Study of technical and financial viability of PV powered water-pumping systems in the Federal University of Ceará

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Abstract - **Due to the climatic characteristics, the use of photovoltaic systems has great potential to supply the crescent electric power demand of the Northeast region in Brazil. The continuous development of the photovoltaic technology has reached in the last years a status that has made possible the use of the technology through decentralized facilities. This viability is translated so much in technical terms as economical. The present paper proposes the use high performance PV powered motor-pump units in the Campus of Pici of the Federal University of Ceará - UFC. Motivated by the need of reduction of electric power consumption supplied by the grid, the study makes the analysis of the investment.**

Index Terms — **photovoltaic power systems, water pumping.**

I. INTRODUCTION

The Electric Power Consumption Efficiency Program of the Federal University of Ceará (PROCEN) has constantly been analyzing the electric power bills of UFC, with the intention of reducing them through energy-efficient measures and improvement in some forms of electric power use. Among the suggested measures it is studied the technical and financial viability of photovoltaic (PV) powered water pumping systems.

Due to the climatic characteristics, the use of photovoltaic systems has great potential to supply the crescent electric power demand of the Northeast region in Brazil. The state of Ceará, for instance, it is characterized by irradiance up to 2,800 hours/year and a daily medium value for the daily solar irradiation on a horizontal surface up to 5 kWh/m^2/day. Due to the proximity of Ecuador, this solar potential is to the disposition in every month of the year, being despicable the climatic changes caused by the seasons.

The continuous development of the photovoltaic technology has reached in the last years a status that has made possible the use of the technology through decentralized facilities. This viability is translated so much in technical terms as economical. A new phase begins in Brazil, following tendency already verified at the industrialized countries, with the insert of the PV technology in urban areas, be integrated into the net or directly coupled (autonomous way).

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Seeking the application of motor-bomb groups of high efficiency with PV panels, in agreement with the climatic characteristics of the area, rising of the current situation of water pumping was accomplished in UFC, more specifically in the Campus of Pici. As result, the characteristics of all the wells of the Campus were classified. Motivated by the need of reduction of electric power consumption supplied by the grid, the study makes the analysis of the investment.

II. CALCULATING THE SYSTEM

A. Methodology of Pumping System

To determine the mechanical power (P_M) necessary so that the group motor-pumps of the pumping system assist a certain flow rate (Q), it is necessary to know the efficiency (η_{MP}) of the involved mechanisms and the total head (H). The power will be then expresses for [6]:

$$P_M = \frac{2{,}725.Q.H}{\eta_{MP}} \qquad (01)$$

Were:
Q - flow rate [m^3/h];
H – total head [m];
η_{MP} – motor-pump efficiency;
P_M – mechanical power [W].

The total head should be calculated taking in consideration the pressure increase caused by friction through the pipework and expressed as an equivalent height in meters [2]-[5]. The criterion used for choice the pipe diameters it was the economical speed, for being simple and efficient [2]; this speed should vary from 0.5 to 2.0 m/s. To determine the diameter starting from this criterion, the equation is used:

$$D = \sqrt{\frac{4.Q}{\pi.S}} \qquad (02)$$

Were:
D – great Diameters of the pipe [m];
Q - flow rate [m^3/s];
S - speed [m/s].

Knowing the nominal mechanical potency of the group motor-bomb, the appropriate model of bomb is determinate using the technical catalogs.

B. Methodology of Photovoltaic System

The knowledge of the radiation intensity is of fundamental importance for the good project and future acting of the pumping installation.

Starting from data picked by the Group of Energy Processing and Control - GEPEC, laboratory linked to the Department of Electric Engineering of the Federal University of Ceará and regional reference in the research of the use of the solar energy for half photovoltaic, was arrived to the graph shown in the fig. 1 where it can be observed the radiation values (kWh.m-2.day-1) for the period of one year, understood between the months of April of 2003 and March of 2004.

The described values are characterized not only for your high magnitude, compared with the industrialized countries (the ones that makes more use of solar energy technologies), but also for your little variation during the year, this confirm the potential of the state of Ceará in the use of the sun's energy.

The precise estimation should happen not only in the correct determination of the necessary potency, but also in the determination of the available solar radiation in the place (fig.01), in function of the best angle of inclination of the panels PV, so that there is a maximization of the incident solar energy along the year and in relation to your demand [1]. The electric potency (P_{EL}) of the pumping system it is calculated for:

$$P_{EL} = \frac{2{,}725.Q.H}{\eta_{MP-PV}} \tag{03}$$

Where $\eta_{MB\text{-}PV}$ is the group motor-pump efficiency multiplied by the arrangement PV efficiency.

