Design of an Optimised PV System for a Remote Himalayan Village

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Abstract

While significant progress during the last two decades has been made in rural electrification through extending electricity services to rural villages, it also became clear that with mere traditional electrification methods such as grid connection, most of the remaining, isolated rural villages in the developing world will not be reached within the foreseeable future. Geographical and climatic conditions in combination with low population density, minimal energy demand levels and low growth potential, are some of the reasons that make rural electrification costs often prohibitive. The continuously increasing rates of migration and urbanisation, in particular in developing countries, often support the decision by governments to redirect their effort to the improvement and extension of urban electrification systems. This paper aims to draw renewed attention to the urgency for basic, sustainable rural village electrification for isolated villages in remote and difficult-to-access areas. With this raison d'être, the paper focuses on a set of parameters that are important to define in order to build a sound basis for the design and calculation of a sustainable rural PV village electrification system for lighting purposes. The paper examines the village PV power system as an integral part of a community's long term holistic development. Considering the parameters defined, an installed project of representative size in the remote Himalayan district of Humla, Nepal, is presented. The initial experiences and lessons learned are discussed.

KEYWORDS: Renewable Energy Resource, Elementary Rural Village Electrification, Holistic Community Development, Solar PV System, Sustainability

1. INTRODUCTION

Today almost all of the identified 1.6 – 2 billion people without access to electricity live in developing countries (Mills, 2002), and four out of five live in rural areas (IEA, 2002). While the annum per capita electricity consumption in 2000 was about 2,500 kWh in OECD (Organisation for Economic Co-operation and Development) countries, it was 900 kWh in developing countries (Hunwick, 2002), and 68.5 kWh during the 2003 - 4 fiscal year in Nepal (Kathmandu Post, 2005).

88% of Nepal's 27.5 million people live in rural areas, with roughly half of that number in such remote and difficult to access areas that neither a road nor the national electricity grid will reach them for decades to come. These families have no choice but to cut down precious trees for firewood to fulfill their needed energy services for cooking, room heating and light.

While easy access to electricity by the flick of a switch is an important goal and a means to increase living standards, it is important to recognise it is only the means, and not the end in itself. Thus rural electrification, in order to be relevant and sustainable, has to be embedded in projects addressing also health, food security, drinking water, indoor pollution and education issues. While this is a basic necessity to the approach of sustainable development, and has been addressed in another paper by the authors (Zahnd and McKay, 2005A), in this paper we concentrate solely on rural village electrification through PV systems. Issues such as identifying and specifying the social and technical parameters to define an elementary lighting service, tools to gain access to the available energy resource, and suggested software tools to simulate PV systems appropriately will each be highlighted and discussed.

2. ELEMENTARY VILLAGE ELECTRIFICATION

Under rural electrification, or RAPS (Remote Area Power Supply) systems, a wide range of power generation systems can be defined. In Nepal the traditional thinking among government and rural electrification agencies is that each household needs access to a minimum power rating of 100 watt (Craine, 2004). Thus homes in the rural mountain areas, powered by a micro-hydro power plant (8 - 20 kW), and sometimes even by PV systems, have 2 - 3 incandescent bulbs per household, each consuming 25 - 60 watt. Seemingly not much, that approach denies remote mountain villages any possibility for a basic electrification system. The relationship between poverty, remoteness and access to energy services can be further understood by contemplating the higher transport costs and increased effort to build, operate and maintain a power plant in these areas. These circumstances demand new approaches, with new appropriate technologies to reach these villages. A first time electrification of a community is often best addressed with a step-by-step approach, starting with minimal energy services, initially providing only light inside the homes, one of the key initial energy services identified (Reddy, 2000). Thus, a basic village electrification system can be defined as a power system providing DC (direct current) electricity only for lighting purposes inside homes, for a few hours a day. In order to cut down on the equipment size and weight, saving on infrastructure and transport costs, only the minimum lighting service is considered. Thus a basic village electrification system is a small embedded power generation unit just for minimal lighting purposes, utilising and converting the local available renewable energy resources into electric power through solar PV systems, or a pico hydro power plant[1] (< 1 kW).

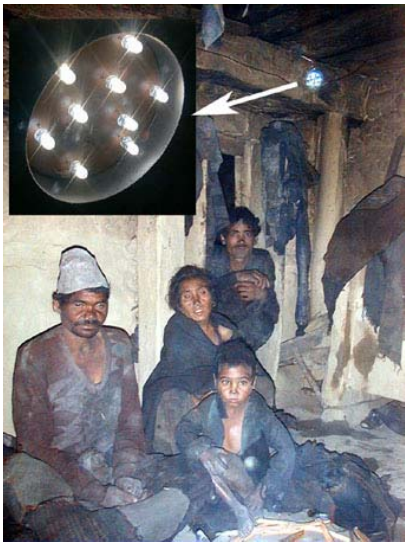

Figure 2-1: Three 1 watt WLED lamps in the home, just sufficient for basic needs.

