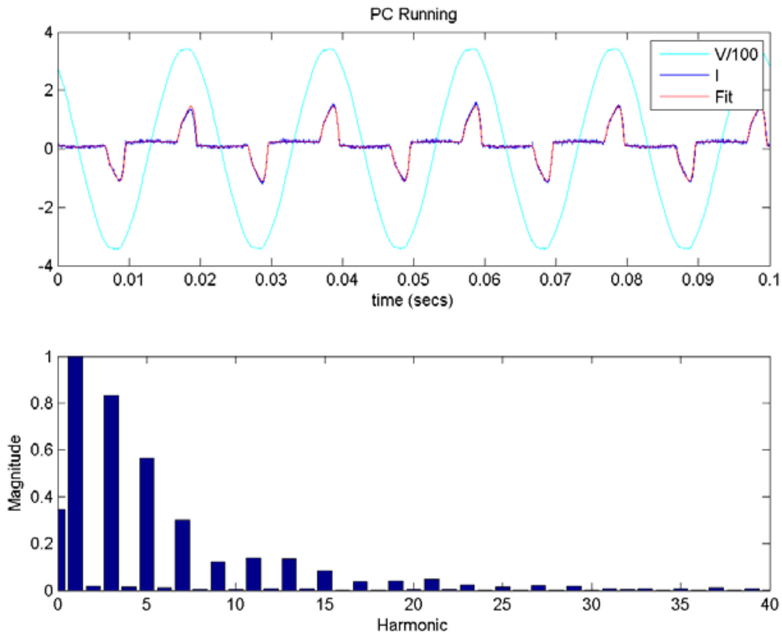

Figure 5: Current Waveform and Harmonics from a PC power supply[5]

In the past the measurement of harmonics has required the use of expensive power quality analysers. When the utility becomes aware of potential issues they respond by visiting the site to install a power quality analyser. After the measurements are complete another site visit is then required to retrieve the equipment, making the measurement expensive. Several members of the BRWG have suggested that this functionality would have advantages for smart meters and should be considered for inclusion in the SMI F.S.

There is a trend to incorporate functionality traditionally only available in power quality analysers into modern electronic electricity meters. While harmonic analysis has become a common feature of top end three phase CT connected meters. There is a desire to offer the functionality in all meters including those for domestic use. While the Smart Meter Communications Network (SMCN) would be used to retrieve the harmonic measurements it is emphasised that this would only occur on an audit basis. As such the benefits would be derived from remote collection of power quality information without the need for a site visit.

Many electricity meters available on the market-place utilise highly integrated metering chips. It is therefore possible to gain an insight into future meter vendor products by investigating recent developments in the metrology offered by available metering chips. Taking this approach it is easy to find that several chip vendors are considering supporting harmonic measurement. One example has been introduced by Cirrus (www.cirrus.com), their CS5463 Single-Phase Bi-Directional Power/Energy IC is described on their website as:

[5] Figure provided by Dr John Ward of the CSIRO

> Designed for residential single-phase or industrial three-phase power meter applications, the IC accurately measures instantaneous current and voltage while calculating instantaneous power, I_{RMS} and V_{RMS}, real power, apparent power, reactive power, fundamental power, harmonic power, power factor and line frequency.

While it is acknowledged that the cost of measuring harmonic content is falling, depending on how often the measurement is made and the number of harmonics which are measured, recorded and reported, there is the potential to significantly increase the memory requirements of the meter and to increase the amount of data carried on the SMCN.

Further justification would need to be provided before considering the addition of harmonic measurement to the SMI F.S. As stated at the beginning of this section, harmonic measurement is only included here to complete the discussion of Power Factor.

2.8 The Case For Not Measuring Reactive Energy

The discussion has so far focussed on the benefits of adding reactive energy measurement into the meter. While this functionality can be included in the meter at minimal cost, it is important to note that once the meter measures the energy data, there are the communications costs to collect the data, and data processing and storage costs that will be incurred in back-office processing.

The assumed usage of reactive energy measurement is to perform occasional audits of the power factor around the grid. All the meters in the area being audited would have the reactive energy data collected which can then be summated to estimate the system power (and determine if power factor correction equipment is needed and the required size). This leads to an assumption that only a small percentage of meters will have the reactive energy data collected at any one time. This was explicitly stated in version 0.26 of the SMI F.S. which included a clause under the performance levels for remote acquisition stating:

> c) The remote acquisition of energy data corresponding to reactive energy is intended to be used for audit purposes and is not defined in this specification.

