DC-AC CONVERTER FOR STAND-ALONE SOLAR SYSTEMS WITH SUBMERGED VIBRATORY PUMP

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***Abstract* – This paper presents a dc-ac converter fed by photovoltaic solar energy with the objective of ac submerged vibratory pump used in the water pumping. The converter is composed of two stages. The first stage is formed by a converter boost of three states with high gain and high efficiency. In this converter is used a technique of control that it search to follow the maximum power point (MPPT) to obtain a more efficient conversion. The second stage is formed by a full-bridge voltage inverter. The inverter operates in low frequency with a strategy of conventional modulation PWM and with fixed width of pulse, to minimize the losses. An efficiency global average of 90,5% is obtained. Qualitative analysis and experimental results, obtained of a prototype of 400W, are presented.**

***Keywords* – Vibratory pump, Boost, Solar Energy**

I. INTRODUCTION

The water supply for countryside population, especially on northeast of the Brazil, presents many problems. Nowadays, the water supplied on many remotes communities, done by water trucks, has reasonable quality and high cost price. The water pumping on these areas is related the availability of the energy resources and that in many cases, it does not have conventional electricity.

Photovoltaic generation has an important way to social development of many regions and it is a competitive solution. Many advantages of this solution can be showed: the durability, about 20 years for photovoltaic panels and 3 years for batteries, trustworthiness, low maintenance, and principally the fact of it are being renewable and clean.

The objective of the proposed converter is supply a water pumping system, based on a vibratory submerged pump which will be functional during a few hours a day. The whole system is supplied just by photovoltaic cells with no backup batteries.

II. STUDY CASES

Water pumping may be done by different ways. The vibratory submerged pump was chosen for this application by its low cost, simplicity, robustness, the pumping capacity in deep waters and its can be easily found in all regions of Brazil. The pump used on this project and its equivalent electrical model was showed on fig 1.

It is internally constructed by two magnetic pieces: a fixed piece and the piece that vibrates. The fixed part is the core of the inductor and the mobile part is connected to a rubber diaphragm that is responsible by pump water. The magnetic field, created by current flow moves this diaphragm on the applied frequency. On this kind of pump, the outflow of the water depends on the applied voltage. Thus, even on low voltages, the pump stills working with a smaller outflow and draining a small current. This behaviour is interesting because the system can be work on situations of low solar irradiation.

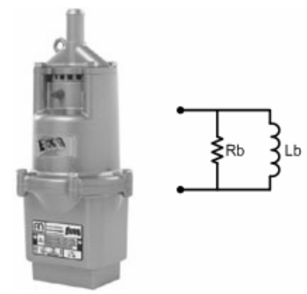

Fig. 1. Pump equivalent electrical model.

On the fig. 1, the value of Lb and Rb represents the inductance and the resistance of the pump and they can be calculated by (1) and (2) respectively, applying on the terminals one sinusoidal voltage [1].

$$Rb = \frac{Vb}{Ib \cdot \cos\varphi} \tag{1}$$

$$Lb = \frac{Vb}{2 \cdot \pi \cdot f \cdot Ib \cdot \sin\varphi} \tag{2}$$

Where:

Vb – rms voltage;
Ib – rms current;
Φ – angle between voltage and current;
f – voltage frequency;

On the table 1 were showed the electrical characteristics of a commercial vibratory pump of 300W.

TABLE I
Electrical characteristics

Model (Anauger ECCO)	
Power	300W
Voltage	220V
Current	5,5A
Power factor	0,27
Frequency	60Hz
Maximum depth	50m

A current-fed parallel resonant push-pull inverter was used to feed the pump system proposed in [1]. Their circuit is showed on the fig. 2.

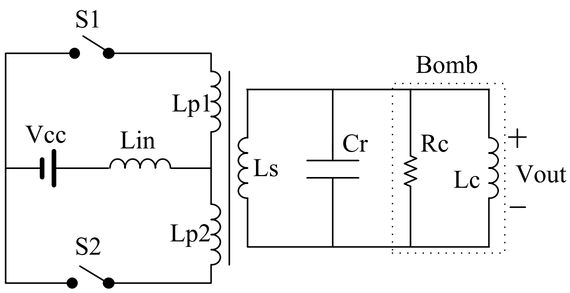

Fig. 2. Converter proposed in [1].

