# Solar PV Systems in Himalayan Villages: Problems and Possible Solutions

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*Abstract*

*Over the last decade Nepal has experienced a steady growth in solar photovoltaic (PV) system installations in remote mountainous communities. The reason for this is the growing understanding that grid connected infrastructure will never be feasible for these inaccessible parts of the country. Government subsidy programs, funded by foreign governments and INGOs, have caused a mushrooming of solar PV companies in the country's capital, Kathmandu. However, while the development of a renewable energy industry is to be welcomed, the standard of the majority of the solar PV systems installed is questionable from a sustainability point of view. The designers, manufacturers and policy makers' view of rural village electrification through solar PV systems is driven and biased by an urban, academic and business oriented perspective. Their perception does not take account of the end users' local context and needs. Likewise the end users lack awareness and education about the use of renewable energy systems, which results in inappropriate and unrealistic expectations. These two mismatched worldviews threaten the long term relevance of the local renewable energy industry and the improvement in living standards of these remote mountain communities. The major problems fall into two categories, technical and non-technical. This paper explores the range of these problems and suggests some possible remedies. Through the examples of installed solar PV system projects these remedies are reflected in practice in one of the most remote and impoverished areas of Nepal. The case studies are from three villages, in each of which a different solar PV system approach has been followed, according to differing geographical and cultural conditions. Each village has one system-specific data monitoring system, recording data for detailed, long-term understanding of the solar PV system's performance and interaction with the users. This paper reflects on monitoring results and the practical experience gained over 10 years of installing solar PV systems. It provides recommendations for improved and context related solar PV village system projects.*

## Keywords:

Solar PV Village System, Technical and Non-technical problems, Appropriate equipment design, Monitoring, Training, Maintenance, Follow-up, Remote Area Power Supply

## 1. INTRODUCTION

Nepal is a developing country and UNDP ranks it 138th out of 177 countries in terms of Human Development Index (UNDP, 2006). CIA (2007) ranks Nepal at 197th out of 225 in terms of income, with a GDP per capita estimated at US$1500. However, UNDP ranks Nepal as 68th out of 102 developing countries with an annual GDP per capita of US$252 (UNDP, 2006). This gap shows how difficult it is to describe the state and condition of Nepal using conventionally available data. The authors' practical experience has also shown that urban Nepalis earn multiple times more than people in rural areas, and that there is no, or just minimal, cohesion between them. Even in the context of this diversity of living standards, Humla, our project site, stands out, with a per capita GDP of only US$72 (KIRDRC 2002).

In September 2006, Nepal had an estimated population of 28.3 million (CIA 2007), of which 40% were aged 15 or less. Approximately 80% of the population lived in rural areas. In terms of energy, traditional fuel (biomass) consumption represents 93% of total usage nationwide, and 100% in the remote mountain areas such as Humla. With an average annual per capita electricity consumption of only 91 kWh, accessible only to about 25% of the nation's population, Nepal ranks very low globally. Infant mortality, compared to developed nations, is high, ranging from 86 to 53 per 1000 live births for the poorest and richest 20% respectively. Humla district is known as a permanent food shortage area and ISIS/RIDS-Nepal's surveys agree with the Humla District Development Plan (HDCP 2003) that 65% of Humla's children under five years of age are malnourished. These alarming statistics reflect the serious situation for rural people in Nepal, and show that rural village electrification, in order to be relevant and sustainable, needs to be embedded in long-term holistic community development projects addressing also health, food security, drinking water, indoor pollution and education issues. Driven by this need, the basic development model followed by ISIS/RIDS-Nepal is a holistic, multi-pronged approach focusing on small scale sustainable development. The approach has been described in another paper by the authors (Zahnd and McKay, 2005A). In this paper, we concentrate on one component of our holistic approach, namely on rural village electrification through solar PV systems. Here we describe a typical solar PV home system, and we address issues relating to the technical and non-technical problems of installed solar PV systems. Strategies aimed at preventing future installations' premature and unnecessary failure are presented through case studies, practical field experience and our evaluation of other published reports of similar projects.

## 2. BACKGROUND TO SOLAR PV SYSTEMS INSTALLATIONS IN NEPAL

Nepal has no fossil fuel resources but is rich in renewable energy resources, in particular water and solar energy. Hydro power plants provide 98-99% of Nepal's grid electricity, with 3 small diesel RAPS (Remote Area Power Supply) systems making up the rest. This enables ~25% of the population, mainly in cities, to have access to electricity. With ~80% of Nepal's inhabitants living in remote and difficult to access areas, pico/micro hydro power plants and solar PV systems provide appropriate and sustainable solutions for minimal electric energy services for these communities.

In 1998 the Nepali government, supported by foreign investment, started the first five-year solar PV subsidy programme, making it possible for rural communities to purchase solar PV home systems (SHS) initially at 50% of the market price. The subsidy was gradually reduced by 10% per year, so that after the first five-year phase ended, the SHS set price reflected the going market price. Unsurprisingly, fewer and fewer rural Nepalis were able to purchase a SHS for their families over the course of the subsidy programme, since hoped-for improvements in their economic status over the years did not keep pace with the reduction of the subsidy. There is a direct relationship between remoteness and poverty. The more remote a community lives, the poorer its people are. This is further highlighted by contemplating the higher transport costs and increased effort required to build, operate and maintain power plants in these areas.

Thus a second five-year SHS subsidy programme, which was revised after the reception of an additional EU (European Union) grant, was introduced, with new subsidy rates (AEPC 2006). They were defined according to the remoteness of the end users. For very remote mountain communities such as Humla, US$ 107 Nepali Rupees (NRp) equivalent (July 2007 currency exchange rate) per

SHS with a 10-18 $W_R$ solar PV module system and US$ 154 NRp equivalent per >18 $W_R$ solar PV module system are now available. Further, 75% subsidy for the PV system cost is granted for community, health post or school buildings. These government solar PV subsidy programs caused a mushrooming of solar PV companies in the country's capital, Kathmandu. Up from the three solar PV companies existing in 1997, now 46 registered companies help meet the needs of the population and benefit from the subsidy programs. While the development of this renewable energy industry is encouraging and can only be welcomed, we would argue that the standard of the majority of the solar PV systems installed is questionable from a sustainability and end user satisfaction point of view.

## 3. PEOPLE AND CLIMATE IN HUMLA

Hagen (1980) divides Nepal into seven, clearly distinguished natural topographical "units". One of these regions is known as the Inner Himalayas. These are valleys which lie to the north of Nepal's well-known chain of mountains, the Himalayas. They are described as "the real high mountain valleys of Nepal, surrounded on all sides as they are by ice clad giants". The Humla Valley is one such valley, located in the far north-western part of the country (Figure 2). Humla has a variety of cultural groups and ethnicities. As in other rural areas of Nepal, in many villages the Hindu caste system is still rigidly observed and in Humla one meets members of all four of the major caste groupings. These groups include Brahmins (Bahun), from the priestly, highest caste, Chetris, from the warrior caste, Thakuris from the kingly caste and Dalits, from the lowest, untouchable caste, who are often enslaved to the wealthier high caste people. They are the cobblers and blacksmiths in the villages (DPH 2004).

In other villages, one finds a separate ethnic group. This group is collectively referred to as the Lama population, referring to its observance of Lamaism, or Mahayana Tibetan Buddhism. The ancestors of the Lama population migrated into these valleys from Tibet (today part of China) in the ancient past, with distinct populations in Humla reckoning descent from founding fathers of both Western and Eastern regions of Tibet. Both Kagyu and Nyingma lineages of Tibetan Buddhism may be found in practice among ethnic Tibetans of Humla.

**Figure 2: Some 150 villages are spread throughout the remote, high altitude Humla valley. They are isolated from the main stream development of the country.**

**Figure 3: Open fire place cooking and heating, signs of poverty.**

Of Nepal's 75 districts, Humla ranks second to last for poverty (Figure 3), deprivation, socioeconomic and infrastructural development, and female empowerment, and 72nd in terms of socio-economic and infrastructural development (ICIMOD 2003). Humla, with its main district centre Simikot, lies 430km air distance northwest of Kathmandu. With a considerable district size of 5355km$^2$, its inhabitants number only 40,000-45,000. Migration was very high during the last decade due to the 10 year civil war, several years of ongoing drought, and population pressure on dwindling arable land. Less than one percent of the total land is arable due to steep slopes, snow covered mountains, rocks, rivers and forests (DPH 2004).

A relatively new road project is underway in Humla, aiming to link the Western Tibetan highlands with Simikot in 10-15 years. Aside from this project, there is no road access into Humla. In fact one has to trek for 17 days over high, often snowed covered mountain passes to reach the district. Flights into Simikot are also available, though irregularly for most of the year. The upper Humla district villages where our projects are located, lie between 2400–5000 meters elevation, allowing potatoes, wheat, barley and oats to be grown once yearly. Vegetables can be grown only during the 3-4 month rainy summer season. Apples and hard-walnuts are the major fruit production of the district. Simikot experiences 199 frost days a year (the number of days for which the temperature falls below 0°C, calculated from air temperature at 10 meters), with an average air temperature (at 10m height) of 4.35°C. These harsh climatic conditions demand high human labour input with low output, contributing toward Humla's permanent food shortage. Further, minimal, unreliable health services and poor basic education infrastructure do not provide local people with a solid foundation for development of any kind.

This remote area has remained under the powerful influence of superstition, and culturally conservative belief systems, giving Humla a reputation for social backwardness which contributes to its social and economic marginalisation. These conditions adversely affect the governance, human rights and the equitable functioning of Humli society. Women in particular suffer from the influence of superstitious beliefs, for example, Humli women are still routinely compelled to stay in filthy cowsheds whilst menstruating, and also during and for several days after childbirth.

## 4. HIGH ALTITUDE RESEARCH STATION (HARS)

**Figure 4: Solar PV home systems, solar PV central systems, high altitude solar water heating systems, solar drier, parabolic solar cooker, greenhouse, and smokeless metal stoves are some of the newly developed and locally manufactured technologies under field testing at the RIDS-Nepal HARS in Simikot Humla.**

In Simikot, a High Altitude Research Station (HARS) was initially established by The ISIS Foundation and Kathmandu University in 2002. HARS serves as a research station, where newly developed, Humla-specific technologies are put to test under real field conditions. The data we collect and the "real life" applications provide valuable feedback for the new technologies. Necessary technical modification and improvements can take place, enabling these new, locally developed technologies to be more appropriate and sustainable for the locally defined context. Since 2004, HARS (Figure 4) also acts as the base from which RIDS-Nepal, an independent Nepali-based NGO, conducts long-term community-based Holistic Community Development (HCD) projects in the villages north of Simikot. At HARS, new and context-appropriate technologies are integrated into the HCD projects.

