HOW TO CARRY OUT PV-PROJECTS IN THE TROPICS

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ABSTRACT: The article presents recommendations for the planning, installation, operation and monitoring of autonomous photovoltaic (PV) systems based on experiences within rural communities in Brazil. Successful PV application depends on a broad range of financial, technical, climatic and social parameters: funding, demand, infrastructure, importation, electrical properties, thermal layout, climate, material selection, installation, operation, maintenance, environmental impact, and communication. The recommendations provided, which are derived from practical, real life applications, will enhance the implementation, reliability, operation lifetime and acceptance of autonomous PV-systems. The following areas are covered: pre-installation issues (location, load requirements, dynamics of development, financing, importation, language barriers, bureaucracy), technical issues (mounting, wiring, theft, electrical safety, non-MPP operation, energy storage, power conditioning equipment) as well as monitoring and maintenance issues.
Keywords: rural electrification, developing countries, education and training.

1. INTRODUCTION

The basic layout of a typical PV system for off-grid applications (grid connection plays a minor role here, most systems are used for rural electrification) is relatively simple: PV generator (consisting of a number of PV modules), energy storage (mostly a lead-acid battery), and power conditioning devices (consisting of a charge regulator and, optionally, an inverter), as shown in Fig. 1.

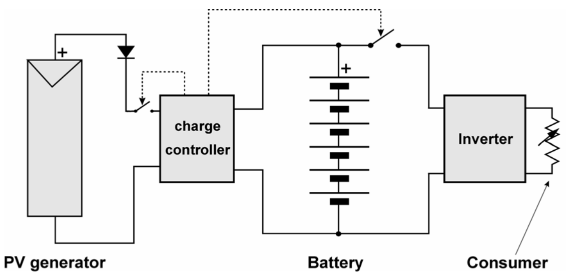

Figure 1: Scheme of a typical autonomous PV system with a single-phase AC outlet, including PV generator, energy storage, charge controller and DC-AC converter (inverter).

In total about one million such systems have been installed worldwide [1]. Nevertheless, in practice, frequent failures have been reported; many of them are not of technical nature. Based on ten years of practical experience in Brazil, this article highlights some important considerations and best-practice examples of how to implement a reliable, efficient, long-lasting and cost-effective PV power supply [2]. Some of the recommendations given may seem trivial, but apparently have not been considered in many system layouts in the past, even at large scale rural electrification programs.

2. PRE-INSTALLATION ISSUES

2.1 Planning

2.1.1 Determination of load requirements - While the price of a PV installation is increasing roughly lineally with the electricity consumption, customers tend to underestimate design loads during the planning phase in order to save costs, thus making the system sub-dimensioned and unreliable. The best method is to measure power consumption over a period of time.

2.1.2 Dynamics of development vs. time constrains - Time from project definition, layout, financing, ordering, shipping to turn-key installation can take years (considering bureaucracy for project legislation, import taxation and liberation). Importation often gets that time-consuming, that costly external services by so called “despachos” should to be used. Waiting times of 1 to 1.5 years have been reported, so packaging of goods may degrade and equipment may “disappear”.

During that whole process side-conditions of the project could have altered: people to whom the power plant was designated to could have moved, electrical grid-lines could have been installed, diesel-generating-sets could have been bought; even the planned installation site could be flooded or be transformed into a landfill.

Straight-forward planning from the scratch to the turn-key energy supply system rarely happens and often the design requires re-evaluation and noteworthy modifications. To accomplish that, constant alertness, observation and controlling are a must.

2.2 Financing

Looking for support programs for the project is an important, but time-consuming task. Often a lot of restrictions are bound for such aids: limited time periods for installation, obligatory use of national equipment (e.g. batteries), cooperation with local companies and utilities, long-term power delivery guarantees, certification by local authorities, hard bidding competition. Whereas financial compensation is given in local currency and local interest rates apply, risks associated to that have to be taken into account, such as fluctuation of the exchange rate. A local production or assembling-line for components could reduce these risks, because salaries, rental fees and raw materials are also paid in local currency, and for most cases this measure will allow to bypass high import taxes.

2.3 Importation

Import of equipment and materials is a tricky and time-consuming issue: In order to protect some local industry from cheap imported products import taxes may be high and can have a large impact on the budget (import taxes may double the price of some goods, principally electronics). Knowing the fact that these regulations are not economically sustainable and possibly will paralyze a country's economy on the long term, authorities frequently exclude goods of strategic interest – such as renewable energy technology – from high taxation, but this requires knowledge, extensive paperwork and the declared goods have to precisely fit into the exemption categories.

