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Pico PV in Peru

Laboratory tests of eleven different LED lamps for Pico PV Systems

Manfred Horn
National Engineering University
Av. Tupac Amaru 260, Rimac, Lima, Peru
Tel: 00511-999283537, Fax: 00511-4810824
mhorn@uni.edu.pe
http://fc.uni.edu-pe/mhorn

Abstract

In the frame of a project of the Peruvian Government, supported by EnDeV/GIZ, to install 50 000 Pico PV systems in remote rural regions, eleven different LED lamps used in Pico Solar Home Systems were evaluated in a laboratory test, with the objective to select the lamps with the best laboratory performance in order to make then a field test with these selected lamps, before, finally, implementing the main project. The result of this laboratory test, showing a wide range of qualities and characteristics of Pico PV LED lamps, is presented in this paper.

Why Pico PV in Peru?

20 % of the Peruvian population has no electricity at their home. These six million people live mostly in rural regions, far away from the public electricity grid and to connect one house in these regions to the grid costs today in the average more then US$ 1500, with a tendency to increase as the remaining families without electricity live more and more far away from the grid.

On the other side, roughly one third of the Peruvian grid connected households consume monthly below 30 kWh, with an average of 12 kWh/month. (according to OSINERG report 2007: About one third of Peruvian hoseholds consume above 100 kWh/month of electricity and one third, 31 – 100 kWh/month). Rural families with grid connection are mostly in the range of en electricity consumption of about 12 kWh/month, or less. The main use of this electricity is for illumination, using typically incandescent bulbs of 50 – 100 W, and to a minor degree is for telecommunication (radio, b/w TV, cell-phones). As incandescent light bulbs have an efficacy of about 11 lm/W, with 10 kWh/month and using light bulbs, one gets a luminous energy of 110 klmh/month. As modern LED lamps have an luminous efficacy of 110 lm/W (see below), this luminous energy of 110 klmh/month can be obtained with 4 LED lamps of 2 W each lighting 4 -5 hours each day and consuming 1 kWh/month of electricity, that can be obtained with a solar PV panel of 5 -10 Wp, depending on the local climate (In the Andean region a 5 Wp panel is sufficient.) Therefore a Pico PV system consisting of a 5 – 10 Wp Solar PV panel and 4 LED lamps of 2 W each can produce practically the same benefits as the benefits people in rural areas of Peru get from a grid connection. Adding the recent development of more efficient and more durable batteries to store electricity, mainly of the type Li-Ion, and of more efficient and cheaper PV panels, one can reasonably assume that Pico PV systems are a real alternative to satisfy the basic needs for electricity of rural people living in remote regions of Peru at quite lower costs as a grid connection and (hopefully) better sustainability.

Based on these arguments the Peruvian Government started in 2010 a pilot project with the goal to install 50 000 Pico PV systems in remote rural areas. As a first step of this project, and with support of EnDeV – GIZ, the Photometry Laboratory of the National Engineering University in Lima evaluated 11 different LED lamps used in Pico PV systems. The objective of the test was to select the lamps with the best laboratory performance in order to make then a field test with these selected lamps with 100 – 200 families, before, finally, implementing the main project. In the following the results of these tests are presented.

Laboratory test results

The following 11 commercial lamps were evaluated:

A. Power Mundo / Nova (portable)
B. Phocos (portable)
C. Cosmos (portable)
D. Sundaya / Phaesun (fix installation)
E. Fosera 4200 (fix installation)
F. Fosera 7000 (fix installation)
G. Suntransfer 2 (portable)
H. Suntransfer 10 (fix installation)
I. Barefoot - Firefly 12 (table lamp)
J. Barefoot (fix installation)
K. Barefoot portable

The evaluated lamps have different physical configurations and different types of LEDs (high and low power LEDs) and batteries (gel lead, NiMH and Li-ion). Different parameters were measured and evaluated, being the most important:

- Luminous flux , spectrum, color temperature, color rendering coefficient, using a integrating sphere spectrophotometer
- Time (hours) the lamps stay turned on with initially fully charged batteries and luminous flux decrease during that time

- Capacity of battery (in Ah and Wh) and DOD
- Power consumption and luminous efficacy (lm/W)
- Achievable illumination (in lux) on a working table of 1 m^2.

For the photometric measurements a spectrophotometer with integrating sphere was used, getting luminous flux measurements with an error of less then 3% and electrical measurements with an error of less then 0,1%. The results of these measurements are resumed in Table 1 and Table 2.

