Identification and Evaluation of the Losses Occurring in a Solar PV System under Real Field Conditions for Rural Electrification in Humla, Nepal

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ABSTRACT

Nepal, which is situated along the solar belt of 30° northern latitude, is blessed with an average of 300 days of sunshine a year. Over the last decade, private companies and local NGOs/INGOs have been increasingly providing electricity services through government subsidised Solar Photovoltaic (PV) Systems to the local communities for basic indoor lighting in rural areas. In many cases, the users consider PV technology to be inappropriate when the performance of their solar PV system is less than what they expected or were initially promised. The understanding of the real field conditions in a set environment, as well as the losses occurring due to PV cell temperatures, PV module mismatches, wrong battery bank usage etc. are lacking, not discussed or considered in the design of a PV system prior to its installation.

In order to identify and understand the losses which may occur in installed solar PV systems, and thus understand their limited performance in greater detail, Kathmandu University (KU) and Rural Integrated Development Service (RIDS)–Nepal, with the support of the ISIS Foundation, have started monitoring several solar PV systems' performance on a continual basis within their installed geographical, meteorological and users' context in one of the remotest and poorest communities in Humla, Nepal. This paper aims to identify and present the main losses in a solar PV system. In particular, losses occurred due to non-standard temperature conditions (STC), non-ideal PV module angle position, increased PV cell temperature, PV module mismatch, and battery bank and wire losses, are discussed and presented with data, graphs and pictures.

Keywords: Losses, Solar Photovoltaic, STC, Mismatch, Battery

INTRODUCTION

Lighting is often the first use of electricity in a developing country and people are willing to invest in home or village electrification. Solar photovoltaic (PV), a renewable energy technology, is increasingly viewed as an important option, especially by governments in developing countries with a limited and poor national grid network. Also among policy makers, lending and sponsoring institutions, the solar PV technology enjoys a good reputation in regard to generating electricity, especially for rural elementary lighting purpose in developing countries and for remote and difficult to access areas. Nepal has plenty of renewable energy resources, including an average solar insolation of 5.5 – 6.0kWh/m^2 per day.

Each solar PV system needs to be defined according to the given environment and the user's needs. It is important to know the on-site conditions and challenges, and to design the PV system accordingly. This approach helps to ensure the system's performance and reliability.

OBJECTIVES/PROBLEM STATEMENT

A typical solar PV system consists of a solar array, its mounting structure, DC wiring, a battery bank, and an inverter in case of an AC load demand. All of these components must be designed, sized and installed correctly.

The DC rated output of each solar PV module is provided by the PV manufacturer in the form of the values measured under Standard Test Conditions (STC), which are: Global solar radiation of 1000W/m^2, with a standard spectral distribution corresponding to the sun at vertical Air Mass of 1.5 and with the PV module temperature held at constant 25°C during the measurement. This defined environment allows the direct comparison of different solar PV modules.

Based on the local solar radiation received, installation issues such as the correct array orientation, tilt angle and partial shading considerations play a crucial role in the overall power output of a solar PV system.

In order to design solar PV systems professionally and with an increased assurance of it performing to the end users' satisfaction it is crucial that PV system's performance under real field conditions are monitored over different seasons of the year. This allows a responsible, contextualised design and choice of technologies for a village solar PV system in a defined context.

METHODOLOGY

Monitored System

A Datataker DT80 datalogger was used to monitor meteorological and fundamental physical system parameters as well as derived parameters (see Table 1).

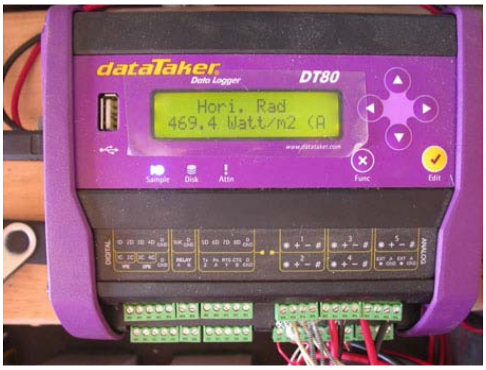

Fig. 1: Data Logger (DT80)

Table 1: Monitored fundamental parameters

Parameters	Details
1. Temperature in °C	➢ Ambient ➢ Battery Bank ➢ PV Module
2. Global Solar Radiation in W/m^2	➢ Horizontal ➢ 30° South Inclined ➢ 2-Axis Tracking (POA)
3. Power generation and output in Voltage (V) and Current (I)	➢ PV (V, I) ➢ Battery (V, I) ➢ Load (V, I)

Fig. 2: RIDS-Nepal Simikot office in Humla Nepal at 3000 meter altitude, with a $900W_P$ monitored Solar PV system. The system is monitored in detail since 2004 for its performance throughout the years.

The PV system is located in Humla, RIDS-Nepal Simikot office as seen in figure 2 (Latitude: 29°58'22.07" North, Longitude: 81°49'05.63" East), and lies on 3,000 m altitude. The office is powered by a 900Wp (3 systems each with 300Wp), 2-axis Solar PV tracking system. While the sun's daily East–West path is tracked automatically, the sun's seasonal angle at the horizon is adjusted bi-weekly manually. In this way the PV modules are exposed almost all the time perpendicular to the sun's incoming radiation every day of the year. The PV system provides AC output through an inverter. Each tracker is composed of four PV modules. Two modules are connected in series and two in parallel so that the maximum power point current of an array (Impp) is 8.90A and the maximum power point voltage (Vmpp) is 34.00V at STC, generating 300W_P per tracker. The three trackers are connected in parallel, thus generating at the MPP 26.70A at 34.00V, delivering around 900W_P under STC.

In total, 12 x 75Wp BP275F PV modules are used to power the battery bank which consists of 16 x 100Ah @ 12VDC flooded lead acid deep cycle batteries, connected as a 24 VDC system. Thus a total energy capacity of 19.2kWh is available.

Table 2: Main technical specifications for one BP275F Solar PV Module

Nominal Peak Power (Pmax)	75.00W
Voltage @ maximum power (Vmpp)	17.00V
Current @ maximum power (Impp)	4.45A
Short-circuit current (Isc)	4.75A
Short-circuit current (Isc)	4.75A

Fig. 3: One unit of the 2-Axis Solar Tracker in Humla with four BP 275F PV Modules

Data Analysis

Throughout the paper, the analysis is based on averaged hourly data recorded all through 2006-2007 for all the monitored parameters including soil temperature data for 2009. The system losses were calculated with reference to the PV module's rating under STC.