Recommendations: Make sure that every component of your system is well described (in the local language!). Aside from detailed records of the equipment, the background of the project-partners has to be accurately documented as well (e.g. company's founding certificate, financial and technical capacity proofs). Units mentioned in the documentation (per piece, per volume, per kg, British/American/local measures) are a critical issue, as well as currencies and its exchange rates and which one is to apply (e.g. Brazil has six different official exchange rates for R$ vs. US$). Sometimes parts have to be divided into sub-components: general electronics, processing units, memory, transformers, terminals, instrumentation, displays, PV units, often with different import tax rates and separate forms to be competed and to be certified. Often importation is not taxed upon the value of the imported goods only, but on the total expenditure, including freight costs.

2.4 Language barriers

2.4.1 Within bureaucracy – Fund and credit applications, certification and importation forms require profound knowledge of the local language. Especially juristic and technical expressions may provide difficulties. Terminology could deviate within the "same" language. (e.g. Portuguese from Portugal vs. Brazilian Portuguese or British / American / Indian English). Authorities and officials are often quite sensitive in respect of the "correct" use of their terms and in respect of their position. They may deliberately delay processes if they feel offended. On the other hand they don't bother if you frequently ask (in a friendly manner) about the actual project status (a situation where usually European officials would become annoyed). Best strategy is to "involve" the officials in your project, i.e. explain them how important the project is for their country, so they feel proud being a part of it.

2.4.2 At the location of installation - Aside from the general language barriers, remotely located individuals are often not familiar with basic technical terms. Interactive training is a must, even if it becomes time consuming. The use of well-illustrated training material is important. Illiteracy is widespread (often more than government statistics indicate), especially at remote sites where children are needed for work. You cannot expect to meet people that speak a foreign language on-site.

3. TECHNICAL ISSUES

3.1 Mounting

Harsh environmental conditions such as high temperatures, high humidity, high irradiance, strong winds (at locations close the sea connected with salty air), and difficult accessibility for repair requires the use of best materials. Often stainless steel components are not available locally and have to be imported.

3.1.1 Fixation - Mounting and fixing should preferably be carried through the utilization of rivets instead of screws in order to avoid becoming loose and deter theft. Additionally, stainless steel screws may be difficult to obtain, and may even be subject to theft (see below).

3.1.2 Wiring - Local electricians do not generally work with high current, low voltage DC wiring (besides car electricity) and therefore flexible UV-resistant cables with an adequate diameter and color are difficult to obtain. The same is true for switches, fuses and terminals. Often these parts are not available locally and must be imported.

3.1.3 Theft - Increasing theft of PV panels is a serious issue in tropical locations, especially in Africa. South African Telecom decided to acquire exclusively orange PV modules in order to ease identification of stolen PV panels. Components may be mounted by rivets, rather than screws in order to make theft more difficult (see above). Often even smaller components, such as instrumentation, terminals, plugs, cables or even water tabs are subject to theft, because for poor people these objects already represent a huge value. A community-adaptation of the system and the nomination of a responsible local person in-charge are most helpful to avoid this issue.

3.1.4. Safety - Batteries should be stored in a secure location, apart from the living area. Metallic objects deposited on the battery terminals may provoke severe accidents [6].

3.2 Non-MPP operation of PV generator

Due to the typical *I-V* characteristics of solar cells and PV modules, electrical power output decreases in an almost nearly linear manner when the load curve meets the *I-V* curve of the PV generator on the "left" side of the Maximum-Power-Point (MPP), towards lower operating voltages. On the other side, power declines exponentially when the load curve cuts the *I-V*-generating curve on the "right" side of the MPP, towards higher operating voltages. The latter occurs when the voltage of the generator is reduced (e.g. for high operational temperatures at single- or multi-crystalline silicon solar cells, which typically feature a voltage-temperature coefficient of -0.4%/K to -0.5%/K), as shown in Fig. 2.