C. Methodology of economical viability analysis

The investment decisions in alternatives and economy projects and efficient use of energy pass, necessarily for an analysis of economical viability. These subjects can come in two ways: or it is wanted to decide mutually on the choice among two alternatives excluding, or it is wanted to know if some alternative is economic. These analyses use economical indexes that allow translating the attractiveness of an investment.

The applied methods for the verification are: liquid present value (VPL) and time of capital return or payback (n) [3].

$$VPL = I + CO.\left(\frac{(1+i)^n - 1}{i.(1+i)^n}\right) \tag{04}$$

$$n = -\frac{\ln(1 - I/A.i)}{\ln(1+i)} \tag{05}$$

Where:

I - value of the investment;

CO - operation cost and maintenance;

i - interest rate;

A - benefit for period;

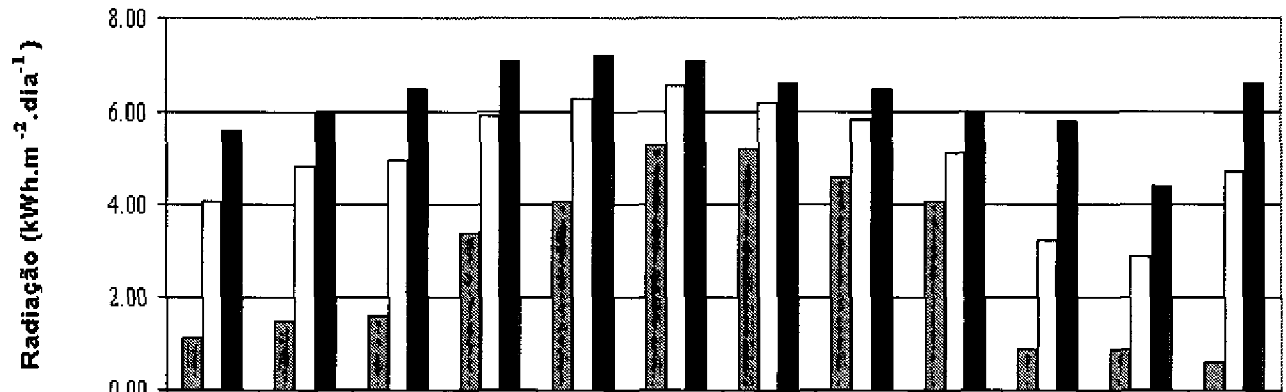
n - number of periods.

III. Study of Case

The study of presented case refers to the Campus of Pici of UFC, which consumes a month about 628MWh of electric power and 17,238m^3 of water of the company of water and local sewer.

The table I shows the accomplished rising of the wells of the Campus of Pici. They are twenty-five wells, for which were calculated, to analyze technical and financial viability, the necessary pipes, the group motor-bomb and the panels PV for feeding of the group. These wells, in the general, they are not being used now.

The illustration 02 display one of the reservoirs located



	abr/03	mai/03	jun/03	jul/03	ago/03	set/03	out/03	nov/03	dez/03	jan/04	fev/04	mar/04
Menor valor	1.10	1.50	1.60	3.40	4.10	5.30	5.20	4.60	4.10	0.90	0.90	0.60
Valor médio	4.07	4.84	4.95	5.92	6.28	6.56	6.22	5.84	5.13	3.25	2.87	4.73
Maior valor	5.60	6.00	6.50	7.10	7.20	7.10	6.60	6.50	6.00	5.80	4.40	6.60

Fig. 01. Valores mensais de radiação para o período de Abril de 2003 a Março de 2004 para a cidade de Fortaleza.

close to the entrance of the campus, where she can observe the privileged location for PV pumping.

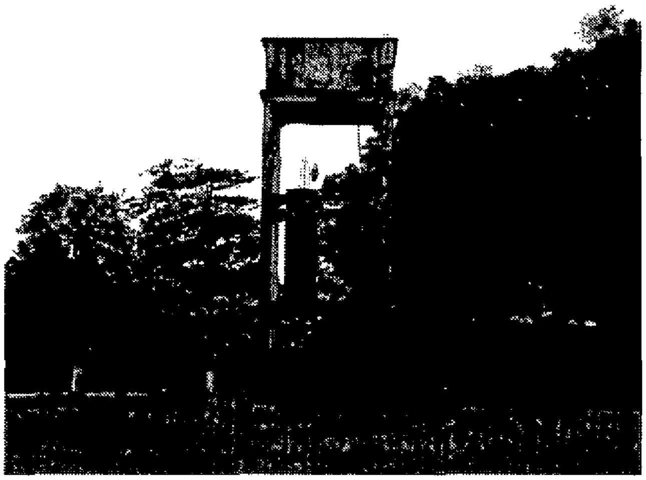


Fig. 02. One of the reservoirs of the Campus of Pici, privileged location for PV pumping.