In Table 1 are resumed the results of the evaluation of the batteries: The column "Intensity" indicates, if applicable, the different steps of luminous intensities that can be chosen with most lamps. The values of the measured capacities given in column 1 (in Ah) and 3 (in Wh) refer to the whole charge and energy stored in the batteries, not only the charge and energy that is consumed till the electronic circuit disconnects the lamps from the batteries. Columns 5 and 6 give the efficiency of the batteries (charge that can be extracted / charge necessary to recharge the battery). The DOD (depth of discharge) in column 7 indicates the percentage of the total electrical charge of the battery that is withdrawn until the electronics disconnects the LED lamp. The DOD of 60 % of lamp A indicates a good protection against deep discharges of the lead battery (SLS = sealed lead battery), whereas the high DOD of the batteries G, H and J, that are also lead batteries, will result in a shortened lifetime of these batteries. On the other side, the high values of the DOD of the batteries B, C, D, E, F, I and K are reasonable for the kind of batteries used in these lamps (Li-Ion and Ni-MH).

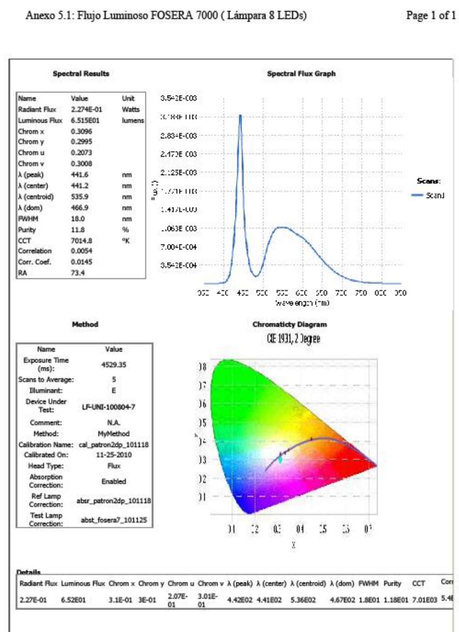

Fig. 1: Example of the results of a photometric measurement

In Table 2 are resumed the photometric and electrical characteristics of the evaluated lamps: In columns 1 – 4 are indicated the total luminous fluxes corresponding to the different eligible steps of light intensities (in lumen, lm). The lamps were connected to its own electronic circuit and batteries (completely charged) and put in the integrating sphere spectrophotometer ("Ulbricht" sphere of 1 m diameter). The luminous flux measurements (using calibrated standard lamps for comparison) were corrected for absorption in the lamp, using an auxiliary lamp. In columns 5 – 8 are indicated the electric power extracted from the batteries (in Watt, W), at the different levels of light intensities, that is, in each case, is given the total consumption of electrical power consumed by the LEDs and the corresponding electronic circuit. In columns 9–12 are indicated the measured luminous efficacies, measured in lm/W.

In columns 13 - 16 are given the times, in hours, the lamps are turned on till they are turned off automatically by the electronic circuit, with the batteries initially fully charged. In column 18 is given the maximum illumination Ib, measured in lux (lx), one can get on the edge of a 1 m^2 working table, if the lamp is put at a height h (column 19, in cm) above the table. In column 17 is given the illumination Ic that one obtains in this case at the center of the table. Finally, in column 20 is indicated the reduction of the luminous flux, in %, during the time the lamps are turned on (corresponding to column 13).

An evaluation of these data indicates that there is a marked difference in luminous flux and also in luminous efficacy, of the different lamps: lamp D has a flux of 211 lm, lamp B of 129 lm and lamp F of 122 lm. The other lamps have a flux in the range of 34 – 77 lm. The luminous efficacy varies from 119 lm/W of lamps D and F, and 104 lm/W of lamp B, down to 40 lm/W (lamp H). It has to be stressed that these flux efficacies correspond not just to the LEDs, but to the whole lamp, that is “lumen obtained” / “Watt extracted from the battery” (some of the power is consumed in the electronic circuit.) The illumination obtainable on a 1 m^2 table varies from 41 – 63 lx for lamp D, 19 – 173 lx for lamp F, 25 -134 lx for lamp B, down to 11 – 50 lx for lamp K, getting the most uniform illumination with lamp D.

Conclusions

From these laboratory tests we arrived at the following conclusions:

- There exists a wide range of different Pico PV systems with different characteristics and also quite different qualities. The technology of pico PV lamps is at this moment in a very strong development: After having measured initially all 11 lamps (during 4 months at the end of 2010), several of the companies involved sent us newer models of their lamps, with much better results (as reported in this paper).
- For the field evaluation with rural users, we recommended to use several types of lamps: lamps to be fixed on the ceiling as well as portable lamps.
- In the case of lamps used for room illumination, we suggested a field evaluation of the lamps B, D and F.
- In the case of portable lamps, we suggested a field evaluation of lamps B & K.