## 5. THREE APPROACHES TO SOLAR PV VILLAGE ELECTRIFICATION

Over the last decade, the first author, together with RIDS-Nepal, developed and installed three different approaches to solar PV village electrification systems. Each approach depends on a village's context in regard to geography, village cohesion and locally identified needs, which are in most cases basic lighting services. In collaboration with PPN (Pico Power Nepal) WLED (white light emitting diode) lamps were developed. They consume very little power (1 watt per lamp) and have a very long life expectancy (up to 25 years).

### 5.1. Central Village PV System

First is the "central village solar PV system" (Figure 5). If the houses in a village are built very closely to each other, as in many villages in Humla (see Figure 6), and the community is made up of mostly the same caste, the central PV system presents a technically, socially, and economically viable solution. The community as a whole takes the responsibility to participate in the building of the village system, maintenance of the system by trained local people, and the collection of monthly user fees. With a mere 3 watt per household energy demand, a 2-axis tracking frame with 4 x 75$W_R$ modules can provide up to 60 homes with ~7 hours lighting per day, with a minimal battery bank DoD of ~20%.

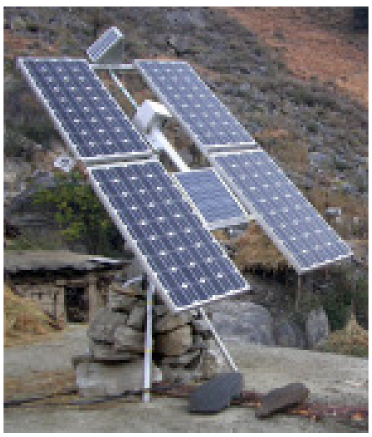

**Figure 5: A central 2-axis tracking solar PV system provides 30%-35% more daily energy generation compared to a fixed angle installation over the course of a year.**

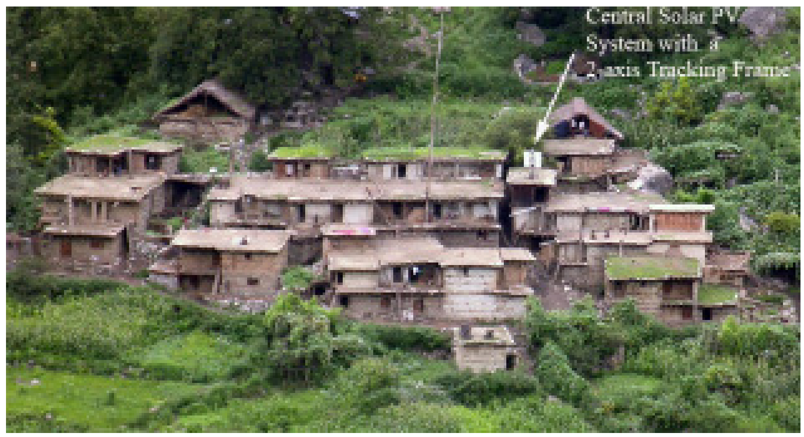


**Figure 6: The 27 homes (190 people) in Tulin village are closely situated. This constellation provides a feasible solution for a central solar PV system with a 2-axis tracking frame (300$W_R$), and a central battery bank (24V with a capacity of 400Ah). All homes are connected through armoured underground cabling, saving precious trees.**

### 5.2. Cluster Village PV System

Second is the "cluster village solar PV system" (Figure 7). If the homes in a village are built separate, in small groups or clusters at some distance from each other, the cluster PV system approach provides a technically and economically viable solution. A cluster is made up of six to twelve homes, sharing one solar PV module (often 75$W_R$), mounted on a 1-axis adjustable aluminium frame and a common battery bank. The interconnection of all the cluster homes to the solar PV cluster system is through armoured underground cables, powering three 1 watt WLED lamps per home for ~7 hours a day. In Nepal, a clustered spatial arrangement of homes often also maps caste, with people of different castes residing in different clusters. The cluster PV system takes advantage of cultural coherence within caste groupings in management and maintenance of each cluster in the system.

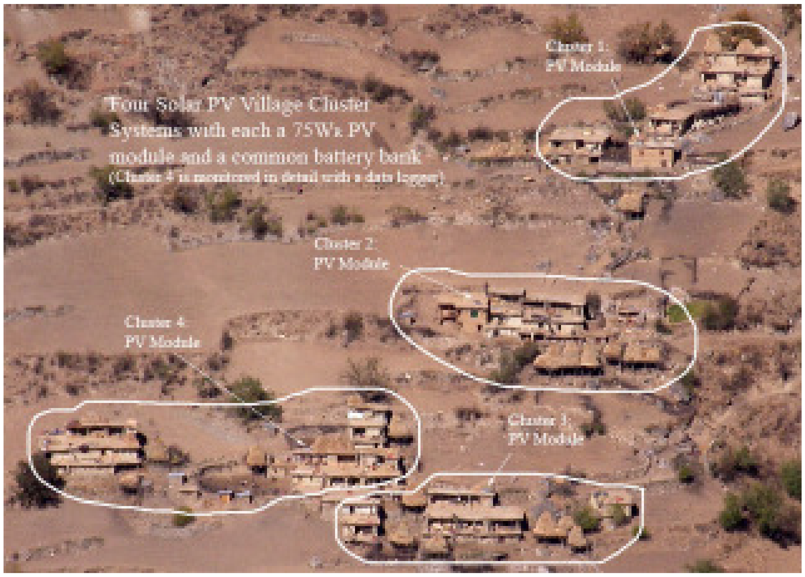


**Figure 7: Pamlatum village Cluster Solar PV System with 4 clusters. Each cluster has one $75W_R$ BP275F solar PV module and a battery bank (12V with a capacity of 200AH).**

**Figure 8: Each cluster has a 1-axis, seasonally adjustable aluminium frame, providing 10%-15% more energy generation. All cluster homes are connected with the power house through armoured underground cabling.**

## 5.3. Single Solar PV Home System (SHS)

Third is the single SHS (Solar Home System). A single SHS is appropriate when a village has its houses randomly scattered as in the village of Darapori as shown in Figure 9.

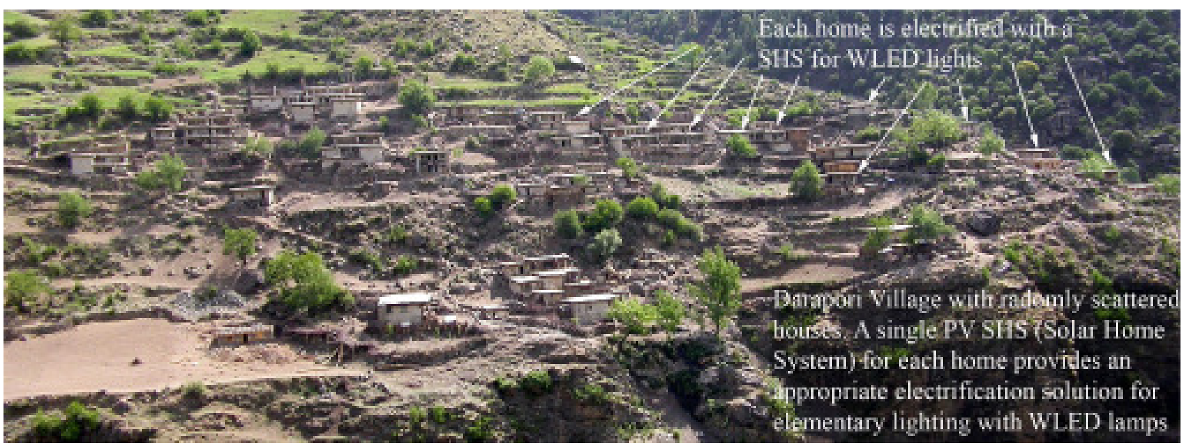


**Figure 9: For the Darapori village a single SHS is the most appropriate lighting solution. Each SHS has one 16 $W_R$ solar PV module (Kyocera KC16T), and a protected and insulated sealed lead acid battery bank (12V with a capacity of 14.4Ah), powering 3 WLED lamps.**

Each house has one solar PV module mounted on an aluminium frame (adjustable or fixed angle), its own battery bank, providing up to 5 days of lighting services for the three WLED lamps per household without sunshine. If a village consists of several different castes and considerable distance between the houses, the single SHS approach provides a sustainable solution. This approach requires that each household owner is responsible for his or her own system. Frequently, we have observed that a healthy competition arises due to each owner's pride for their single SHS. That increases the likeliness that more care and maintenance takes place, increasing the SHS's reliability and life expectancy.

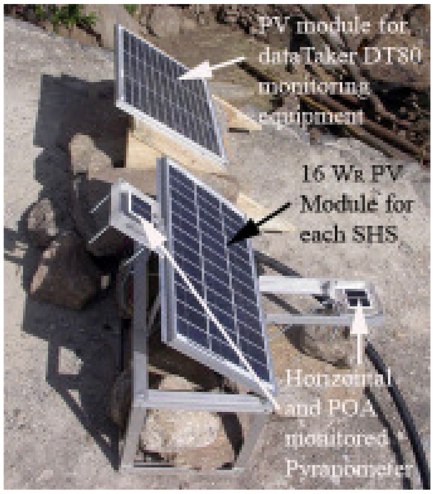


**Figure 10: SHS with a 1-axis, seasonal adjustable or a fixed angle aluminium frame. 15 parameters of the above single SHS system are monitored 24/7 and recorded with a dataTaker DT80. This provides detailed system performance.**

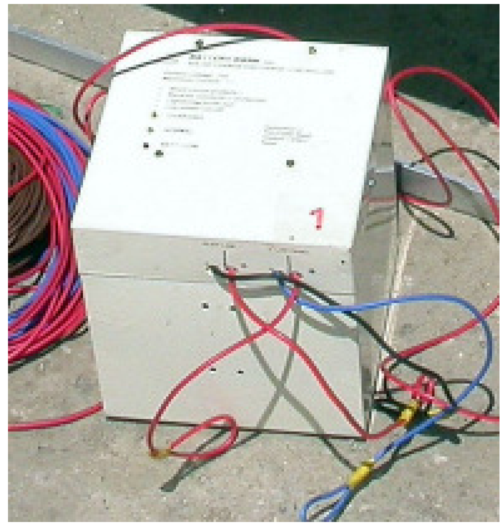

**Figure 11: Each SHS has an own, insulated battery box. Included is the battery bank's charge and discharge controller, protecting the batteries from being overcharged or too heavily discharged.**

In the following sections of this paper, the technical and non-technical issues associated with the sustainability of each of these systems are analysed. We will show that when choosing among the options outlined above, it is critical to consider the differing social and spatial factors in the target environments, as well as load demand in the target community and the differing power-generation abilities of each of the systems.