The pumping system chosen was the direct joining, without use of batteries, storing water in tank for the readiness of twenty-four hours (Fig. 03).

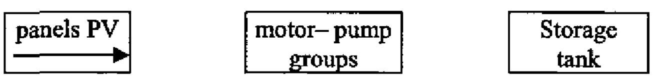


Fig. 03. Basic structure of PV water pumping system.

A. Pumping System

Of ownership of the rising, the first step was to calculate the total head [5]. To do it was necessary estimate the pipe and to calculate the suction losses and press down. The used model was the one of a foot valve and a knee of 90° for suction; a drawer valve totally open and a knee of 90° for it press down (fig. 04).

Then, applying in the equation (01) the total head and the flow rate obtained in the picked data (table I), the Requested Power for the requested flow rate (P_M) was found.

To calculate the electric potency the concept of full sun was used. It can be said that if all the daily solar energy available it was obtained under a constant radiation of 1000 W/m^2, every daily consumption should be supplied in this interval of time (full sun) [4], for the studied case, it is considered five hours of full sun a day.

The table II shows the result of the estimate of the pumping system using a group motor-bomb with efficiency of 85%. To the daily flow rate of approximately 649m^3/day, needs 11.5kW; to this it was necessary twenty-three motors of continuous current coupled to centrifuge pumps.

TABLE I

PICKED DATA ABOUT WELLS IN CAMPUS DO PICI

	Wells' Depth (m)	Wells' Diameter (m)	Static Level (m)	Dinamic Level (m)	Flow Rate (m3/h)
1	35.50	5.00	11.00	25.00	3.60
2	64.00	5.00	9.00	48.00	2.00
3	40.00	8.00	4.50	25.50	5.00
4	95.50	0.00	8.50	60.00	1.90
5	64.00	6.00	7.00	45.00	0.80
6	24.70	5.00	6.00	13.00	5.00
7	41.00	5.00	9.00	17.00	0.90
8	57.00	6.00	8.00	25.00	5.00
9	40.00	5.00	7.80	41.00	5.00
10	40.20	5.00	6.80	22.00	5.00
11	42.00	5.00	3.60	9.70	5.70
12	44.00	5.00	11.80	25.00	5.00
13	62.50	5.00	4.00	30.00	3.00
14	40.00	5.00	5.40	24.00	6.00
15	48.50	5.00	7.00	18.00	5.00
16	58.00	5.00	5.50	35.00	5.00
17	46.00	6.00	10.20	15.80	6.80
18	50.00	5.00	4.30	13.50	10.00
19	50.00	5.00	9.70	16.00	7.92
20	50.00	5.00	7.70	38.00	8.00
21	50.00	5.00	2.70	17.50	10.00
22	50.00	5.00	6.00	22.40	10.00
23	50.00	5.00	0.00	27.50	7.54
24	50.00	5.00	9.20	17.00	6.89
25	50.00	5.00	7.00	24.50	5.28

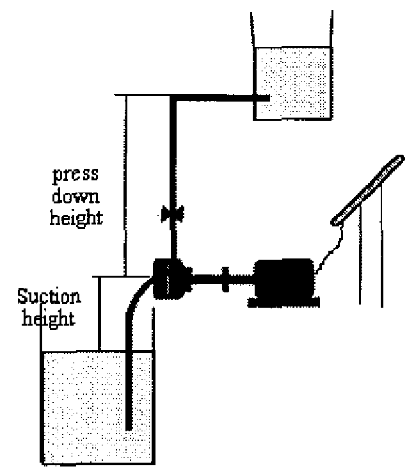


Fig. 04. Model of adopted.

TABLE II

MECHANICAL POWER REQUIRED FOR A MOTOR PUMP 85% EFFICYENTE

Daily Flow Rate	**648.63**	**m^3/day**
Power Required	**11,409.79**	**W**

Needed Motor-Pump Groups	**Power (cv)**
14	0.50
1	0.75
5	1
3	1.5

B. Photovoltaic System

The system adopted in the analysis it was the system of direct joining without batteries; such choice implicates in smaller implantation cost and lower maintenance level, just periodic verifications of the spinning and periodic cleaning of the module. It presents easy installation, because the spinning is connected directly to the motor of the pump.

Using the methodology of analyses curves of performance of the systems, normograms, to determine the nominal potency necessary PV, it was found the total value of 33.4kWp, to accomplish the pumping in all the listed wells (table I) of the case study.

C. Economical Viability

The time of capital return and the liquid present value were calculated for the water pumping system of the Campus of Pici. For each well, was considered the necessary mechanical potency for it presses down it, the electric potency of the panels PV (Wp) and the diameter of the hydraulic pipe.