KEY SYSTEM LOSSES

Module Production Tolerance

The BP275F solar PV module manufacturer guarantees that each module generates a minimum of 70W_P under STC. This amounts to 5 watt or 6.7% less than its intended peak power. Consequently, for the RIDS-Nepal Simikot Office Solar PV system, the manufacturing tolerance related loss of the whole PV system can amount up to 60W (12 modules x 5 watt).

Tilt Angle and Sun Tracking

The global solar radiation incident angle on the PV module should be as close to 90° under the sun's daily path as possible right throughout the day. Thus manual or automatic tilt angle adjustment can increase the total incoming solar radiation-to-electricity conversion efficiency considerably. In Humla, for fixed angle installed small solar home systems (16Wp), the yearly average maximum power output is achieved with a PV module tilt angle of 30° south inclined, equalling the location's northern latitude. In order to maximise the power output of the RIDS-Nepal Simikot office PV system, three 2-axis tracking frame systems are installed.

The sun's daily East-West path is automatically tracked and the seasonal North-South angle manually adjusted on a bi-weekly or once a month basis. The trackers' manual North-South angle adjustment, to comply with the sun's changing altitude angle over the year between the horizontal and the line to the sun, various for Humla between 5°-60°, the minimum and maximum values in June and December respectively. This manual North-South tracker axis adjustment, which takes less than a minute, has the following values for each month of the year.

Table 3: Manual adjusted North-South angle for the RIDS-Nepal Simikot Office PV system trackers according to the month

Month	Degrees South Inclined	Remarks
January	50 - 55	= Latitude + 20 to +25 degrees
February	40 - 45	= Latitude + 10 to +15 degrees
March	30 - 35	= Latitude + 0 to +5 degrees
April	20 - 25	= Latitude - 5 to -10 degrees
May	10 - 15	= Latitude - 20 to -15 degrees
June	5 - 10	= Latitude - 25 to -20 degrees
July	10 - 15	= Latitude - 20 to -15 degrees
August	15 - 20	= Latitude - 15 to -10 degrees
September	25 - 30	= Latitude - 5 to +0 degrees
October	35 - 40	= Latitude + 5 to +10 degrees
November	45 - 50	= Latitude + 25 to +30 degrees
December	55 - 60	= Latitude + 25 to +30 degrees

Thus, alongside the daily East-to-West automatic tracking for the maximum power output throughout the year, the tracking frames' North-South angle can be manually adjusted within above indicated angles. This allows the PV modules to be exposed daily perpendicular to the sun's varying path over the course of the year.

The following two graphs in figures 4 and 5 show the difference of the intercepted global solar radiation measured at horizontal position (international standard to measure global solar radiation), 30° south inclined (standard angle for fixed installed PV systems in Nepal) and the 2-axis tracking frame for the years 2006 and 2007.

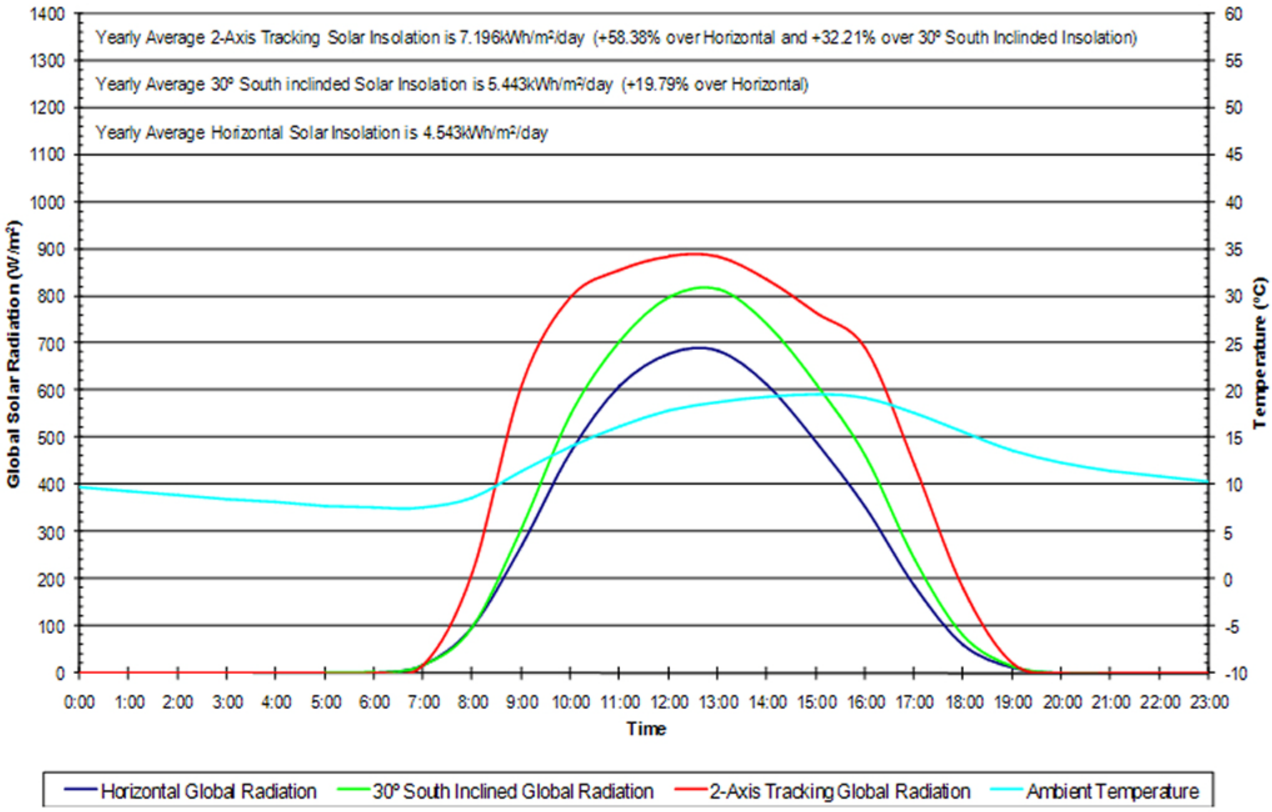

Fig.4: Hourly Averaged Global Solar Radiation and Ambient Temperature for the year 2006