An elevator transformer, two switches, an input inductor Lin and a resonant capacitor Cr in parallel with the load, forms the inverter. The converter is a PWM controlled at 60 Hz frequency, same as the classical push-pull converter. A self-resonant circuit with two auxiliary windings adds to the transformer makes the control. The system is supplied by a bank of batteries that is charged by solar energy through a charger controller without MPPT. The efficiency of the converter is around 80% and the transformer is the major source of losses.

The topology proposed in [2] consists on push-pull voltage inverter with output transformer. Their circuit is shown in Fig. 2. In this system, PV array fed the inverter. The vibratory pump is connected in the secondary transformer, in parallel with the Cr capacitor. The capacitor is used to supply reactive power of the pump. The isolate transformer adapts the nominal output voltage of the pump.

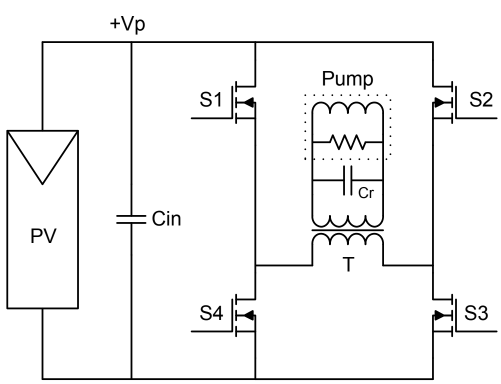

Fig. 3. Converter proposed in [2].

The MOSFET's operates in low frequency with S1/S3 or S2/S4 being simultaneously commuted.
The control acts in order to keep the output voltage in the nominal value, in function of the Vp input voltage. The control does not use MPPT technique and is formed by a PIC microcontroller, that makes the reading of the output voltage, having supplied a PWM signal to the interruptors with width of pulse controlled in function of the Vp voltage.
This topology does not use batteries. With this, it does not allow the pumping in conditions of low radiation. On the other hand, it eliminates the necessity of a auxiliary circuit for to load the batteries and requires little maintenance. The efficiency with this topology is of 86%, being the transformer the source of losses.

III. THE PROPOSED STRUCTURE

Ahead of the presented systems previously, it was opted to developing a converter that presents high efficiency, little maintenance and low cost. The converter topology proposed is shown in Fig. 4. This is composed by two stages. The first stage consists on boost converter with high voltage gain and high efficiency [3]. In second stage a full-bridge voltage inverter is used. The inverter operates in 60Hz and to set in motion the pump using conventional PWM modulation.

A. PV array

In the prototype, a PV array composed by eight Siemens SM55 panels was used (available in laboratory) [4], being connected in a series-parallel configuration, as shown in detail in Fig. 5. Each panel own a nominal power of 55W, in the conditions test standards (1000W/m2; AM=1.5, 25ºC).

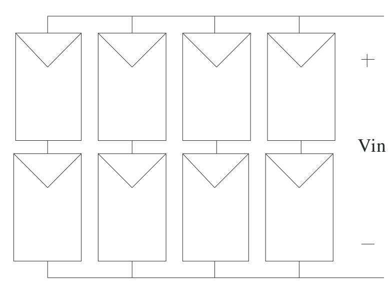

Fig. 5. PV array.

