Design of a software tool for PV-system-specific lightning protection

Linhart, F. ; Calais, M. ; Cole, G. ; Hinrichsen, V.

Presented at: Solar 2006 Australia - New Zealand Solar Energy Society Annual Conference, Canberra, Australia, September, 13-15

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Keyword(s): Photovoltaic systems; Lighting protection; Software tool
More info: Solar Energy and Building Physics Laboratory

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Design of a software tool for PV-system-specific lightning protection

F.Linhart, M.Calais[1], G.Cole[1] and V.Hinrichsen[2]
Solar Energy and Building Physics Laboratory (LESO-PB), Swiss Federal Institute of Technology in Lausanne (EPFL), 1015 Lausanne, Switzerland
E-mail: friedrich.linhart@epfl.ch

1 School of Electrical, Energy and Process Engineering, Murdoch University, Perth, Australia
2 TU Darmstadt, FG Hochspannungstechnik, Landgraf-Georg-Str.4, 64283 Darmstadt, Germany

Abstract

Photovoltaic (PV) systems are often installed on rooftops or as freestanding systems with no higher surrounding structures. This is why they are often exposed to the influences of lightning which can severely damage these expensive systems. Lightning protection considerations are therefore very important during the design process of a PV system and various standards should be followed when developing lightning protection strategies for PV systems. The application of these standards can, however, be a complex task. Based on the Australian Standards AS/NZS 5033:2005 "Installation of Photovoltaic (PV) Arrays" and AS/NZS 1768 (Int):2003 "Lightning Protection", recent publications by the IEC, recommendations by the European Commission and other previously published research results, a new software tool ("Flashprotect PV") for PV-system-specific lightning protection has been developed. Flashprotect PV makes it possible to quickly assess damage risks for PV systems resulting from lightning discharges without an in-depth knowledge of the different standards. It also makes recommendations on appropriate design of external and internal lightning protection strategies. When using this new software tool, PV System designers do not have to carry out complicated risk assessments by hand and can therefore save valuable time. In addition to that, the software can speed up the design of the actual lightning protection system.

1. INTRODUCTION

Photovoltaic (PV) systems are either installed on top of buildings or as freestanding systems; they are therefore often strongly exposed to all sorts of climatic and environmental influences. One of these is exposure to thunderstorms and lightning.

In the case of roof-mounted systems, the presence of a PV system on top of a building does not significantly increase the building's likelihood to be struck by lightning. The probability that a part of the PV system being hit in the case of a direct strike to the building is nevertheless very high as strokes are more likely to hit metallic structures with sharp edges than other parts of the building (VDE, 2001). Freestanding PV systems are often not situated within the lightning protection zones of any surrounding structures. They are therefore often exposed to the influence of lightning discharges.

The effects of lightning strikes can be powerful enough to significantly damage PV systems (Häberlin, 2001). It is therefore essential to assess the risk of damage through lightning strikes on a PV system and to take appropriate measures in order to avoid different types of destruction due to the effects of lightning.

There are already a few software tools (for example by Aixthor (www.aixthor.com, 2006)) which can help during the design process of a lightning protection system. The EXCEL spreadsheet which accompanies the Australian Standard AS/NZS 1768 is also an efficient tool in as much as it does not require detailed knowledge of the corresponding standard. Nevertheless, these tools are designed to assess risks for building structures in general and the application to PV systems is not always evident. In addition to that, the mentioned spreadsheet only assists in calculating risks but does not make recommendations which particular protection measures should actually be applied.

The developed software tool presented in this paper makes it possible to carry out an appropriate risk assessment for two types of PV systems (roof-mounted or freestanding) and then makes suggestions for external and internal protection depending on the outcome of this risk assessment. The main objective was to create a tool which is easy and quick to use and which provides practical recommendations for PV-system-specific lightning protection measures.

This paper first discusses the relevance of lightning protection for PV systems in Section 2. Relevant standards for lightning protection in PV systems are then reviewed in Section 3. Section 4 gives an overview of the developed software tool for PV-system-specific lightning protection and presents an application example. Conclusions and an outlook on further work are given in Section 5.

2. RELEVANCE OF LIGHTNING PROTECTION FOR PV SYSTEMS

There are three possibilities for a lightning discharge to interact with a PV system (von Dohlen, 1993):

- **direct strikes to the system**
- **inductive coupling**
- **capacitive coupling**

The most harmful event for a PV system in relation to lightning discharges is the case that the system is directly hit by a lightning strike. In this case, very high currents will flow over various system components and destroy some of them (Häberlin, 2001). Because of these very high currents, high resistive voltage drops occur throughout the system and flashovers are possible due to potential differences. Even in system components which are not traversed by the lightning current itself, high voltages can be induced due to the electromagnetic field associated with the discharge. This electromagnetic field is a result of the so-called lightning electromagnetic pulse or LEMP. It leads to inductive and capacitive coupling in nearby conductor loops.

