OCCUPATIONAL, SAFETY AND HEALTH ISSUES: RISK MANAGEMENT IN REMOTE PHOTOVOLTAIC STAND-ALONE SYSTEM INSTALLATION

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Abstract: Photovoltaic industries have begun to secure a positive pace in the local energy market with more photovoltaic (*PV*) systems are being installed currently. For stand alone applications, most of the *PV* systems are installed in remote sites which are almost inaccessible by roads. This can result in risks that are not limited to the actual sites. Therefore, there should be an effective risk management process to ensure the safety of workers involved. This paper discusses about the risks associated with *PV* installation in isolated areas. Identification, analysis and evaluation of these risks are explained in details to confront the safety issues during PV installation.

Keywords: Photovoltaic (*PV*), Risk, Likelihood, Consequence

INTRODUCTION

Solar energy supply had been promoted in Malaysia since 1980s by Tenaga Nasional Berhad (TNB). Since then, numerous photovoltaic (PV) applications have been implemented to provide an alternative source of energy to Malaysian energy resources. Correspondingly, in the eighth Malaysian plan, the government has pointed out that at least 5% of total electrical energy supply has to come from renewable energy resources by year 2005. As a tropical country which is located very near to the equator, Malaysia has a great potential of utilising the ample sunshine for generating electrical energy. In fact, the solar generators are most beneficial in rural parts of Malaysia where the costs of supply electricity from the grid to these areas are very high and uneconomical. However, the process of rural *PV* electrification is hindered by the isolated location of the rural areas. Most of the times, the contractors need to travel inland in a four-wheel drives or small trucks to access the desired sites. Normally, they will bring along all the equipments and heavy-weight components required for PV installation such as solar modules, batteries, inverters, regulators, mounting frames and cables [4]. Apart from that, as the sites are usually remote from other dwellings as well as clinics, police stations or fire stations, *PV* installation could be considered as a very risky task for the contractors. Therefore, in line with the Occupational, Safety and Health Act 1994, a safety and health policy should be implemented in the *PV* sites where more than five workers are normally involved [2]. For a jumpstart, risk assessment associated with *PV* installation has to be formulated effectively to ensure the safety and health of those workers involved. Concurrently, a well organized risk management needs to be developed to minimize accidents in the workplace.

MATERIALS AND METHODS

A field survey and interviews with related contractors were conducted to analyse the potential risks involved during photovoltaic (*PV*) installation in rural areas. As there is no standard on safety procedure for managing risks in *PV* installation in Malaysia, the Australian standards AS/NZS 4360 Risk management process and AS4509 Stand Alone Power system were adopted for evaluating the associated risks.

The core steps in risk management process are described in Figure 1. Despite having the different steps, only risk identification, risk assessment and risk treatment were focused in this project as they form the integral part of risk management process [1].

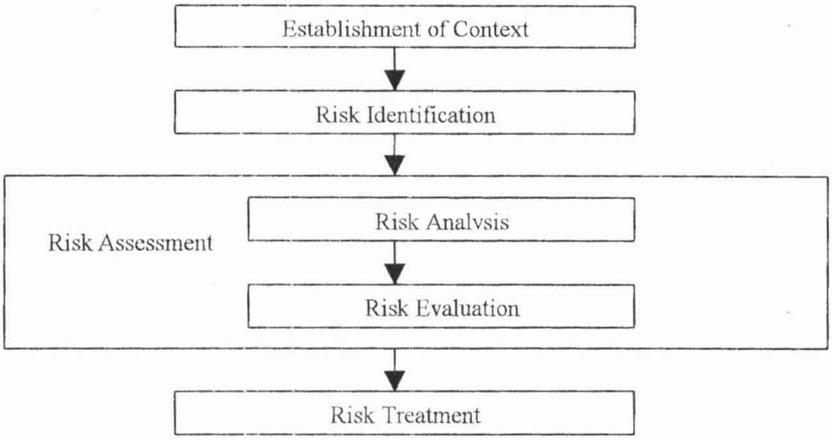

Figure 1: Core steps in risk management process
(Source from Professor Jean Cross, University of New South Wales, Australia)

First and foremost, from Figure 1, risk identification basically began with the identification of the general sources of risks and the areas of influence. Critical risks were then crucially distinguished in more details to determine the types and causes of accidents that may occur [1]. Apart from that, the identification of risks was conducted intensively to ensure the success of the whole process as any unidentified risk will not be handled in later risk management steps. For a start, comprehensive understanding of *PV* installation and imaginative thinking were used to identify any dangers and eventualities that may arise during *PV* installation. In risk identification, the pathway analysis was utilised in recognizing the risks. This analysis employs a concept that there are sources of risks, a party which might suffer losses and a pathway between the two. In addition, there are also barriers that could be exercised to prevent the sources of risks from affecting the potential targets [1]. This concept is illustrated in Figure 2.

