# PRODEEM - The Brazilian Programme for Rural Electrification Using Photovoltaics

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*ABSTRACT: This work describes several technical and managerial aspects of the Brazilian PRODEEM Program, which comprises installation of thousands of PV systems for several applications in Brazilian outback. The equipment were acquired through international bidding and CEPEL was specially concerned about the its quality and lifespan, as well as about the correct sizing of the systems. The purpose of this work is to present a history and the technical experience obtained by CEPEL after several years of involvement in PRODEEM activities.*
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## 1. INTRODUCTION

The Brazilian Federal Government established the Programme for Energy Development of States and Municipalities (PRODEEM – Programa de Desenvolvimento Energético de Estados e Municípios) through a Presidential Decree of December 1994. The objective of the PRODEEM is to promote the supply of energy to poor rural communities that are far away from conventional electric systems. In such cases, the cost of transmission/distribution lines extension is high, due to several factors: large distances, vegetation, rivers, etc, and normally is considered not economically viable, since the expected energy consumption is very low.

The PRODEEM is coordinated by the National Energy Development Department (DNDE), of the Brazilian Ministry of Mines and Energy (MME). The CEPEL - Electric Power Research Centre (Centro de Pesquisas de Energia Elétrica), which is a Federal Company located in Rio de Janeiro, is responsible for the technical guidelines for projects, comprising equipment specification for the bidding, project evaluation, technical personnel training, installation standards, installation verification, performance and failure analysis.

The organization of PRODEEM also includes a "Regional Agent" in each Federal State (normally a State public officer), along with a small staff. The Regional Agent is responsible by the assessment of the communities, identification of their necessities and proposal of projects (based on some established criteria) of PV electrification to the MME, which grants the systems in first out basis.

The PRODEEM is mainly based on PV systems and since May 1996 CEPEL and MME have already carried out six International Bidding (CEPEL, 1996a; CEPEL, 1996b; MME/CEPEL, 1997; MME/CEPEL, 1998; MME/CEPEL, 1999 and MME/CEPEL, 2001) for acquisition of the necessary equipment, known as Phase I, II, III, IV and V, respectively, and a special phase named Pump.

Three types of stand-alone systems have been considered in PRODEEM: PV electric energy generation systems, PV water pumping systems and PV public lighting systems. The systems are intended solely for community applications, what means that they must improve the communities' quality of life and are not intended to private use.

The amount of PV power already involved in the six phases of PRODEEM now comprises about 5.2MWp, with over 8700 PV systems. The systems are installed (except recent Phase V – Dec. 2001) scattered throughout all the 26 Brazilian Federal States, but specially in the Northeast (semi-arid) and North (Amazon) regions of the country.

This programme can be considered one of the largest PV based rural electrification programs in the developing countries in the world. We do believe that this experience is useful and should be shared with other international institutions running similar PV programs around the world.

## 2. HISTORY

Table I below presents the quantities of systems and the total amount of PV power comprised by the PRODEEM up to the present.

**Table I - distribution of the systems and PV power in PRODEEM**

| Phase | | I | II | III | Pump | IV | V | TOTAL |
|---|---|---|---|---|---|---|---|---|
| PV electric energy systems | Qty | 190 | 387 | 677 | x | 1,660 | 3000 | 5,914 |
| | *kWp* | *87* | *200* | *419* | *x* | *972* | *2,172* | *3,850* |
| PV water pumping systems | Qty | 54 | 179 | 176 | 800 | 1,240 | x | 2,449 |
| | *kWp* | *78* | *211* | *135* | *235* | *696* | *x* | *1,355* |
| PV public lighting Systems | Qty | 137 | 242 | x | x | x | x | 379 |
| | *kWp* | *7.5* | *17* | *x* | *x* | *x* | *x* | *24.5* |

| | | |
|---|---|---|
| TOTAL | Qty | 8,742 |
| | *kWp* | *5,209.5* |

Qty: quantities - kWp: PV power

The current status of the six phases of the PRODEEM are summarized in table II below, and are also further discussed in sections 3.1 to 3.3.

