Impact of Small Decentralized PV Grid-Connected Plants on Load Shedding in Nepal

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Abstract: The current unreliability of the electrical network in Nepal, and the growing needs of users, together with the high level of losses in the electricity distribution grid can be partially resolved by means of a decentralized and partly autonomous electricity supply.

The Nepali grid is characterized by weak stability, frequent accidental powercuts and regular planned load shedding schemes (up to 20 hrs. a day in the dry season), causing particular suffering to SMEs (Small and Medium Enterprises). A feasibility study [1] has demonstrated the cost advantages of a small solar PV grid connected system in combination with a battery back-up, compared to traditional petrol gensets or battery chargers from the grid with stand-alone inverters.

The pilot project foresaw the design, construction and monitoring of 5 grid-connected 1.11 kWp PV plants at three different strategic locations, P1, P2 and P3, in the urban and semi-urban environment of the Kathmandu valley. While four of the PV systems are standard grid connected systems, of which three are installed in "No-Load Shedding Zone" P2 and one in "Load Shedding Zone" P1, the fifth system P3, is installed in a "Load-Shedding Zone", but is designed with a battery bank backup system, and can therefore function as a micro-grid. The setup parameter limit of the grid-connected inverter was adjusted in accordance with the effective situation of the distribution grid (voltage and frequency limits, duration of power cut, etc.). Performance monitoring of the plants started in late 2012. The first 9 months of analysis shows energy generation losses of about 47.6% (475kWh) at P1, due to the load shedding schedule at the time. The performance of the three PV plants at P2, where no load shedding occurs, was as expected, with all generated energy fed into the grid. The 1.11 kWp PV grid-connected plant with a battery backup at P3 in effect performs as a stand-alone system providing enough energy for one household and an NGO office.

Keywords: Small Grid-connected PV System, System Performance, Grid Stability, Grid Integration, Developing Countries.

1. Introduction

The Nepalese national grid is weak, unreliable, undersized and of poor quality. It cannot meet the electricity demand of Kathmandu, the capital of Nepal. In addition to the high electricity distribution losses, the grid cannot keep up with the annual growth demand, which has amounted to of 8-10% annually over the last decade. The government was therefore forced to introduce load shedding in 2001, resulting today in up to 20 hours per day during the dry season with no access to electricity. So it is not surprising that local users and small/medium sized enterprises (SMEs) have been demanding a more reliable, more adequate power supply, in order both to reduce interruptions to family life, and to support their businesses.

A feasibility study [1], carried out in 2009-2010, showed that the present situation could be partially solved through decentralized solar PV roof-top systems. The study showed a cost advantage of a solar PV roof-top grid connected system in combination with a battery back-up, compared to a traditional petrol genset, or a battery charging system, charged from the grid, when available, with a stand-alone inverter.

1.1 Grid Reliability in Nepal

The current unreliability of the electricity network in Nepal, and the growing needs of users (SMEs as well as the population), together with the high level of losses in the electricity distribution grid can be partially resolved by means of a decentralized and partly autonomous electricity supply. In terms of stability, the Nepali grid is weak, unable to meet the load demand and experiences frequent accidental power cuts in addition to the regular, planned seasonal load shedding schemes.

The power supply system of Nepal is suffering from lack of production, forcing the distributor to practice regular load shedding, which can reach up to 20 hrs./day in the dry season, causing particular suffering to SMEs. The problem of load shedding has become drastically more serious since 2005.

The electricity distribution grid presents a very high level of loss (about 26%, of which ~19% in the distribution system, ~ 5% in the transmission system and about 1% in the generation system [2]).

The growth in demand cannot be covered by the production capacity because this capacity has not been developed sufficiently; there are significant losses in the system and insufficient hydro reservoir capacity. Moreover, the current use of a battery-inverter back-up system increases consumption because of system losses (up to 50% of losses), worsening the situation of electricity supply. In comparison, the use of grid-connected PV systems would provide additional energy to the grid and consumers and therefore limit the necessity for load shedding, which causes severe socio-economic damage to Nepal.

1.2 Main Obstacles to Decentralized Small PV Systems

In order to deploy small, decentralized PV systems throughout the country it is necessary to address the main obstacles that hinder the wider dissemination of solar PV grid connected systems in Nepal. The main impediments are: no legal framework (policies, subsidies or feed-in-tariffs in place), the technical features of the grid (voltage and frequency fluctuation out the limits, frequent interruptions, flickers, etc), economic viability, lack of public awareness and trained professionals.