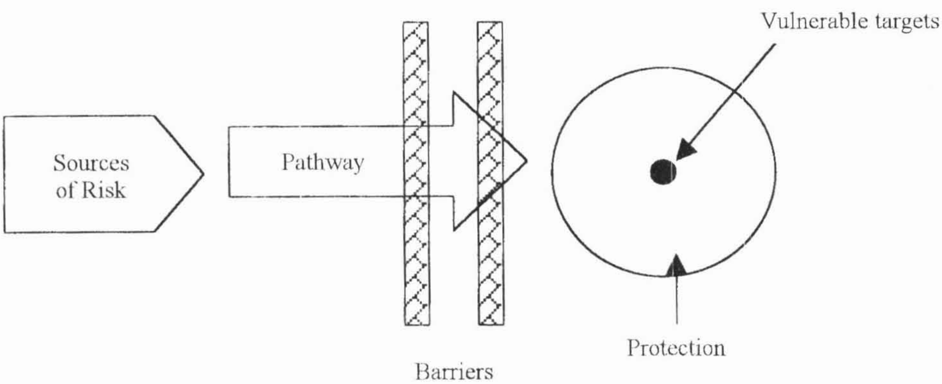

Figure 2: Pathway analysis
(Source from Professor Jean Cross, University of New South Wales, Australia)

In Figure 2, the targets in this research were the personnel working in rural *PV* installations. Barriers can be physical or in the form of procedures while protection can be special equipment or clothing used by the workers to avoid any losses caused by the sources of risks. Besides, pathway allows the sources of risk to reach the target.

Secondly, after knowing all important risks, the risks were then assessed through detailed analysis and evaluation. This process is called risk assessment. In risk analysis, the severity of a risk was ascertained qualitatively by evaluating the potential consequences and the probability of the consequences to occur [1]. Because there were insufficient statistical data on accidents in *PV* industry in Malaysia, most risks were weighed based on qualitative judgment from *PV* experts. In this paper, a level of risk was estimated by combining the severity of consequences with the likelihood of the consequences. Prior to that, the likelihood and consequence of risk were categorised into five-point and four-point descriptive scale respectively. In this case, consequence was classified based on severity of a risk while likelihood was ranked based on probability of a risk. Later, both of them were combined and plotted qualitatively on a risk chart to provide a clear comparison of the risks. Additionally, the area of the chart is divided into four segments that represent low, medium, high and extremely high risk respectively as part of risk evaluation. This step was done by prioritizing and assessing the risks involved after comparing with a set of predetermined criteria [1]. At this stage, a particular risk in *PV* installation was judged whether it is acceptable or has to be moderated. In addition, perceptions of risks and legal requirements also influenced the end decisions. Subsequently, the results were used to provide significant information for *PV* workers about the degree of the risk. Moreover, the results will enable the workers to have a good insight in treating the risks. Finally, each risk was treated accordingly to overcome the adverse effects. This is known as risk treatment. Based on risk assessment, specific methods or procedures were formed to minimise each risk.

RESULTS AND DISCUSSIONS

The area of impact being considered in this study was the personnel working on rural *PV* installations. These workers are vulnerable to various sources of risks. The potential losses that may be experienced by these personnel include injuries, disabilities, sickness, and death. Obviously, each loss is caused by certain sources of risks. After the latter factors have been discovered, the associated risk identification becomes more prominent. Using pathway analysis, the relationship between the sources of risks, pathways, risks and the possible barriers or protection are described in Table 1. Note that the target of interest in this study was only the workers installing *PV* systems in remote areas.

Table 1: Results for pathway analysis

Source of Risk	Pathway	Risk
1) Physical Hazards		
Exposure to sun	-sun is brightest with no shading exists	*R1*: result in dehydration
		R2: may cause sun burns
	-metal objects (aluminum frames, metal array frames and roofs exposed to high sun intensity	*R3*: may cause thermal burns
Insects, Snakes, and etc	-animals inhabit junction boxes, array frames and other enclosures	*R4*: being bitten by the animals
Working with metal frames, junction boxes, bolts, nuts, guy wires, etc	-sharp edges of these components	*R5*: may cause body injuries
Walking while lifting heavy components	-rough terrain and high roofs	*R6*: may cause falls, sprains and strains
2)Electrical Hazards		
High voltage (from as low as 20V)	-sweaty hands	*R7*: electric shock may occur

3)Chemical Hazards		
Lead-acid batteries	-spillage of electrolyte during battery charging	*R8*: can cause acid burns to unprotected part of body
Gas explosion or fire	-hydrogen gas released from battery is in contact with flames or sparks	*R9*: may cause major chemical and physical burns

From Table 1, walking while lifting heavy components such as batteries is considered as a source of risk while rough terrain is regarded as pathway that may lead to risk of falls, strains or sprains. This is an example of how the pathway analysis works. Nevertheless, the barriers and protection will be discussed further as part of risk treatment. The next step of risk management is risk assessment. At this stage, likelihood of a risk in Table 1 was evaluated qualitatively using five-point descriptive scale whereas consequence of a risk was assessed based on a four-point descriptive scale. The severity scale and likelihood scale used for this research are illustrated in Table 2 and Table 3 respectively.