The extended and ongoing government solar PV subsidy programs in Nepal brought forth a significant growth in Nepali solar PV companies. While we consider this to be a positive development, the increased availability of solar PV equipment also increased price competition. Because national standards for solar PV systems are not comprehensively developed in Nepal, it is not surprising that the quality of available PV systems has dropped as market competitiveness intensified. Retailers' small price margins forced system installations to be done under time pressure, without appropriate training for end users to learn how to run and maintain their newly purchased solar PV system. Further, follow-up visits are rare due to their expense, especially for remote places such as Humla District. It is in this context that we introduce the types of technical and non-technical problems that we have experienced in our work in Humla and our solutions to them.

## 6. TECHNICAL PROBLEMS

The issues described above created a business environment for solar PV systems in Nepal that has not rewarded quality. Cheap materials and equipment easily entered this open, unregulated market. The pressure to take advantage of available subsidies resulted in rapid turn-over of system components, and quick solar PV system dissemination into the rural areas. Lacking pre- and post-sale examinations of solar PV systems entering the market, combined with little or no follow-up trouble shooting in the villages aggravates these problems and undermines end-user confidence in the new technology. Despite the fact that we strive to avoid these pitfalls by using high quality materials, extensive training and trouble-shooting support, as well as on-going research into system refinement as appropriate to the challenges encountered, we still experience a variety of challenges. Major technical problems and/or shortcomings, which we outline next, are often experienced in SHSs installed by Kathmandu based, commercial solar PV companies in Humla, some 17 days walk away from the next road head,. Many of these SHS were installed for some of the poorest and most disadvantaged groups (e.g., among Dalits, the 'untouchables'), and were partly subsidised by the government subsidy scheme.  All of these systems use DC power only for lighting and there are no inverters used.

## 6.1. Solar PV Module

In most of the ~ 300 SHS followed-up in our project, the solar PV module was the piece of equipment that performed the best. In Nepal, all available solar PV modules are imported from one of the major PV module manufacturing countries, including Japan, Germany and India and China. Significantly, SHS module failures were most commonly caused by no-name Chinese PV modules, which performed poorly when compared to branded PV modules. The most common technical fault that we identified in damaged PV modules was the broken and corroded connections of the serially connected PV cells and the connection box.

## 6.2. Solar PV Module Frame

Most of the SHS that we inspected are installed at a fixed angle, usually inclined at 30°-45° south (Figure 12). That angle is appropriate for Humla's northern latitude (30°). The PV module frames are usually a simple steel construction clamped to a wooden pole (Figure 13). The soft Himalayan pine wood tree is in high demand for firewood and substantial deforestation is occurring in Humla. It is also a very soft wood, and needs replacement every 2-3 years. For these reasons, the wooden poles, though chosen because they are locally available, are not ideal for mounting the PV modules.

**Figure 12: Unstable frame installations on soft tree poles can not maintain appropriate PV module positioning for year-round highest energy yields.**

**Figure 13: Due to the softness of the wood, this frame position can not withstand strong winds/winter snow.**

## 6.3. Solar PV Module – Charge Controller Wiring

In many cases, the solar PV module extension cable to the charge controller is non UV-stabilised, normal house wiring cable. The sun's high UV content in this high altitude area makes such cable brittle in less than two years, exposing the copper wire to the elements. In a few instances, we have seen the wires being used for clothes drying, adding increased weight and moisture to the cable mantling, which was already weakened by the weather.

## 6.4. Charge– and Discharge- Controller

The charge- and discharge-controller is a central piece of equipment of any solar PV system. It is required to charge and discharge the battery bank in a regulated fashion. An overcharge-protection prevents the battery from excessive charging and gassing, which would otherwise result in loss of distilled water and increased temperature, increasing the corrosion of the positive grid. Likewise it must protect the battery bank from being excessively discharged. That is most easily achieved by cutting the load off after reaching a certain battery voltage. Measurements of available charge controllers (CC) on the market have shown that there is reason for serious concern in regard to the deep cycle discharge protection of SHS battery banks. Battery voltage cut-off values as low as 10.2V have been measured. That coincides with the findings in the Sukatani report (Reinders 1999) which identified the same concerns. Further, as the Sukatani report recognised, Humli users also by-passed the charge controller and connected the battery directly to the load (see Figure 15). While that initially provided longer periods of energy for their lights, it shortened the battery's life expectancy significantly because the battery was discharged daily far below the allowed DoD (Depth of Discharge) recommended by the battery manufacturer.

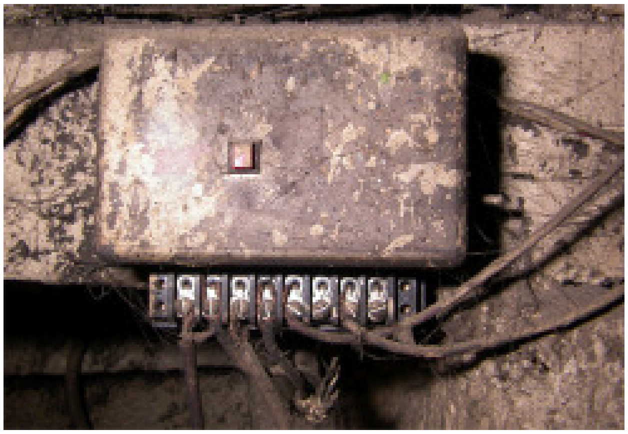

**Figure 14: The soot of open fireplaces inside homes create a harmful environment for solar PV equipment, especially the CC. Additional installation issues can lead to unexpected short-cuts, damaging the CC.**

**Figure 15: The damaged CC forced the user to connect the battery direct to the PV module and load. After that, the battery lasted only another 2 months.**

## 6.5. Battery Bank

Due to the intermittently available solar energy as well as the time mismatch between its availability during the day, and the main use of electricity in a SHS for lights in the early morning and evenings, the solar energy generated during the day has to be stored. This is still done most economically with deep cycle flooded lead acid batteries, even though this storage technology has been in use now for over 150 years. It stores and delivers energy directly as DC electricity. The widespread use of lead acid batteries and the moderate cost per unit of energy stored, combined with good energy efficiency and the ease with which they can be re-cycled (if the infrastructure is available), account for this battery's popularity. However, as there is no lead acid battery recycling programme in Nepal, it is of great importance that the solar PV system battery bank has as long life expectancy.

**Figure 16: Some common problems with battery use in the field: Dirt, low distilled water level, uneven placement, no climate protection, corroded battery connections.**

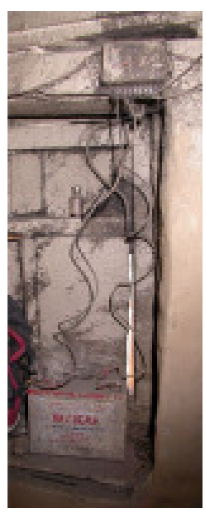

**Figure 17: No temperature protection.**

**Figure 18: Another commonly reported issue: Battery is directly connected to the PV module and to the load.**

We have observed that inappropriate battery bank design, installation and use are the main reasons for the premature failure of solar PV systems. In order to achieve a long battery life expectancy, certain installations and operational criteria have to be followed. The main issues are:

- Charge and discharge protection through voltage and ampere limitations
- Appropriate current charge/discharge (to avoid excessive temperature build-up and corrosion)
- Correct sulphuric acid density and periodic topping up with distilled water
- Operation in the correct temperature range
- Shallow DoD cycling
- Clean battery connections
- Correct battery connection cable sizes (according to charge and discharge current)
- The battery bank capacity needs to match the load demand and the load growth over at least half of its expected lifetime.

The installation settings shown in Figures 16-18 demonstrate conditions often observed in the field. The lifetimes of these batteries were shortened because they were not protected against the varying climatic conditions, or against the high indoor air pollution in the average Humla home where people cook and heat on an open fire. Further, we observed that the electrolyte within the battery is often not maintained at a level high enough to cover all the battery's cells. Thus it does not come as a surprise when the SHS users interviewed mentioned that their batteries lasted only 6-9 months, and in some cases even less.

## 6.6. House Wiring

**Figure 19: Loose house wiring is soon damaged and can pose a danger for children.**



**Figure 20: Mice find it easy to nibble on these house wiring and battery cables. Further, it is never permissible to join different kinds of batteries of different brands or capacity.**

Humla homes are made of stones, wooden beams and mud. Most homes have their food grain storage inside, which attracts mice. They eat everything they can get hold of, and they have a special fondness for PVC copper wire mantling. Further, many homes have open cooking and heating places, creating enormous amounts of smoke, soot and particulate matter, endangering people's health as well as potentially harming indoor solar PV system equipment. These circumstances demand understanding of the local conditions and thus special care in the way house wiring takes place.

## 6.7. Indoor Lighting

SHS are PV systems generating very small amounts of energy. Relative to the amount of energy generated, they are expensive to purchase. In order to get the highest benefits from a given SHS, it is thus important that lights with low power consumption and long life expectancy are used.

Many of the SHS that we inspected in the field have 10W fluorescent tube lights, three for each home, powered by a $10W_R$ solar PV module with a 20Ah capacity battery. It can be expected that the battery is deeply discharged every day, and, if a charge controller is used, the lights can be used only for a very short time per day.

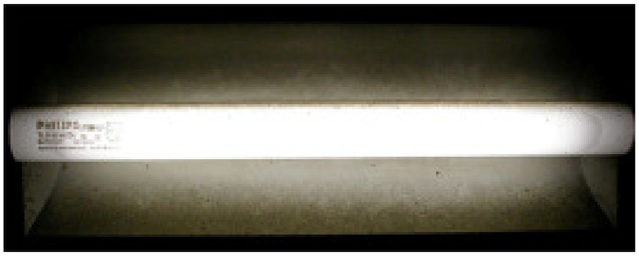

**Figure 21: 10 watt tube light, horizontally installed at the wall, allowing mud and dirt from the home's ceiling to fall on the tube and reflector.**


**Figure 22: Many SHS visited have a $10W_R$ solar PV module, three 10W fluorescent tube lights and a 20Ah 12V battery.**

## 7. NON TECHNICAL PROBLEMS

Projects are not designed, implemented and operated in a vacuum, but in set cultural contexts for particular groups of people. For projects to succeed, planners and implementors must recognize how culture has defined and shaped local subsistence patterns and customs. We believe it is critical that the cultural context, the "software" issues of a project, are taken into consideration from the beginning of a project. This demands that the local context, language and customs have to be learned and understood by the project partners before the project is initiated, in order to comprehend the unspoken and invisible "software" issues of the community. This demands time, compassion and dedication - crucial parts of a project.