In the context of remote and impoverished mountain villages in Nepal, we designed an elementary village electrification system, with a power generation system utilising a local renewable energy resource, to provide energy for low power (1 watt) lights, such as white LEDs (Light Emitting Diodes, or WLED lamps). The light service provided is enough for people to see one another and to do daily indoor tasks such as cooking, cleaning, socialising and school homework. We consider this the first step on the path charted from a traditional energy use system (using only biomass) to introduce, learn to use and live with a commercial, cleaner, and more convenient energy source.

3. IMPORTANT PARAMETERS TO BE IDENTIFIED AND SPECIFIED

A basic rural electrification system aims to have improved lighting services for the community, thus improving overall living conditions. This is a long term process, as cultural and living conditions change at a far slower pace than such a project’s implementation. That means that the new energy services need to be reliable, able to cope with the assumed growth (load and population), maintainable, and affordable for the local people. Thus, besides the technical specification for a design of a rural power generation system, the local context and conditions of the end consumers also play an important role. Thus “social parameters”, such as the level of education, economic status and growth of the community, as well as more technical parameters, such as the available solar energy resource, initial and future load demand and days of independency, need to be identified.

3.1. Social Parameters

3.1.1. Population Growth and Civil War

Many developing countries are continuing to experience high urbanisation rates. High unemployment rates, poor education facilities, a shortage of arable and irrigated land, and political instability are

[1] A pico hydro power plant is considered in this paper as a power generation system with < 5 kW power output.

some of the main reasons that people (usually the young) leave their rural heritage for the brighter future promised by an urban environment.

Figure 3-1: Old and young remain in the remote mountain villages, while the working age people migrate to the cities.

That leaves many rural areas with a population distribution deficient in the important middle age, working and income generating group. For example, in Humla, the annual average population growth between 1981 to 1991 was 5.41%, while the annual average population growth between 1991 and 2001 was 1.71% (Zahnd and McKay, 2005B). Increasing food shortage through natural calamities, customary land distribution among family heirs, political instability and civil war are local reasons supporting migration to urban areas in Nepal and India. A rural village electrification scheme is often designed for a 10 – 20 years life expectancy, thus the end user community's population growth and age distribution over this time needs to be known. It influences the system's size, the kind and quality of lighting services, and its ability and need for expansion.

3.1.2. Economic Capacity

Rural village electrification is expensive, and therefore the economic side of each project has to be defined before a project can go ahead. The initial and the ongoing (for generation, maintenance and repairs) project costs are usually higher per kWh of generated energy than for urban dwellings, due to remoteness, low capacity level and need for high sustainability. With increased migration of the working age group, the already economically weak rural communities are increasingly likely to lack access to cash. This demands a clearly defined financial plan for the life cycle cost of a rural village electrification project, in order to provide the community with realistic services according to their economic capacity. It is necessary to also include any long term government subsidies, grants or loans (based on the present and emerging policies) in a project's economic plan, as well as initial project, installation, training, maintenance and repair costs throughout the power plant's lifetime. Issues such as future access to a road or other transport or communication infrastructures can have an important influence on the local income economy, and thus have to be realistically evaluated. Another factor to account for is the "external" earned revenue sent back to the families in the village. In the case of Nepal, the revenue earned through migratory workers in foreign countries and sent back periodically to their family members is greater than the total revenue of Nepal's government. Thus a factor which cannot be neglected is the economic capacity of a rural village.

3.1.3. Education Experience

While the literacy rate for Nepal nationwide is 40% - 60%, the literacy rate for the women in Humla is only 4.8%, and the average years of schooling is just 0.88 years per person (Karnali, 2002). Studies show consistently that improved access to energy services (in particular lighting) increases education, which has a direct influence on improved health of the whole family, the productivity of people, their income generation capacity, and gender equality (Saghir, 2005; Choe, 2001; Goldemberg, 2000), increasing the people's overall living standard on a long term basis. Thus the initial education level of a community will determine also the need for appropriate awareness raising and non-formal education programmes, alongside the rural electrification (Zahnd and McKay 2005A). Further, the existing education level indicates as well the approach to initial instruction and training programmes to be developed for the village's electrification scheme installation, operation and maintenance personnel.