**Table II – current status of PRODEEM phases**

| Phase | Bidding | Current Status |
|---|---|---|
| I | Jun-1996 | Installed and in operation; significant number of systems not functioning; end of lifespan of the batteries; |
| II | Mar-1997 | Installed and in operation; |
| III | Nov-1997 | Installed and in operation; |
| Pump | Oct-1998 | partially installed; problems of corrosion of pumps; |
| IV | Sep-1999 | final of installation; problems of corrosion of pumps; |
| V | Dec-2001 | delivery of equipment scheduled to mid 2002 |

As Brazilian Government Agencies, CEPEL and MME must establish the technical specifications of the equipment, which is to be acquired through International Bidding. In this scope, CEPEL carefully developed its own specifications for the equipment and systems, which evolved within the several Phases, always aiming to acquire the best cost/benefit equipment, commercially available. Furthermore, the strategy of the implementation of the PRODEEM also evolved, as discussed in section 3. This evolution represents a better understanding by CEPEL and MME of the issues related to the acquisition and deployment of large numbers of stand-alone PV systems for rural electrification.

## 3. IMPLEMENTATION

The evolution of the strategy of implementation of PRODEEM and of the technical specifications of the systems are summarized in table IV below and is further discussed in following sections 3.1 to 3.3.

**Table IV – implementation strategies**

| Phase | Strategy/Specifications |
|---|---|
| I | Conducted by CEPEL; Individual projects for each PV electric energy generation system or PV water pumping system, based on actual field information; 12Vdc systems; dc loads; Installations performed by CEPEL; |
| II | Conducted by CEPEL; Individual projects; 12Vdc, 24Vdc and 48Vdc systems; ac loads (inverters); Installation performed by regional agents; |
| III | Conducted by MME; 12 types ("kits") of PV electric energy generation systems and 16 types of PV pumping systems, based on the statistical distribution of Phases I & II; PV public lighting systems cancelled definitively; Installation performed by regional agents; |
| Pump | Conducted by MME; Equivalent of the PV pumping systems of Phase III; Installation performed by regional agents; |
| IV | Conducted by MME; 10 types ("kits") of PV electric energy generation systems and 7 types of PV pumping systems; Installation performed by regional agents; |
| V | Conducted by MME; 1 type of PV electric energy generation system; PV water pumping systems cancelled temporarily; Installation performed by suppliers ("turn-key"); |

### 3.1. PV electric energy generation systems

The PV electric energy systems are aimed to electrify buildings such as schools, health clinics, churches, community centers, FUNAI posts (Indian reservations), forest police posts, telephone posts, etc, and are comprised of PV modules with installation fixtures, batteries, charge controllers, inverters and lighting fixtures. The other electric loads (TV, VCRs, refrigerators, etc) are not supplied by PRODEEM and shall be obtained either from the local State or Municipality authorities or from other Federal Government Programs (Ministry of Education, Ministry of Health, etc)

**Phase I**

Phase I (CEPEL, 1996a) was led entirely by CEPEL, and the strategy established for this phase was the sizing of individual projects taking into account the daily consumption (Wh/day), the maximum load expected (Watt), the number of days of autonomy and the average solar radiation ($kWh/m^2$.day – global on horizontal plane) of the place in which the system would actually be installed. The data for the projects were based on information from local agents of the PRODEEM and on the technical expertise of CEPEL in similar projects (knowledge about the characteristics of the schools, health centers, etc.). The number of days of autonomy was fixed to 2 for all applications, except for the health centers, which should have 3 days of autonomy. The nominal voltage of all the systems was fixed to 12Vdc, and the systems were aimed to drive primarily dc loads. Where small ac loads were present (refrigerator, TV), then small inverters (250W) were available.

Based on these information, the bidders should present in their proposals a project of a stand-alone PV system for each item. All of the projects presented by the bidders were checked by CEPEL, according to a methodology based on CEPEL/CRESESB (1999/1995), which present a simplified design method for stand-alone PV systems. The projects must consider a lifespan of 4 years for the batteries. The parameters for this methodology (coulombic efficiency, wire loss, etc) were fixed by CEPEL according to its experience, and several projects were refused, as being undersized according to this approach. Within this work, CEPEL checked a huge number of projects.