Such invisible "software" issues are often the cause of unforeseen problems during the project implementation phase, causing delays, massive increased costs, and even project failures, because uptake of new innovations by local people usually occurs at a far slower pace than scheduled project implementations.

While in some villages uptake of new innovations and willingness to learn new behavior patterns is quick and uniform, in other villages change is slowly accepted and/or actively resisted by some members of the population. From our experience of implementing projects and observing other projects, it appears that villages comprised of certain castes or mixes of castes experience innovation uptake at different rates than others. For instance, in our own experience in Humla, villages comprised of members of Hindu castes known for their cultural conservatism or risk aversion, have a slower and patchier uptake pattern of new innovations than villages comprised of Buddhist villagers.

Thus, besides the technical specification for the design of a solar PV system, the local context and conditions of the end consumers plays an absolutely central role in the success of a project. These issues are often subtle and require excellent knowledge of the local populations. For every project site, we have found it important to identify and plan for ways to adapt project implementation strategies to the local cultural context, and to budget and "sell" the importance of this piece of the project to partnering donor agencies.

In the following discussion, we identify some important "software" issues and lessons learned.

## 7.1. Energy Demand / Need Assessment

Solar PV systems for remote and impoverished communities are designed primarily to provide lighting services that they have not previously had. In order to understand the local population's need for indoor lighting, one has first to recognize how homes were lit previously. In upper Humla, all families traditionally use *jharro* to light indoor living spaces. *Jharro* is a resin rich wodden stick from the high elevation Himalayan pine tree whose flame provides smoky but minimally adequate indoor lighting (Figure 23 and 24). *Jharro* is gathered by inducing a deep cut on the soft pine tree, forcing it to produce resin in order to "cure" the wound. This resin-rich layer of wood is cut away after a week and chips of this wood are burned to generate light.

To understand the traditional use of *jharro*, we measured illuminence levels in homes where it was in use. Illuminence levels of just 2 lux on the floor of the home surrounding the fire pit or cooking stove where *jharro* is burned were standard. This lighting level is only enough to move around the room and see the people and items in it. At an illuminence level of 2 lux, it was not possible to read. In order to get enough light to read, one had to sit right beside the smoky *jharro*, and hold the reading material at just the right angle.

The illuminence level on the cooking stove or fire pit varied between 5–15 lux, depending on its height (Figures 24, 43).

**Figure 23: Dim and smoky light from *jharro*. Particulate matter produced by burning this resin-rich wood poses a real danger to respiratory health.**

**Figure 24: Families in Humla traditionally burn *jharro* for indoor lighting, as kerosene is typically unavailable or unaffordable.**

## 7.2. Awareness Raising for the Need of Improved Lighting Services

Having understood and measured the traditional indoor light source, it becomes clear that it is important to alert local people to the damaging health consequences associated with *jharro* use (Bhusal & Zahnd 2007). It is also helpful to explain to people that *jharro* is an extremely inefficient type of lighting. This is true whether we are thinking in terms of the energy expended by humans in procuring *jharro* from the forest, or in terms of the amount of luminous flux produced by *jharro* (usually measured in lumens), as a ratio of the amount of energy consumed to produce it (usually measured in watts). Measurements indicated that the luminous efficacy of *jharro* (0.04lm/W) is half of the efficacy of a kerosene fuel based lamp (0.08lm/W (Mills 2005)) and more than 300 times less than the 9 diode WLED (white light emitting diode) lamps used in the villages with solar PV systems installed by ISIS/RIDS-Nepal from 1999 – to early 2006 (Figure 28).

Figure 25: RIDS-Nepal's manufactured 12 volt DC WLED lamp with 12 NSWP510CS diodes, consuming a total of 1 watt.

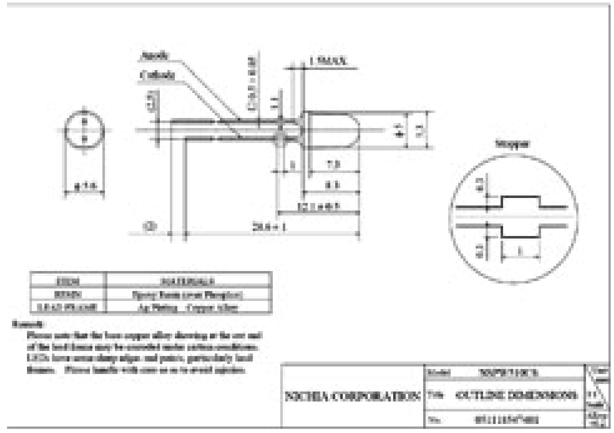


Figure 26: Technical specification of the NSWP510CS white LED, with a life expectancy of ≥50,000 hours, or ≥ 20 years.

Since mid-2006, RIDS-Nepal has shifted from our original 9 diode (Nichia NSWP510BS) WLED lamps to 12 diode lamps, using Nichia's most recently offered diodes (Nichia NSPW510CS (see Figures 25 & 26). This allowed us to produce lamps with a 60% higher luminous intensity (Nichia 2007). Further, in collaboration with local users, we determined that the baseline illuminence level that a solar PV system has to provide is 5-15 lux for general tasks, and 25 lux for reading. This lighting level can easily be provided with RIDS-Nepal's 9 diode Nichia WLED lamps (Bhusal & Zahnd 2007), and is even more readily achieved with our new 12 diode lamps.

Based on our experience, we would argue that higher power consuming lamp technologies such as CFL, tube lights or even incandescent bulbs are not appropriate for solar PV systems. Providing the right lighting level, using a technology that is affordable and sustainable, has proven to be crucial for context-appropriate design and cost-effective solar PV systems in these rural areas.

## 7.3. Training for Solar PV System Operation & Maintenance

Under the government subsidy scheme, solar PV system operation or maintenance training is not offered, nor are end users typically trained during the installation phase of their system.

**Figure 27: Without training on maintenance and use, SHS often break down rapidly.**

**Figure 28: The three blackened WLED lamps after 6 months in a home without a smokeless stove where the family still cooks and heats using an open fire. In this condition, the lamps fail to provide any light. This shows the importance of applying the "Family of Four" HCD concept.**

While people are happy to have electric light in the mornings and evenings once the system is in place, without training they are unprepared to operate their system appropriately. Basic maintenance of batteries, such as topping them up with distilled water (clean rain water), cleaning the battery bank's terminals, checking the charge controller connections, fuse and indicators, and cleaning the solar PV module during longer periods without rain is neglected. Villagers are not to be blamed for this, however, since in most Nepalese SHS projects training is not funded.

Often system owners try to add features to their system that will damage its integrity, for example other lights, radios, or battery chargers. Due to lack of training, they could not have known this would jeopardize the system's life expectancy and performance, or even damage the system. Due to a lack of training, short circuits are frequently caused by bad DC wire connections, which cause the charge controller's glass fuse to burst. As there are no spare glass fuses sent along with the initial system and new glass fuses are not available in Humla, the end users usually remedy the situation by taking the charge controller out and joining the solar PV directly to the battery (see Figures 15, 18, 19). Without the charge controller, the battery rapidly becomes so deeply discharged that it can not be re-charged again (Figure 27).

### 7.4. Installation and Follow-up

Villagers in Humla frequently reported that the company they bought the subsidised solar PV system from installed it, charged them extra for the installation, and left as soon as the system was put in. End users were not given contact information in case a technical problem arose, or if a piece of equipment needed to be repaired or exchanged.

Previously, one of the main Kathmandu-based solar companies had a solar PV shop in Simikot, Humla's district center. But due to low turnover, high staff and transport costs the company closed the shop. Currently, there is no support or technical staff in all of Humla for follow-up on the many solar PV systems installed by a variety of companies. The full time, in-District staff of the ISIS Foundation/RIDS Nepal projects do support, maintain and follow-up their projects but are not able to provide support to all of the others.

### 7.5. Performance Monitoring

"Out of sight out of mind". That is the harsh reality of most of the village-based solar PV systems, in particular those installed under the government subsidy program. There is a preventative measure working against this failure, in the form of a clause in the subsidy programme, which says that the last 10% of the subsidy shall be paid only after the first annual inspection. But 10% does not provide enough incentive to actually maintain and troubleshoot for the installed PV systems. Instead, the margins are calculated in such a way that the 90% subsidy plus the end user's cash payment makes a reasonably profitable business.

We do not mean to unfairly heap blame upon the retailer, since to be fair one has to recognize the time and cost demanded by ongoing system follow-up, due to the days or even weeks of hard trekking away from the next road head. Thus, aside from the ISIS/RIDS Nepal projects, there is not one longitudinally monitored solar PV system in the Humla region known to the authors for which field data are available. This makes comparisons and evaluations of the various systems' performance difficult.

## 8. POSSIBLE REMEDIES

The experiences and circumstances described above demand a fresh look at the procedures and implementation of rural village solar PV systems. Some of the issues we have outlined, such as the lack of training typically provided by SHS companies, suggest that the basic approach to this type of community development has to be reexamined. Toward this end, possible remedies for the technical and non-technical problems identified in Section 7 are discussed next.

## 8.1. Solar PV Module

As indicated above, our experience with solar PV systems in rural Nepal shows that the fewest problems are caused by the solar PV modules. This industry is well established with standards and good quality controls, and the good record of the modules should persist if retailers continue to import quality solar PV modules. RIDS-Nepal uses two solar PV module manufacturers for our three different solar PV system approaches. The first is the BP275F (75$W_R$ as seen in Figures 4, 5, 8) mono crystalline PV module from BP, manufactured in their highly automated production plant in Bangalore, South India. This PV Module is used for the central as well as for the cluster PV system approach (Figures 5, 8). Since 2003, not one of these panels has been defective or otherwise the cause of any PV systems failure. The other module we use is the 16$W_R$, polycrystalline PV module K16T from the Japanese manufacturer Kyocera (Figures 1, 10), with equally excellent performance.

