TOWARDS A MEANINGFUL STANDARD FOR PV ARRAY INSTALLATION IN AUSTRALIA.

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ABSTRACT: Photovoltaic (PV) arrays have been installed for many years in a very wide range of applications from very small one or two module installations to megawatt grid connected systems. Technology is moving rapidly, particularly in the area of inverter topologies with moves toward higher voltages, high frequency transformer isolation and topologies without galvanic isolation. Systems include voltages ranging from 12 volts to in excess of 600V in earthed and floating systems. Systems may also include batteries and may be grid connected or stand-alone. Standards have not yet addressed the very significant safety issues raised in the installation of these systems. Australia has set a high priority on the development of a standard for PV array installation.

This paper discusses important safety issues with respect to the design and application of PV arrays in a range of applications and discusses moves toward the formulation of a comprehensive standard for PV arrays in Australia. This will include industry best practice for connection configuration, over-current protection, cabling, earthing and personnel protection

Keywords: PV Array, Qualification & Testing, Safety

1. INTRODUCTION

Photovoltaic (PV) systems technology has come a long way in the last 20 years. Earlier in the development of PV systems there was a very limited choice of system configurations and voltages available for both stand-alone and grid connected applications. Now in 2002 there is a plethora of systems available. They range in power from a few watts to multi megawatts and in voltages from 12V to in excess of 600V. Systems are being installed as both earthed and unearthed systems. The inverter technology includes isolated and non isolated varieties with the isolated inverters using line frequency and high frequency transformer isolation systems. Much of this development has occurred without the guidance of standards specific to PV technology.

PV arrays have a number of unique features that are different from the usual household wiring and appliances.

- The wiring is dc (except for module inverters) and so is generally unfamiliar territory for electricians particularly when voltages exceed 120Vdc. Even at low dc voltages arcing faults are a problem.
- PV arrays are not readily turned off because: they are generally distributed over an area on an array frame, roof or exterior surface of a building and they are live while exposed to light.
- The modules and associated wiring are frequently exposed to rain, extreme temperatures and ultraviolet radiation.
- PV Arrays are a current limited source and because of this, conventional over-current protection systems do not work under all fault conditions.
- PV arrays are frequently used in conjunction with other electrical sources such as batteries or the grid. This means that protection systems must provide protection covering two or more sources of current.

It is because of these unique features that standards specific to PV applications are needed: to provide safety, electrical and fire protection for: the general public, electricians and emergency workers; to provide a level of quality & reliability for installations and to inform and give guidance on installation practice for a range of systems. Australia is implementing a wide variety of both stand-alone and grid connected PV systems and it is for this reason that a project was started to look into standards for PV arrays. Firstly existing standards in other countries were investigated and a summary of the major ones found follows in the next section. The standards found mostly covered grid connected applications with the US and the UK having the most comprehensive guidelines. The US standard requires earthed arrays while the UK guideline recommends unearthed arrays, but does not specify requirements if the array is earthed, nor does it cover stand-alone systems or systems with batteries. It is for these reasons that a project was started to develop a standard for PV arrays for both stand-alone and grid connected applications in Australia.

2. EXISTING STANDARDS IN OTHER COUNTRIES

US – National Electrical Code, Article 690. [1] Contains wiring and safety requirements for PV systems consistent with US electrical installation requirements. In contrast with the European guidelines, the protection philosophy is based on earthed systems.

IEC 60364-7-712.[2] contains good definitions, some recommendations, but little safety requirements.

DRAFT-IEC61730-1&2 “Photovoltaic module safety requirements” [3] is a new draft standard for PV modules which incorporates amongst many other things, requirements for PV modules for different insulation classes and for earthing of frames.

UK - Guide to the installation of PV systems. [4].Focuses on grid-connected systems. It reflects European practice and is a well developed guide for installation and site work safety requirements, as well as commissioning procedures.

Netherlands – Guidelines for the Electrical Installation of Grid Connected Photovoltaic (PV) Systems [5]. Sets out the minimum requirements for grid connected PV systems, including PV array wiring and safety requirements. it reflects European practice and introduces the “fail safe” philosophy (class II).

Another very useful document which summarises earthing issues with respect to grid connected PV systems is an IEA PVPS report [6]

3. SCOPE OF THE AUSTRALIAN DOCUMENT

The draft Australian standard [7] sets out the general installation requirements for photovoltaic (PV) Arrays with d.c. open circuit voltages up to 600 V between positive and negative conductors. The limit of 600V is still under discussion and may be widened to 1000V.