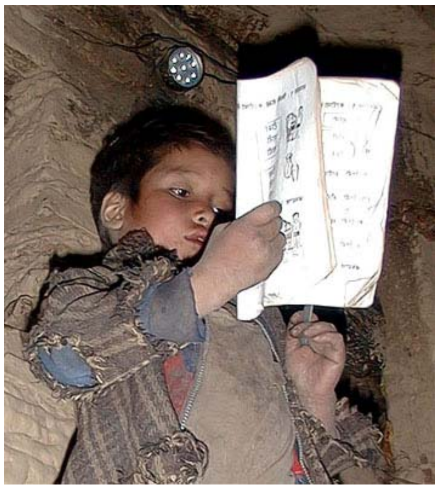

Figure 3-2: A WLED light, consuming 1 watt, enough to read and to do the school home work

3.1.4. Lighting Services Needed

What is the appropriate light output needed in the homes of the remote mountain villages for different tasks, and what is the primary function of lighting? In summary, the Australian Government defined the primary functions of a lighting system in the home and the working place as following (Energy 1994):

- To provide a safe visual environment.
- To make it possible to easily see the task.
- To provide a comfortable, pleasant visual environment.
- To achieve the lighting function as efficiently and cost-effectively as possible.
- To be easy to clean and maintain.
- People must be able to safely orientate themselves and move about within buildings.

While for developed countries defined levels of lighting according to the task are available (AS1680-1990), no such standard is available for rural and impoverished villages in Nepal. Applied local knowledge, experience and realistic expectations allow to come up with a lighting level to be recommended for a defined context (Zahnd, 2004).

The following rungs of a "Lighting Service Ladder", identified according to the lighting services needed, are proposed for a basic rural village electrification system with future capacity expansion possibilities.

Figure 3-3: Two WLED lights in the living room with a smokeless metal stove.

No	Lighting Technology	Units	Lumen/ Watt	Watt Used	Life Expectancy (hours)	Price/Unit Lamp US$	Remarks
1	White LED (WLED)	9	27	1 Watt	50,000-100,000	22.14	Nichia NSPW510BS diodes[2]
2	White LED (WLED)	12	27	1.4 Watt	50,000-100,000	29.52	Including always 15% wire losses
3	White LED (WLED)	18	27	2 Watt	50,000-100,000	44.29	Prices in Nepal for local manufacturing
4	CFL	1	60	7 Watt	~ 8,000 - 12,000	5.43	High quality Compact Fluorescent Lamps
5	CFL	1	60	11 Watt	~ 8,000 - 12,000	6.43	High Power Factor PF 0.95 CFLs
6	CFL	1	60	15 Watt	~ 8,000 - 12,000	6.86	All CFL from Ultralamp AC & DC available[3]

Table 3-1: The rungs of the proposed "Lighting Service Ladder" for a basic rural village electrification system

The calculated life-cycle cost (AS3595-1990) is decisive at which rung of the light service ladder the community can start to climb, as this cost has to be covered and maintained on a long term basis by the community, in order to achieve a sustainable project with lasting benefits.

3.1.5. Ownership

Another important factor is the ownership of the power generation plant. Is it a private home, using daily light mostly in the evening and early morning, or a public building, with classes during the day which do not really need light, but where evening community gatherings or presentations takes place on occasion, demanding higher light output. Further, publicly-owned projects need organised management in order to be sustainable, as cooperative responsibility for a project is often not taken as seriously as the responsibility for a privately owned project.

[2] as used in all Humla elementary rural village electrification projects, see Figures 3-2, 3-3. Detailed technical specification for the Nichia NPSW510BS WLED diodes are available at: http:// http://www.nichia.co.jp/specification/led_lamp/NSPW510BS.pdf

[3] as used in Humla and other projects for office and higher light output needs. http://www.ultralamp.com/english_company.htm

3.2. Technical Parameters

3.2.1 Load Demand and Load Growth

The size of a basic rural village solar PV system depends directly on the load demand and number of homes. In the project we designed, all homes have the same number of WLED lights. Through a centrally located on-off switch, a trained operator provides a defined and affordable number of hours of light per day. In discussions with the village eldership, the historical population growth over the last 20 years was identified and averaged (see 3.1.1). Experience shows that a population and load demand growth over the coming 5 - 10 years for the system design is critical to include. The ten year end-limit is identified because the battery bank[4], consisting of locally available batteries, typically needs replacement after a maximum of 10 years (see 3.2.4.). Therefore the initial battery bank's designed capacity has to reflect the realistic initial daily load demand during the next 10 year period. It must also be able to provide the energy needed by the community to get through predictable number of sunshine-independent days.

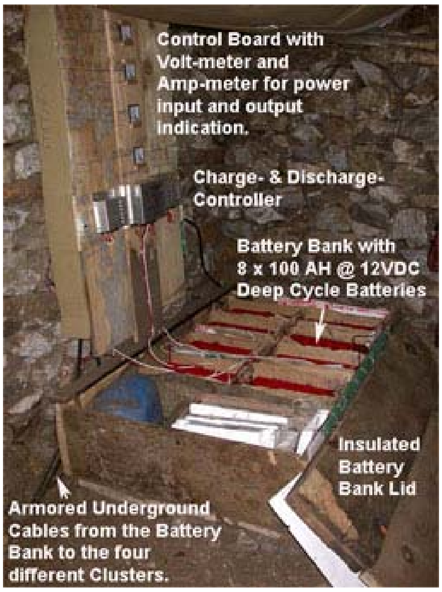

Figure 3-4: Battery Bank well insulated in a locally made wooden box, designed to last 8-10 years, including the load growth.