As with all of the equipment we install, investment in high quality, standardised solar PV products is worth the additional cost, especially due to the remoteness of the target communities and the need for high durability and minimal maintenance. The investment will easily pay for itself over the life cycle of a village solar PV system (Zahnd 2004).

The efficiencies of solar PV modules in real field applications are always lower than their STC performance under lab conditions. Our field experience since 1998 and the data we have collected on efficiency since 2003 show that if all of the generated power is fed into the battery bank, a ~2%-3% efficiency drop from STC performance for a high quality, single installed PV module and a ~3%-4% drop for serial and parallel connected central solar PV arrays can be expected. Our data agree with Reinders' results (1999), which show that the single 40$W_R$ solar PV modules installed in that project have a STC efficiency of 11.1%, while in the field they achieved only 8.1% when all the generated power was fed into the battery. The main reasons for this drop are (1) the PV module is operating above 25℃, (2) the PV module was not operating at the MPP (Maximum Power Point), (3) the intercepted global solar radiation is below the STC-defined 1000 W/m$^2$, and (4) there are ohmic losses in the cables. Our experience also showed that additional losses occurred through PV module mismatch in solar PV arrays (with serial and parallel connected PV modules), such as used in the central solar PV village approach as seen in Figures 4, 5, 6.

## 8.2. Solar PV Module Frame

Alongside the three solar PV village electrification approaches described above, we developed three other solar PV module frame concepts, to maximize utilisation of the available daily solar radiation, and the occurring cost for the frame. The first is a 2-axis self-tracking (rotating daily from East to West), with a manual weekly or bi-weekly North-South adjustment to accommodate the sun's seasonal path. Figure 4 shows three such 2- axis tracking frames, installed at the RIDS-Nepal Simikot office and HARS since 2004. Figure 5 shows the central solar PV village system of Tulin village, powering 27 homes for 190 people. This system produces an average of 30%-35% more energy than a similar system with a traditional fixed angle frame system. The installation of the 2-axis tracking frame does not require cement, which is advantageous in a place like Humla, where cement is always very expensive and often unavailable. The frame we designed uses locally available stones to secure it against all occurring climatic conditions. Figures 8, 29, and 30 show the 1-axis aluminium frame used to mount one BP 275F PV module used for solar PV cluster systems. It allows seasonal adjustment of the frame from 5° (January) – 60° (August) south. The 1-axis frame increases average yearly energy production by 10%-15%. As with the 2-axis model, stones are used to fix and secure the frame. Figures 1, 10 show the single SHS, which also consists of an aluminium frame to mount the 16 $W_R$ PV module. This frame can be delivered with either a 1-axis edition (Figure 10), or with a 35° South-inclined fixed angle edition.

Though there were some minor shortcomings in the initial design of the 2-axis tracking frame (problems existed with the locally manufactured gear box), we have had no failures or breakage in the other, thus far eleven, installed systems. Our experience has taught us that it is worth the extra initial cost required by context related PV module frames and high quality material. Power output increases and maintenance demand decreases, both of which are important features in this remote, harsh and often hostile environment.

## 8.3. Solar PV Module – Charge Controller Wiring

In all of the systems that we have installed, we use armoured (for central and cluster systems) cables with UV stabilized mantling for the cabling running from the PV module to the charge controller. Where the installation site is heavily trafficked, the cables are hidden for additional protection in a polyethylene pipe. The pipes are installed in such a way that their openings are always downwards, so that no condensation can remain inside and no rain water can enter.

**Figure 29: In the systems we install, cables run the shortest distance from the PV module to the charge controller. The charge controller is located inside the main cluster house, together with the battery bank. Armoured UV stabilized cables are used for maximum protection.**

**Figure 30: In our systems, rooftop cables are hidden in polyethylene pipes as the house's roof is also used as a work and crop drying place. Instead of cement, the module frame is weighted with stones and, in this case, a beehive (the wooden box under the PV module) against the local winds and snow during the winter months.**

## 8.4. Charge – and Discharge- Controller

Without the charge- and discharge- controller (CC), a solar PV system is not properly designed and will not work for long. In order to have a reliable, long-lasting CC it is important that this critical piece of equipment is well designed. Its high and low voltage cut-out, designed to protect the battery bank, needs to be adjusted according to the battery technology. It needs to be tested over the whole range of voltage, current and temperature before it is delivered. Further, it needs to be properly installed.

Reinders (1999) identifies four different mechanisms for extracting more energy from a battery bank. Namely

(1) by-passing the CC,

(2) the prolonged use of small power appliances (such as the use of the WLED lamps),

(3) demand-side management, and

(4) a low voltage value for battery deep-charge-protection specified in the CC.

While (1) and (4) permanently damage the battery, and should be avoided by any means, (2) and (3) are to be encouraged and are practiced in all of the Humla solar PV village projects we have thus far undertaken.

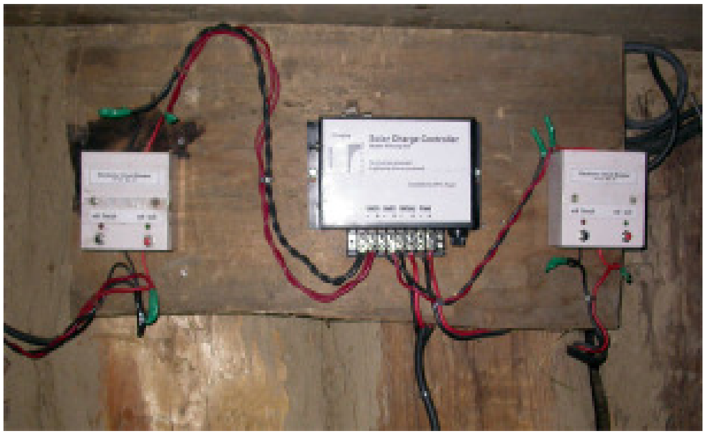


**Figure 31: Cluster PV System: From the right side power generated by the PV Module comes in via armoured cable. It travels through an electronic fuse into the charge controller (CC) in the middle. The CC is the energy management unit and keeps track of the charge and discharge of the battery bank for maximum security, energy service towards the load and life cycle. From the CC the load line goes through an electronic fuse, protecting the CC and the WLED lamps from any mishaps or misuse.**


**Figure 32: The charge- and discharge- controller for the single SHS is included in the protected and insulated battery box. Three LED indicators at the outside of the metal box show the charge level of the battery bank. The high and low voltage cut-off levels are 14.7V and 12.2V respectively for these sealed AGM batteries.**

RIDS-Nepal has a close partnership with the local Nepali company Pico Power Nepal (PPN) which developed and tested all of the locally manufactured solar PV components used in our projects. This includes the various CCs installed in our village PV electrification projects.

While each project has various charge and discharge currents according to the solar PV array size and daily user load demand pattern, the rule of thumb is that each flooded lead acid battery has an over-voltage protection (14.4V), and a discharge protection cut-off for minimal voltage (12.0V-12.5V, dependent on the appliances and battery technology used).

The CC also protects the battery from excessive temperature generation during the discharging process, by limiting the out-flowing current. Additional temperature-adjusted battery charging is a feature of the CC as well.

## 8.5. Battery Bank

In the evaluation of a battery, the CC and the battery bank have to be analyzed together. The life expectancy of a battery depends strongly on the charging and discharging pattern, managed by the CC, while the CC's functions are designed and adjusted according to the chosen battery technology.

**Figure 33: Battery bank consisting of 2 equal (brand, capacity and age) flooded lead acid batteries, well insulated and protected with spare distilled water. This 200Ah solar PV cluster battery bank, with 8 homes and total 24, one watt WLED lamps for up to 7 hours a day, has an average daily DoD of 6%-8%, providing up to 5 days the needed energy without sunshine with a maximum DoD of 30%.**

**Figure 34: The battery bank should be fully covered and protected e.g. in a locally made wooden box. In our projects, the wooden box is sealed with cow dung and covered with additional heavy jute sacks to protect it from mice and dirt.**

In order to understand a battery bank's performance and condition at least three parameters need to be monitored: the battery voltage, the battery sulphuric acid density and the battery's temperature. In order to have more information on the life expectancy of a battery bank, the Ah (Ampere hours) into the battery bank and out of the battery bank have to be monitored as well. Even with these data at hand, there is a rather broad range within which a battery's state, condition and life expectancy can be defined. These are some reasons why even manufacturers provide only very general data and information about their product, as the circumstances, context and maintenance of a battery can strongly impact on its performance. Through manufacturers' specification sheets one learns of a battery's best theoretical working conditions. Considering these, and adding the practical experience from the battery banks that we installed, a range of parameters can be defined as the best working conditions. Thus for the most common battery, the flooded lead acid battery, performance is optimal if it is kept throughout its life under the following working conditions:

- Battery charging and discharging temperature range between 15°C – 25°C (with short term maximum of 30°C and minimum of 10°C)
- Battery voltage is kept between 12.0V – 14.4V
- Battery sulphuric acid density initially is adjusted to 1230g/dm$^3$-1250g/dm$^3$
- The battery is periodically (once a month) charged up to 15V – 15.5V. This process is called gassing and helps to provide a better stratification of the sulphuric acid and leads to less sulphation (formation of large lead sulphate crystals at the positive anode terminal, which hinder the reversible chemical reactions at the pure lead plates).

Even though the CC includes a battery temperature compensation in order to accommodate wider temperature ranges, the battery banks that we install are all well insulated and protected from climatic conditions. Locally made wooden boxes are used for the central and cluster solar PV systems, and an insulated metal box is used for the single SHS. These boxes, often installed inside the main living room, keep the battery temperature range throughout the year at a comfortable 10°C–25°C, even through the freezing cold four winter months when ambient temperatures reach -15°C.

In order to maximize life expectancy for a battery bank, the daily DoD (Depth of Discharge) needs to be as low as possible. Quality battery manufacturers do provide DoD versus time of cycle diagrams, indicating what life expectancy their product can achieve with a defined DoD. Field experience and the rule of thumb shows that a maximum DoD, even after 3 days without sunshine, of 20%-35% should not be surpassed, in order to achieve as many charge- and discharge- cycles as possible. That range agrees with the daily mean value of 12.7% DoD for six monitored SHS's battery banks in the Sukutani solar PV project (Reinders 1999). While such shallow cycling demands a bigger battery bank capacity, and adds initially to the project's budget, it pays back in the long run, as the number of cycles is not proportionally declining with increasing DoD but, assumes a parabolic shape. Thus it is crucial that one knows all the manufacturer's specifications for a chosen battery technology and brand before the whole system design is finalised. This is another crucial factor for the sustainable operation and long-lasting performance of a solar PV system in a remote area like Humla, where all the equipment has to be air lifted and then carried by porters into the project sites.