4. NEED FOR FLEXIBILITY IN SYSTEM CONFIGURATIONS

It is important when developing a standard to ensure that all the important safety issues are covered without being exclusive of any existing or possible future technology unless there is a very good reason for exclusion. There already exists a wide range of system configurations and inverter types. The aim of the standard is to be inclusive of this range, making sure that safety is maintained across the range.

A wide range of inverter topologies can be found on the market. Some include isolation between ac and dc sides, and some of them are transformerless; some require the PV array not to be earthed; some require the PV array to be earthed and some effectively earth the array internal to the inverter. An illustration of the range of possible system configurations is shown in Figure 1. The implications for safety and protection of these systems are many and varied and these are discussed in the next section.

As can be seen it is not possible to make a standard for PV arrays that is independent of the inverter system to which it is connected because earthing and isolation issues are inextricably linked to the inverter type and topology.

5. SYSTEM CONFIGURATIONS EARTHING & ISOLATION

Figure 1 shows a wide range of system configurations which are currently in use in various parts of the world. The diagrams illustrate only the earthing arrangement and if the inverter has an isolation transformer or not. The ac side of the inverter may be connected to a stand-alone house or to the grid and the dc side of the inverter may be connected to a battery system. Whether there is a grid connection and/or battery involved obviously significantly affect the possible fault currents which may flow in sections of the system.

5.1 Configuration A (Refer Figure 1 a)

This is a very common system arrangement. A single earth fault will not cause fault currents to flow. Personnel contact between one of the current carrying conductors and ground can lead to discharge of distributed capacitance (possibly a danger for electricians working on the system). The recommendation is to use Class II equipment in order to reduce possible leakage paths/parasitic elements. The main issue is whether it is necessary to include alarm and/or shutdown of the system if an earth fault develops on the dc side of the system because if an earth fault develops it may not be otherwise detected and if the array becomes earthed then the personnel safety and second fault issues are immediately changed to those for an earthed array.

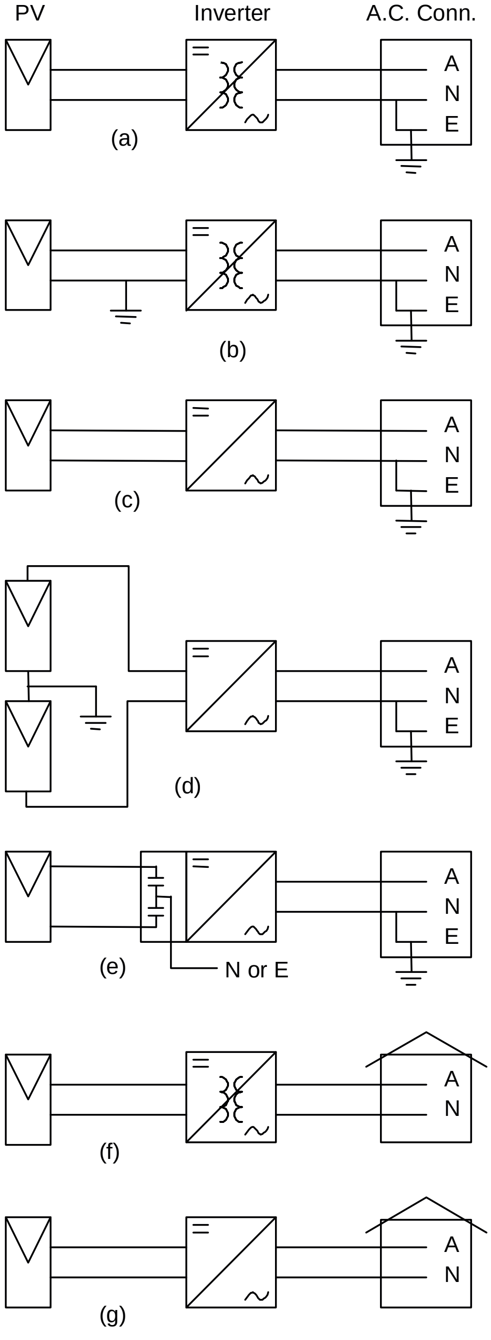

Figure 1: System Configurations.

5.2 Configuration B (Refer Figure 1 b)

Earthing of the dc side of systems is mandated by the

National Electrical Code (NEC) in the US. Because of the earth on the dc side the system constitutes a shock hazard and if an earth fault develops fault currents will flow. The only way of interrupting current in this earth fault situation is to disconnect the dc side from the earth. Providing personnel protection is possible by measuring currents in the PV array earth cable if only one earth point is used. Issues of stray leakage currents may be an issue in the sensitivity of this protection.