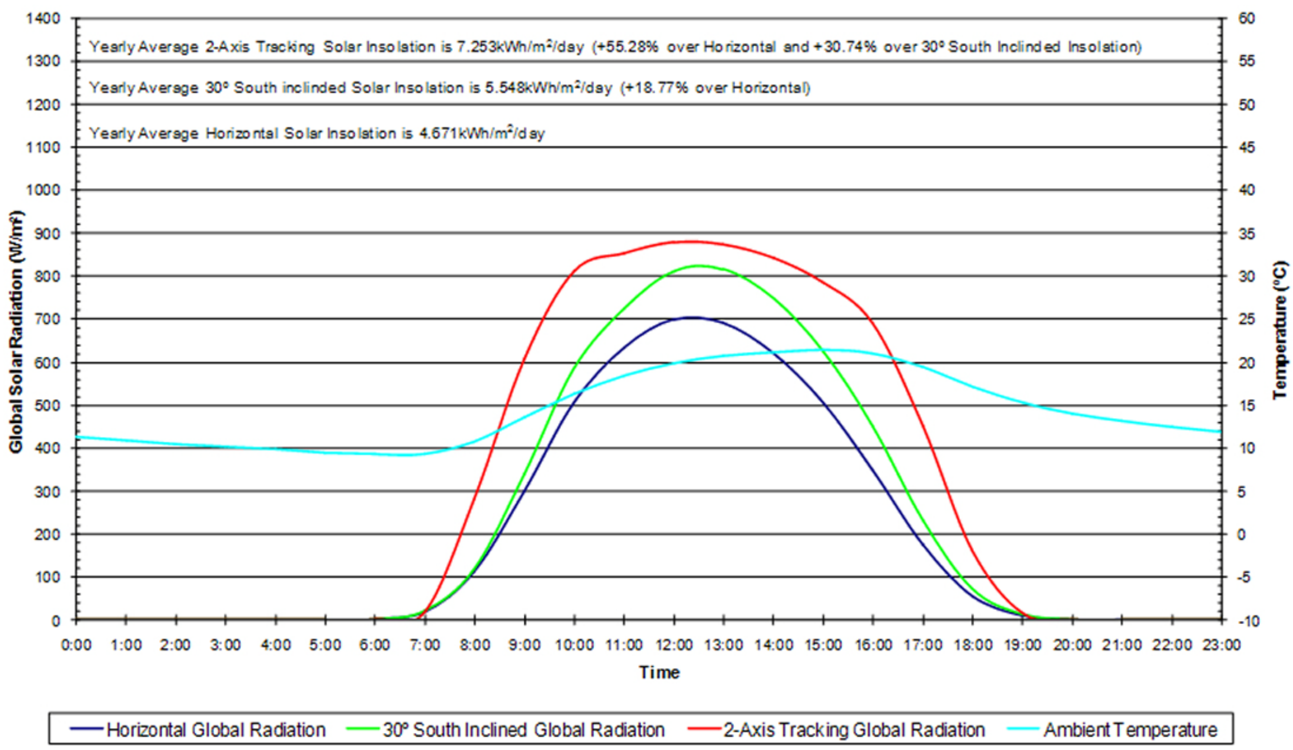

Fig.5: Hourly Averaged Global Solar Radiation and Ambient Temperature for the year 2007

The main findings can be summarised in the following points:

1. Over the course of these two years, the maximum averaged horizontal global solar radiation was 692W/m^2, the maximum averaged 30° south inclined was 815W/m^2 and the maximum averaged tracked was 881W/m^2. The averaged maximum and minimum ambient temperatures recorded were 20.5°C and 8.4°C respectively. This shows clearly, that the available PV module power output is considerable less under real field condition as compared to the STC all the PV modules are rated.
2. The averaged yearly (over both years) intercepted global solar radiation for the 2-axis tracking system was 7.225kWh/m^2/day, which is 56.82% more than received on the horizontal (4.607kWh/m^2/day) and 31.46% more than received on the 30º south inclined surface (5.496kWh/m^2/day).

Remarks

- From the above data, it can be seen that through the easy periodical manual adjustment of the North-South tilt angle and the automatic East-West tracking system the average daily increased energy generation over the course of the year is around one third more compared to the present Nepali standard of 30° south inclined, fixed position, solar PV installations.

Temperature Losses

The cell temperature of the PV array will vary drastically due to ambient conditions such as sun intensity, air temperature, wind speed and other external factors. Most Crystalline-Si PV module have a temperature related power output reduction coefficient of around -0.40%/ºC to -0.45%/ºC of their rated power output, above STC or 25°C.

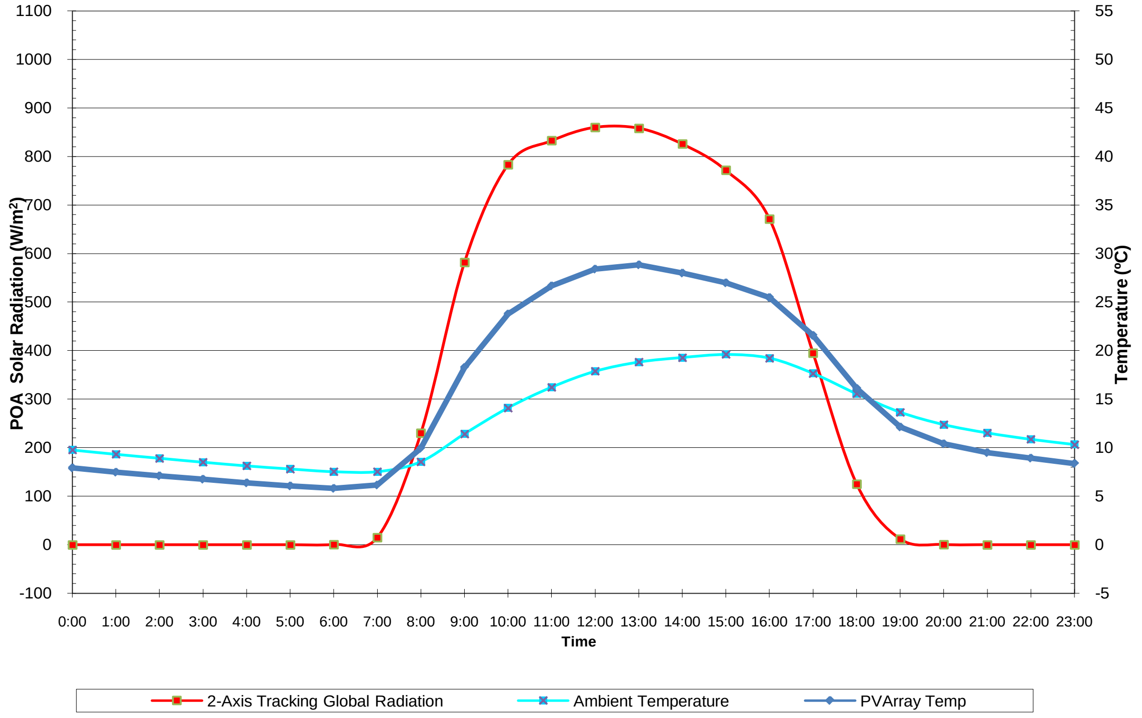

Fig.6: Averaged Daily Global Solar Radiation over the course of the Day Vs Ambient and Solar PV Module Temperatures for the combined years 2006 and 2007