Due to the steep current rise at the beginning of a lightning discharge, significant voltages can be induced in conductor loops which are situated in the proximity of the lightning current via the magnetic field (*inductive coupling*). The magnitude of these voltages depends on the area of the loop and on the distance from the lightning current. Conductor loops can be found at various places in a PV system. The wiring inside the modules might form such loops as does the string wiring and the DC and AC power cables. Even parts of the metal system structure and the lightning protection system are often involved in the formation of conductor loops. Lightning discharges within a distance of 500 metres around the system can be extensive enough to induce damaging over-voltages in PV systems (VDE, 2001). When a lightning discharge occurs, there is not only a transient non-constant magnetic field but also an electric field associated with this discharge. The formation of this field causes a charge separation in its area of influence (*capacitive coupling*). Once the field has collapsed (when the lightning discharge is over), these charges oscillate for a certain amount of time. Up to a distance of 1000 metres around the system, a lightning discharge has a capacitive influence on a PV system (VDE, 2001). Nevertheless, capacitive coupling effects are less dangerous for PV systems than inductive coupling (Häberlin, 2001).

There are two major types of damage which can be the results of the described interactions:

- **mechanical damage (including fire)**
- **damage to electric and electronic devices due to over-voltages**

If a PV array which is not protected by a lightning protection system (LPS) is directly hit by a lightning stroke, the effect is most likely to be catastrophic (Häberlin, 2001). The lightning current will flow through the installation itself and may cause mechanical damage to modules, mechanical and electrical components (mirrors, motors etc.) and electronic components (inverters, adjacent communication and monitoring devices). According to Hinrichsen (2003), the energy associated with the discharge at the lightning strike attachment point can be as high as 3500 Joules. A 10 kg rock would have to be dropped onto the system from a height of 35 m to replicate the same amount of energy at the point of impact as a lightning strike (Linhart, 2006). This example demonstrates how devastating a lightning discharge can be.

This mechanical damage can not only occur in the case of a PV system without external lightning protection. Even if an external LPS is installed, some mechanical damage may occur, especially if the safety distances between the external LPS and the structure are not respected or if the protection zone created by the LPS does not cover the whole system.

Figure 1 shows the internal wiring of two PV strings. The wiring of the first string (Case 1) forms a conductor loop with a large area. This should be avoided under all circumstances because it would allow high voltages to occur. The solution for the second string (Case 2) keeps the loop area much smaller and the induced voltages will therefore be reduced in this case. If the string wiring or wiring inside a module forms a large area, the induced voltage can easily damage the modules because it can lead to insulation failure. Arcs can develop and damage the module. Diodes can also be destroyed. Care should therefore be taken to minimize the area of the wiring in PV modules and strings (Häberlin, 2001). The distance between the cells and potential lightning current carrying conductors should be chosen as large as possible. Other conductor loops can be formed at various locations within PV systems, for example between the different conductors (positive and negative conductor) or between one conductor and the lightning protection conductor.

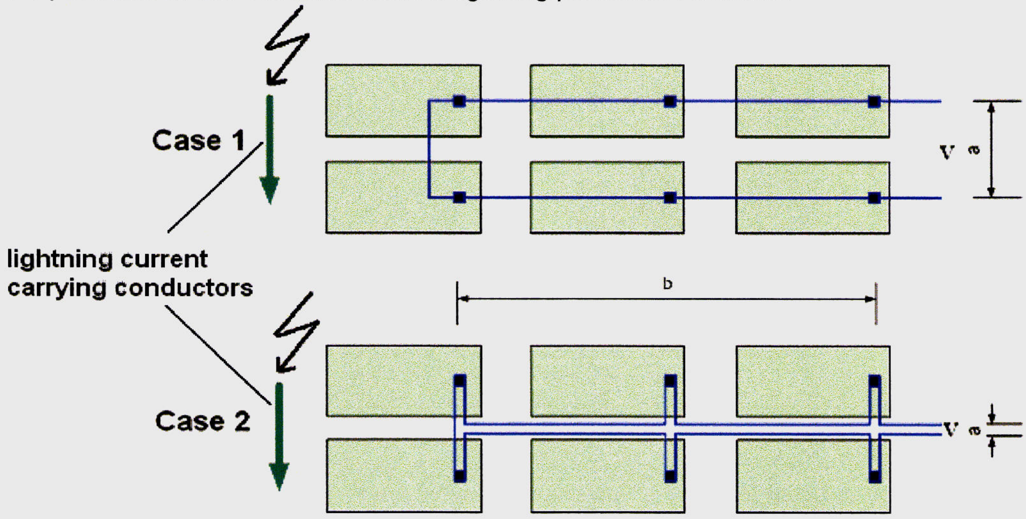

Figure 1: Two possible ways of interconnecting PV modules are shown above. In Case 1, the wiring forms a large conductor loop. This must be avoided because it might lead to high induced voltages. The area of the conductor loop is minimized in Case 2.