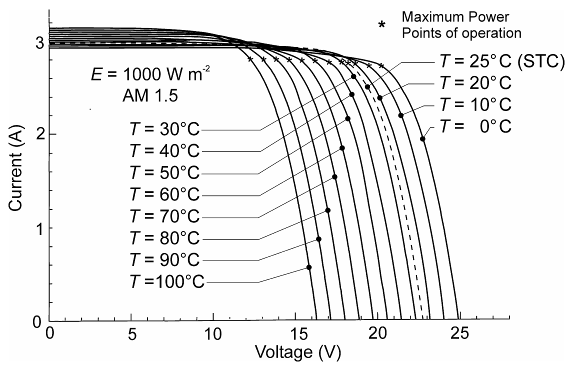

Figure 2: *I-V* characteristics of a PV module for different operation temperatures *T*, incorporating the corresponding Maximum-Power-Points (MPPs).

Therefore, it is recommended to either acquire PV modules that contain a larger number of solar cells in series connection in order to increase the generator's voltage level, or obtain charge controllers with an integrated step-up DC-DC converter and a MPP-tracker in order to enable full battery charge even when a generator's voltage levels are reduced. Unfortunately the industry does not supply such equipment as a standard product.

3.3 Energy Storage

3.3.1 Battery types - while there are many different types of batteries available, lead-acid batteries nevertheless offer the best cost/benefit ratio. Lead-acid batteries are offered in three versions: conventional ("open" - allowing replacement of lost water), "maintenance free" (surplus of electrolyte, reduced gassing), and "sealed gel" (absorbed electrolyte). Whereas maintenance practice is often poor or the replacement of water is carried out with contaminated water, maintenance-free batteries are preferred [7]. Fully sealed batteries are less robust and have shown shortened lifetime in comparison to maintenance-free batteries in warm climates, especially when charge-control is not properly carried out [3].

3.3.2 Nominal voltage level - In most tropical countries solar batteries are derived from car or truck batteries and thus available only in 12V blocks. The maximum storage capacity to be found in Brazil is 220Ah and thus the batteries have to be paralleled in order to achieve a greater storage capacity at a given voltage. Due to tolerances in the production process of the batteries (e.g. at the electrode plate treatment or within a battery's acid concentration), differing electrical characteristics such as internal resistance are likely to occur [5]. In this case, paralleled batteries will suffer from considerable internal currents that result in reduced storage capacity and shortened lifetime of the battery bank. We experienced considerable voltage differences even at more expensive, high capacity batteries. That effect may be caused by a poor fabrication process and the lack of quality control, possibly due to low production number of high capacity batteries [5]. Usually test procedures, as suggested by [4], are difficult to be carried on the installation-site. Batteries also may develop problems due to non-homogeneous storage conditions: exposure to high temperatures (e.g. due to exposure to sunlight) cause additional internal currents and damage.

Because import taxes for batteries are prohibitively high, for most cases the only solution is to use national products with higher voltage levels - thus eliminating the need for paralleling of batteries. Using a 12V-220Ah battery at a 50% maximum depth of discharge, the voltage level has to be increased by an additional 12V for each 1.3kWh of storage requirements. For voltages above 50V additional safety concerns must be addressed. Conventional lead-acid batteries have to be exchanged about four times during the lifetime of a PV system. To keep the system working, a replacement strategy has to be established to have the funds available for the purchase of a new battery and the manpower to replace it. Some refurbishing companies are willing to pay a small amount for old batteries, but unfortunately these companies are located far away from most projects in the big cities and are specialized on automotive batteries.

3.4 Power conditioning equipment

While in developed countries most electrical machinery used as a load features a cos φ between 0.9 and 1, local equipment may show a cos φ as low as 0.6, so the inverters have to be capable to handle such inductive loads. Also friction losses tend to be higher that increase starting currents for the inverter.

3.4.1 Switching devices - Many inverters are driven by MOSFETs. Whereas on one hand MOSFETs can be easily paralleled due the positive temperature coefficient of their on-resistance, this could lead into a vicious circle when the device operates at elevated temperatures: elevated temperatures increase the internal on-resistance and lead to additional more heat-dissipation that will heat up other paralleled MOSFETs mounted on the same heat-dissipating device.

3.4.2 Ventilation - Many inverters use forced ventilation via temperature-controlled fans. Often on-demand fans fail to initiate; jammed by leaves or remains of insects. To avoid that, "cool" operation is recommended, using over-dimensioned switching devices (featuring lofty current reserves and low-on-resistances), that require just natural ventilation. It has also to be considered that surrounding air-temperature could easily reach 60°C in a container, so thermal layout has to be made for operation temperatures of 70°C and above. Usually maximum operation temperature for power conditioning equipment is 55°C, resulting in shortened lifetime and failures (e.g. capacitor de-lamination, display degradation, terminal melting and eventually short-circuiting).