From the graphs in figure 6, the following result emerges:

- The PV solar module temperature exceeds the STC temperature of 25°C on an average from 10:00AM to 4:00PM, or for about 6 hours per day. Thus during the main sunlight hours each day, some small losses, which are induced through increased PV module temperatures have to be considered in the daily energy generation calculation.
- As the solar insolation level increases, the ambient temperature rises with the rise in PV module temperature proportionally. But in the early and later hours of the day, the PV modules' temperatures are even lower than the ambient temperature. That is due to the increased air mass in the morning and later afternoon, enabling less global solar radiation to pass through the earth's atmosphere and reach the solar PV modules and partly due to the design of the 2-axis frame which allows the wind to easily flow through and around the frame to keep the PV modules as cool as possible (see Fig. 3).

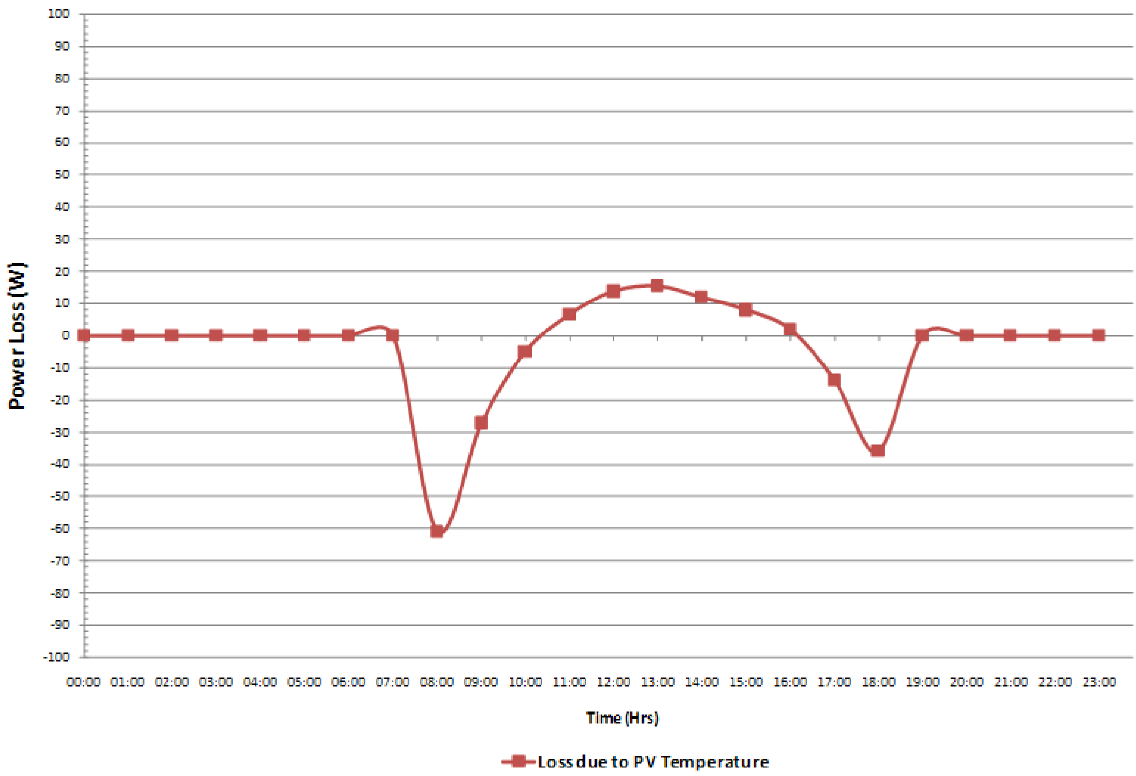

Fig.7: Averaged Daily Solar PV Module Temperature induced Power Generation Variations (Losses and Gains) for the combined years 2006 and 2007

Considering that the average daily sunshine hours are from 8:00AM to 6:00PM and the rated output power of the system is 900Wp (3 systems each with 300Wp), the following findings become apparent from the graph in figure 7:

1. The PV losses are negative for 2 hours in the morning from 8:00AM to 10:00AM and then losses are positive till 4:00PM as the PV module temperature exceeds 25^{o}C. Again after 4:00PM, the losses are negative till 6:00PM. As the graph clearly shows, most of the time during the day the temperature induced losses are very low (PV module >25°C) or at times even negative (PV module

<25°C). This is because the PV system is installed in the cold, high altitude location of Simikot (see Fig. 2). In more temperate or even tropical climates, the power losses due to increased PV module temperature are much greater and thus are often one of the main loss contributors to a solar PV system's non-standard condition performance.

2. In cold areas such as Humla, where the PV module temperatures are often below 25°C throughout the day, especially through the four cold winter months, poly- and mono-crystalline PV modules generate overall more energy compared to amorphous PV modules. Thus, during the shorter winter days, with longer nights, when more energy for lighting is needed, the PV array can generate more power. This is because poly- and mono-crystalline PV modules have in general a greater temperature related power output reduction coefficient compared to amorphous PV modules (often in the range of -0.15%/ºC to -0.25%/ºC) and thus generate more power if operated below 25°C. This important finding, based on the recorded data, shows that it is essential to know and understand the local context for any solar PV system, in order to provide the most appropriate, reliable and cost effective solar PV technology and system design.

3. Poly-/mono-crystalline PV modules are about twice as efficient in converting the received solar radiation into electricity compared to the amorphous PV modules. That is important as all equipment has to be air transported and carried by porters in Humla. Thus weight, which is therefore significant lower for poly-/mono-crystalline PV modules per Wp, plays a notable role.