The over-voltages induced in the conductor loops and the high currents which occur when a loop is closed (formation of an arc for example) can lead to the mechanical damage described above but can also become very damaging to electronic equipment. If, for example, the voltage applied to the DC input of an inverter exceeds the acceptable limits, the device's insulation might fail, large currents may flow and the expensive device is likely to be destroyed. The same applies for other electric and electronic system components such as motors, control units, monitoring equipment and communication equipment. Even small surges which will not be strong enough to physically damage these electronic installations may be a problem because they can have an effect on the reliability of measurements, data transfer and communication channels. As explained by Häberlin (2001), induced voltages can easily exceed 100 kV. A surge in this order of magnitude would already be able to do harm to an inverter if it is applied to its DC input. Examples of damaged PV systems have been published by Phoenix-Contact (2004).

3. RELEVANT STANDARDS FOR LIGHTNING PROTECTION IN PV SYSTEMS

During the design process of any LPS, the application of standards is mandatory. In the case of lightning protection for PV systems in Australia and New Zealand, the Standards AS/NZS 5033:2005 "Installation of Photovoltaic (PV) Arrays" (Standards Australia and Standards New Zealand, 2005) and AS/NZS 1768:2003 "Lightning Protection" (Standards Australia and Standards New Zealand, 2003) apply. AS/NZS 1768:2003 is an interim standard published in 2003 which was prepared to supersede AS 1768–1991, submissions relating to the 1991 standard and International Electrotechnical Commission (IEC) Technical Committee TC 81 documents on lightning protection have been used to develop AS/NZS 1768:2003. It will be valid until end 2006 and will then either be superseded by another standard, confirmed for another two years, or withdrawn. The IEC are currently preparing a new standard on lightning protection; a final draft has already been published (IEC, 2005).
In order to carry out a lightning risk assessment for a PV System, engineers and designers first of all have to become familiar with the standards mentioned above. This can, however, be a complex task because they are tedious to read and because their general approach makes the application to specific building structures (for example PV systems) difficult. In order to make the application of AS/NZS 1768 easier, this standard incorporates an EXCEL spreadsheet. Its existence in itself admits

that the standard requires a tool to make it easier to apply. After having judged the risk of a potential lightning strike to a PV system by application of an appropriate risk assessment, the designer faces the task on how to design the lightning protection system which reduces the risk to acceptable levels. This requires knowledge on effective, project specific lightning protection measures.
Information by Bopp & Laukamp (1993), Dehn & Söhne (2005), von Dohlen (1993), Häberlin (2001), Phoenix Contact (2004), Schletter Solar-Montagesysteme (2005), Standards Australia and Standards New Zealand (2003, 2005) and VDE (2001) was used to incorporate this knowledge in the software tool which is described in Section 4.
During the development of the software tool, some PV system specific risk assessment parameters have been preset. A good example is the choice of appropriate damage factors as explained by Linhart (2006).

4. THE SOFTWARE TOOL

The developed software tool is based on AS/NZS 5033 and AS/NZS 1768, the final draft of the new IEC Standard on lightning protection (IEC, 2005), recommendations by the European Commission (Becker *et al,* 2000), information by Kuleshov *et al* (2001) and the Australian Bureau of Meteorology (www.bom.gov.au, 2005), as well as the other sources cited in Section 3. It gives the user the option to carry out a risk assessment for two types of PV systems (grid connected and stand-alone). Then, depending on the outcome of the risk assessment, suggestions for external and internal protection are made.
The software tool is designed for application within Australia and New Zealand because the main risk assessment is carried out according to AS/NZS 1768. Nevertheless, adapting the software for applications at other locations is possible in the future.

4.1. Description structure of the software tool

Figure 2 gives an overview of the different program components and the program flow of the software tool which has been named "Flashprotect PV".

After the user has been given some general information about the tool, the program enters its Risk Assessment component. After the general data acquisition (e.g. system location, system type etc.), a new window becomes visible to the user. Depending on the system type, further information is gathered either for a roof-mounted or a freestanding system. The software tool then performs a risk assessment based on AS/NZS 1768. If, according to this standard, external protection is necessary, the Risk Assessment results are presented. If this is not the case, an additional economic risk assessment is carried out and the results are presented on the Risk Assessment results page. This additional risk assessment is carried out because the economic risk assessment based on damage factors as prescribed in AS/NZS 1768 is not always satisfactory for expensive structures. In AS/NZS 1768 the decision on whether protection is needed or not is not based on absolute monetary values but on relative ones. The economic risk assessment suggested by the European Commission (Becker *et al*, 2000) however, uses absolute monetary values in order to calculate the acceptable risk rather than relative damage factors. The additional economic risk assessment can assist the user in investigating a possible significant economic loss which may lead to the decision to install protection measures even though this is not required according to the standard. The risk assessment component in this software tool therefore calculates the risk for a given PV system according to AS/NZS 1768 and, if necessary, according to the recommendations by Becker *et al* (2000). Data published by Kuleshov *et al* (2001) and www.bom.gov.au (2005) has been used to estimate the number of thunder-days for the different locations. More detailed information on assumptions and estimations made during the software design process has been given by Linhart (2006).