Technical obstacles refer to the grid instability and poor grid quality characteristics, where the standard limits are often exceeded. In addition to the diffused load shedding schemes (up to 20 [hrs/day] of electricity cuts), frequent short blackouts can create problems in the operation of electronic equipment (PV inverters and chargers). The inability to purchase appropriate inverters locally (PV grid-connected and bidirectional battery inverters for mini-grid purpose) can slow down the deployment of this technology.

Economically, the high initial investment costs represent a considerable obstacle, together with the need to develop specific markets (appropriate inverters and PV modules) and import channels. Despite recent decreases in the price of PV systems, PVGC systems remain affordable only for the middle upper class.

Institutionally, the current legal context does not yet allow the grid connection of PV systems and would need to be adapted, as would existing standards and norms, and finally the policy and decision makers are not yet aware of the potential and advantages, for Nepal, of grid-connected PV technology; they need clear evidence of its appropriateness in order to support its development.

Solar Home Systems (SHS) are very common in rural and urban Nepal. Many companies are installing stand-alone systems all over the country, particularly in rural areas. The Alternative Energy Promotion Centre (AEPC) organizes training courses on stand-alone systems, but solar PV companies do not have the knowledge or skilled professionals required in order to design, install and maintain grid-connected solar PV systems or mini-grid systems. Therefore, in addition to the five pilot PV grid-connected plants installed and monitored, the project also includes training activities. Furthermore, an important part of the project is the specially designed web site, which aims to demonstrate and disseminate the technologies used (http://pvnepal.supsi.ch/howitworks/), and the performances of the five plants by means of a live performance data site (http://pvnepal.supsi.ch/livedata.php).

1.3 Project Partners

In order to include all the stakeholders and line agencies in the solar PV sector in Nepal, the project set out with partnerships with the Government, academia, the solar PV business community. The project therefore includes the participation of Nepal Electricity Authority (NEA) and Alternative Energy Promotion Centre (AEPC) from the Government side, with the main project implementing partners, the University of Applied Sciences and Arts of Southern Switzerland (SUPSI), Rural Integrated Development Services (RIDS-Nepal) as the local NGO, the Centre of Energy Studies (CES) of Tribhuvan University (TU), the Nepal Solar Energy Society (NSES) and Gham Power, a local, Kathmandu based solar PV company.

2. Methodology and Approach

2.1 PV Systems Layout and Real Time Monitoring

Five 1.11 kWp solar PV grid-connected systems were installed between October and December 2102 in the Kathmandu Valley in three different, urban, locations.

At the CES (Centre of Energy Study) Pulchowk Engineering Campus of Tribhuvan University, Nepal's first Government University, a standard grid-connected 1.11 kWp PV plant, P1, was installed. This location is subjected to the regular planned load shedding schedule, reaching up to 20 hours per day with no grid power supply during the dry season.

Figure 1: standard grid-connected 1.1 kWp PV plant at the CES (Centre of Energy Study) Pulchowk Engineering Campus of Tribhuvan University, Nepal's first Government University (P1)

At the NEA (Nepal Energy Authority) Min Bhawan office three equal, standard grid-connected 1.11 kWp PV systems (together called Plant P2) were installed and connected to the grid. This location experiences no load shedding and thus is considered as the reference location for the project. In particular, this setup allows the measurement of the energy output, under the climatic conditions of Kathmandu, without the hassles of electrical network found elsewhere. Three different grid connected inverters were installed to compare their performances.

Figure 2: three 1.1 kWp PV systems were installed and connected to the grid at the NEA (Nepal Energy Authority) Min Bhawan office (P2)

In the third location, P3, in Imadol, Lalitpur district, in the outskirts of the main urbanized, densely populated city area, a 1.11 kWp solar PV grid-connected system, with a battery bank as back-up system, was installed, since this building also experiences the enforced daily load shedding. It is positioned on the roof of the NGO RIDS-Nepal office, providing electricity to the NGO and to a private household when load shedding take place. The building itself is connected to the grid at a considerable distance away from a transformer.

Figure 3: 1.1 kWp PV system with a back-up battery at the main head office of RIDS-Nepal in Imadol, Lalitpur district (P3)

The setup parameters of all the 5 inverters in the three locations were chosen so that the energy fed into the grid is maximized, limiting the interruptions due to poor grid quality, but without compromising the security of the grid system at any given time.