Battery Losses

The RIDS-Nepal Simikot Office PV system has a battery bank with a total energy storage capacity of 19.2kWh. It consists of 16 flooded lead acid, deep cycle batteries, manufactured in Bangladesh by the company Volta. Each battery has 12V and a capacity of 100Ah (C_{20}). Being a 24 VDC system, the battery bank consists of 2 battery strings of 8 parallel and 2 serial connected batteries. The detailed specifications are as following:

Manufacturer	Volta
Country	Bangladesh
Model	6SB90
Type	Flooded lead acid
Rated voltage [V]	12
Capacity [Ah]	100
C value	C_{20}
Temperature	20°C

Table 3: Technical specification of the batteries used in the RIDS-Nepal Simikot Office

Fig.8: Installed Battery Bank

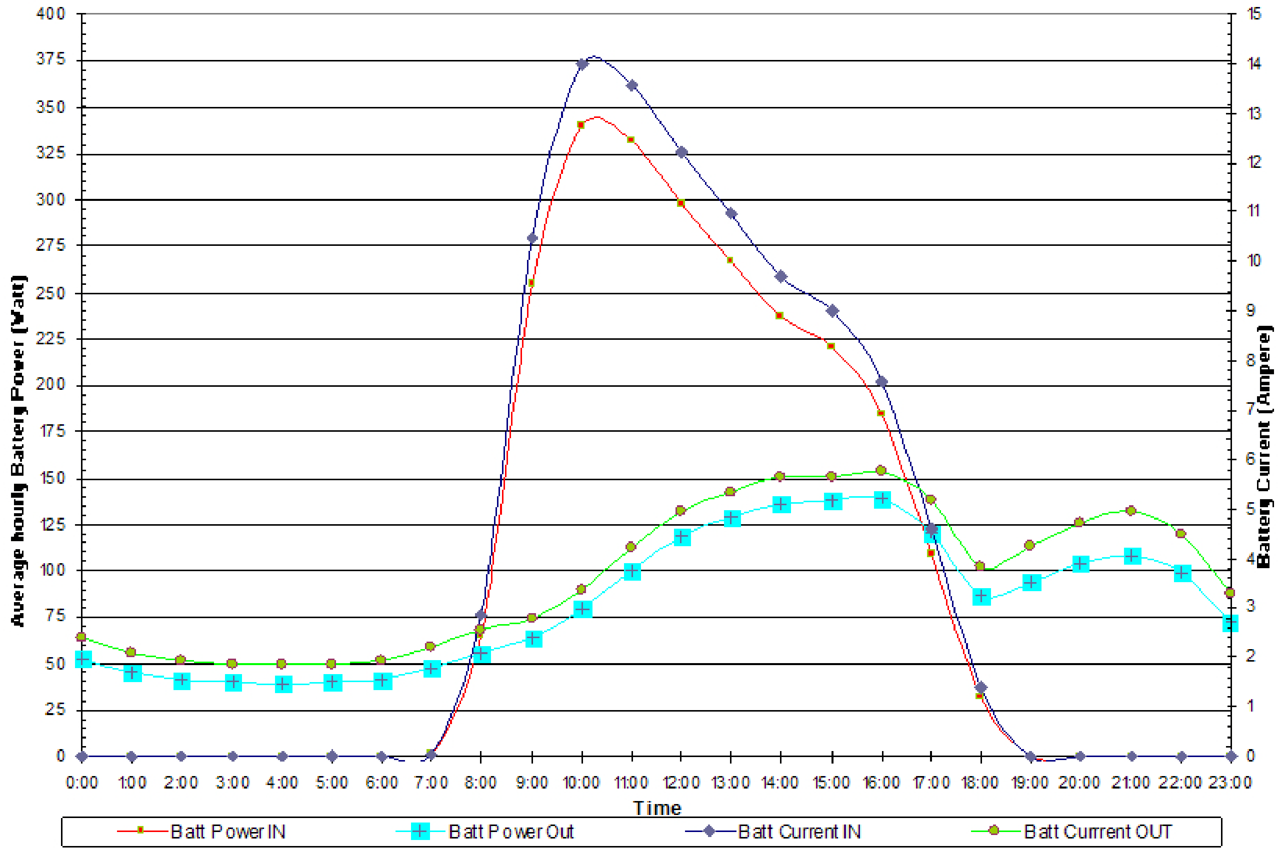

Fig.9: Power In and Out of the Battery Bank for the combined years 2006 and 2007

From the above, averaged hourly graphs, the following findings can be extracted:

1. An average daily energy of 2344Wh is fed into the battery bank while an average daily energy output from the battery bank is recorded with 1992Wh. Hence the battery bank's overall energy input to output efficiency is 85%, with an average daily energy loss of 15%.
2. An average daily current flow of 96.5Ah is going into the battery bank while an average daily current output of 87.05Ah per day is withdrawn from the battery bank. Hence the Coulombic battery efficiency is 90%.
3. The battery power and current graphs show that the evening and night time power demand is significant with over 100 watt between 8:00PM and 9:00PM. Thus in order to provide the peak evening demand as well as the overnight energy demand with an acceptable average daily maximum battery bank DoD of up to 10%, the battery bank needs to be of significant capacity.