3.2.2. Life Expectancy

The solar PV modules are often the most expensive equipment in a PV system. Thus, it is important that they generate maximum power, with as little down time as possible. Today manufacturers give a 25 years life expectancy guarantee (≥.80% rated power output). Accordingly all the peripheral equipment has to be designed to either match that, or some multiple of it, for the duration of the project. This is important for remote and difficult-to-access villages, and a mark of good professional design. Periodic maintenance, check-ups and power plant journaling, helps to identify potential shortfalls and needs for parts to be serviced or exchanged in time. The power plant journal allows different operators to know the exact status of the power plant. That keeps the down-time minimal, the services provided reliably, the capacity factor of the power plant high, and the end consumers satisfied. Approximate lifetime expectancies for some of the more important equipment are:

- Solar PV modules and PV array frame: 25 years
- Battery charger and discharger: 8 - 10 years
- Battery bank with conservative design (see 3.2.4.): 5 – 10 years
- Lights (dependent on the technology and use, see 3.1.4.): 4 – 25 years
- Transmission cables: Underground 25 years, untreated wooden poles: 3 – 5 years
- Switches: 3 - 5 years

3.2.3. Solar Energy Resource Assessment

Without proper knowledge and assessment of the locally available renewable solar energy resource, a PV system is destined to disappoint all stakeholders, in particular the end users. But for remote and rural villages, carefully recorded solar irradiation data are rarely available. What follows is a short description of available tools, software and information required to assess the locally available solar irradiation resources:

- Average number of sunny days a year, over at least 5 years. Often available at the national meteorological institute. Needs adjustment to the local geographical and climatic conditions.
- National solar radiation data bank (usually from a weather station installed at the national airport), adjusted for the local village's geographical and climatic condition.

[4] As a rule of thumb, once a battery bank is a few months in use, no additional batteries should be added, even if they are new, from the same brand and capacity.

- RETScreen PV system design tool (http://www.retscreen.net). This is a Canadian government sponsored, freely available resource on the Internet. It is an Excel-based spreadsheet that directly accesses NASA satellite solar radiation data, integrating the data in its calculation spreadsheet.
- SWERA (http://swera.unep.net/swera/index.php), initiated by NREL (National Renewable Energy Laboratory). It assesses the local solar radiation and wind resources. High resolution solar radiation data (10 km x 10 km surface area) for Nepal over 3 full years, are freely available.
- NASA satellite solar radiation data are freely available for any place on the globe with the input of the latitude and longitude for the location in question, from: http://eosweb.larc.nasa.gov/.The NASA satellite data bank generates monthly solar irradiation data, averaged over 10 years.

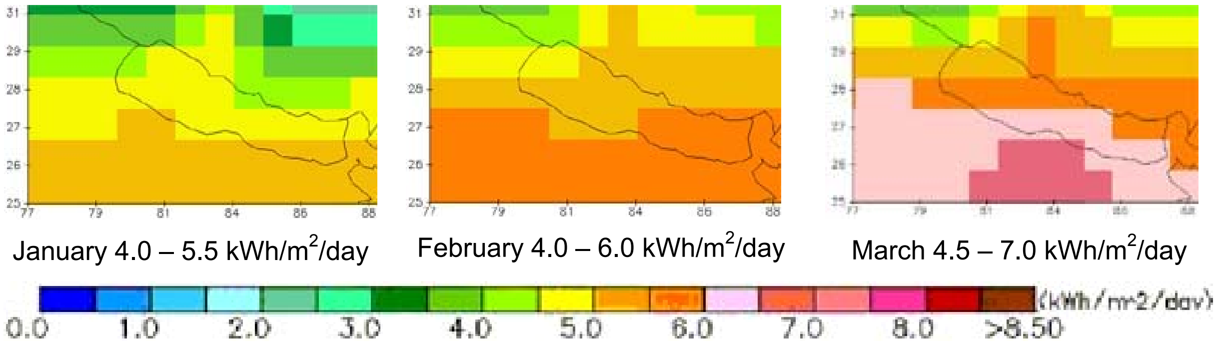

Figure 3-5: Average Solar Irradiation on a flat surface tilted at 30º towards Equator for 1983 – 1993 for Nepal

- Solar Radiation Calculator SolRC. A freely available Excel spreadsheet showing a solar irradiation calculation programme for a defined place (http://www.pvresources.com/en/software.php).
- METEONORM (http://www.meteotest.ch/en/mn_home), a commercial software tool that provides hourly and monthly solar irradiation data for any defined place in the world.
- Measurement of the locally available solar radiation on surfaces with different angles to the sun, as done in our project area. This is the most reliable, though also time demanding and expensive way. Pyranometers need to be installed and the data recorded and interpreted over at least 3 – 5 years (see Figure 3-6).