The value of the investment is about of R$ 812.000,00, with an annual cost of maintenance and operation of R$ 40.600,00. The time of return of the investment, considering the annual medium expense with the company of water and local sewer of R$ 780.000,00, is of 1 year.

In the table III, can be verified that the application of the pumping PV in UFC is economically viable. The present value of the installation and of the operation and maintenance, considering the time of useful life of the system represents only 2% of the liquid present value for payment of the bills of water to the company of distribution of water of the state for the period of 25 years.

IV. Results

The Campus of Pici, that has a daily consumption of 543m^3 of water, can have your demand only supplied by the existent wells, which has capacity to supply 649 m^3. Today the totality of those wells is not almost being used.

In agreement with the financial indexes and with the found technical perspectives, the technology PV is an excellent alternative for the supply of water in the Campus of Pici, also showing that this generation way in urban areas is applicable.

Bringing for the present the value that would be paid by the bills of water of the object of case study and the total value of the investment, taking in consideration the maintenance cost and annual operation of the system PV, if maintained the pattern of consumption of water, it is arrived to an economy, at the 25 year-old end, of the order of 98%.

V. Acknowledgments

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VI. Bibliography

Books:

[1] CRESESB/CEPEL; Photovoltaic Systems: Handbook of Engineering. Workgroup of Solar Energy, Version 1.0, Brazil, 1995.p. 12-50.

[2] F. C. de Souza Neto – Program of Industrial Efficiency ELETROBRÁS/PROCEL – Pumps Module Bombas, 2003, p. 91-116 e 307-320.

[3] FUPAI, 2001; Conservation of energy: energy efficiency of facilities and equipments. – Itajubá, MG, p. 149-164.

Papers:

[4] C. B. MARTINEZ, Proposal and Evaluation of methods of photovoltaic water pump system, 2001, XVI SNPTEE.

Dissertations:

[5] M. C. Fedrizzi, : "Supply of water with photovoltaic pumping systems: simplified calculus and analysis of competitiveness for systems of small load ." São Paulo, 1997. Dissertation - Programs of Interunits of Masters degree in Energy, University of São Paulo. .

TABLE III
RESULT OF THE ANALYSIS OF FINANCIAL VIABILITY.

Proposed system		
Annual benefit	R$	779.824,50
Interest rate		0,12
Investment	R$	811.999,72
Cost of maintenance and annual operation	R$	40.599,99
Time of Return of Capital in years		1,0
Factor of Recovery of Capital		0,13
Factor of Present Value		7,84
Life time in years		25,00
Liquid Present value	R$	1.130.431,06
Current system		
I cost annual	R$	779.824,50
Present value of the cost for 25 years	R$	73.395.264,44
Percentage of VPL of the investment in relation to VPL of the cost with supply of water during the 25 years of useful life of the system		2%

VII. Biographies

Leila Cristina Jovina da Silveira was born in Teresina, Brazil in December of 1978. Graduate in the Federal University of Ceará - UFC in 2003 in Electric Engineering and doing master degree since January of 2004. During the graduation, participated in group of study of alternative sources of electric power, especially wind power. Actually is member of PROCEN - Electric Power Consumption Efficiency Program of UFC and study conservation of energy and alternative sources of energy.

Adriano Holanda Perreira was born in Fortaleza, Brazil in June of 1977. Technician in Electricity and Electronics, Graduate in the Federal University of Ceará - UFC in 2003 in Electric Engineering and doing master degree since January of 2004. Actually is member of PROCEN - Electric Power Consumption Efficiency Program of UFC and study the area of industrial energy efficiency and potency electronics.

Adson Bezerra Moreira was born in Fortaleza, Brazil in September of 1979. Graduate in the Federal University of Ceará - UFC in 2003 in Electric Engineering and doing master degree since January of 2004. Actually is member of PROCEN - Electric Power Consumption Efficiency Program of UFC and study conservation of energy and alternative sources of energy.

Celso Rogério Schmidlin Júnior was born in Guaratuba, Paraná, Brazil, in March of 1980. He graduated in the year of 2003 in Electric Engineering, with emphasis in Systems of Energy, in the Federal University of Ceará. Now it is studying master's degree in the area of Energy Efficiency in the same university.

Paulo César Marques de Carvalho, was born in April of 1963 in Fortaleza, Doctor for the University of Paderborn - Germany 1993-1997, Teacher of the Department of Electric Engineering of the Federal University of Ceará. Researcher in the area of Systems of energy, with several publications in the area of photovoltaic and wind power generation.

Tomaz Nunes Cavalcante Neto was born in September 1954 in Fortaleza, Brazil. Master in electric power Distribution in the University of São Paulo, teacher of the discipline of electric power conservation and coordinator of PROCEN - Electric Power Consumption Efficiency Program of the Federal University of Ceará.