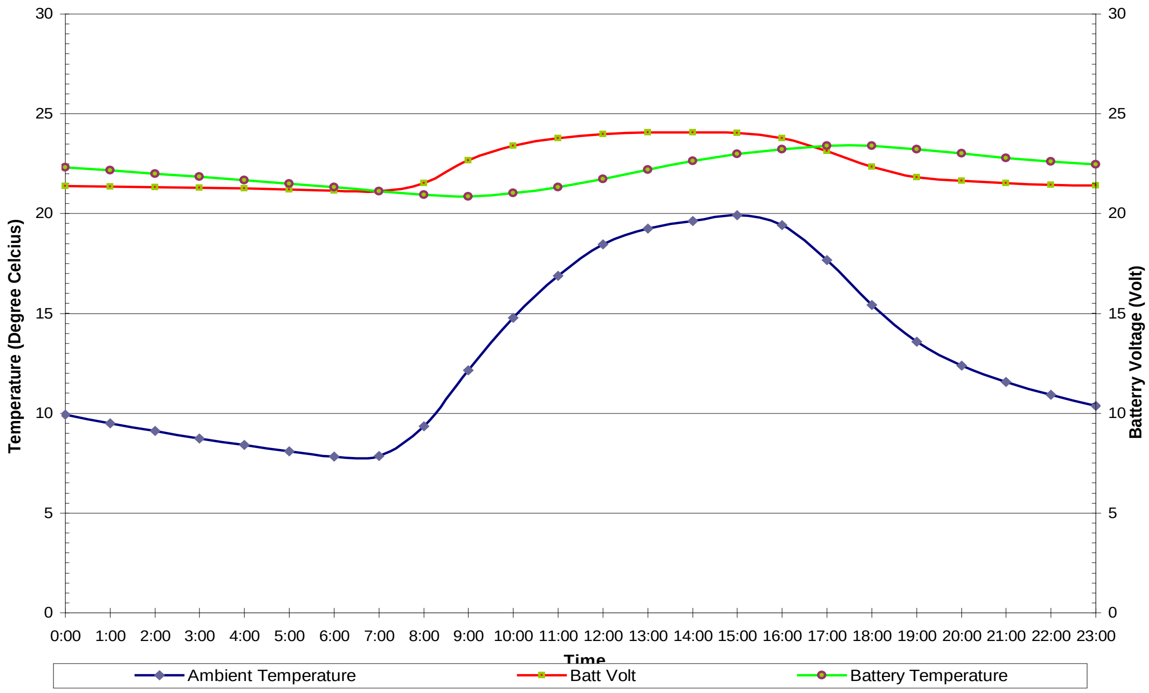

Fig.10: Daily averaged hourly Battery Bank Volt Vs. Temperature for the combined years 2006 and 2007

From the graphs in figure 10 the following can be said:

1. On average the battery bank's voltage over the year was between 22.28V-24.06V, which is not ideal, as the lower battery bank's average voltage rating should not be below 24.00V.
2. A clear daily pattern of the battery bank's voltage can be seen, which is directly related to the daily solar PV array energy generated input and the daily battery bank output, defined by the daily office load demand.
3. Also an unambiguous trend is seen in the battery bank's temperature variations, which is directly related with the chemical process of charging and discharging the battery bank. Higher current input during the day, demanding a faster chemical reaction, increases the battery bank's temperature, while lower current output during the evening and night times, decrease the battery bank's temperature. The gradual raise and decline of the battery bank's daily temperature curve indicates that no significant daily peak load demands occur.
4. While the average ambient temperature was 12.97°C with a minimum of 7.83°C and a maximum of 19.93°C, the average daily battery bank temperature over the year was 22.2°C, with a minimum of 20.86°C and a maximum of 23.4°C. This is within a battery's ideal "comfort" zone, allowing it to perform at its best in regard to energy intake, energy storage and energy output. Further, in order to have a low self-discharge rate, it is crucial for a flooded lead acid battery bank to be kept within the battery's "comfort" temperature range of ~15°C to ~25°C. Thus the battery bank's good performance values achieved in the overall energy and Columbic efficiencies of 85% and 90% respectively.

Array Mismatch

	PhotoWatt PW 750	FEE-20-12
Nominal Peak Power (Pmax)	80.00W	19W
Voltage @ maximum power (Vmpp)	17.30V	16V
Current @ maximum power (Impp)	4.60A	1.18A
Short-circuit current (Isc)	4.75A	1.45A
Open-circuit Voltage (Voc)	21.40V	22.8V

Fig.11: The combination of poly-crystalline PV modules (PhotoWatt PW 750) combined with amorphous PV modules (Free Energy Europe FEE-20-12) results in increased energy generation losses due to solar PV technology, size and brand mismatches.

Fig.12: This amorphous PV Module (three Free Energy Europe FEE-20-12 modules) array's daily energy generation output is strongly affected by daily, long-term partial shading and insufficient free air flow around and through the array.

Mismatch losses are caused by the interconnection of solar cells or modules. Mismatch losses are already induced by connecting several PV modules from the same brand and type and even more losses have to be calculated for, and thus should be avoided, if different PV types, brands of sizes are interconnected with each other. This is because none of the PV modules, not even from the same brand, type or lot have identical performance properties. Thus, the output of the entire solar PV array is determined by the solar cell/module with the lowest output under worst case conditions. Following the common professional practice of not joining different PV technologies, brands and sizes of modules in one array, to include in the design a cell/module mismatch value of 5% for the same PV modules interconnected in an array is standard practice.

Dirt and Dust

Over time, a PV Array will be affected with fine dirt and dust particulates from the prevailing winds or even covered with snow during the several winter months in high altitude places such as in Humla. All these have an effect on the interception of the global and diffuse solar radiation on the surface of the PV modules and thus decreases the array's power generation. The amount of power loss due to these factors depends on the location, season, and types of dust and particulates as well as their frequencies and time of occurrence.

Thus in any solar PV system design such kind of losses have to be considered and kept to a minimum. That is done by surveying the local situation and conditions and bearing in mind that periodical maintenance is needed to keep the losses at their minimum. However, a realistic value for the power/energy loss calculation varies between 2%-5% depending on the local circumstances and occurrences, which have to be identified in the initial survey. In Humla, it is not infrequent that during the 4 winter months from November to February snow covers the solar PV array fully. So the dirt/dust/snow deratting factor of 2%-5% is a conservative estimation.

Figure 14: In Humla, it is not infrequent that during the 4 winter months from November to February snow covers the solar PV array fully.

Cable Sizing

Proper wire sizing is another essential aspect of solar PV system design. It is important to choose the proper sized wires in PV systems to ensure safe operation and to minimise voltage and therefore power losses due to increased resistance and heating up of the cables in the system. There are detailed wire sizes Standards for most countries which have to be strictly adhered to in order to fulfil the local norms.

Three different sized armoured cables are used in the Humla Solar PV system (see Fig 15). They are reinforced with galvanised steel wires and underground buried for additional protection and minimising the losses due to increased temperatures. Their conductor sizes are $4mm^2$, $2.5mm^2$, $1.5mm^2$, respectively. Each of the copper strings, inside and outside, is covered with a PVC layer, providing additional protection. The cables are manufactured in Nepal. According to the manufacturer, the $4mm^2$, 2 strings with 7 copper lids, can carry up to 41 Amps and 1100 Volt, at up to 70°C conducting temperature. It has a maximum resistance of 1.23Ω/km at 20°C. The total outer diameter of the wire is 7 mm including 1mm thick insulation. The cables are 400mm-500mm underground buried.