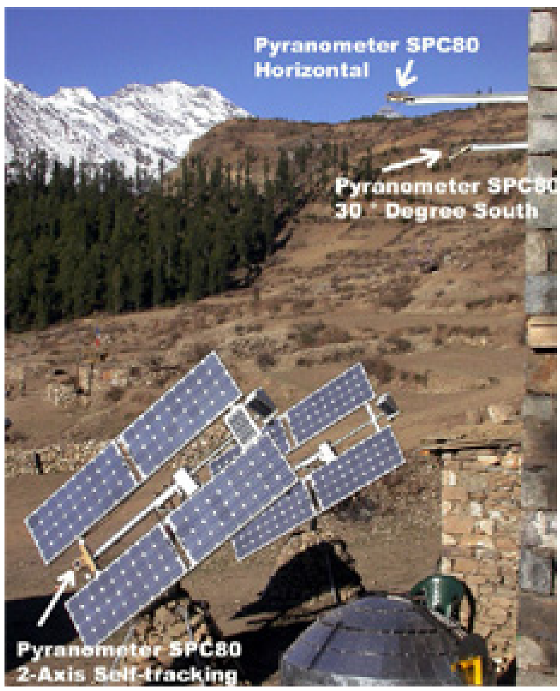

Figure 3-6: Three Pyranometers with different angles to the sun measuring and recording the solar radiation. A 2-axis Self-tracking Solar PV frames for rural villages, with ample gaps for the wind.

Two additional parameters to consider for the design of a solar PV village system are the geographical and climatic conditions. A village in a deep valley, surrounded by high mountain ranges, has significantly shorter sunshine hours per day, particular during the shorter winter months, with lower solar altitude angles. While METEONORM is able to include the surrounding mountain ranges (360° horizon) in its simulation, in most other tools' generated solar irradiation data, a realistic factor (e.g. 0.9 – 0.7) has to be chosen to account for the shorter sunshine hours. The climatic conditions need to be known, because solar PV modules' power output are directly related to the modules' temperature, which can be estimated by knowing the ambient temperatures throughout the seasons. Mono-crystalline and polycrystalline PV modules have an average power output reduction of 0.4% - 0.5% per increased °C. That means for every degree above 25°C (the standard temperature at which all PV modules are rated) these modules lose 0.4% - 0.5% of their power output. Thus if a village is in a tropical climate where ambient temperatures reach 40°C during the summer months, the PV modules will reach 60°C - 70°C under direct solar beam radiation. That results in 15% - 22% power output reduction per module. Smart design, positioning and installation techniques can help to increase the natural air and wind flow between the solar PV modules on the array to cool the PV modules down (see Figure 3-6). In the high altitude Himalayan villages, the ambient temperature during the sunny winter months is around the freezing point. If the PV modules' temperature reach 9°C under direct solar beam radiation, their power output increases up to 8% compared to the manufacturer's rated power output. These significant differences have to be recognised, identified and accounted for. They have to be included in the available local solar energy resource on a monthly basis, so that the PV system is able to generate the expected energy for the defined lighting services.

3.2.4. Availability, Reliability, Days of Independence

A basic rural village electrification system is often not designed to deliver energy services at the discretion of each consumer. Rather, in the initial project steps the local villagers themselves decide how many hours a day they want light, and are able to afford it, as this directly impacts the size and cost of the energy generation system. For the initial introduction of electricity into the village it is desirable to provide the power reliably and the lights available as required. Reliability and availability depend on the quality and size of the system, which is directly related to its costs, and the personnel operating and maintaining the system. For a remote village it is good practice to aim for high sustainability rather than highest possible efficiency with new, untested and unreliable equipment. Thus it is advisable to limit the energy services to a minimum, though consistently provided, if costs are the limiting factor. Being most of the time a community-owned system, an elementary rural village electrification system needs trained people to operate, service and maintain it. They will be trained in the basics of solar PV and practical installation and maintenance skills before the project installation. They are chosen by the village eldership or the village electrification committee.

Figure 3-7: A project staff member trains the chosen local people in how to install and maintain the WLED lights, switches and house wires.

Figure 3-8: A project staff member teaches the local trainees how to check, clean and maintain the battery bank.