The main drawbacks faced in Phase I were:

- The nominal voltage of 12Vdc fixed to all of the systems proved to be a problem to the large systems. In these cases, large gauge wires had to be used in the installations, and the number of 30A charge/load controllers in parallel reached the number of 6 in some systems;
- The 12Vdc lighting fixtures showed not to have the same quality of their conventional ac counterparts and presented many failures. They also use lamps (8W tubular fluorescent T5) which are difficult and expensive to replace in Brazil;
- The use of 6V flooded batteries also showed not to be convenient since they are also difficult and expensive to replace in Brazil. Moreover, field inspections detected a low level of electrolyte in most of them and water refilling is difficult to be accomplished in the field, and represents a major difficulty;
- The small (250W) inverters were intended to run small refrigerators, TV reception stations (TV 20”, VCR, satellite antenna) or other small appliances. Unfortunately, the experience with these inverters was not good, since their surge current capacity was not enough to drive the refrigerators and some other loads which require high start currents;
- Most of the systems were installed by CEPEL (Antonio L. de Sá et *al,* 1996), what obviously proved not feasible, even considering the small number of systems of Phase I, since CEPEL has a small, although highly trained, laboratory staff.

**Phase II**

The bidding for the Phase II (CEPEL, 1996b) was also conducted by CEPEL, and presented an evolution in the specification of the equipment, according to the experience gained running Phase I. The first improvement was to settle that CEPEL would perform acceptance tests, if necessary, in order to verify if the supplied equipment meets the specifications of the bidding document. If these tests indicated that the requirements were not met, then equipment could be refused and returned to the supplier for replacement, which has really occurred (inverters).

For the second phase the strategy of individual projects proposed by the bidders and checked by CEPEL in a one by one basis (using the same methodology) was also employed. However, a single value of solar radiation, valid for each State of Brazil in which the equipment would be installed were used, instead of one value for each project. This led to some simplification on the overall bidding process and analysis of the proposals.

Three values of nominal voltages of the systems were adopted: 12Vdc, 24Vdc and 48Vdc, depending upon the power requirements of the load for each system (360W, 720W and above). This new requirement aimed to keep the dc currents under 30A in order to make the installations easier and to reduce wire losses.

Only no-maintenance (sealed) lead-acid, 12Vdc batteries, would be accepted, so the systems have 1, 2 or 4 batteries in series. This makes the replacement of the batteries easier and eliminates their need for distilled water replacement.

The systems of Phase II are designed to be completely ac, not driving dc loads directly (with exception of a few very small systems-lighting only). Every system will have an inverter, so, 5 different sizes of inverters were specified, depending upon the load power requirements (and nominal voltages) for each system. Additionally, the power surge requirements for the inverters were carefully specified, accounting for the single-phase electric motors (loaded) that should be driven, so that the problems with starting currents were eliminated

The lighting fixtures for Phase II are conventional (ac) with electronic ballasts and compact fluorescent lamps. Of course conventional ac lighting fixtures rely on a technology much more established than dc ones. There is a suite of international standards that assures their quality and makes easy to perform accredited tests, what can easily be done in CEPEL’s lighting laboratory.

The systems’ installation were a responsibility of the regional agents, either using their own staff or hired companies. They are also in charge of arranging the material needed for installation (wires, connectors, switches, power outlets, grounding rod, conduits, etc), according to CEPEL's specifications. CEPEL prepared very detailed installation manuals (CEPEL, 1998) for the PV electric energy generation systems that were distributed to regional agents. The personnel training for installation was also done by CEPEL.

**Phase III**

From Phase III (MME/CEPEL, 1997) on, the PRODEEM was conducted by MME, with technical advisement of CEPEL, and a new approach was used: the number of different PV electric systems was reduced to twelve standard sizes ("kits"). These twelve types of systems and the number of systems of each type were chosen based on a statistical analysis of the distribution of sizes (daily consumption and maximum load) of the systems included in Phases I & II. In Phase III, the systems were assigned to the applications on a best fit basis, according to the project criteria.

A single mean value for the solar radiation in Brazil (4.3kWh/m2.day) was used for sizing all the systems. The methodology used by CEPEL to check the proposals in the bidding of Phases I & II led to doubts by the suppliers. So, the methodology was formally presented in the bidding document for Phase III, as a set of 4 simple formulas, related to: charge balance, load balance, charge controller balance and load controller balance. These improvements simplified significantly the analysis of the proposals.