5.3 Configuration C (Refer Figure 1 c)

The array in this system although it is not directly connected to earth is in some way (dependent on the inverter topology) referenced to earth. The array may then constitute a hazard to personnel while it is connected to the inverter. For the same reasons a single earth fault on the array will cause fault currents to flow. Protection for this system may be provided by a residual current device (RCD) (which has to be DC and AC sensitive), placed on the ac side of the inverter. A significant issue for the RCD may be the level of stray leakage current to earth from the system which may require a relatively high threshold setting on the RCD, which may compromise the effectiveness of the personnel protection.

Depending on the inverter topology and control method there may also be significant high and/or low frequency voltage components impressed on the array and wiring. [8]. These voltages may through capacitive coupling induce currents in people in contact with the array surface or in structures adjacent to the array.

5.4 Configuration D (Refer Figure 1 d)

Centre tap earthing of the array will generally remove any risk of high frequency voltages on the array. This arrangement also ensures a well defined array voltage with respect to earth. The obvious disadvantage of this arrangement is that the array may then constitute a hazard to personnel and if an earth fault develops then fault currents will flow. The problem in this situation is how to detect and then protect the installation. This is non trivial because of the earth connection to the centre of the array and possible supply from both the ac and dc sides to the fault.

5.5 Configuration E (Refer Figure 1 e)

A centre tapped filter arrangement connected to neutral or earth within the inverter will also generally remove any risk of high frequency voltages on the array. This arrangement also ensures a well defined array voltage with respect to earth. The disadvantage of this configuration is that the array voltage is (as in D) referenced to earth all be it via capacitive coupling. Because the capacitors are the main filter capacitors for the dc buss on the inverter these capacitors are relatively large in capacitance. As such they constitute a shock hazard to personnel. If a single earth fault occurred on the array, the system would not sustain dc fault currents because of the capacitive coupling, however dependent on the inverter circuit's, response to unbalance on the input, ac fault currents may be sustained. If the capacitor centre point is connected to neutral then personnel protection is possible using an RCD on the ac side of the inverter (subject to sensitivity issues relevant to leakage currents).

5.6 Configuration F & G (Refer Figure 1 f&g)

Both F & G systems where the complete system is floating are only possible in stand-alone applications. These are not allowed in Australia according to AS3000 [9]. They are used in some instances in other countries in "small" systems. The implications here are the same as for any floating system. One fault may go undetected but the system then constitutes a hazard to personnel and a fire risk if a second fault develops.

6. INTERNAL ARRAY WIRING PROTECTION

Issues of string wiring protection and appropriate wire sizing within arrays are generally well understood. On floating (completely separated from earth) arrays the only risk is a short circuit within the array wiring. The most likely place for this to occur is in a junction box. When dealing with earthed array configurations then there also exists the problem of an earth fault causing over current within an array. There are two philosophies which can be adopted:

- avoid the possibility of short circuits by appropriate class II style barriers within the boxes.
- provide over current protection if more than 3 parallel strings.

These methodologies do not however deal with the possibility of a short-circuited bypass diode.

7. EARTHING – STRUCTURES

Most international codes and standards agree on earthing of equipment conductive parts. The general requirement is that all exposed conductive parts, which are not intended to be energised in normal operation, be earthed as a protective measure against indirect contact. This ensures that all metallic parts remain at an earth potential in case a fault in the insulation occurs.

AS/NZS 3000 [9] allows for exemptions to protective earthing (of exposed conductive parts) when the electrical systems fulfil the requirements of protection by electrical separation, SELV, PELV or when the system components and installation comply with class II. However, even in these cases, protective earthing of large area conductive metal parts, which are within arm's reach, could be advisable, because earthing of frames and structures provides a path to earth for surge currents induced by nearby lightning strikes. Earthing may also enable the operation of some protective devices such as over-current and residual current devices, in the event of a fault to frame.

Equipment earthing of PV structures is a straightforward practice. However, PV module frame earthing is another area where compliance with standard wiring rules within countries may be difficult given many manufacturers framing arrangements. Many modules are produced with frames constructed of four separate anodised aluminium pieces with little or no earthing connection facilities. Because the frame pieces are anodised it is impossible to ensure adequate earthing of the frame without puncturing the anodising on all of the frame pieces. This has serious consequences for corrosion, long term viability of the earth connection, earthing complexity and guarantee implications. The new draft IEC 61730 [3] it is hoped will help in this area.