After the risk assessment results have been shown, the tool enters the External Protection component where suggestions for an external LPS are made depending on the system type and the outcome of the risk assessment. If further information on the different steps in the design process of the LPS is needed, the user can access external help files through the External Protection window.

In most cases, the External Protection component will suggest the following steps for an external LPS:

1. Design of an air termination network (includes downconductors) which creates a protection zone large enough to protect all system components against direct lightning strikes.
2. Design of an earth termination network which safely distributes the intercepted lightning currents in the earth.
3. Identification of all metal components within the system. All of these components should be earthed (equipotential bonding).

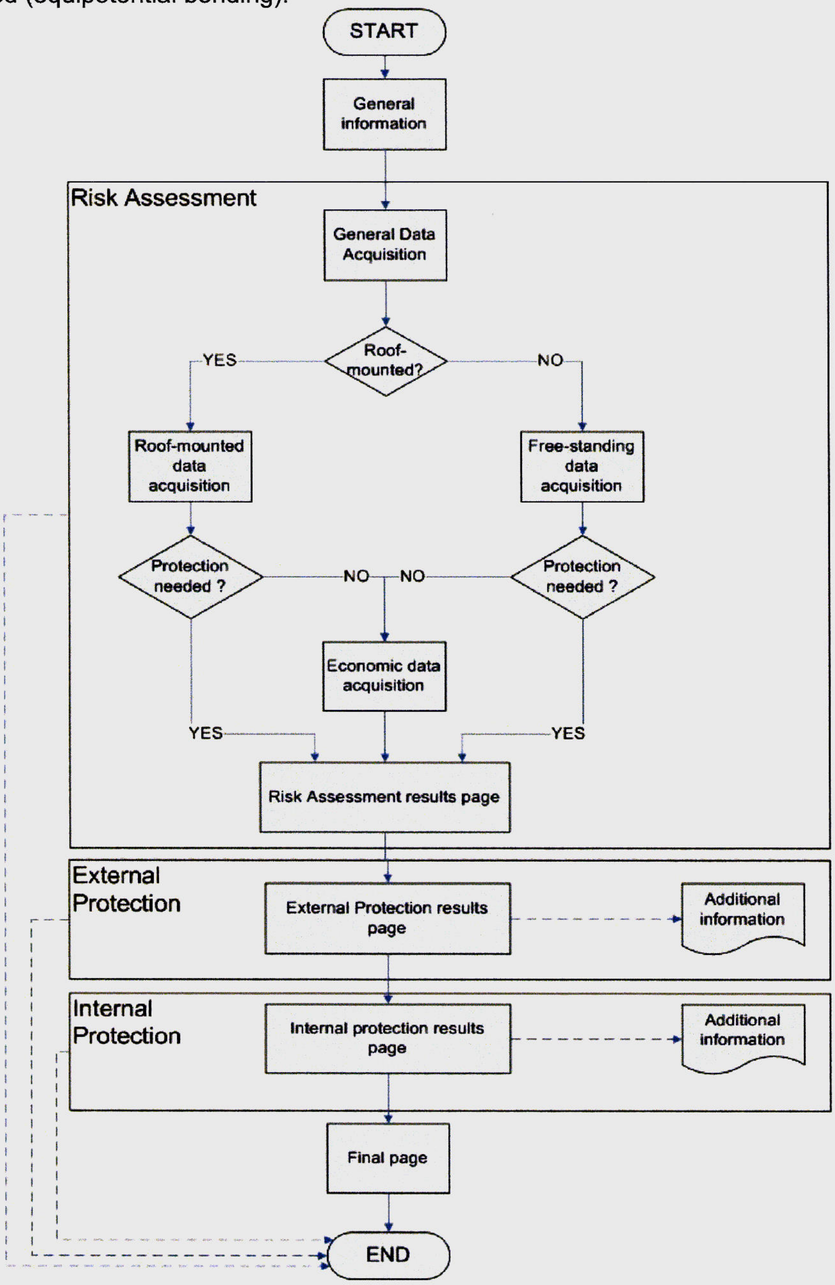

Figure 2: Flowchart showing the three software components Risk Assessment, External Protection and Internal Protection and the program flow between them.