The load profiles in P1 and P2 are defined only by internal power supply for internet communications, monitoring system and its back-up system.

All five grid connected solar PV system parameters are monitored in great detail (in 10 minute values), with their hourly average performance values updated live on our specifically designed SEPV Nepal website (http://pvnepal.supsi.ch/livedata.php), available for registered users.

3. Results

At the CES (P1) solar PV system location, 46% of the time during sunshine hours, when energy could have been generated, the grid was not available in January and February 2013. Thus, potential energy generation corresponding to 54% of the total potential solar energy converted electricity was lost due to load shedding.

In the third location in Lalitpur district, the 1.11 kWp solar PV grid-connected plant with battery backup is still performing as a stand-alone RAPS (Remote Area Power Supply) system, since NEA permission to connect it to the grid was not granted until the end of February 2013. However, as it has been designed as a RAPS system with battery bank back-up, it provides the NGO RIDS-Nepal and one household with their daily electricity requirements during the daily enforced load shedding periods.

All five grid connected solar PV system parameters are monitored in great detail, with their hourly value life updated on our specifically designed SEPV Nepal website(http://pvnepal.supsi.ch/livedata.php), available for registered users. The paper will discuss the detailed operation of each of the three site specific solar PV grid connected systems over their first 6 months of energy generation. It will highlight the individual performances of the systems in terms of energy conversion, efficiencies, induced losses, as well as the performances and energy conversion efficiencies of the three different grid connected inverters, by means of diagrams, pictures and live data.

3.1 Load Shedding Conditions and Grid System Losses

The country is currently passing through a severe energy crisis. Each year, load shedding is increasing [2].

NEA had predicted resorting to a maximum of 18 hours of load shedding per day per consumer during the driest months of January to April 2013. However, they succeeded in restricting the load shedding hours to an avg. 12 hrs/day per consumer, with peaks of up to 20hrs/day.

A new Nepal Load shedding schedule is announced every week for the 7 regions. There are two load shedding events per day.

Table 1: Load shedding and blackout events in P1 & P2.

Main param.	Time without grid	Load shedding cut events	Short power cut events
P1 (during no load shedding)	38%	524	71
P2, SMA	1.1%	0	40
P2, Samil	1.1%	0	40
P2, Fronius	1.1%	0	40

Between February 2013 and September 2013 595 blackout events were recorded in P1 (Table 1). Two planned outages typically occur every day and we can estimate 524 planned load shedding events. There were also 71 other short events.

In P2 only 40 events occurred during the whole period of observation, corresponding to 1.1 % of the time. Therefore P2 can be considered the reference location for evaluating Energy production.

According to the NEA 2012 Annual Report [2], System losses are as high as 26.4% of the total consumption. This figure includes technical and non-technical losses, where the proportion of non-technical losses is quite high. Strict measures for electricity theft control are also taken, such as confiscation of electrical equipment and legal action against culprits. In the last fiscal year the NEA was able to reduce system losses by around 2%.

3.2 Grid Measurements

The Nepali grid is characterized by weak stability, frequent accidental power cuts and regular planned load shedding schemes (up to 20 hrs. in the dry season), and SMEs in particular suffer from this situation. Distribution lines are also often overloaded. An analysis of changes in the voltage and frequency of the power grid has made it possible to define the inverter setting parameters.

Table 2 shows the values for average frequency and mean and maximum voltage; periods without outage (P1 and P2) or when P3 was connected as a mini-grid, were the only periods considered.

Table 2: frequency and voltage limits in the three locations (P1, P2, P3).

Main param.	Mean f [Hz]	Mean Volt. [V]	Max Volt. [V]
P1 (during no load shedding)	49.84	226.1	245.8
P2, SMA	49.33	215.6	238.4
P2, Samil	49.33	217.6	238.2
P2, Fronius	49.33	215.2	237.2
P3 (as mini-grid)	50.0	218.4	226.1

Mean frequency values are critical for normal inverter reconnection parameters (P1 and P2). The frequency at P3 is defined by the mini-grid inverter, and is thus precisely 50.0 Hz.