Table 2: Severity categories

Category	Degree	Description
I	Minor	Slight injury to part of body with almost no effect to success of PV installation
II	Critical	Serious injury that may halt PV installation temporarily
III	Major	Very serious injury that may postpone the PV installation on another date
IV	Catastrophic	Very serious injury that is potential for total permanent disability or fatality and requires review of PV system being installed.

Table 3: Likelihood categories

Level	Probability	Description
A	Frequent	Likely to occur frequently
B	Probable	Normally occur several times during installation
C	Occasional	Likely to occur some time during installation
D	Remote	Unlikely but possible to occur during installation
E	Improbable	So unlikely to occur during installation

In Table 2, a risk in Category *IV* is considered the most undesirable while a risk in Category *I* is the most desirable. On the other hand, a risk of Level *A* has the highest probability to occur while a risk in Level *E* is the most unlikely to occur during *PV* installation in remote areas. After classifying the risks, risk prioritization was made based on all possible combinations of severity levels and likelihood levels. This analysis was done to rank each risk according to its priority [1]. The risk evaluation is described in Table 4.

Table 4: Risk evaluation table

Severity / Likelihood	Minor I	Critical II	Major III	Catastrophic IV
Frequent A	M	H	E	E
Probable B	L	M	H	E
Occasional C	L	M	H	E
Remote D	L	M	H	E
Improbable E	L	L	M	M

Legend:
L : Low risk; Managed by practicing safe working habits.
M : Moderate risk; Standard safety procedures must be formed apart from practicing safe working habits.
H : High risk; Prompt action and urgent attention are required while following standard safety procedures and maintaining good working habits.
E : Extremely high risk; Top priority should be given. Installation should be ceased until risk is reduced to a satisfactory level.

After characterizing each risk in Table 1 into these categories, the risks were combined and plotted on a risk chart shown in Figure 3. The likelihood was plotted along the horizontal axis while the consequence or severity was plotted along the vertical axis. Three diagonal lines were formed across the plot area of risk chart to divide it into three level of risk; low, medium and high. The latter step is part of risk evaluation.