The following Internal Protection component is based on the same format as the External Protection component: giving the user information on the necessary steps of the design process for an internal LPS and providing access to further information (through help files) if required.
The five recommended steps on the Internal Protection results page are the same for every system type, location and dimension:

1. Minimize the area of conductor loops within the system by putting power conductors as close together as possible.
2. Protect the system against incoming surges and currents through incoming service lines by installing Surge Protection Devices (SPDs) at all entry points of these lines.
3. Shield DC and AC power lines if possible.
4. Protect the PV modules by installing SPDs of class II in junction boxes where this is possible.
5. Protect all electric and electronic components by installing SPDs of class II or III at their inputs.

The suggestions given by the software tool are mostly based on recommendations by Bopp & Laukamp (1993), Dehn & Söhne (2005), Häberlin (2001) and Schletter Solar-Montagesysteme (2005).

On the final page, the user can select to print out certain parts of the results and then exit the program. Another way to exit the program is by closing the underlying background form. This can be done at any time and is indicated in Figure 2 by the three dashed arrows which link the components to the "End"-button.

4.2. Application Example

The very small PV system on Mt. Elizabeth Station off the Gibb River Road between Derby and Kununurra will now be used as an example in order to demonstrate how the software tool works. This station is not connected to any power grid but is completely self-sufficient in terms of energy supply. The PV system is part of a power generation system which also includes a certain number of batteries as well as a diesel generator. The PV system is shown on the left in Figure 3. The screenshot on the right of Figure 3 shows the first part of the Risk Assessment component for this PV system. According to the thunder-day map suggested by www.bom.gov.au (2005), 65 thunder-days have been chosen for this location. The system is freestanding and a stand-alone system.

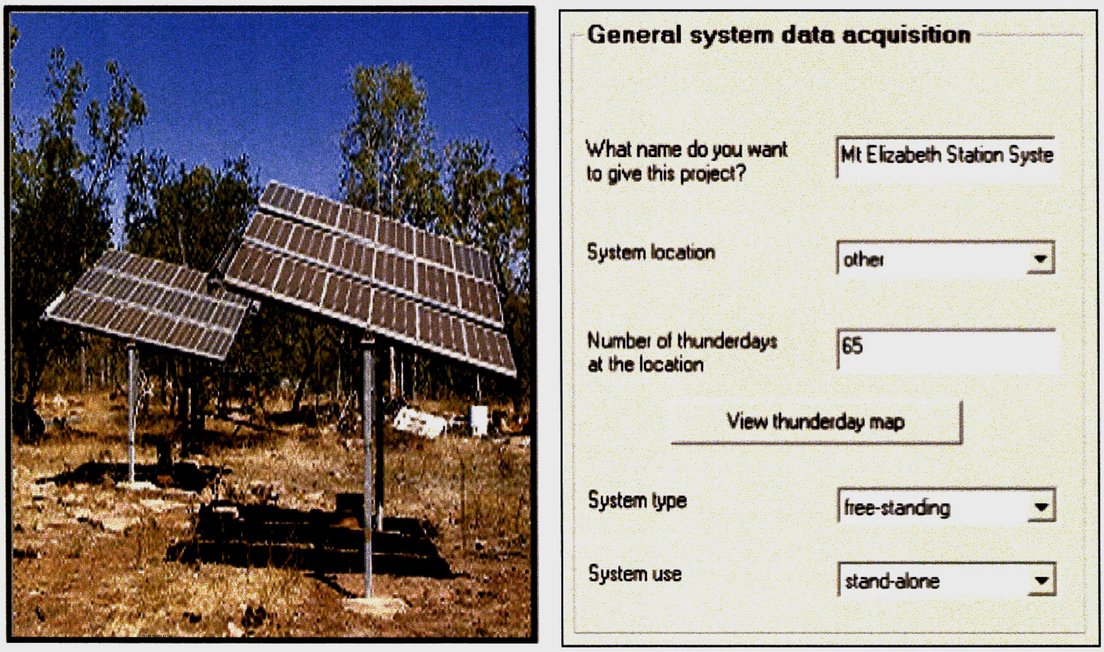

Figure 3: PV system on Mt. Elizabeth Station (left), first form shown during the application of the software tool to this PV system (right).

On the next form shown in Figure 4, the system dimensions have been set to 5 m x 5 m x 3 m. The system is not surrounded by a fence. Buildings around the system are higher than the system itself.

Figure 5 shows the optional form for the additional risk assessment according to Becker *et al* (2000). This form is shown by the program because according to AS/NZS 1768 no external protection is necessary for this system.