Table 1: Measured parameters of the batteries

						1	2	3	4	5	6	7
	Lamps	**Photos**	**Battery Type**	Nominal **Voltage (V)**	**Position**	**Charge (Ah)**		**Energy (Wh)**		**Charging Efficiency %**		**DOD (%)**
						Discharging	**Charging**	**Discharge**	**Charging**	**Coulomb**	**Energy**	
A	**Nova**		SLA	6	high	1,34	1,45	7,99	9,53	0,92	0,83	0,60
B	**Phocos**		Ni-MH	5	medium	1,98	1,99	9,86	11,93	0,99	0,83	0,99
C	**Cosmos**		Ni-MH	3,6	high	2,00	2,09	7,20	9,14	0,96	0,79	0,99
D	**Sundaya**		Li - Ion	7,4	high	2,17	2,17	16,43	17,18	1,00	0,96	0,86
E	**Fosera 4200**		Li - Ion	3,2	4 LEDs	4,73	4,77	14,86	15,19	0,99	0,97	0,99
F	**Fosera 7000**		Li - Ion	3,2	8 LEDs	7,71	7,77	24,60	25,95	0,99	0,95	0,98
G	**Suntrasfe2**		Gel -Pb	6	medium	5,46	5,75	33,09	38,79	0,95	0,85	0,91
H	**Suntrasfer 10**		Gel -Pb	12	x	18,40	18,80	222,20	242,40	0,98	0,92	0,97
I	**Firefly 12**		Ni-Cd	3,6	high	0,67	0,78	2,36	3,38	0,86	0,70	0,97
J	**Barefoot**		SLA	12	x	4,89	4,96	58,41	63,50	0,99	0,92	0,95
K	**Barefoot Mobil**		Li - Ion	3,2	x	0,96	1,53	2,98	5,19	0,63	0,57	0,97

Table 2: Measured photometric and electrical parameters of LED lamps

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Lamp model		**Luminous flux (lm)**				**Power (W)**				**Efficacy (lm/W)**				**On time (h)**				**Illumination***			**∆ I (%) ****
		High	**med**	**low**	**very low**	**High**	**Med**	**low**	**very low**	**high**	**med**	**Low**	**very low**	**high**	**med**	**low**	**very low**	**Ic (lx)**	**Ib (lx)**	**h (cm)**	**High**
A	**Nova**	49	32	18		1,04	0,64	0,31	0,03	47	51	56		4,8	8,4	21,0	302,0	53	12	53	92,6
B	**Phocos**	129	60	14	x	1,80	0,57	0,15	x	72	104	94	x	5,3	18,3	72,5	X	1355	25	63	98,4
C	**Cosmos**	77	58	28	x	2,22	1,74	0,81	x	35	33	34	x	2,6	3,7	11,4	X	85	21	71	77,7
D	**Sundaya**	211	102	24	x	1,93	0,93	0,20	x	110	110	119	x	7,6	16,8	65,5	X	63	41	61	97,4
E	**Fosera 4200**	61	x	X	x	0,55	X	x	x	111	x	X	x	8.8(1)	X	x	X	66	20	78	55,6
F	**Fosera 7000**	122	x	X	x	1,03	X	x	x	119	x	X	x	13.8 (1)	X	x	X	173	19	62	74,0
G	**Suntransfer 2**	75	36	5	x	1,60	0,71	0,15	x	47	50	29	x	15,5	46,2	222,8	X	87	12	78	96,6
H	**Suntransfer 10**	68	X	X	x	1,75	X	x	x	39	x	X	x	30.5 (2)	X	x	X	71	19	61	91,4
I	**Firefly 12**	34	18	2	x	0,64	0,33	0,05	x	39	55	44	x	5,6	10,5	x	X	X	X	x	14,1
J	**Barefoot**	54	x	x	X	0,72	x	x	x	75	x	X	x	47,9 (1)	X	x	X	47	23	96	X
K	**Barefoot Mobil**	53	x	x	x	0,64	x	x	x	83	x	X	x	4,6	X	x	X	51	11	93	95,4

x: not applicable (1) with two lamps turned on (2) with four lamps turned on

* Illumination, in lux, on a working table of 1 m^2, with the lamp in the optimum position h above the table (column 19)

** Luminous flux reduction during the time the lamp is turned on (column 13), with reference to the initial value, put as100%