Fig 15: The three different sized, 4mm^2, 2.5mm^2, 1.5mm^2, armored cables used in the Humla Solar PV systems.

	Length of the wire
PV Array to Battery Bank	Maximum 10m underground buried

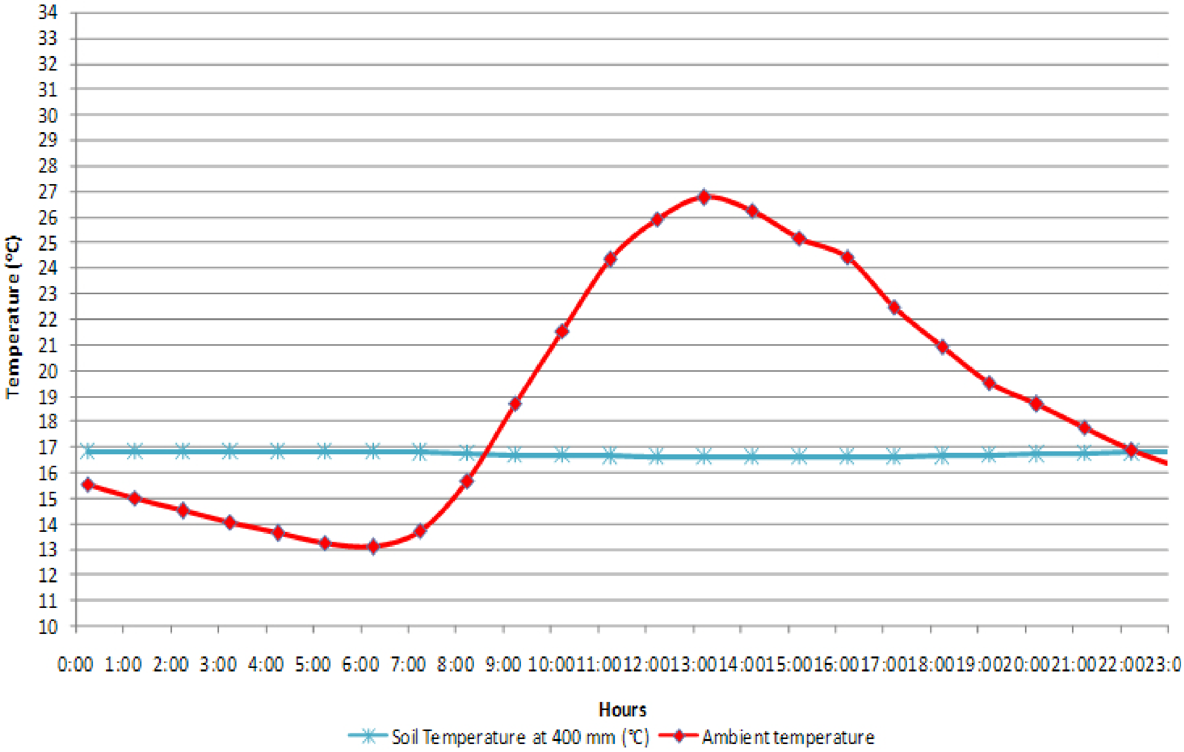

Fig 16: Daily Hourly Average Soil and Ambient Temperatures for March-May 2009

From the graphs in figure 16, the following can be said:

1. On average the soil temperature at 400mm depth remains almost constant at 16.7°C throughout the three months, whereas the ambient temperature has a clear daily pattern with a minimum of 13.6°C and a maximum of 26.75°C.
2. A constant, low temperature of the transmission cables keeps the ampere flow losses at a minimum. Transmission losses are further minimised with an increased system voltage, which is 24VDC in the Humla PV system.
3. Additional, the underground buried cables provide high protection and security for the solar PV system and for people, which is important in a village setting.

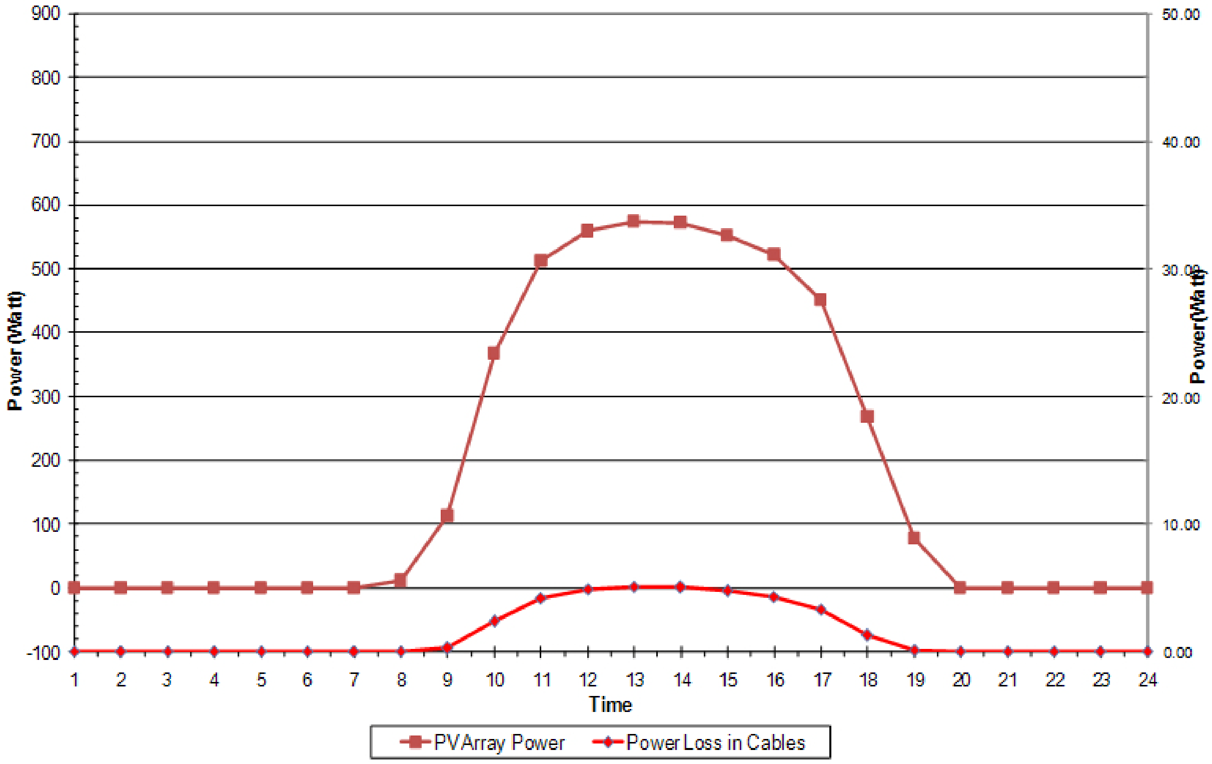

Fig. 17: Daily average solar PV array power Vs Power loss in for the combined years 2006 and 2007