The comment was removed from later versions of the SMI F.S. because:

- The comment is wrong as some customers will be billed for reactive energy (this was why the NERA study recommended power factor measurement for three phase meters), and for these customers service levels agreements would include the delivery of reactive energy data.
- The SMI F.S. describes the meter functions, it does not describe how the functions will be used or limit access to the functions (for example only for audit purposes)

The BRWG discussed introducing a limit on the amount of reactive energy data that was included in the performance Level, however the limit would vary between jurisdictions (dependant on the mix of meter configurations especially two element meters) and dramatically across regions within a distribution network (depending on mix of commercial & industrial or domestic premises). It was therefor left to the party deploying the SMI to determine the relevant amount of reactive energy data to include in their tender documentation (in exactly the same manner as the SMI F.S. does not attempt to describe the number of two element meters or the number of interval energy channels that will be acquired). For clarity removal of the clause should not be interpreted to mean that reactive energy measurements are always acquired.

The decision to separately enable storing interval energy channels and acquisition of the resulting interval energy channels was made due to restrictions enforced by AEMO’s service level requirements (for types 1 – 4) we note:

> 2.4.6 Where the metering installation includes the measurement of reactive energy, the metering data provider is required to store this metering data along with the metering installations active metering data in the metering data provider’s metering database. The metering data provider is required to include the provisioning of all reactive metering data to registered participants who have right of access to that data.

As such *current* AEMO service level requirements will require the remote acquisition of reactive energy data for all meters. This matter should be discussed in appropriate forums to determine if a similar requirement will be enforced once Smart Meters are deployed more widely.

Another advantage of separating the storing and acquisition of interval energy data is that when a meter is reconfigured to change the measurements the meter stores in trading intervals (interval energy data), the majority of meters will delete all historical data. While it is noted that back office processes and procedures can be used to ensure that no energy data is lost the situation is avoided by separating the storage of reactive energy data in the meter and the remote acquisition of reactive energy data. The SMI F.S. includes this separation in order to support occasional power factor audits without the need to reconfigure the interval energy data being stored in the meter.

2.9 Existing Support for Reactive Energy

The original NERA cost benefit analysis stated that reactive energy measurement was a zero cost option in three phase meters and therefore recommended the functionality. NERA also noted that there may be a cost associated with back office systems required to process the reactive energy data. The National Electricity Market (NEM) already supports reactive energy measurement and many existing back office systems are capable of handling reactive energy data (to support existing customer tariffs including a reactive energy component).

If all meters support the functionality this may result in additional costs associated with the augmentation of these existing back office systems in order to effectively handle larger amounts of data.

It is noted that augmentation will be necessary to calculate the system power factor at points throughout the distribution network (using the algorithm depicted in Figure 2). A necessary change will be the ability to determine which meters are fed from a specific distribution asset (e.g. distribution transformer). This would require integration between several existing back office systems.

2.10 Local Power Factor Correction

Another concern raised at the BRWG is that the measurement may result in individual customers being forced to correct their power factor. The distribution businesses have repeatedly stated that the intention is to gain geographical information allowing them to identify poor power factor at points lower down the distribution network. Identification of areas with poor power factor enables the distribution network service provider to improve the efficiency of the distribution network by identifying where the installation of power factor correction equipment would have benefits.

An advantage of being able to identify where power factor is poor is depicted in

Figure 6. The figure depicts a distribution feeder leading into three sub-networks, where one of the sub-networks presents a poor power factor (resulting in reactive energy flows). The left hand figure depicts the situation today, where the network operator installs power factor correction equipment on the main feeder, reactive energy flows must still continue amongst the three sub-networks. In the right hand figure the network operator is able to identify the sub-network with poor power factor and only installs power factor correction equipment on that sub-network, greatly reducing reactive energy flows between the other two sub-networks.