Another important factor the local end users have to decide at the initial project step is, how many days of lighting services do they want, and can afford, if the sun is not shining? These are the days of independence, when the battery bank has to provide the whole energy without being charged and without being too highly discharged, leading to a shorter life expectancy. An advised maximum DoD (Depth of Discharge) for a battery bank for remote areas is 0.35 (35% of its full capacity)[5]. Thus the more days of independence, the higher the battery bank's capacity needs to be, hence also higher costs. In areas such as Humla, where the annual monsoon covers the sky for days at the time, one may better know beforehand what services are available, and what restrictions are designed into the system. The real state of a battery's charge can reliably only be defined through the battery's sulphuric

[5] The DoD defines the capacity (Ah) drawn in percentage from the battery's full capacity. For remote installed battery banks it is advised to limit DoD rates to ~ 35% of its full capacity, as the number of times and depths a battery is discharged is related to its life cycle expectancy. A battery bank for a rural system should be designed to last between 5 – 10 years, as transport costs are very high, system down time should be kept low, and recycling opportunities are e.g. in Nepal not yet available.

acid specific gravity, the voltage and the internal battery temperature. As this is technically difficult and expensive to do, the battery bank is protected through a defined minimum voltage, built-in in the discharge controller. Once reached, it cuts the power to the consumers.

Another factor related to high availability and reliability is that the whole system is protected at various crucial points against short cuts and overloads due to unauthorised misuse. Thus for the installed systems in our projects in Humla, an electronic fuse was developed (as glass fuses are seldom available in remote areas) which triggers when a pre-defined maximum current flows. Thus the battery bank, the DC transmission lines, and the WLED lights are reliably protected.

3.2.5. Maintenance and Repair

Clearly defined system parameters, the use of appropriate and reliable material, whenever possible locally manufactured, are important parts of a long term sustainable and successful basic rural village electrification system. Once the system is installed, checked and in operation, it needs ongoing maintenance and repair. Local people, chosen by the system committee, are trained by the project staff (Figures 3-7 and 3-8). They participate in the initial installation, which provides them with the due respect in the community as the ones to be in control. Further, the operating and maintenance team are provided with the following tools, to which they were introduced as part of the initial skill training:

- Operation list to be filled in periodically with the most important system parameters, such as battery bank voltage and specific gravity, when, why and which fuse triggered, when solar PV modules were cleaned and lights cleaned/exchanged. All maintenance and repair work is recorded in the power plan journal.
- Basic tools including also a voltage meter and battery specific gravity measurement tube. A set of spare WLED lights in case some fail, or for newly built homes. A roll of house wire and underground cable[6], in case a new house (due to population growth) has to be electrified.
- A defined communication procedure (through letters or mail runners) between the system operator or maintenance staff and the project designer. That allows information about failures or untimely breakdowns, which cannot be fixed or handled by the locally trained staff, to be communicated[7].
- Monthly visits by the project designer[8], and a yearly comprehensive family survey is carried out in the village. That provides crucial long-term feedback and information on the system performance and how to change/adapt future approaches and technologies for context related increased appropriateness and sustainability. It also provides crucial information on the long-term impact lighting in the home has on the whole life and development of the people.

4. THE OPTIMISED BASIC RURAL VILLAGE PV SYSTEM

When all the different social and technical parameters are identified in the end user community, they can be used to form the basis for the design of the actual rural village PV system. Knowledge of these parameters is essential for the design of village power systems that suit the local context with ample provision for the future. Consideration of the social context, or "soft" issues of a project, along with the important technical issues, pays respect to the owners' and consumers' living context. It also recognises and in fact honors their choice to remain in the village and work on improving their living conditions. Lighting of their homes is one of the most important aspects of a holistic community project. In our work, it is embedded within the wider scope of a holistic community development project approach, which also addresses health, education, indoor air pollution, clean drinking water, and food security, all urgent and interrelated issues of remote and impoverished mountain communities.

[6] In the realised Humla projects in Nepal only armored underground cabling is used,. The main reasons for that are the harsh climatic conditions with snow, storms, torrential rains, and floods. Additionally, the area suffers from dramatic deforestation due to heavy reliance on forest resources, and in any case the soft Himalayan pine tree poles, would last only for a few years due to rotting. These, plus the aim for high reliability and sustainability of the system justifies the substantially higher costs for underground cabling. The armored underground cables are initially defined so that they are able to carry twice to three times the initial current, dependent on the systems load demand, growth and defined light services.

[7] In the case of the systems installed in Humla there is a well established project office and high altitude research station in Simikot, Humla's district center, able to be reached from any place in Humla within maximum 4 days of walk.

[8] One of the project's main aims is to gain long-term experience with elementary rural village electrification schemes, thus an intensive baseline and then follow-up research programme is part of the design of each village system.