3.4.3 Charge-controllers - Non-temperature controlled charge controllers may cause excessive gassing at high operating temperatures [3]. This leads to a loss of electrolyte, which should be replaced which is not possible at "maintenance-free" and sealed batteries, so capacity and lifetime will be reduced.

4 OPERATION AND MAINTENANCE

4.1 Pollution and degradation of system components

While the fauna & flora is prevalently richer in topical locations, it will be more likely that it will affect components of a remotely located PV system: bird droppings, seeds, pollen, leaves, branches, dust and dirt spots may accumulate on the PV panel and lead to significant performance losses (see Fig. 3).

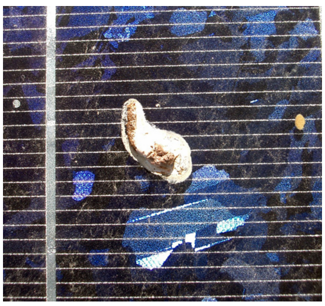

Figure 3: Bird dropping, dirt spots, and light dust accumulation on a PV module.

Usually the solar cells inside a PV module are connected in series, so the most shadowed cell dominates the output current of the circuit. If bypass diodes are not properly applied, permanent damage of the cells by "hot spots" [9] may occur (see Fig. 4).

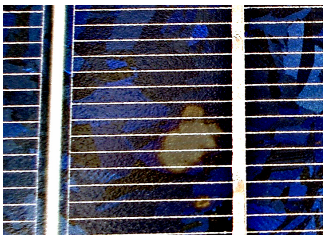

Figure 4: Permanent "hot spot" at a solar cell (light grey area in the center).

The self-cleaning effect requires an adequate inclination angle of the panel, but at tropical locations the PV-panel is mounted almost horizontally to capture a maximum of irradiance, thus inhibiting self-cleaning to a large extend. In the shelter for batteries and power conditioning equipment birds, mice, rats, snakes, spiders, cockroaches, termites, anions, scorpions, frogs, lizards and bats may find their home also may corrupt cables, terminals and relays within a short time period (Fig. 5). Also the psychological effect has to be taken into account: if the location is dirty and smells, maintenance tasks are not attractive and will not be carried out.

Recommendations: On one side the hut has to offer good ventilation to keep temperatures at a supportable level and allow the escaping of battery gases, on the other hand the invasion of insects and animals has to be prevented (e.g. grids, solid nets). Keep it nice and tidy.

Figure 5: New battery after a couple weeks: rats liked the place, leaving excrements.

4.2 Monitoring

Local personal may have difficulties to identify and to describe the state of the system (or is afraid to do so). and is hardly capable to carry out the appropriate actions, so training and capacity building of the local personnel is essential. Also adequate easy-to-read instrumentation and logical, easy-to-explain, fail-save switches with optical and/or acoustical feedback - best within a flow diagram of the system - are important as well as the long-term supply of spare parts, adequate tools. A local responsible person in charge of the plant has to be nominated and paid; this measure also prevents vandalism and theft (see above). A remote monitoring system (via cellular phone line or via satellite [10]) could be tremendously helpful to identify problems or to initiate preventative maintenance.

4.3 Further Recommendations

Each successful implementation counts much more worth than a lot of advertising and many words. Considering the recommendations given, chances are pretty good to carry out an effective project; in order to keep it operating, keep the local person in charge motivated, by supplying him/her with sufficient documentation, spare parts, an adequate salary and maintain communication with him/her. Regular visits secure that the system stays in good shape. Even if the cost/befit ratio of your project is decreasing - keep it working: consider it as a demonstration project and set a positive example. Potential new clients, in form of visitors the plant, are very likely appear. New projects may come into sight just by carefully observing the environment. Often solutions seem to be obvious, but are not carried out (see Fig. 6).

Figure 6: Diesel-powered cellular phone transmitter with refilling-boy arriving (Cancun, Mexico): noise, smoke, frequent fuel refills – why not PV?

5. CONCLUSION

While conditions are principally very favorable for the implementation of PV at tropical locations, such as high irradiance with low seasonal variation and the necessity for rural electrification, many obstacles have to be overcome. Considering the recommendations given above, the chances are good to implement a successful project. Whereas not each and every aspect could have been analyzed into its full detail, moreover abilities for improvisation, persistence, compassion and good humor are essential to carry out PV projects in the tropics.

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