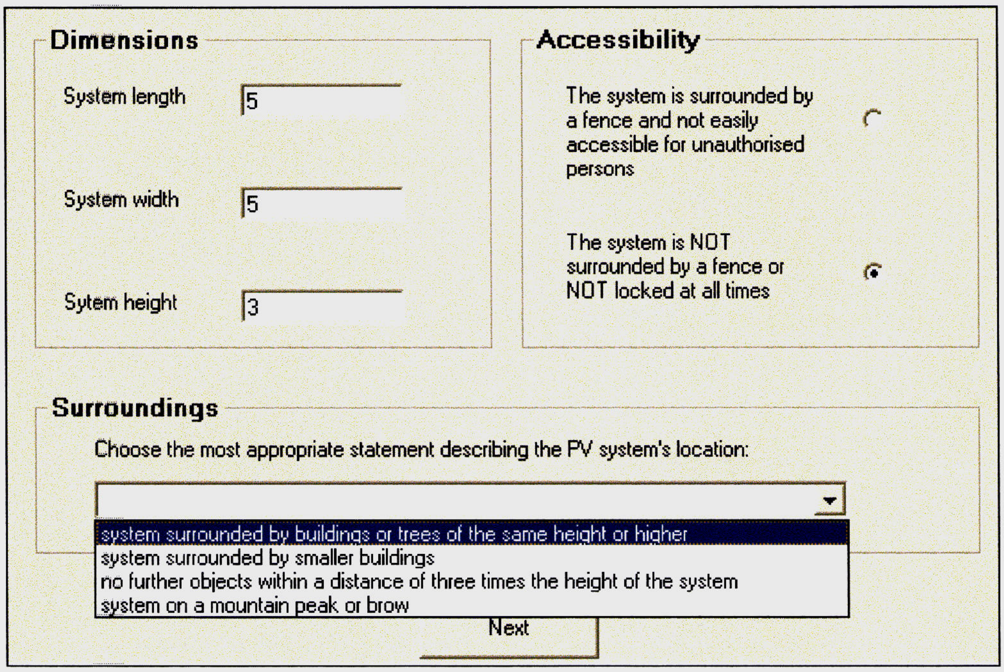

Figure 4: Second form shown during the application of the software tool to the Mt. Elizabeth Station PV System. The user makes the choices concerning the accessibility of the system, enters the system's dimensions and chooses the surroundings factor.

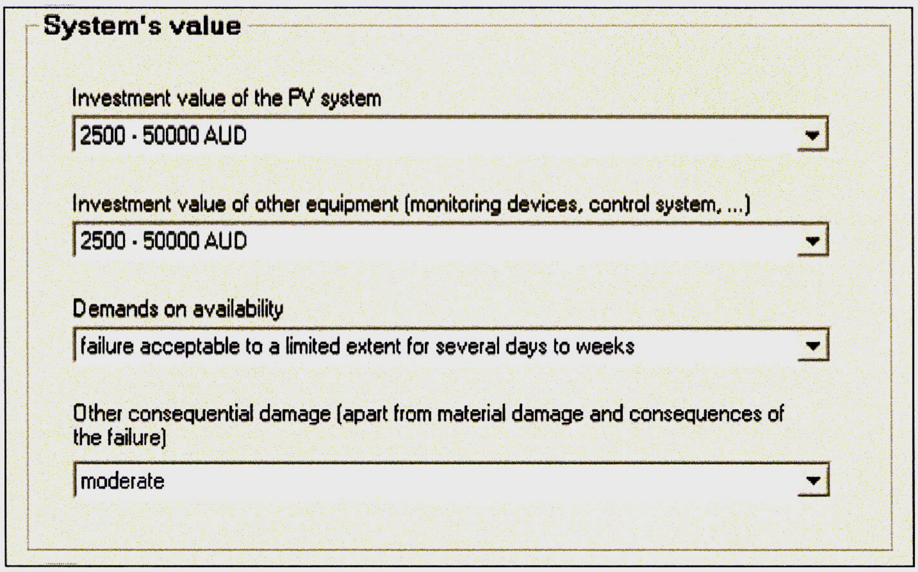

Figure 5: Third form shown during the application of the software tool to the Mt. Elizabeth Station PV System. An additional economic risk assessment is carried out.

The investment value of the PV system has been estimated to lie within the 2,500-50,000 AUD range. The investment value of other equipment is higher in this case than in the case of a standard PV System because it comprises of batteries and a diesel generator as mentioned before. These devices can also be damaged by lightning currents and over-voltages because they are electrically connected to the PV system. A value between 2,500-50,000 AUD has therefore also been chosen for this parameter. Failure is acceptable to a limited extent for several days to weeks. This choice has been made because the station can be powered by the diesel generator as long as diesel is available. The risk of other consequential damage has been set to moderate because the station is isolated and a power outage will not only have economical effects but may cause harm to human beings and cattle. The screenshot in Figure 6 shows the results of the Risk Assessment. According to the additional economic risk assessment, external protection is required. It also shows that "Loss of human life" is a relevant loss type. This is the case because the system is not surrounded by a fence. Human beings could therefore be endangered due to touch and step voltages if they for example shelter under the panels during a thunderstorm.