4.1. Tools for the Simulation and Design of a Basic Rural Village PV System

For the actual calculation and design of the village PV system, various approved software tools are available. They require various levels of detailed input of technical and financial data. Whichever "tool" is used, what makes the "optimised" design different from the standard design method is that defined numeric values of the various parameters identified in section 3 are input. The following two recommended software programs have been used for the Humla PV village system design:

- PVSyst. version 3.4 (http://www.pvsyst.com/) is a commercially available, very detailed sizing, simulation and data analysis tool for complete PV systems design. It can import solar irradiation data generated by METEONORM and TMY2 (Typical Meteorological Year, version 2) from NREL. It offers an extended and detailed data bank with the technical specification of the important PV components. It can simulate stand-alone and grid connected PV systems. It allows in-depth technical specification input for most of the equipment needed for the design simulation, and the detailed financial module included provides a thorough treatment of investment, payback period and price of the generated energy. Its sheer scope and ability to present data in graphical and report form is praiseworthy. A free, 10 days, full edition version, can be downloaded.
- RETScreen PV module version 3.1 (http://www.retscreen.net). More than a mere solar PV system calculation and design program it is a "clean energy awareness, decision-support and capacity building tool" (pvresurces, 2005). The energy production, the greenhouse gas emission reduction and the life cycle cost of a solar PV system can be simulated according to the input data. It has a link to the NASA solar radiation databank and thus can calculate values for any system worldwide. It is based on an Excel spreadsheet with a good user manual, and is freely available.

5. THE DHADHAPHAYA VILLAGE PV SYSTEM

Dhadhaphaya village[9] belongs to the poorest, undeveloped mountain villages in the remote district of Humla, Nepal. Based on the village's request for a holistic community development project, meetings between the village elders and the project staff of the RIDS-ISIS[10], Humla project took place. A detailed holistic community development project plan was developed, including the following projects.

- A basic rural village PV electrification scheme for 3 WLED lights per household
- A smokeless metal stove for each household
- A pit latrine for each household
- A village drinking water scheme
- Five greenhouses to grow vegetables
- Two non-formal education classes, one for mothers and one for out-of-school children
- A village solar water heated bathing centre for men and women

In this paper we only consider the basic rural village PV electrification project in Dhadhaphaya, as part of the village's larger holistic community development project. The following parameters for the solar PV system design were identified and deemed critical to the success of the electrification project:

- During the detailed survey (August 2004), Dhadhaphaya village had 167 homes and 1,067 people. The average historical population growth is 2.2% – 3%, or 3 – 5 additional homes built each year.
- With the METEONORM software and the NASA Internet based solar radiation data bank, the locally available solar irradiation has been simulated in hourly and monthly values. Further, in the 3 hours walk away RIDS-ISIS High Altitude Research Station (HARS) in Simikot, the local solar radiation has been measured on three different surfaces (Figure 3-6) since May 2004. Though still limited and not representative, these data provide a comparable set to the METENORM and NASA simulated data. Thus the solar irradiation data used for the Dhadhaphaya village was an average of the three data sets, multiplied by a factor of 0.8, as a high mountain range towards East, shortens the morning sunshine hours significantly.

[9] Is located at 29° 59' Northern Latitude, 81° 57' Eastern Longitude, and at 2,550 metres above sea level.
[10] Rural Integrated Development Services, a locally registered NGO, and ISIS Foundation, an INGO headquartered in Bermuda.

- The village is surrounded by high mountain ranges, thus a 360° horizon silhouette (with the NASA 90-m horizon tool) was created of all the mountain peaks around and included in the PVSyst 3.4 simulation design. Thus due respect is paid to the shorter daily sunshine hours in the village.
- The average ambient temperature during the day ranges from 0°C to 35°C, thus the assumed solar PV module temperature under direct beam radiation is estimated to vary from 10°C - 65°C.
- Due to the layout of the 170 homes (September 2005) in the village, we used a "cluster" PV system approach (Figure 4-1), rather than a central solar PV system with 2-axis self-tracking frames (Figure 3-6). Thus various clusters, each with 4 - 15 homes were defined, with most clusters having one BP275F 75W mono-crystalline solar PV module with its own battery charger, discharger and battery bank.
- From each central cluster home with the power system, armored underground cables lead the power to individual cluster homes, powering the 3 WLED lights in each home.