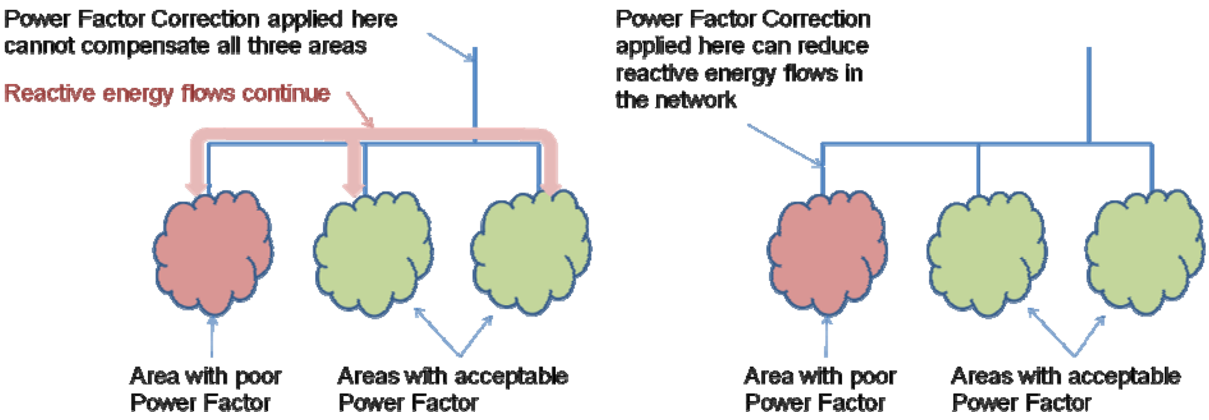

Figure 6: Depiction of Advantage of Targeted Power Factor Correction

2.10.1 Solar Inverters

While discussing local power factor correction it is worthwhile noting that some solar inverters are now designed to generate reactive energy flows. With appropriate control the inverters could be used for power factor correction in the local area[6]. One such example of this type of product is the SMA 9000TLRP inverter (see www.sma.de).

While it is commonly assumed that the inverter will generate unity power factor, local distribution network rules generally specify that the power factor of the inverter should fall between defined limits. Taking the 'ActewAGL Guidelines for Grid Connected Photovoltaic Installations'.

2.10.2 Power Factor

The power factor of the PV system shall not exceed the limits defined in section 4.4 of AS:4777.2.

Referring to AS:4777 Part 2 (2005)

2.10.3 Power Factor

The power factor of the inverter, considered as a load from the perspective of the grid, shall be in the range from 0.8 leading to 0.95 lagging for all output from 20% to 100% of rated output. These limits shall not apply if the inverter is approved by the relevant electricity distributor to control power factor outside this range for the purpose of providing voltage support.

Attention is drawn to the last sentence which indicates that the use of localized power factor correction is being considered.

[6] The author acknowledges that the information was provided by Dr John Ward of the CSIRO

3 Conclusion

Reactive energy measurement will be supported by all meters described in the SMI F.S. This includes both single and three phase meters. This decision is based on

- Reactive energy measurement being the most versatile measurement technique for power factor.
- Reactive energy measurement being offered by meter vendors at minimal incremental cost.
- Existing procedures and back office systems in the NEM already support the processing of reactive energy data.

The NERA CBA only anticipated that power factor data would be collected from a small percentage of the total number of meters. Provided that reactive energy data is only collected from those customers on reactive energy tariffs and for occasional power factor audits, it will not increase the cost of the SMCN required to carry the data.

The SMI F.S. allows the smart meter to be configured to record reactive energy data and separately to enable and disable the remote acquisition of reactive energy data. The separation allows distributors to periodically acquire reactive energy data during network audits across their distribution network.

Appendix A – Glossary

The following acronyms are in the NSMP Glossary.

ACOSS	Australian Council of Social Services
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AMI	Advanced Metering Infrastructure (Victorian smart metering program)
AS	Australian Standard
B2B	Business to Business
BPRG	B2B Procedures Reference Group (established under the IEC)
BPPWG	Business Processes and Procedures Working Group (established under the NSSC)
BRDRG	Business Requirements Definition Reference Group (established under the AMI program)
BRWG	Business Requirements Working Group (established under the NSSC)
CATS	Consumer Administration and Transfer Solution
COAG	Council of Australian Governments
DNSP	Distribution Network Service Provider
DRET	Commonwealth Department of Resources, Energy and Tourism (also referred to as RET)
EEEC	Equipment Energy Efficiency (E3) Committee
ENA	Energy Networks Association
ERAA	Energy Retailers Association of Australia
ESC	Essential Services Commission
FRC	Full Retail Contestability
FRMP	Financially Responsible Market Participant
HAN	Home Area Network
IEC	Information Exchange Committee (established under section 7.2A.2 of the Rules)
IHD	In-home Display
LNSP	Local Network Service Provider
MCE	Ministerial Council on Energy (established under the COAG)
MDA	Metering Data Agent
MDF	Metering Data File
MDFF	Metering Data File Format
MOU	Memorandum of Understanding
MRG	Metrology Reference Group (established under the RMEC)
MSATS	Market Settlement and Transfer Solution
MTWG	Metering Technology Working Group (established under the AMI program)
NCRE	National Consumer Roundtable on Energy