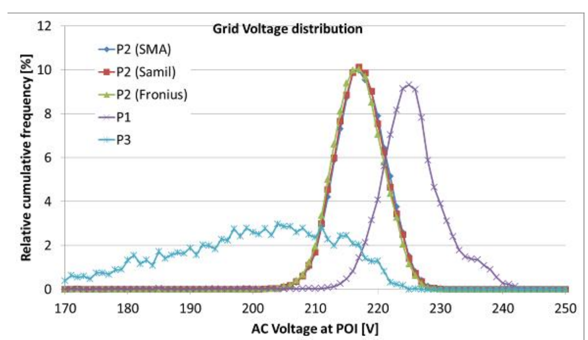

Figure 4: Grid voltage distribution in the three locations (P1, P2, P3)

Figure 4 shows the relative cumulative voltage distribution. In P2, the reference location in the NEA Min Bhawan Office, the voltage remains very stable with an average of 217.3V (standard voltage: 220V). The installation is located near three HV-MV and MV-LV transformers, so the line losses and voltage drops are very limited.

P1 is located in the Pulchowk University Campus in the middle of the city of Kathmandu, where an MV-LV transformer provides energy to the buildings and laboratories. The distribution voltage in P1 is therefore similar to that recorded in the P2 location, but shifted to an higher level (avg. 226.1V).

The situation of distribution voltages in P3 is quite problematic. It was not possible to fully connect the mini-grid system (with backup) to the grid because of lack of NEA permission. It was only possible to connect the system for 37 days, for research purposes. P3 is located in the outskirts of the main, densely populated, urbanized city area, far away from the MV-LV transformer. This results in significant voltage losses at peak user times, when the voltage can drop to 170 Volt AC. The injection of only 1kW peak power has no relevant impact on improving the poor conditions of the line voltage grid.

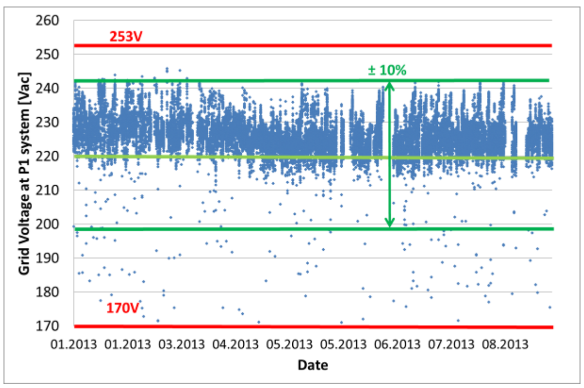

Figure 5: Grid voltage variation during the selected period of analysis of the P1 PV system, at POI

Figure 5 shows the voltage variability at point of injection (POI) in the P1 location, and the setting limits defined in the inverter parameters (170V to 252V). The frequent voltage reductions caused by the planned and unplanned blackouts can be seen clearly.

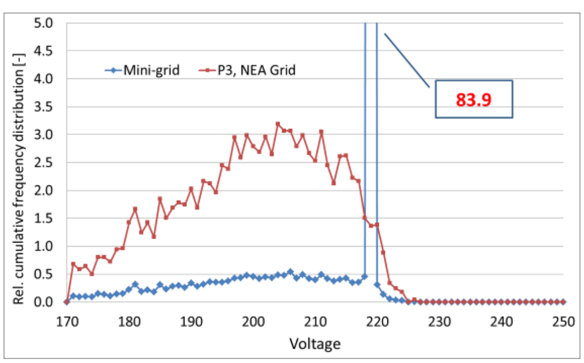

Figure 6: Relative frequency distribution of voltage at the P3 power plant operating in grid connected mode (red) and with Mini-grid mode (Blue)

The distribution of AC voltage at the P3 power plant during the period of analysis (1.2.2013-24.09.2013), illustrated in Figure 6 in red, is fixed at 220V for most of the time, because of the inverter output voltage regulation during Mini-grid mode. In Grid-connected mode (Figure 6 in blue), the voltage is very irregular and varies typically from 170 to 225V.

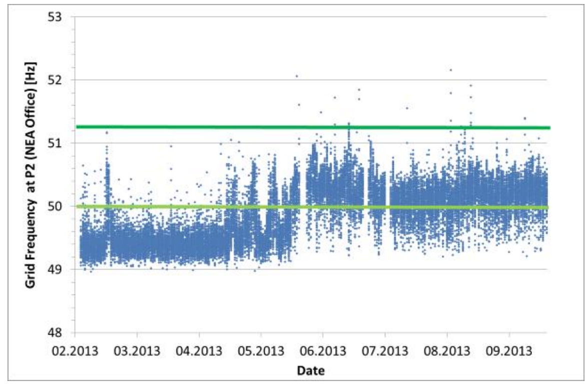

Figure 7: Grid frequency at reference location P2.