The examples above show locally made wooden boxes used to house battery banks (Figures 33, 34) with styrofoam covering the batteries and additional external insulation used for the cold winter months. These boxes keep the battery banks within an acceptable temperature range at all times. With one or two spare bottles of distilled water (Figure 33), appropriate maintenance for the batteries is made simple. In Humla, rain water serves this purpose. Periodic cleaning of the battery connections, greasing of the connectors and storing rain water for the batteries in a cool, dark place, are easy steps which positively enhance a battery banks' service and life expectancy. Last but not least, we provide a blank data sheet for each battery bank, allowing users to chart when the battery was topped up and serviced. That helps us and users to understand the frequency and time needed to maintain the energy storage system.

## 8.6. House Wiring

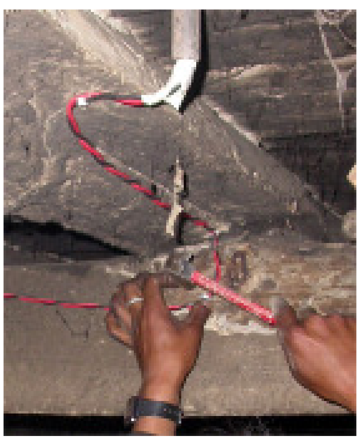

**Figure 35: The house cable enters the home via an open ended polyethylene pipe. Cables are mounted underneath the wood beams.**

**Figure 36: Armoured cables from the PV module to the CC, PVC mantled house wiring inside, placed out of reach of children.**

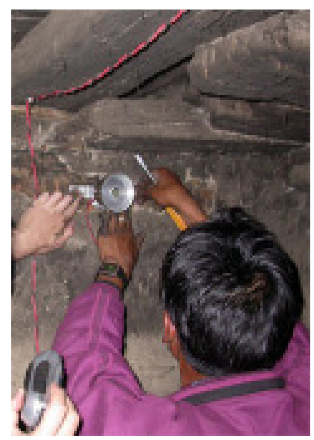

**Figure 37: The WLED lights are installed in a place where they can be turned on 2 axes so that they can be used for different tasks at different times**.

The house wiring comes into the room through an open ended polyethylene pipe (Figure 35). In order that the mice cannot get to the PVC copper wire mantling, the cables are fixed on the downside of the overhanging wooden beams that carry the roof (Figures 35, 37). Wires, switches and connection points have to be high enough so that children cannot reach them (Figure 36).

If available, wiring clips (Figures 35, 37) are useful and handy to fix the cables underneath the wooden beams. These are small issues which do not add substantial cost, but can be crucial to the long-term sustainability of a solar PV system. Finding and fixing mouse damage can be very time consuming and inconvenient to repair, thus it is well worth preventing through proper and innovative wiring installation.

## 8.7. Indoor Lighting

Each home electrified with a solar PV system has three WLED lamps installed, usually in two rooms. We like to locate two in the main cooking, living and sleeping room, and one in the store room. The three WLED lamps consist of two Nichia WLED lamps with each 12 NSPW510CS (since 2007) white LEDs, providing 42lm/W (Figure 25), consuming 1.1 watt each, and one 1 watt Luxeon WLED (30lm/W) lamps from Lumileds, consuming 1.3 watt. That amounts to a total of 3.5 watt power consumption per household.

**Figure 38: Reading under a WLED lamp**

**Figure 39: Indoor Lighting for the first time .**

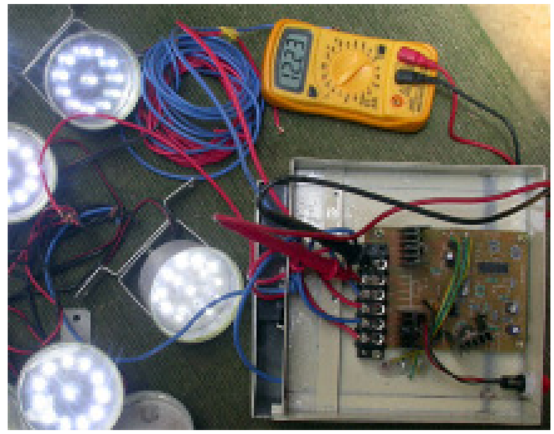

**Figure 40: Each house's WLED lamps and CC are tested and adjusted beforehand.**

These WLED lamps provide an illuminence level that is sufficient for the daily indoor tasks and reading as defined by Bhusal & Zahnd (2007). WLEDs are known to have a long life expectancy if they are operated under normal operating conditions (not over heated during soldering, and limited to 20mA of current). Typically, a life expectancy of >50,000 hours can be expected before brightness begins to substantially reduce. With an average of 7 hours per day this is 20 years of use, after which the technology will be long superseded.

Considering the fact that white LEDs should reach 100lm/W by 2010, providing a life expectancy of ≥ 100,000 hours (Zukauskas 2007), there is a hopeful future for WLED lamps. Thus for the present and coming decade, one can say with some certainty that the WLED technology will continue to provide a very appropriate first time indoor lighting solution for the communities of Humla.

It is important to mention that in our projects, a solar PV system for elementary lighting in a village or home is never implemented alone. Rather, solar PV systems are always introduced alongside the "Family of Four" HCD concept that RIDS-Nepal developed and implements in Humli villages. The negative health impacts of indoor air pollution caused by open fire cooking and heating is so enormous that electric lights alone can not make a substantial positive change in quality of life. Additionally, to introduce the WLEDs into homes that continue to use open fires for heat and cooking would massively shorten the life expectancy of the solar PV system equipment due to the damaging impact of the particulate matter of open fires upon optimal functioning of the system (Figure 28).

Thus, in our projects, solar PV systems are always installed alongside a smokeless metal stove (Figures 42, 43) and two other crucial health-impacting innovations heretofore unused in the project area: pit latrines in every household, for the disposal of human waste, and clean drinking water systems for potable water. This HCD approach is called the "Family of Four" (Figure 45).

**Figure 41: Two adjustable WLED lamps are installed in the main room.**

**Figure 42: A solar PV lighting project with WLED lamps is never implemented on its own. It is always installed alongside a smokeless metal stove project, pit latrine and safe drinking water system, as part of our HCD approach, the "Family of Four".**

## 9. NON-TECHNICAL REMEDIES

As described in Section 7, projects unfold within a set cultural context, where behavioral patterns, local expectations, and personal and community goals precede the arrival of the innovations we introduce. These factors have to be taken into consideration, and constitute what we call the critical "software" issues of a project.

People's education, expectations of the project's outcome, their economic conditions and ability or inability to maintain the system, are just some of the important "software" issues to know and understand in order to define the scope of a project. It is crucial that the community or household is able to take full ownership and pride in the implemented project, and for that they have to participate in all stages of a project. From the very beginning of a project to the point when control is completely handed over to the community, the end user has to play an active role. Thus in a solar PV project, local people have to participate in defining the lighting service they feel that they need and can afford.. They have to be willing to send several people per village central system, one person per cluster system and if possible one person for 3-4 single SHS for the two week solar PV training course that RIDS-Nepal developed and holds before every project's implementation. In the early stages of project planning, end users have to understand, agree and sign an agreement describing that they need to pay a per-family amount per month in order to maintain the system.

### 9.1. Energy Demand / Need Assessment

As described in Section 7.2., an illuminence level $\geq 25$ lux for reading tasks is recommended for a first-time elementary lighting service, while an illuminence of about 5 - 15 lux is recommended for general purpose tasks (Bhusal & Zahnd 2007).

With the locally developed WLED lamps these illuminence levels can be achieved. The long life expectancy, low power consumption and 2 year guarantee provided by PPN for of these WLED lamps make them very affordable in regard to the running cost, once the initial purchase cost has been paid by the project. Thereafter, a monthly fee payment of 15 NRp (~ 0.3 AUS$) per family is sufficient to maintain the solar PV system.

**Figure 43: From a smoke filled, open cooking fire place and use of *jharro* lighting to ….**

**Figure 44: … clean indoor air with a smokeless metal stove and WLED lights.**

## 9.2. Awareness Raising, Lighting Technology and the "Family of Four" Concept

By demonstrating the brightness and illuminence of the WLED lamps, the local people are introduced to their new indoor lighting. They are also made aware that if they do not change their method of cooking and heating by purchasing and installing a highly subsidised smokeless metal stove, the new electric lights will not be able to provide the intended services and thus the holistic approach to improving health and quality of life will be undermined (Figure 28).


**Figure 45: Awareness-raising about the reasons for and benefits of the holistic "Family of Four" project in a village community.**

Further we are careful to emphasize the negative health impacts the traditional open fire and use of *jharro* has, especially on small children and women. We explain, many times if necessary, the importance of an holistic approach to community development and the long-term benefits and living standard improvements that come along with it.

Therefore, along with the research, development, installation and trouble shooting that our on-the-ground team do, an enormous amount of time and effort is put into teaching about the "Family of Four" concept. This approach bundles the solar PV powered indoor lighting with WLED lamps together with a smokeless metal stove, a pit latrine for each household, and the building of a communal safe drinking water system, as depicted in Figure 45.

## 9.3. Training for Solar PV System Operation & Maintenance

We have observed that understanding and maintaining one's own solar PV system creates a sense of pride and ownership in end users, and also has the beneficial impact of teaching valuable skills and knowledge that can be useful in and outside the community. These are important steps toward a new technology being accepted and integrated into the local community over time.

However, insuring that local users have the required knowledge demands theoretical and practical training, which is time demanding and costly. We recognise that these costs are a critical part of a sustainable solar PV village electrification system, and are as important as the hardware and transport costs. The cost effectiveness of an investment in these sorts of “software” features may not be obvious initially, but can easily be seen in the mature stage of a project, when systems are operated and maintained in the way they are designed and built for.

Understanding of a solar PV system's working principles, scope and limits of service provision helps the owner to use the system properly. The majority of Humlis are illiterate. However, our experience shows that although many local people never had the privilege to go to school, they are quick and eager learners .Thus some basic theory, hands-on practical training and inclusion in the planning and installation of the PV system is fruitful, satisfying to everyone, and always needs to be a core part of a project.