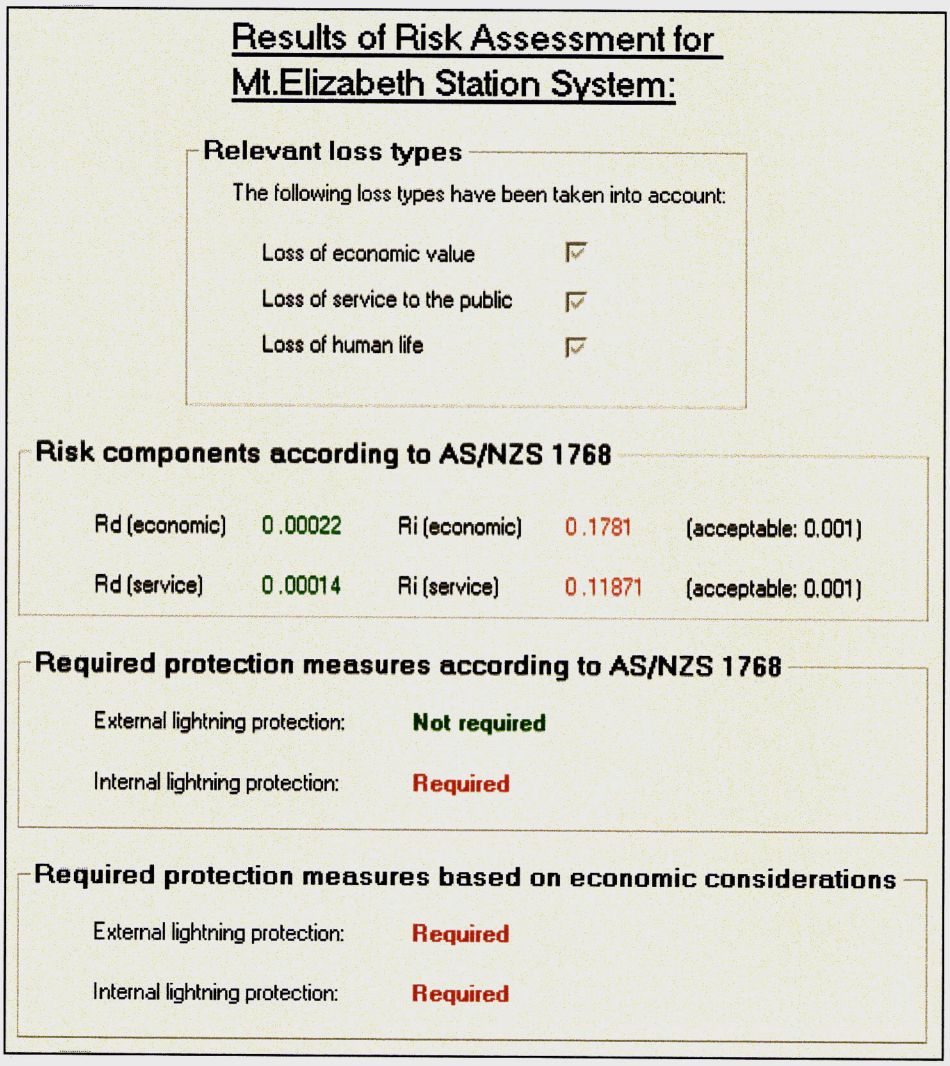

Figure 6: Fourth form shown during the application of the software tool to the Mt. Elizabeth Station PV System. This form shows the results of the risk assessment according to AS/NZS 1768 and according to the economic risk assessment.

The recommendations for external protection for the PV System on Mt. Elizabeth station are shown in Figure 7. The three "more information"-buttons lead to the previously mentioned help-files which give further information on the necessary design process of an external LPS.

After the form shown in Figure 7 has been viewed by the user, a similar page describing the necessary internal LPS (more help files are accessible at this point) becomes visible, and the user also has the option to print out some of the results before terminating the program.