8. OVERALL PROTECTION PHILOSOPHY

The overall protection philosophy for PV arrays, wiring and the over current and earth leakage protection required for each system is still under discussion and will be the subject of extensive industry workshops within Australia in February 2003. A philosophy that has been suggested in the first draft of a standard is to use predominantly class II insulation to avoid the possibility of indirect contact and to avoid internal or earth faults developing. In other words, the adoption of an inherently safe system philosophy. This has been combined with string over-current and array over current protection. The issue of earth leakage protection is yet to be determined as this is complex and varies with system topology as can be seen from Figure 1. The philosophy is aimed at simplicity while still maintaining an adequate level of safety.

9. NEED FOR RELAXED REQUIREMENTS FOR SMALL – LOW VOLTAGE SYSTEMS

Industry and committee reviews, have identified the need for less stringent requirements for “small” PV systems. The initial definition of a small system has been agreed upon to be within the limits of 75 V open circuit voltage, 20 A short circuit current and 500 W rated PV power (all at STC). Requirements under consideration for softening or removal for “small” systems are the following: double insulation ie class II, string fusing and disconnecting means, earth fault protection, automatic emergency shutdown, fault alarms and interlocks, some marking requirements, and a substantial amount of documentation.

10. OTHER STANDARD AREAS COVERED

Mechanical requirements (compliance with wind loading code and possibly with other loading codes such as live and dead loads snow and ice loads, etc.); component requirements (PV modules, junction boxes, switching devices, plugs, sockets and fuses); automatic emergency shutdown and alarms; guidelines on simple lightning protection precautions; marking requirements (signage); documentation (electrical and mechanical design, commissioning records and maintenance procedures); commissioning tests; and a guide on maintenance requirements.

11. INDUSTRY ACCEPTANCE

The initial draft Australian Standard was presented to Australian system installers at their annual meeting in Sydney in August 2002. The general feeling was that the draft was severe for smaller systems and it is difficult to decide where the boundary between small and large systems is to be placed. This boundary will undoubtedly be the subject of considerable discussion at industry workshops and standards meetings. It is also clear that particular care must be exercised where dc systems are involved. Even simple four series module single string systems although not generally a shock risk, can under fault conditions sustain dc arcs over a distance of 8mm and this represents a significant fire hazard.

12. SUMMARY & CONCLUSIONS

A large range of system configurations and voltages are currently in use in the PV industry. It is important for the industry to have clear, concise and safe standards in place for all types of PV array configurations considered acceptable and to prevent the use of unsafe/ unacceptable configurations. This paper has presented a wide range of system configurations and some of the implications for protecting these systems. An area which still needs significant international debate and data gathering on systems is: to what extent does class II insulation alone remove the need for other forms of protection. Does this level of insulation remove the need for string overcurrent protection? Does it remove the need for earth fault detection? These are serious questions because every joint or extra connection placed in a dc array may have the potential to create an arc if the connection becomes loose. Reducing complexity is important in crafting safe systems. The total level of protection requirements will be discussed at industry workshops and standards forums in Australia in 2003 and will be the subject of future publications.

13. ACKNOWLEDGEMENTS

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14. REFERENCE

[1] US – National Electrical Code,(NEC) Article 690 Solar Photovoltaic Systems. USA, 1999

[2] IEC 60364-7-712 Ed. 1.0 Electrical installations of buildings - Part 7-712: Requirements for special installations or locations - Solar photovoltaic (PV) power supply systems. May 2002.

[3] DRAFT-IEC61730-1&2 “Photovoltaic module safety requirements” Pt.1: Materials, Pt.2 Testing, 2002

[4] UK Department of Trade and Industry (DTI) Photovoltaics in buildings: Guide to the installation of PV systems, DTI/Pub URN 02/788, ETSU Report No. ETSU S/P2/00355/REP1 www.dti.gov.uk/renewable/index.html or email: NRE-enquiries@aeat.co.uk.

[5] EnergieNed, Guidelines for the electrical installation of grid connected photovoltaic (PV) systems, December 1998

[6] B. Verhoeven, Utility aspects of grid connected photovoltaic power systems, Technical Report IEA PVPS T5-01:1998, International Energy Agency, IEA, Photovoltaic Power Systems Programme, December 1998.

[7] Draft Australian Standard, PV array installation requirements, 2002
www.standards.ee.unsw.edu.au/PVarray.htm

[8] Meinhardt, M. and Mutschler, P.: Inverters without transformer in grid connected photovoltaic applications. Proceedings of the European Conference on Power Electronics and Application, Vol. 3, Sevilla, Spain, September 1995, pp. 86-91.

[9] AS/NZS 3000 “Electrical installations” (known as the Australian/New Zealand Wiring Rules) 2000.