**Figure 46: Periodic checks of the battery bank's voltage with a multimeter, and topping up of the battery with distilled water (rain water) should be done by the person who owns or is responsible for the solar PV system.**

**Figure 47: In our projects, practical sessions for local people on how to maintain their solar PV system are provided as part of the initial two week RIDS-Nepal solar PV training programme. How to operate the system, what to check periodically, and how to identify and communicate problems to the RIDS-Nepal staff are part of the curriculum. This provides experience and confidence for locally trained people.**

## 9.4. Installation and Follow-up

With the basic training course that we provide, it is possible for local people to participate in the solar PV system installations. This provides the local trainee with the knowledge of where each cable goes and where the main connections are, which are critical to understand in a solar central or cluster PV village system.

Our project staff periodically follow-up every system that we install, interviewing the owner of the system as well as the trainee who is responsible of the system's operation and maintenance. Every system has a number and the results of the interview are recorded in the project's data bank. This gives us a simple and easy system for tracking the performance of the SHS, and helps us identify any shortcomings which have to be addressed. In this way ongoing local equipment development can occur, improving the systems' performance and sustainability.

**Figure 48: Learning by doing. Joint installation of the solar PV system after a two week solar PV training. The training creates experience for the trainee and confidence in the users. The trainees also earn a small salary from the monthly users' fees for their services.**

**Figure 49: Participatory installation of the charge controller and the battery bank, putting theory into practice. This teaches new skills and creates a strong ownership feeling in the SHS users. It also engenders respect in the local "specialist".**

## 9.5. Performance Monitoring

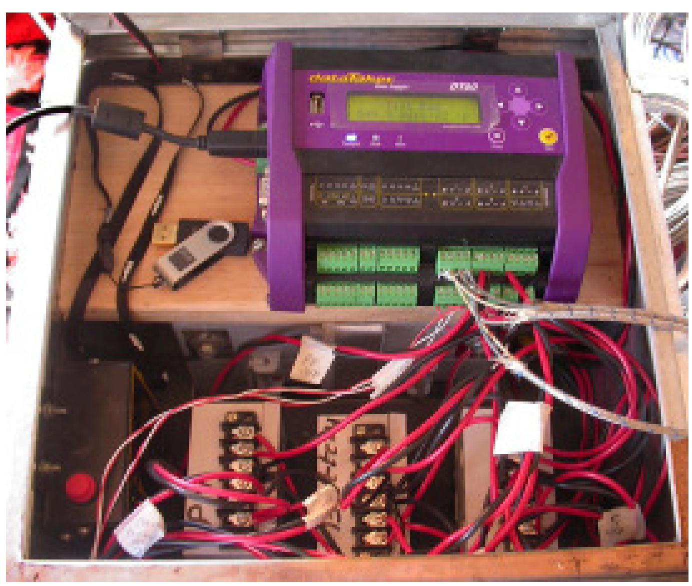

**Figure 50: DT80 Data Monitoring Box with independent Solar PV Power System (see Figure 10)**

**Figure 51: 24/7 the DT80 data logger records and calculates 22 parameters in four different time schedules for all three different solar PV system approaches.**

Having recognised the lack of monitored, followed-up or even anecdotal field experience of installed solar PV systems, RIDS-Nepal made it a policy from the beginning of its long-term Humla based HCD project in 2002 that all the staff have to live in the project area. We also require that each solar PV system installed in the village has a number and is listed in RIDS-Nepal's data bank with relevant owner and household data. This ensures that each system is followed-up, inspected and reported upon as a regular part of the ongoing work schedule.

Since 2006 we have collected data to monitor the performance of the central solar PV system approach and the cluster solar PV system approach. Since April 2007 we have also been monitoring the single SHS approach. The functioning of each system is monitored in great detail by a carefully designed data monitoring system (see Figures 50, 51). For each of the three solar PV system approaches, a DT80 dataTaker, powered by its own solar PV system, records and calculates data on 22 parameters being monitored 24/7. Data is recorded on four separate, time-averaged schedules, 1 minute, 5 minutes, hourly and daily (24 hour average).

Understanding these data is vital for the evaluation and re-design of more efficient, economical, and sustainable solar PV systems. The following 20, most important parameters recorded in each of the three monitored representative solar PV system approaches are:

- Global Solar Radiation measured with a calibrated silicon cell pyranometer on a horizontal surface (international standard)
- Global Solar Radiation measured with a calibrated silicon cell pyranometer on the POA (plain of the array) of the solar PV module
- Generated solar PV module voltage (direct voltage measured with the DT80)
- Generated solar PV module current (current measured and transformed into voltage by a calibrated current transducer)
- Power generated by the solar PV module (calculated parameter)
- Solar PV module efficiency under the measured conditions
- The solar PV module manufacturer's efficiency minus the measured "field" efficiency
- Current flowing from the charge controller into the battery (current measured and transformed into voltage by a calibrated current transducer)
- Battery charging voltage, measured between the charge controller and the battery (direct voltage measured with the DT80)
- Power flowing into the battery bank (calculated parameter)
- Current flowing from the charge controller to the load (current measured and transformed into voltage by a calibrated current transducer)
- Voltage measured between the charge controller and the load (direct voltage measured with the DT80)
- Power demanded by the load (calculated parameter)
- Current flowing from the charge controller to the air heater dump load (current measured and transformed into voltage by a calibrated current transducer)
- Voltage measured between the charge controller and the air heater dump load (direct voltage measured with the DT80).
- Power flowing to the air heater dump load (calculated parameter)
- Solar PV module temperature (T-type thermocouple direct measured with the DT80).
- Ambient air temperature (T-type thermocouple direct measured with the DT80).
- Temperature difference between the solar PV module and the ambient temperature (calculated parameter used for the solar PV module efficiency calculation)
- Battery bank temperature (T-type thermocouple direct measured with the DT80).

Data are saved on a USB memory stick in the field and downloaded on the main HARS PC. Then they can be presented in tabular and graphical forms, such as in Figure 52.

The data monitoring system was designed with the guidelines proposed by IEC (1998), which suggests, for example, that measurement of generated PV power instead of just current (due to the different charging and discharging voltages) is needed, as well as power into the battery and out of the battery. That leads to more accurate analyses and better insight into the performance of the battery bank. Further, it allows the calculation of the non-availability of generated power to the load due to a full battery bank. These factors are needed to calculate the performance ratio (PR) of the solar PV system, which reveals the interaction between the solar PV system under the prevailing meteorological conditions and the user. This in turn provides feedback about the initial design assumptions and parameters that were originally specified, compared to the real field application and use of the PV system.

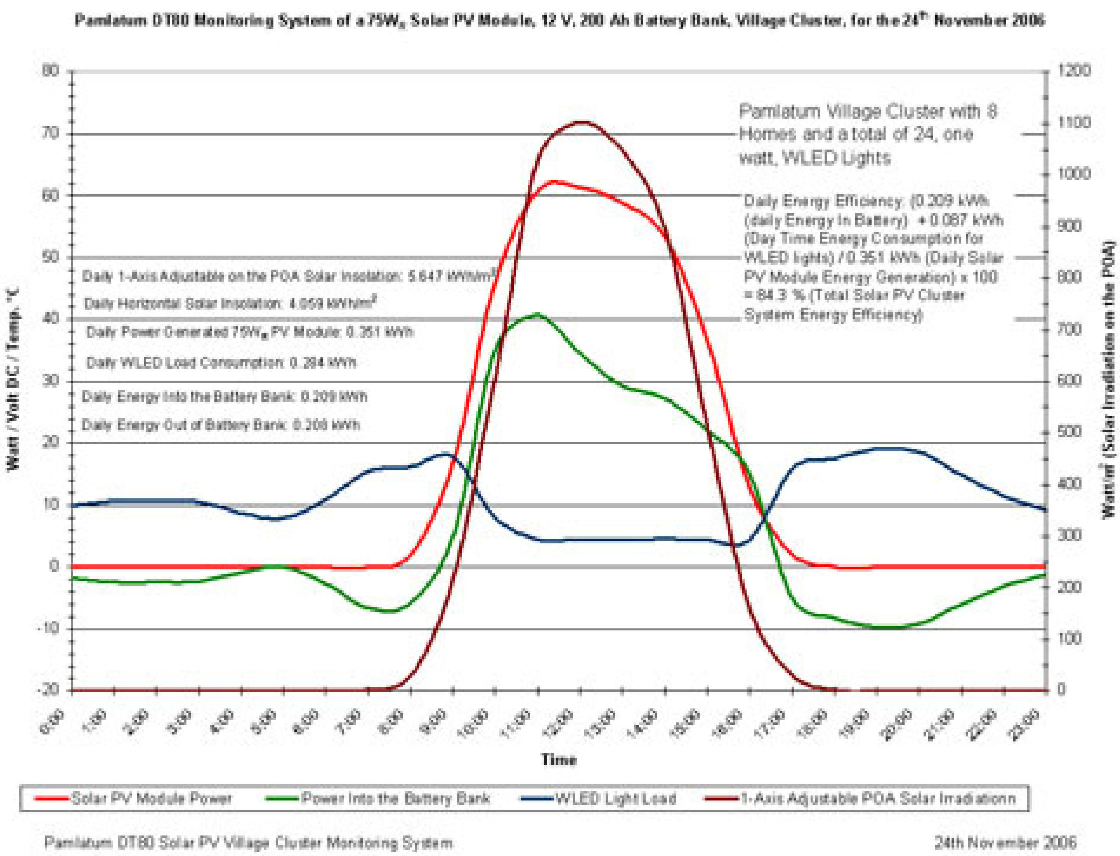


**Figure 52: A 24 hour (23.11-24.11 2006) solar PV cluster (cluster 4 with 8 homes in Figure 7) power generation and load demand under the given local climatic and geographical conditions of Pamlatum village (Figure 7). Detailed evaluation of the PV system's performance and user demand on the system is possible using these data.**

Figure 52 reveals the solar PV cluster system's performance and use. The red curve shows the instant power output of the 75W$_R$ BP275F solar PV module, dependent on the available global solar radiation on the plane of the array (POA), which is plotted in brown. The green line represents the power going either into the battery bank, which is mostly during the day when the power input from the solar PV module is greater than the WLED light load, or out of the battery, which is after the sunset, during the night and early morning hours.