The Frequency ranges from 48.5 Hz to 52.1 Hz (Figure 7). The frequency in the systems under consideration remained within the limits of the standard range. However, the frequency can remain at low or high levels for weeks, preventing inverters with normal settings from connecting to the grid, so the upper reconnection frequency limit has been set at 51.25Hz, and the lower reconnection limit at 47.25Hz.

3.3 Inverter Setup for Poor and Fluctuating Grid Conditions

With the national grid mean Frequency of 49.37 Hz (with a Frequency range between 48.5 Hz to 52.1 Hz), and a voltage range between 170 V and 255 V, the set-up parameters of all five grid connected inverters had to be adjusted in order to accommodate these enormous fluctuations while still being able to feed into the national grid.

New inverter new settings for Nepal grid conditions:

- *Maximum voltage:* *253 V*
- *Minimum voltage:* *170 V*
- *Lower max threshold:* *+ 1.25 Hz (51.25 Hz)*
- *Upper min threshold:* *- 2.24 Hz (47.75 Hz)*
- *Lower min threshold:* *- 2.49 Hz (47.50 Hz)*
- *Reconnection delay:* *15 s*

The other inverter parameter settings must also be considered. In particular, the P/f function (reduction in active power vs. frequency) should be disabled.

3.4 *Energy Production without Load Shedding (P2)*

After adjusting the input and output parameters of the three inverters in order to accommodate the weak grid quality, the three PV systems performed rather well, with average monthly performance ratios of between 80-90% (Table 3).

The differences between the three PV systems are mainly due to the performances of the grid-inverters, and amount to only 2.3%.

Table 3: Monthly irradiation, energy production, final ac yield and PR from 1.2.2013 to 24.09.2013* of the three systems in the NEA Min Bhawan Office.

2013	Irradiation Hi [kWh/m2]	PV1 (SMA) Energy ac [kWh]	Yf-day ac [kWh/kW/day]	Monthly PR ac [-]	PV2 (Samil) Energy ac [kWh]	Yf-day ac [kWh/kW/day]	Monthly PR ac [-]	PV3 (Fronius) Energy ac [kWh]	Yf-day ac [kWh/kW/day]	Monthly PR ac [-]
February	128.5	126.4	4.07	98.3%	129.9	4.18	101.0%	127.6	4.10	99.2%
March	171.6	145.5	4.68	84.8%	152.7	4.44	89.0%	146.2	4.25	85.2%
April	152.9	131.8	4.24	86.2%	134.5	4.04	87.9%	133.5	4.01	87.3%
May	138.9	105.4	3.39	75.9%	88.5	3.62	63.7%	110.1	4.51	79.3%
June	124.8	94.2	3.03	75.5%	100.4	4.11	80.5%	96.0	3.93	76.9%
July	127.9	101.0	3.25	79.0%	106.4	4.36	83.2%	102.2	4.18	79.9%
August	149.7	121.6	3.91	81.3%	128.0	5.24	85.5%	123.6	5.06	82.6%
September*	123.3	106.9	3.44	86.7%	114.2	4.68	92.6%	110.3	4.52	89.5%
TOTAL	**1'117.6**	**932.8**	**3.75**	**83.5%**	**954.62**	**4.33**	**85.4%**	**949.46**	**4.32**	**85.0%**

The irradiation during the period was 22% lower than the meteorological data analyzed in 2010 [1], and the Final Yields (Yf) are therefore 20% lower than expected. The PR is very high, however, thanks to the use of inverters with high performance at high irradiation.