A set of project criteria, developed by CEPEL (MME/CEPEL, 1999b), established guidelines for the projects presented by the regional agents, addressing the characteristics (power and daily utilization) of the electric loads accepted by PRODEEM (density of power (W/m2) and number of hours of daily utilization (h/day) of lighting for each application, etc). Other characteristics, are also determined: minimum distance from the grid, etc. CEPEL also prepared very detailed installation manuals (Aroldo J. Borba et *al* 1999) for Phase III.

**Phase IV**

The strategy and the specifications for Phase IV (MME/CEPEL, 1999a) suffered only minor changes from Phase III, for instance: the number of types of kits was reduced form 12 to 10, and the number of different types of inverters was reduced from 5 to 4.

The preparation of the installation manuals in Portuguese, following CEPEL's standards, was a duty assigned to the supplier, which, unfortunately, was not able to accomplish it satisfactorily. Therefore, CEPEL had to answer many doubts about the installation, posed by the regional agents, and to publish guidelines to help them.

**Phase V**

As the number of systems has increased steeply from Phase I to Phase IV, the installation of these systems have become a major difficulty for the regional agents, growing the concern about the quality of the installations. Therefore, the bidding for Phase V, performed recently on Dec 2001, (MME/CEPEL, 2001) includes not only the equipment, but also the installation of the systems, that shall be delivered by the suppliers completely installed and in operation ("turn-key"). The installation standard developed by CEPEL was carefully detailed in the bidding document, and shall be strictly followed. All material to be used must conform to Brazilian Technical Standards and to CEPEL's specifications. Each installation will be inspected and comissioned by the technical staff of CEPEL and MME. The exception is the North region of the country (Amazon), where the systems will still be installed by the regional agents, as the large distances and the natural environment render the installations extremely difficult end expensive.

The specifications of the equipment did not change significantly from Phase IV. However, only one type of kit is specified for Phase V, namely that kit considered the most used in the former four Phases of PRODEEM, what simplified exceedingly the bidding process, as well as several other aspects: preparation of manuals, installation and maintenance.

In order to assure the quality of the equipment, the requirements for the acceptance tests were also greatly improved and strengthened, and are completely detailed in the bidding document. The tests will be performed in independent laboratories, at expenses of the suppliers, and shall include the PV modules, batteries, charge controllers, inverters and the systems themselves. The installation and maintenance manuals, written in Portuguese, are considered part of the systems, and shall also be subjected to acceptance.

### 3.2 PV water pumping systems

The PV water pumping systems are intended to supply water primarily for human consumption, but also for animal consumption and irrigation in small scale. The equipment acquired in the bidding included the pumps (any type of pump and motor) and the PV modules with installation fixtures. The inverters (or other electronic devices, such as mpp-trackers, dc/dc converters, etc.), submersible cables and check valves were also to be supplied, if necessary. The systems should be of direct pumping type, without any electrical energy storage (batteries).

**Phase I**

The strategy for the acquisition of the PV water pumping system was based in the same as for the PV electric energy systems. The data for each individual project was the daily amount of water needed ($m^3$/day) the total head (m), the type of the pump (surface or submerse) and the solar radiation (kWh/$m^2$.day - horizontal plane) of the place in which the system would actually be installed. The data for the projects were based on information from local agents of the PRODEEM and on the technical expertise of CEPEL in similar projects.

The checking of the projects presented by the bidders was performed by CEPEL based on sizing information (graphs, tables, etc) supplied by the bidders, which proved to be a very difficult task and lead to several doubts, since each manufacturer has its own algorithm for sizing. Of course, this methodology, is not to be as straightforward as in the case of the PV electric energy systems, anyway, led to refusals of proposals.

The main drawbacks faced in Phase I were:

- As the information about the water boreholes of remote places is often inaccurate, many of the original PV pumping projects of Phase I had to be resized;
- There were failures in the pumps and controllers, and the manufacturer replaced the equipment, still covered by the warranty, by a new version, with better overload protection;
- inadequate installation – the pump sucked mud from the bottom of the well

**Phase II**

The requirements for the PV water pumping systems for Phase II were not significantly different from Phase I. The strategy of implementation was also not diverse.

Only one value of solar radiation was specified for each State of Brazil.