NECF	National Energy Consumer Framework
NEL	National Electricity Law
NEM	National Electricity Market which excludes Western Australia and Northern Territory
NEMMCO	National Electricity Market Management Company
NEO	National Electricity Objective (as set out in section 7 of the NEL)
NER	National Electricity Rules
NERA	National Economic Research Association
NSMP	National Smart Metering Program
NSSC	National Stakeholder Steering Committee (National Smart Metering Program)
NT	Northern Territory
OMRV	Operating Model Requirements Version (Victorian AMI Program)
PDRG	Business Process & Data Reference Group (established under the RMEC)
PwC	PricewaterhouseCoopers
PTWG	Pilots and Trials Working Group (established under the NSSC)
RET	Commonwealth Department of Resources, Energy and Tourism
RIS	Regulatory Impact Statement
RFP	Request for Proposal
RMEC	Retail Market Executive Committee (an advisory committee to AEMO)
RP	Responsible Person
RPWG	Retail Policy Working Group (established under the MCE)
RWG	Regulation Working Group (established under the NSSC)
SCO	Standing Council of Officials (as established under the MCE)
SM	Smart Metering
SMCN	Smart Metering Communication Network
SME	Subject Matter Expert
SMI	Smart Metering Infrastructure
SMI FS	Smart Metering Infrastructure Functionality Specification
SMMS	Smart Metering Management System
SMWG	Smart Metering Working Group (established under the SCO)
SWIS	South Western Interconnected System in Western Australia
TFWG	Testing Framework Working Group
TOR	Terms of Reference
TRWG	Technical and Regulatory Working Group (established under the AMI Program)
VA	Volt-Amps
WA	Western Australia
WAIMO	Western Australian Independent Market Operator
WEM	Wholesale Electricity Market (Western Australia)
WIGS	Wholesale Inter-connector Generator and Sample
WG	Working Group

Appendix B – Mathematical "Stuff"

The following section is only included to highlight that there are a number of measurement techniques used to measure reactive energy and to highlight the arithmetic cost of apparent energy measurement.

Technical Description of Active Energy Measurement

There is an unambiguous definition of the active power, measured in watts:

$$Active\ Energy = \int^{Time} v \times i\ dt$$

From this it is possible to measure power

$$Active\ Power = \frac{1}{Time}\int^{Time} v \times i\ dt$$

Technical Description of Apparent Energy Measurement

There is also an unambiguous definition of the apparent power, measured in Volt-Amps (VA)

$$Apparent\ Power = V_{rms}\ A_{rms}$$

The measurement of voltage and current is also readily defined as:

$$V_{rms} = \sqrt{\frac{1}{Time}\int^{Time} v^2\ dt}$$

and

$$A_{rms} = \sqrt{\frac{1}{Time}\int^{Time} i^2\ dt}$$

Where *rms* indicates the mathematical function root mean square.

There is the potential for some ambiguity in the measurement when considering the *Time* period for the measurement. If *Time* is an integral multiple of the mains cycles the measurement is repeatable, which is why the measurement standard IEC61000-4-30 specifies measurement time periods related to the applied mains frequency.

Apparent energy is then given by

$$Apparent\ Energy = \int^{Time} V_{rms}\ A_{rms}\ dt$$

Technical Description of Reactive Energy Measurement

There is no standard or unambiguous definition of how to measure reactive energy.
A common definition for reactive energy is:

$$Reactive\ Energy = \int^{Time} v^{\perp} \times i\ dt$$

where

$$v^{\perp} = 90^{\circ}\ phase\ shifted\ version\ of\ v$$

There is no standard definition of how to apply the 90° phase shift to the voltage leaving vendors free to select their own method. All will achieve a 90° phase shift of the voltage waveform at 50Hz, so when 'pure' 50Hz signals are tested all methods produce the same value. Practical voltage and current waveforms will experience frequency variation and also include harmonics, leading to different measurements from each technique.

Early electro-mechanical meters used cross wiring of the three phase voltages to derive the required 90° phase shift of the voltage reference.

Technical Description of Power Factor Measurement

True power factor[7] is formally defined as the ratio of the active power flowing in the network to the apparent power. An instantaneous measurement is given by:

$$True\ Power\ Factor = \frac{Active\ Power}{Apparent\ Power} = \frac{Active\ Power}{V_{rms}\ A_{rms}}$$

Note that this leads to the common definition of power factor

$$Active\ Power = V_{rms}\ A_{rms} \cos\emptyset$$

Where the displacement power factor[8] is defined as:

$$Displacement\ Power\ Factor = \cos\emptyset$$

Referring to Figure 2, it is also possible to determine power factor using Pythagoras's Theorem.

$$Apparent\ Power = \sqrt{(Active\ Power)^2 + (Reactive\ Power)^2}$$

Resulting in:

$$Power\ Factor = \frac{Active\ Power}{\sqrt{(Active\ Power)^2 + (Reactive\ Power)^2}}$$

It is important to note that the SMI F.S. does not require the meter to calculate power factor. This calculation can be performed in back office systems.

[7] The definition of True Power Factor has been taken from IEC61000-4-30
[8] ibid