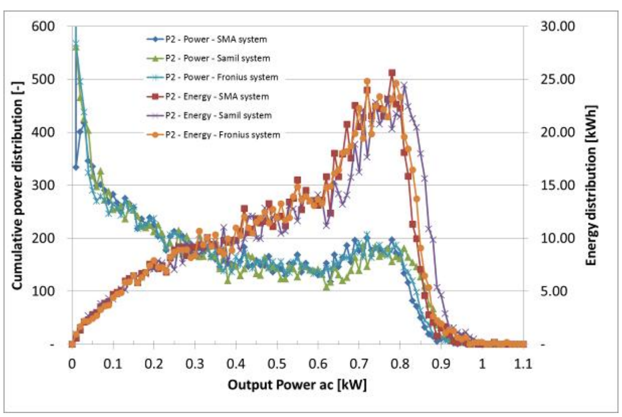

Figure 8: Power and energy distribution at the P2 Nepal reference location in the NEA Min Bhawan Office, Kathmandu

The power distribution reflects the local climatic conditions (Figure 8); as expected, the irradiance level is very high in the Kathmandu area, despite the fact that the analysis period includes the monsoon months. The energy distribution is therefore high, amounting to between 0.6 and 0.9 kW of the power level, corresponding to between 700 and 1000 W/m2 of the irradiance level.

Table 4: summary of the Energy production, Final yields, load shedding losses and Performance Ratios of the five PVGC systems in Kathmandu

Period: 1.2.2013 – 24.09.2013	Edc [kWh]	Eac [kWh]	Yf-ac [kWh/kWp]	Load shedding Losses [kWh]	Load shedding Losses [%]	PR [-]
P1	669.5	524.1	472.1	475.4	47.6	51.3
P2, SMA	1028.2	932.8	840.4	14.0	1.5	75.2
P2, Samil	1021.8	954.6	860.0	13.5	1.4	77.0
P2, Fronius	1310.3	949.5	855.4	14.5	1.5	76.5
P3 (as mini-grid)	879.8	806.8	726.8	-	-	61.6

Table 4 summarizes the values for energy production during nine months of operation, the Final Yields and Performance Ratios of the five PV plants connected to the grid. The losses caused by the planned load sheddings amount to 47.6% of production at the P1, while in P2 the losses caused by unplanned outages correspond to only 1.5% of the 9 months energy production.

3.5 *Energy Production in a Load Shedding Context (P1)*

The CES (P1) PVGC system has no storage system and can supply energy only during normal operation. From 1.1.2013 to 24.09.2013, there were 596 power outage events (524 load shedding events and 71 other short blackout events).

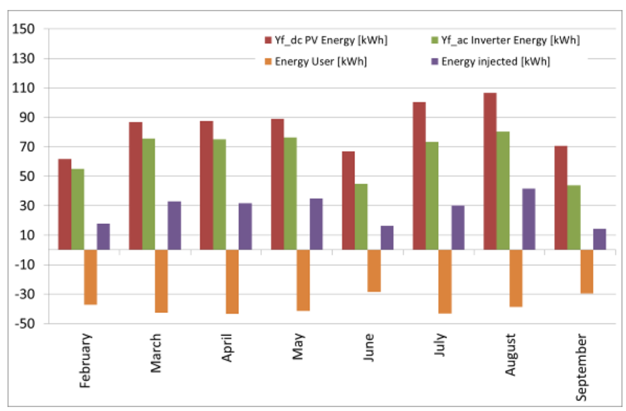

Figure 9: dc final yield, ac final yield, losses during load shedding events, energy used and energy injected into the grid in location P1, CES/IOE Tribhuvan University, Kathmandu, Nepal

These blackouts correspond to 38% of the time period, and generated 47.6% of losses (475kWh) in the injection into the NEA electrical grid (Figure 9). Storage systems are necessary if the supply conditions do not improve.

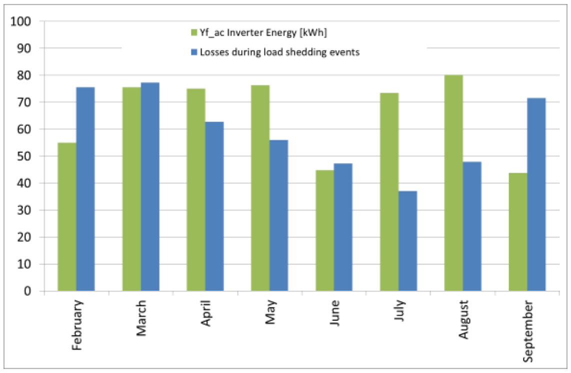

Figure 10: Energy production (Yf_ac final yield) and calculated losses during load shedding events; location P1

Figure 10 shows the substantial energy losses resulting from the load shedding events. In particular, during the months of February, March, June and September 2013, the calculated production losses exceeded the effective real production (> 50%).