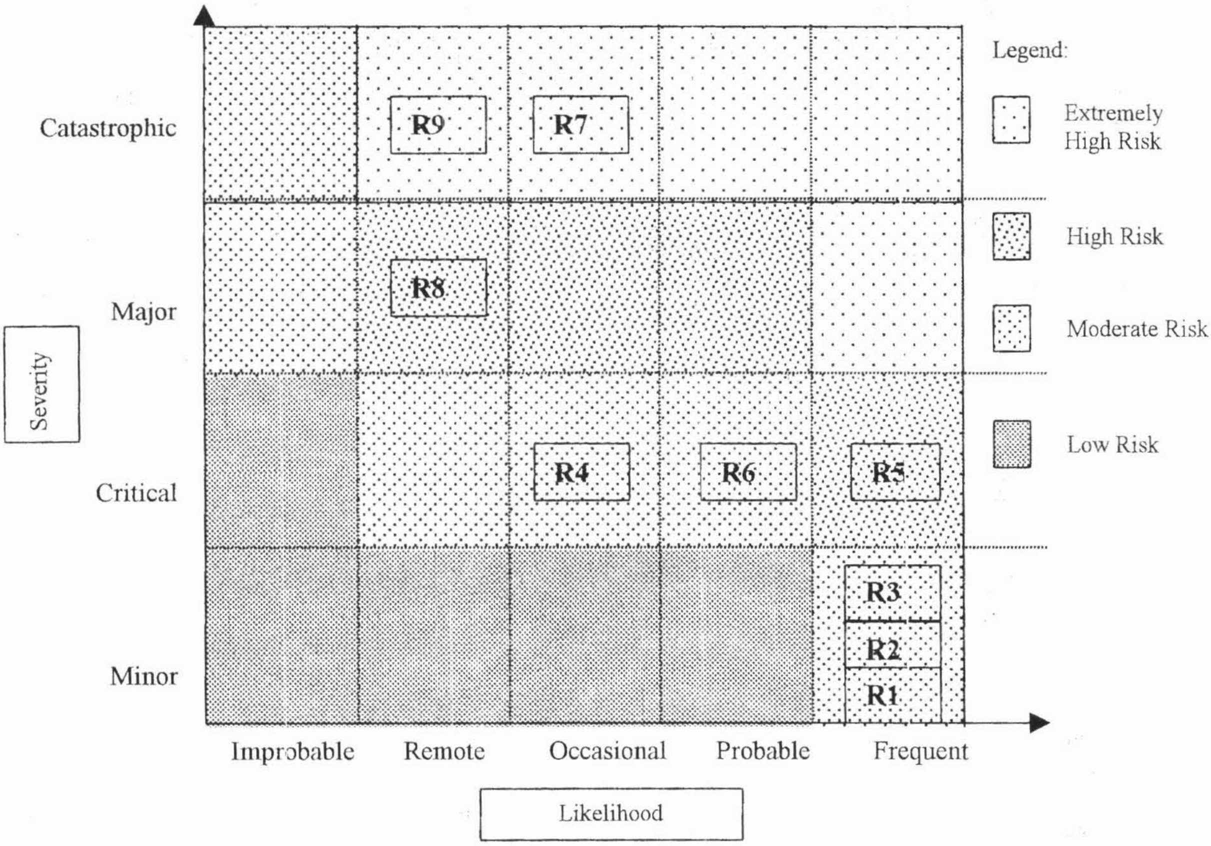

Figure 3: Risk map

From the risk map in Figure 3, risk of having electric shock, *R7* and risk of having physical or chemical burns, *R9* should be given the highest priority with greatest attention as they were classified as extremely high risks. Normally, these risks should be minimized as soon as possible to ensure the safety of workers. On the other hand, risk of suffering from dehydration, thermal burns or sun burns was given the lowest priority and slightest attention during *PV* installation. This type of risk can be moderated by following safety practices while abiding standard safety procedures. Apart from that, risk of having acid burns due to spillage of electrolyte and risk of having body injuries due to metal sharp edges were considered as high risks. Immediate attention is required while quick response is important to reduce these high risks. Besides that, no risk is treated as low risk as stand alone systems are deemed to be critical, particularly due to their isolated location. Additionally, high risks and extremely high risks should be major concerns for each personnel working on *PV* installation in remote areas as medical assistance is apparently unavailable near the sites. In fact, most sites are so inaccessible that any mishaps would bring disaster not only to the system installed but also to the workers themselves.

For instance, if fire or explosion occurs on a remote site, it is very unlikely that a fire engine can get into the site. As a result, prompt rescue effort may turn into failure.

Eventually, suitable measures for treating the risks were identified. In this paper, all risk treatments are described in Table 5 as barriers and protections. These barriers and protections are aimed to treat risks by reducing the likelihood or severity of the risks. This is the most typical technique that can be directly explained to *PV* workers during installation. However, it is important to note that the risk is not necessarily reduced to zero using this method. Risk elimination should be employed instead of risk reduction. For example, using gelled electrolyte batteries instead of lead acid batteries for the *PV* system is an effective option to totally eliminate the risk of having acid burns because in gelled electrolyte batteries, the hazardous electrolyte is immobile and therefore the probability of having electrolyte spillage is completely negligible [4].

Table 5: Risk treatment using barriers and protection

Risk	Barriers	Protection
R1		-drink plenty of water
R2		-wear hat
		-apply sunscreen regularly
		-cover limbs
R3	-survey the system to be aware of potentially hot elements	-wear gloves
R4	-be prepared for the unexpected	-wear gloves
R5		-wear gloves when handling metals
		-wear dielectric hard hat if working with hardware higher than head
R6	-use ladder and safety harness accordingly on roofs and elevated sites	-wear comfortable shoes
R7	-always measure voltage and current prior to any wire connection or disconnection	-wear dry leather gloves
	-cover all the potential live wires	
R8		-wear non-absorbent rubber gloves -wear protective eyewear -wear neoprene-coated apron
R9	-keep any equipment that can cause spark away from batteries	
	-store batteries in well-ventilated area	

From Table 5, both barriers and protection are critically exercised to minimise risk 7 and risk 9 as they are classified as extremely high risks. Nonetheless, this technique is not restricted to risks with very high priorities. It is highly recommended for *PV* system installers to utilise as much barriers and protection as they could to prevent them from bearing any undesirable consequences [1]. These barriers and protection would stop the sources of risk from affecting the personnel.

In conclusion, risk management is extremely important to ensure the safety and health of personnel installing *PV* stand alone systems in rural areas. It should be employed as the most preliminary tasks for a company who decides to install *PV* systems in isolated areas where emergency aid is really difficult. It is always a crucial responsibility for employers to provide a safe working environment for their employees [3].

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