Figure 4-1: Cluster PV System

- A total of 18 clusters (with 1,182 W_R)[11], for 170 homes, with 510 WLED lights were installed.
- The armored underground cables are able to cope with a tripling of the power in the years to come. They have a life expectancy of 25 years, similar to the solar PV modules.
- The battery banks are designed to cope with a doubling of the daily load, and an independency of up to 5 days. Its life expectancy is designed to be 8 - 10 years. It is installed in a well insulated and aerated locally made wooden box, so that the battery temperature does not rise over 25°C, or drops under 10°C, even not during the harsh winter months (similar as in Figures 3-4, 3-8).
- The charge and discharge controller are defined for a life expectancy of ~ 10 years, and able to cope with a doubling of the power input (if the cluster community decides they want to add another solar PV module) and power output (load growth due to population and consumption growth).
- Due to the extreme poverty of villagers in this community, the initial project costs were raised by RIDS-ISIS through external donors. The local community participated in each project step, from the initial project definition to the project installation stage. They carried all the equipment to the village, dug the canals for the underground cables, and provided all required locally available materials (stones and wood). Thus their overall participation in the whole project, expressed in economic terms, amounts to ~ 25% of total costs, thus creating a stronger feeling of community ownership for the project.
- Being community owned, each family has to raise a monthly amount of 25 NRp (~ US $ 0.36), after the initial payment of NRp 500 per cluster for the maintenance fund. These payments have been approved by the village elders, based on the needs for maintenance and basic repair.
- For each cluster, a person was selected by the community and trained to operate and to maintain the system. This person is paid a small salary from the monthly fees raised from the users.

5.1. Lessons Learned

Some valuable experiences of the implemented basic rural village PV electrification systems are:

- Alongside each project (over the last eight years) constant development of all locally manufactured equipment took place. This has proved to be of key importance. It increases the community's ability to maintain and repair equipment locally, while also allowing local people to learn new skills and improve the local economy. Specifically, the WLED lights, solar battery charge and discharge controller, the electronic overload protection, and the 2-axis self-tracking frame were all developed and manufactured in Nepal.
- Roughly yearly a new, more appropriate WLED light design and solar battery charge/discharge controller have been installed. While in most of the previous years this worked out well, some of the 2005 WLED diodes were purchased (due to time constraints) from a dealer, and not directly

[11] Of these, 15 clusters have one 75 Watt PV module, and three clusters one 19 Watt PV modules, as these three small clusters have only 4 - 6 homes per cluster. Thus for 170 homes (in Sept. 2005), including an average annual 3% population growth over 10 years, a total 1,182 W_R of PV modules have been installed, 7 Watt per household with each 3 WLED lights consuming each 1 Watt.

imported from the manufacturer. That turned out to be a mistake, as the dealer mixed obviously lower quality diodes with the high quality ones. Various of those WLED lamps have been found to be malfunctioning within the first month of their operation. These malfunctioning lights have now been exchanged with newly, original diodes.

- The newly developed 2005 battery charge controller was for the first time installed with a microprocessor, allowing various battery charging discharging and periodical gasification procedures. However, the software designer was not fully aware of the harsh mountain conditions where the controller was to be used in our project. Thus, considerable failure rates in these units forced the project team to withdraw all 18 charge/discharge controllers and exchange them with the approved 2004 model. Since then, no complaints have come in.

These were valuable lessons. Research and new equipment development has to take place on an ongoing basis, while failure rates and system downtimes have to be avoided as much as possible. And there is often a narrow way in between these two paths. This experience has shown again, that sustainability and appropriateness are key aspects of a project to pursue, in order to deliver the intended services to the beneficiaries. To keep that in mind means to keep the end-users at the centre of our interest, and to develop and install technologies that can be applied to achieve that goal.

6. CONCLUSIONS

It is widely recognised that bringing light into the homes of the poor is a critical component in efforts to improve living conditions. But it has to be re-emphasised that a lighting project should not be considered just as an individual project, but always as an integrated part of a holistic community development project (as discussed in section 5), producing synergetic benefits.

In this paper we try to create an understanding that unless the scope of rural electrification approaches is widened to include small amounts of power generation (in watts rather than kWs), designed according to a particular context and lifestyle of a group of people, we will not be able to reach the almost 2 billion people still living with no electrification in their homes in the foreseeable future. This paper has attempted to identify some of the crucial social and technical parameters, to pay due respect to the local cultural, geographical and climatic context for the design of a village PV system. The described elementary solar PV village system implemented in Dhadhaphaya village in Humla, serves as a practical example of how an optimised design process can be applied. Following our holistic, villager-driven approach, from the project's initial steps the local community was involved in all definitions, decisions and installations. Since May 2005, the 170 households have had 3 WLED lights available and providing light for 5 hours a day. In addition to the light project, two non-formal education evening classes for mothers and children are now running, with their own teaching materials about each component of the holistic community development project, including the new lights, smokeless metal stoves, pit latrines installed for each home, safe drinking water system, and the villagers' newly built greenhouses and consequent increased food security.

The initial baseline survey conducted in each home in the village provides information needed to monitor and assess social and health changes resulting from this project. This will provide important feedback about the solar PV cluster systems' performance, reliability, availability, and last but not least, expected synergetic benefits of the combined projects. We plan to use this information to improve future project and equipment design and to increase the satisfaction of the consumers.

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