From 11:00AM onward, the power into the battery bank drops despite high global solar radiation on the POA. That indicates that the battery bank has reached its full charge and is in the trickle charging mode. Likewise the solar PV module's power generation drops as the CC short circuits and opens the connection of the solar PV module to the battery, according to the trickle charge mode. Thus it can be concluded that over this 24 hours, the battery bank was fully charged, and in fact, that there was more energy available to be fed into the battery bank under the given solar radiation. The blue graph shows the user's load pattern for indoor lighting only. The load consists of a total of 24 WLED lamps, each consuming 1 watt in 8 homes.

The blue graph shows that during the early morning hours, from 6:00AM–9:00AM between 15 to 18 WLED lights were on, or on an average about 2 WLED lamps per household. Likewise in the early evening after sun set, from 17:00PM–20:00PM 18 to 20 WLED lamps were in use. As expected, after 20:00PM-23:00PM more and more lamps are switched off, with 8 to 10 WLED lamps, or an average of one WLED lamp per household, remaining switched on all night long, till the early morning hours at 05:00AM.

While all-night usage was not included in the original load pattern design, we learned that people like to sleep with one WLED lamp on. The majority of people in this region follow a shamanistic folk religion, and believe that evil spirits roam through the dark nights and do not visit even dimly lit areas .Thus the WLED lamps provide a certain security from fear of being visited and possibly even harmed by an evil spirit.

Humli houses are very dark inside, and the blue graph shows that an average of 4 lamps were in use in various homes throughout the daytime during the period measured.

Other important results can be calculated from the data recorded by the data monitoring system, such as the efficiency of the solar PV equipment. 84.3% of the energy fed into the battery bank during the 24 hour period monitored was used to power the WLED lamps. Thus we can conclude that there was a 15.7% loss of energy due to battery storage losses, charge controller losses and ohmic losses in the PV system wiring, monitoring wiring and load wiring. Additionally, the PR (performance ratio) of the whole solar PV cluster system can be calculated as follows:

$$PR = \frac{E_{Load}\ (Ah) \times V_{meancharge}\ (V)}{H_{ref}\ \left(Wh/m^2/day\right) \times \eta_{STC}\ (\%) \times A_{Module}\ (m^2)} = \% \qquad (1)$$

This calculation takes the daily load current $E_{Load}$ for the WLED lamps (21Ah/day) into account at a defined $V_{meancharge}$ (mean value of charge voltage of 13.5V). This value is divided by the product of the available daily global solar radiation $H_{ref}$ on the POA (5647Wh/m$^2$), multiplied by the STC BP275F PV module efficiency (12.04%) and the PV module's area $A_{Module}$ (0.630m$^2$). Thus the PR for the solar PV cluster system for the 23$^{rd}$-24$^{th}$ November 2006 was 66.2%, which we consider to be satisfactory for this installed PV system. Because the system is designed to provide for 95% of user's load demand even during the poorer solar radiation days of the monsoon season, it is rather oversized for the bright and sunny November days, resulting in a somewhat lower PR factor in November.

In addition to the graphs shown above, each of the parameters we monitor can be plotted against one another in relevant and indicative ways. In this way one can learn and understand in great detail how the solar PV system and the user interact with each other and how the system performs under the given local climatic and geographical circumstances. That provides insight into how the system is actually functioning under real field conditions, which is usually quite different from ideal lab conditions or the STC conditions under which each type of solar PV module is defined. Monitoring the equipment this carefully also enables us to understand the system losses incurred through non STC conditions, non ideal MPP power generation, PV module power generation decrease due to increased cell temperatures, battery storage losses and the influence of dirt or shading on the PV array.

Further, monitoring the system allows us to record the load demand for the WLED indoor lighting of the consumers and will allow us to predict the load demand growth pattern in the years to come, as the users experience electric lighting for the first time in their lives. We are also able to study how people learn for the first time to use electric light in their homes and to analyse important anthropological issues for a deeper understanding of the "software" issues of a culture as it adopts and adjusts to a new, life-altering technology.

The monitoring system of all three different solar PV system approaches will continue to provide very valuable insight, not only into the technical performance of the equipment we install, but also how people learn to live with electric light either as an individual family, a group of families or as a whole village or community. As monitoring continues, we expect that there will also be important lessons learned about changing social patterns, which will have an impact on the long-term sustainability and suitability of each of the three systems described above. Can a village community get organised in order to maintain their communally owned solar PV system properly, or is it easier for groups of people to maintain a cluster system? How much does the personal pride of a single SHS system owner drive him or her to carefully maintain the system so that he or she does not lose face with a neighbor whose system is running well? These and other "software" issues of a project with critical impact on its long term sustainability are likely to be revealed as we continue to monitor use, efficiency, issues and solutions.

Undoubtedly, monitoring PV systems costs time and money. The initial monitoring system design and equipment cost is very high, and the ongoing time demand to support the systems and analyse and present the data is significant. Every two weeks the three monitoring systems are visited, data are downloaded and the systems are checked. Frequently, our staff have to trouble shoot novel and nerve-wracking problems that arise. Data have to be carefully checked and cross checked by field staff for inconsistencies and errors. Time spent on these tasks is saved for our field staff since realistic benchmarks were defined for each parameter, in order to help staff immediately identify erroneous readings. There is no short cut in learning to understand how field-based solar PV systems work, perform and interact with their users. But the final outcome is not only worth the effort in regard to new scientific and applied knowledge, but is also invaluable for understanding of how PV systems are accepted in different cultural settings, and how our services and collaborative projects with local people can become better contextualised, appropriate and sustainable.

## 10. CONCLUSION

There are many villages in the high elevation areas of the Nepalese Himalaya that will never see the grid reach their community. Solar PV systems, a mature and approved technology, supported by a government subsidy program, allowed a steady growth in solar PV system installations in the remote mountainous communities over the last decade. Our field experience and observation of other projects has shown that the standard and quality of the majority of the solar PV systems installed by other implementers are not fulfilling the initial design demands in regard to equipment quality, performance and sustainability. End users are often left with additional debts from the initial installation, beside their shattered and short-lived dream of improved indoor living conditions through electrification. As identified and discussed above, there are technical and non-technical reasons for the high failure and user dissatisfaction rate, which should be treated with the same earnestness and respect. This is supported by widely published literature, with a classic case presented in the solar PV – Wind hybrid system in Xcalak village in Southeast Mexico. Here, the author notes that "the technical results of the PV lighting system efforts had proven acceptable, but the resulting social issues in the case of Xcalak have presented much more of a challenge than PV lighting systems". Further, the author recognised that "since the users were not paying for electricity [as there was no mechanism set up to allow for tariff collection], the system saw tremendous load growth [53% within the first 18 months] as more electric appliances were added (Foster 1999)."

The main author's 10 years experience of living and working with solar PV powered energy, in rural as well as urban settings has been priceless for generating an understanding of the need for sustainable and context appropriate electrification solutions. This experience helped shape an appreciation of the quality and value of solar-generated electricity, and that even miniscule amounts of energy, such as light through WLED lamps, can bring forth enormous changes for whole families and communities. The authors' experience strongly supports that these changes are even more beneficial when light projects are integrated in an HCD project using, for example, the "Family of Four" approach that we developed.

The following recommendations, learned through practical experience with installed and monitored solar PV systems by the authors in Humla and Jumla, summarise the main lessons learned over the last 10 years. They are supported by studies of other systems analysed in a similar fashion, such as in

Xcalak, Mexico (Foster 1999), and the findings published by the IEA (1999). The 15 most important recommendations we offer are:

- Before a solar village PV project is even planned, a base-line survey of the community's current living conditions and self-identified needs has to take place. Social issues (the "software" issues in a project) need to be recognised as at least as important as technical issues.
- A solar village PV system project should always be an integrated part of a wider HCD project approach such as the "Family of Four".
- The end users have to take initiative and explicitly express their interest in starting and partnering in a solar PV village system project.
- The available technologies need to be presented, demonstrated and explained to the end users, with attention paid to services and life cycle costs, prior to the project's final planning stage.
- The end users have to take part in defining how the system will be used when it is installed (such as load demand, load growth, fee payment and prohibited loads), and in approving of the project's conditions and partnership with project implementers and third parties.
- The end users need to form a solar PV system committee, responsible to appoint operators, oversee the maintenance schedule, bring in the regularly scheduled fee payments and take the responsibility to implement the rules that the community agrees upon.
- Professional design of the PV system, based on actual local geographical, climatic, meteorological and cultural data and conditions, is essential.
- Locally developed and manufactured equipment is preferred to imported equipment. Equipment has to be checked for appropriate quality and reliability and ability to withstand the local environmental conditions. This is crucial to achieve a high system capacity factor.
- Training the end users on solar PV basics and hands-on system installation has to take place before and during the project's implementation phase.
- After a system's installation, it has to undergo a careful check before a formal handover to the users takes place. This is an intrinsic and compulsory part of the project.
- All users need to be made aware and trained to use the available electricity in the most energy efficient way and to use only energy efficient and approved appliances.
- Each installed PV system should be numbered and registered for monitoring in a follow-up program (usually with spread sheet based data input).
- Initially, for the first 2 years, intensive and then less intensive, but still systematic, periodic system follow-up needs to take place.
- Long-term data acquisition and system performance monitoring of a typical PV system approach (as discussed in 5.1.–5.3) is highly recommended, and indeed required for larger projects, for design evaluation, improvement and technical and economic calculations for best performance.
- The integration of a rural solar PV village project with a University-based academic research program (as is the case with RIDS-Nepal and the Kathmandu University) can help to bridge the existing rural – urban/developed - undeveloped divide, as well as create new knowledge and insights into technical and social science analysis.

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**Authors' Curriculum Vitae**

***ZAHND Alex*** has a mechanical engineering degree from Switzerland, and a Masters in Renewable Energy from Murdoch Australia. His industrial experience ranges from development projects in extrusion technology for the food and plastic industry, to pharmaceutical production plants. He lived and worked from 1996 - 2000 in one of the remotest and poorest mountain communities in the Nepal Himalayas, in Jumla, as director of a holistic community development (HCD) project. Since 2001 he has been a member of expatriate staff of Kathmandu University, involved in teaching Renewable Energy courses as well as in applied research of renewable energy technologies. Since 2002 he combined his extensive field experience and applied academic research projects by developing and leading a long-term HCD project and a High Altitude Research Station (HARS), in the very remote and impoverished north western district of Humla through the established NGO RIDS-Nepal (www.rids-nepal.org). The HCD projects are designed, implemented and followed-up in close partnership with the local village communities and local manufacturing companies. He is currently also working on his PhD in rural village electrification systems and a new HCD approach for Himalayan villages.

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