3.6 Energy Production with Load Shedding and Battery Back-up (P3)

Table 5 shows the irradiation values (Hi) used in simulations, and the simulated results (PR_sim) compared to actual production levels and PRs.

Table 5: Irradiation Hi, energy production (dc and ac), daily final yield and PR (ac) from 01.02.2013 to 24.09.2013 (location P3), compared to previous simulated values Hi (sim) and PR (sim)

2013	Hi sim	PR sim	Irradiation Hi [kWh/m2]	Energy dc [kWh]	Energy ac [kWh]	Yf-day ac [kWh/kW]	Monthly PR ac [-]
January	140	76.9%					
February	145	74.6%	144.0	117.4	110.3	3.55	76.6%
March	186	72.9%	189.1	139.5	124.0	3.99	65.6%
April	204	69.8%	171.9	131.2	121.5	3.91	70.7%
May	213	69.6%	146.9	108.0	99.9	3.21	68.0%
June	175	70.5%	127.4	89.8	80.6	2.59	63.2%
July	149	71.8%	126.8	96.7	89.1	2.87	70.3%
August	147	72.1%	141.6	102.5	94.4	3.04	66.7%
September	146	72.3%	133.0	94.7	87.1	2.80	65.5%
October	163	72.2%					
November	142	74.0%					
December	140	75.9%					
TOTAL	1'950.0		1'180.7	879.8	806.8	3.08	68.3%

till 24.9.2013

Although the system in Imadol, Lalitpur district (P3) was connected in mini-grid mode for most of the observation period, the installation performed very well. The PR ranges between 63.2% and 76.6%.

3.7 Cost of a Small PV Grid-Connected System in Nepal

In a previous Feasibility Study [1] conducted in 2009, the cost of a PV system (17.5 NPR/kWh) was higher than the actual cost.

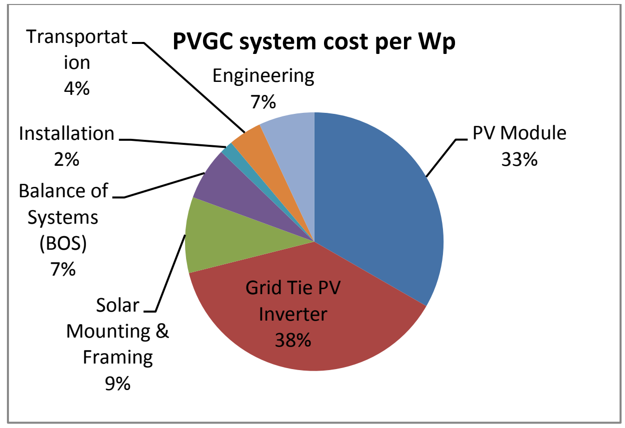

Figure 11: Cost per Wp of a PVGC system in Kathmandu, Nepal

The total cost of a 1.1kWp PVGC system was 11, and today it would cost 324 NPR/Wp (2.4 €/Wp). With a reliable power grid (without load shedding), the annual energy production would reach 1725kWh, and the cost of the energy produced would therefore correspond to 12.5 NPR/kWh (9.25c€/kWh); calculation conditions: no loan, investment paid in cash, VAT included, 25 years of operation, 2%/year O&M (Operation and Maintenance). It should be noted that the cost of the final energy always depends on the O&M activities (2%/year in 25 years correspond to 1/3 of the energy cost).

There is still no market for grid inverters at present, so their cost is high. Costs are expected to decrease substantially in the future.

In the past the common understanding that PV systems are expensive was due to the high initial investment cost. However, in terms of energy costs, PV systems are very economical when compared to other alternatives, because of the long lifespan of the technology (>25 years).

Compared to the current tariff rate for the middle-upper class population, where energy consumption exceeds 250kWh, the cost of PV solar energy is near the level of grid-parity, 12.5 NPR/kWh, compared to 11.0 NPR/kWh. However, after NEA Fiscal Year 2011/2012, the energy tariff increased 20% on average [2].

3.7 Legal Framework and Policies for solar PVGC Power Injection

As yet there is no legal framework or government approved policy for solar PVGC power injection, in either the low voltage or high voltage transmission lines owned by NEA. However, existing regulations allow entrepreneurs to inject micro-hydro based power into the 11 kV NEA transmission line, provided the injection power is no lower than 100 kW. Most micro-hydro power stations are installed in remote areas of Nepal, generally with installed capacities of lower than 100 kW.