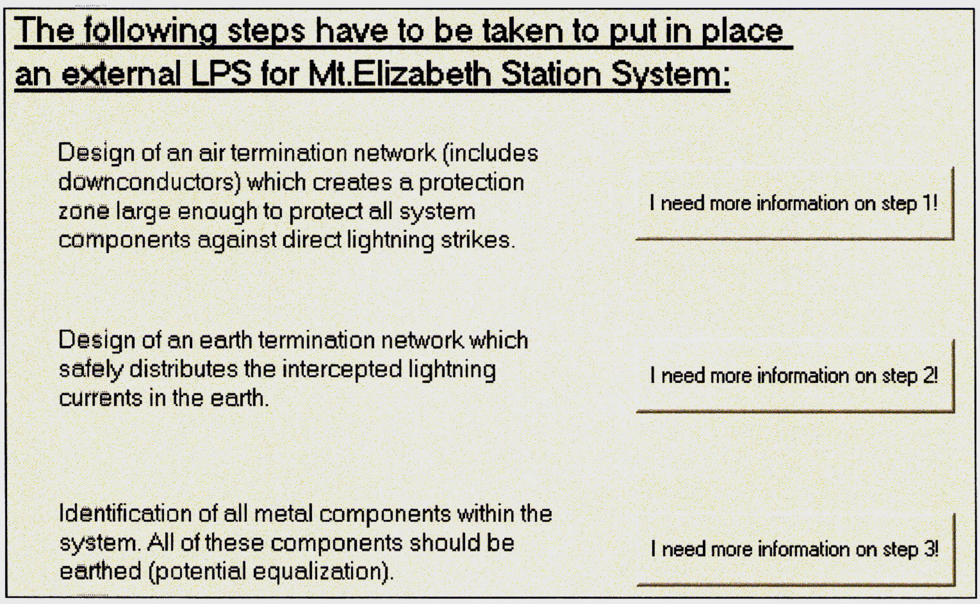

Figure 7: Fifth form shown during the application of the software tool to the Mt. Elizabeth Station PV System. This form makes suggestions on the steps one must follow when putting in place the external LPS and provides access to additional information.

5. CONCLUSION

Based on the Australian Standards AS/NZS 5033:2005 “Installation of Photovoltaic (PV) Arrays” and AS/NZS 1768 (Int):2003 “Lightning Protection”, recent publications by the IEC, recommendations by the European Commission and other previously published research results, a software tool for PV-system-specific lightning protection has been developed. The main advantage of the software tool compared to existing tools is the fact that it has been specially adapted for use during the design process of PV systems. Parameters which can be considered to have the same value for any PV system do not have to be defined by the user. These parameters have been preset during the software design process. Another advantage is the fact that the values which have to be entered by the user are explained in a general manner. The user does not have to be familiar with the different standards. The software tool not only helps to carry out lightning risk assessments for PV Systems, it also makes recommendations on external and internal lightning protection for a given type of PV system.

Further work on the developed software tool is a very interesting option. So far, the External Protection and Internal Protection components of the tool only make recommendations on the steps one has to follow during the LPS design process. The user has to carry out the necessary calculations afterwards. It will not be complicated to implement the possibility to calculate the external LPS in detail (for example the necessary height of air terminals for a given system). If the tool gathers more specific information on the electrical characteristics of the PV system, even the internal LPS (for example necessary surge protection devices) could be calculated within this software. In addition to that, the two risk assessment procedures used by the software tool (based on AS/NZS 1768 and recommendations by the European Commission) could be combined in order to develop one completely new, more efficient and realistic risk assessment procedure.

Flashprotect PV can be downloaded on www.flashprotect.de.

6. ACKNOWLEDGMENTS

The development of the software tool was part of the master thesis “Lightning protection for photovoltaic (PV) systems - Development of a lightning protection strategy for the Rockingham PV System and design of a software tool for PV-system-specific lightning protection” by Friedrich Linhart.

This thesis has been carried out at Murdoch University from May 2005 through January 2006 under the supervision of Dr. Martina Calais, Assoc. Prof. Graeme Cole and Prof. Dr.-Ing. Volker Hinrichsen.

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Suzanne Leplattenier

De : "Friedrich Linhart" <friedrich.linhart@epfl.ch>
À : <suzanne.leplattenier@epfl.ch>
Envoyé : vendredi, 25. août 2006 11:55
Joindre : Lightning Protection for PV Systems___Linhart.pdf
Objet : titre + article + question

Salut Suzanne,

Comme je te l'ai promis il y a dix minutes voici le titre de mon article :

Design of a software tool for PV-system-specific lightning protection

La conférence à Canberra s'appelle:

Solar 2006 --- Australia / New Zealand Solar Energy Society Annual Conference

J'ai mis un PDF de l'article en pièce – jointe...

Et puis je voulais aussi te demander comment il faut faire pour avoir des cartes de visites EPFL... je pense que cela pourrait être très utile d'en avoir pour cette conférence et aussi pour d'autres occasions. D'après ce que je comprends sur le site « Réprographie EPFL », les commandes se font à travers des personnes ayant des droits spéciaux... est-ce que tu es une telle personne ? ;-)

Merci d'avance de ton aide et bon week-end,

Friedrich

Dipl.-Ing. Friedrich Linhart
Laboratoire d'énergie solaire et de physique du bâtiment (LESO-PB)
Ecole Polytechnique Fédérale de Lausanne
1015 Lausanne
Suisse

Téléphone: +41 21 693 4540
Fax : +41 21 693 2722
http://lesowww.epfl.ch