The installation of the systems were responsibility of the regional agents, which are also in charge of arranging the material needed for installation (piping, connections, water tank, conventional wires, etc.). The personnel training for installation was done by CEPEL.

As in Phase I, it was also necessary for the regional agents to resize many systems, often with help of CEPEL. However, since the well data are not accurate, the results can also sometimes be unreliable.

**Phase III**

For Phase III, 16 standard types ("kits") of pumping systems were specified, based on the distribution of types of the Phases I & II, as for the PV electric energy generation systems.

Also, some more accessories were included in the supply, since they are relatively expensive and not readily available locally: a weatherproof on/off switch for each system; stainless steel cables and hardware for fixing the submersible pumps; all the cables (electric, steel) had to be supplied with 25% extra length (due to the frequent resizings).

**Phase Pump**

The Phase Pump (MME/CEPEL, 1998) is an extra Phase comprising 800 PV pumps, performed due to a severe drought occurred in the Northeast region of the country. The specifications and the strategy of implementation are equivalent to Phase III.

**Phase IV**

The number of kits of PV pumping systems was reduced from 16 to 7 types (most used), all the rest was essentially the same of the former Phases.

Part of the PV pumping equipment supplied to Phase IV and also to Phase Pump was afflicted by a severe problem: the pump's shafts were corroded quickly (~6 months) by the often brackish (up to 7000ppm content of salts) groundwater found in Brazil, although this was part of the requirements for the systems, as specified in the bidding document. A careful metallographical analysis, conducted both by CEPEL and the manufacturer, identified a non conformity of the material of the shafts with the specifications. As a result, the manufacturer is being obliged to proceed with the replacement of the necessary parts, including in the systems already installed in the field, at no expenses for the MME.

Besides this, PV pumping equipment from other manufacturer, installed since Phase I presented a failure rate which is considered not negligible, reaching several dozens of systems, and the manufacturer was requested to solve this problem urgently.

Due to these problems with the PV pumping systems, MME decided that such systems should not be included in the next bidding (Phase V), until the present problems be solved satisfactorily.

### 3.3 PV public lighting systems

The PV public lighting systems are similar to those used in electrified areas. Two types of PV lighting systems were specified: one with a 11W PL compact fluorescent lamp and another with 2 11W PL compact fluorescent lamps (12Vdc electronic ballasts). The systems included PV modules with installation fixtures, lamps with fixtures, batteries, charge controllers and photo sensors for automatic on/off switching. The systems should operate 12 hours/day with autonomy of 2 nights.

The requirements for the components and systems were similar to those of the PV electric energy generation systems.

**Phase I**

The boxes for fixing the batteries and charge controllers to the poles were designed and manufactured by CEPEL, which also installed most of the systems. Early after the installation there have been reports of systems not operating properly in the field.

**Phase II**

The PV public lighting systems for Phase II are similar to those in Phase I. All of the necessary accessories were specified and acquired: battery boxes, braces, wiring, etc. Technical problems were also detected soon after the installation.

**Phase III**

The PV public lighting systems of Phase III were cancelled, as their quality and their cost/benefit ratio were considered inadequate in the PRODEEM Phases I & II. The subsequent Phases did not include such systems anymore.

## 4. CONCLUSION

In order to assure the quality of the equipment and projects for the Brazilian PRODEEM programme, CEPEL and MME rely on careful specifications for the components and for the systems, as well as in acceptance tests. The present article shows the evolution of the requirements set by the six international bidding already undertaken.

Although the technical issues here discussed are considered vital to the success of the PRODEEM, some other issues cannot be neglected: the maintenance and the sustainability. According to the present organization of PRODEEM, the maintenance of the PV systems is a responsibility of the regional agents, however, as the number of systems, already big, keeps increasing, it is expected that they will be hardly able to fulfill the task.

Therefore, the ultimate aim is to obtain the long-term sustainability of the systems through funds of the municipalities, or even of the communities.

The last field inspection of the systems, hired by MME from independent inspectors, and done according to a methodology and forms set by CEPEL (Claudio M. Ribeiro et *al*, 1999), showed that a significant number of the systems of Phase I (up to 50% in some States) is not functioning properly. This is absolutely not suprising, as the expected lifespan of the batteries is ending, and makes even more important the concerns about sustainability.

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