A recent exception to this general rule, and the first of its kind in Nepal, is a 680 kWp PV power station, installed in Kathmandu by means of a Japanese Government funded project, and connected to the NEA 11 kV transmission line.

NEA has a plan to connect a 100 kWp PV power station, to be installed at its training center in Kharipati near Kathmandu, to the NEA grid, with the assistance of Asian Development Bank.

There could be significant power injection from 1 to 10 kWp PV roof top systems in urban areas such as Kathmandu. For this to happen, a legal framework must be formulated as soon as possible. The findings of the ongoing research at the three locations (P1, P2 and P3) will definitely help stakeholders in formulating the required policy. The following factors should be considered while formulating this policy:

- the power of PVGC systems installed at roof top level in urban areas should not be less than 1 kWp;
- power injection accounting will be based on annual net metering basis only;
- roof top systems, including all accessories, should be installed as per the guidelines of the Government of Nepal Alternative Energy Promotion Center, and
- incentives of some form (such as tax rebates) should be offered to owners of PVGC roof top systems.

The fact that solar PV grid-connected systems are still generally unknown to most of the institutions and politicians in Nepal makes it difficult for policy and decision makers to have confidence in the capacity of this technology to potentially help improve the availability of electricity. This project aims to highlight the appropriateness of photovoltaic technology in the Nepalese context.

3.8 Training and Dissemination

Solar Home System (SHS) are very common in Nepalese rural and urban contexts. Many companies are installing stand-alone systems throughout the country. The Alternative Energy Promotion Centre (AEPC) organizes training courses on stand-alone systems, but professional companies do not know about grid-connected systems. So in November 2012 a seminar on ‘PV Grid-connected systems’, with 60 participants, was conducted at Tribhuvan University in Kathmandu (Figure 12). It was attended by many students and engineers from solar companies wishing to enter the future grid-connected solar market.

Figure 12: Training course on PV Grid Connected Systems, November 2012, Tribhuvan University, Kathmandu, Nepal

Increasing the local knowhow through specific training programs and using the pilot plants as a demonstration field, helped the main local stakeholders to gain confidence in grid-connected PV technology. In the early stages of the project it was crucial to involve all the main local stakeholders: universities and schools, government, power utilities and interested local businesses.

4. Conclusions

- Five 1.1kWp PV grid-connected systems were installed in the Kathmandu urban area. They have been operating safely for 1 year.
- The voltage and frequency of the Nepali grid vary considerably, so the inverter settings were adjusted accordingly. New inverter settings: V limits = 170 -253 Vac; frequency reconnection limits: 51.25 - 47.5 Hz; delay = 15s.
- The CES (P1) PVGC system has no storage system and can supply energy only during normal operation. From 1.1.2013 to 24.09.2013 there were 596 power outage events (524 load shedding events and 71 other short blackout events). These blackouts correspond to 38% of the time period, and generated 47.6% of losses (475kWh) in the injection into the NEA electrical grid. Storage systems are necessary if the supply conditions do not improve.
- The energy production was as high as expected, comparable to the irradiation level. During these 7 months of first analysis, the irradiation level was 22% lower than NASA meteorological data .
- PRs were slightly higher than expected in the three reference PV systems at the NEA Office (P2).

Short blackout events had little impact on energy production (-1.5%).

- The performance Ratio of P1 was only 51.3% due to the critical load shedding situation. P3 is not yet connected to the grid (no NEA permission) but the storage system makes it possible to increase overall performance by up to 61.6%.
- A small distributed grid-connected system of up to 50MW can be installed in a very short period in the Kathmandu Valley context and would help to improve the energy availability in the country.
- The short-term potential of small rooftop systems across Nepal is greater than 100MW, and a program of 100,000 small solar roofs could be launched. In order to do this, solar energy feed-in must be permitted.
- As yet there is no legal framework or government approved policy for solar PVGC power injection. There could be significant power injection from 1 to 10 kWp PV roof top systems in urban areas such as in Kathmandu.
- In 2012 a seminar on ‘PV Grid-connected systems’, with 60 participants, was conducted at Tribhuvan University. It was attended by many engineers from solar companies wishing to enter the future PVGC solar market.

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