From the graphs in figure 17, the following can be said:

1. Based on the graph in figure 17, the total daily energy loss due to the cables resistance from the PV array to the battery bank, the inverter and the dump load is on an average 35.6Wh, which is about 0.77% of the total daily average PV array energy of 4581Wh generated. The cable's resistance R of 1.23Ω/km at 20°C, was provide by the manufacturer. The cable resistance induced power loss is calculated for 10m length with the formula:

$$\text{Power Loss in Cable} = I^2 \times \text{Resistance(R)}$$

2. As the cable power loss increases with the flowing current in the power of two, the cable resistance induced power losses are much higher during the day time.

3. Considering the average daily energy of 2344Wh fed only into the battery bank, the cable losses account for 12.6Wh, which is about 0.54% of the total energy fed into the battery bank.

Inverter Losses

With the RIDS-Nepal Simikot office being a project office, the needed load is mainly AC. Thus, an inverter (see Fig 17) is used to convert the DC power drawn from the battery bank into AC power for all office equipment. The installed sinusoidal inverter, a Joker from the company Studer in Switzerland, has an AC power capacity of 800W. The following figure provides its main technical specifications.

Type	Joker 802-S (with possible solar charger)
Serial number	MJ02279
Pnom [W]	800 watt constant
Ubatt [VDC]	21-32VDC
Uout [VAC]	230VAC / 50Hz
Power 30 min @ 25 °C	1300VAC
Power 5 sec @ 25 °C	2800VAC
Maximum Efficiency	94%

Fig 18: Joker inverter and its main technical specification

For any solar PV system with an inverter, DC–AC conversion losses have to be included. In the above example, a very efficient, imported inverter is used. While this minimises the losses it adds to the risk of not being able to repair it in case of failure or damage. Thus, it is in most cases preferable to choose locally built inverters. In Nepal the most efficient locally built ones have an efficiency of around 85%. This shows that this significant loss can not be neglected but has to be considered already in the initial design stage. Thus it has to be decided in the initial stages of a project's design between sustainability and local availability, cutting down in efficiency values and price, but increase in local availability and maintainability, or high efficient, and often as well much more expensive, imported equipment.

RESULTS

This paper provides a series of important conclusions regarding the analysis of losses in PV systems:

- The use of a 2-axis PV tracking system results in capturing more energy compared to a fixed angle PV array. The results show a yearly energy generation increase of 56.38% compared to horizontal and 31.47% compared to 30º south inclined systems.

- The solar PV arrays operate more efficiently in cold areas such as Humla, when the solar modules can operate below 25°C. The lower average ambient temperatures and still high average solar insolation help to generate more power in the needed shorter winter months. Mono- and poly-crystalline PV modules generate more energy in the cold season when compared to amorphous PV modules. Additionally the 2-axis tracker design enables air to flow freely through air-flow gaps around the PV modules to keep them as cool as possible.
- The data reveal that the battery bank's energy (Wh In/Out) efficiency is 85% and the Coulombic efficiency (Ah In/Out) is 90%. It shows that maintaining the battery bank temperature through appropriate insulation and air ventilation between 20°C-25°C provides satisfactory results. Further, periodic maintenance (adding distilled water, cleaning of contacts etc.) and a low, daily depth of discharge of maximum 10%, will maximise the battery banks' life expectancy.
- Solar PV arrays suffer from increased mismatch losses due to the use of different solar modules (technologies, brands and sizes), different illumination, shading and dust or dirt. Thus all these factors have to be considered during the survey and designing stage, and need to be minimised for any time of the year.
- Small losses, induced through cable resistance and increased temperature losses have to be calculated in the range of up to 1% of the daily PV array generated energy. In the ground buried cables minimise the temperature induced effect, though the cables and the installation are more costly.
- The losses in the inverter depend on the DC-AC conversion technology used (with transformers or transformer-less), its conversion efficiency (the quality of the equipment and materials used), the current and voltage at the terminals (the higher the current the higher the losses) and the temperature at which the inverter runs (the higher the temperature the higher the losses).

CONCLUSION

Providing electric power to remote, cold regions at high altitude can be an expensive and a technically challenging task. Solar PV systems provide a reliable and cost-effective solution yet their potential is underdeveloped, in part because of a lack of knowledge about their system performance in such regions. This paper identifies the performance of a solar PV system, categorising and evaluating the losses of the system operating in a cold, high altitude climate.

The main lessons learnt from the several year long data recording of the solar PV system at the high altitude RIDS-Nepal office in Humla are:

- Selecting the most appropriate PV module technology for a defined climate and average level of insolation and using only the same kind of PV modules in an array maximises the annual energy yield.

- To insulate the battery bank so that it can be kept within its ideal temperature "comfort" zone of 15°C-25°C, minimises the losses and increases the battery bank's efficiency.
- To limit the daily depth of discharge of the battery bank to ~10% increases the life expectancy of the battery bank.
- Often unexpected high losses are occurring due to dirt/dust/snow covering of the PV modules.
- Inappropriate sized and chosen inverters increase the system losses significantly.
- A professional system design demands that all in the paper discussed and identified parameters which induce losses and thus reduces a solar PV system's performance must be identified through an initial survey of the local context. Considering and integrating these data and information in the initial system design enables a solar PV system to perform later under real conditions more reliable and satisfactory.

The data and experience presented in this paper clearly show that there are huge differences between the PV module manufacturers' performance data, measured at STC and real life conditions. These differences can not be ignored as solar PV systems, once installed, will run most of their life-cycle time under non-standard conditions.

The paper showed and highlighted the major identified losses which have to be considered and accounted for in any solar PV system design, especially for systems for remote and impoverished communities in developing countries, in order to pay justice to professionalism and due respect for those for whom the PV systems are meant for.

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