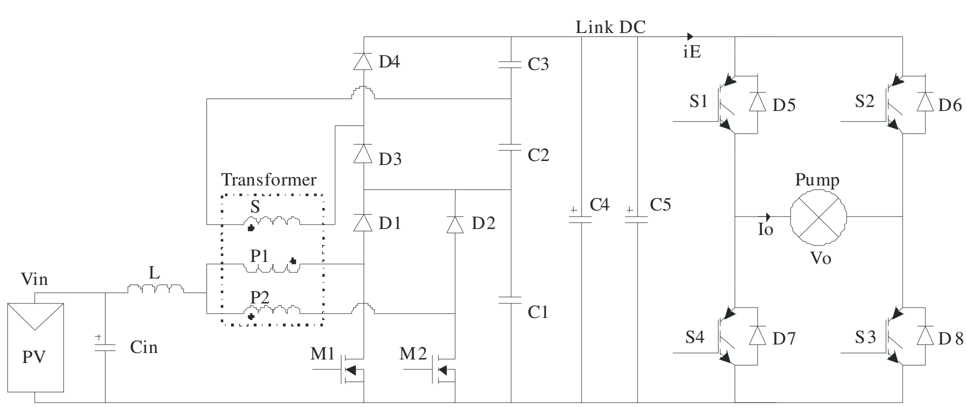

Fig. 4. The proposed structure.

B. The boost converter

The boost converter is responsible for the MPPT and adjusting the voltage of the PV array to the voltage of the dc link inverter. The boost operates in continuous conduction mode (CCM) and the interruptors duty cycle D is always bigger than 0.5 and out of phase of 180º. The main theoretical wave forms of the boost converter are shown in Fig. 6.

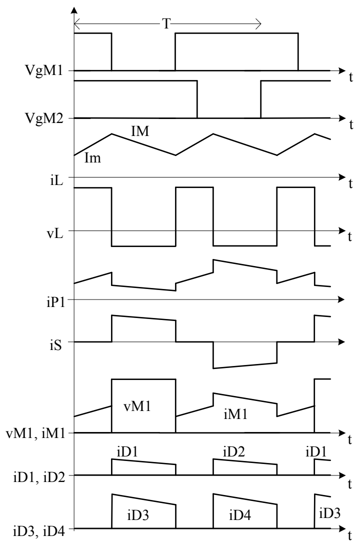

Fig. 6. Theoretical wave forms of the boost converter.

The static gain Gv, defined by relation between the output voltage and input voltage, is given in (3).

$$Gv = \frac{n+1}{1-D} \tag{3}$$

Where:

Gv – Static gain;
n – Turns relation;
D – Duty cycle;

Fig. 7 shows the voltage gain in function of the duty cycle, being taken as parameter, the relation of the turns of the transformer.

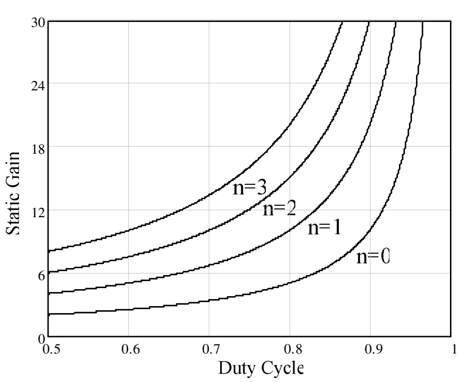

Fig. 7. Static gain curves of the boost converter.

C. MPPT control

The generated energy for a PV array depends directly on the operation conditions (radiation, temperature and aging). The MPPT circuit is added to the control of the converter boost, thus optimizing the operation point and improving the efficiency of the photovoltaic array. The control is implemented with the aid of a PIC16F877 microcontroller. The MPPT technique is based on the Perturb and Observe algorithm (P&O), this algorithm was chosen by being of easy implementation and good efficiency [5]. The flowchart of the control circuit is showed on the Fig. 8, where Vo and D represents to the output voltage and the duty cycle, respectively. The method consists of periodic increments or decrements of the duty cycle of the interruptors of the boost converter. If one given perturbation leads to an increment (decrement) of the output voltage of boost, then the subsequent perturbation is generated in same (opposing) direction.

In the considered converter, the output voltage of the boost converter is used as parameter to determine the maximum power. The bigger the voltage applied to pump, the greater is the drained power of the photovoltaic array. In this way, the control tries to keep the output voltage in the biggest possible value, making with that the pump operates with the maximum outflow, inside of allowed the maximum values of voltage.

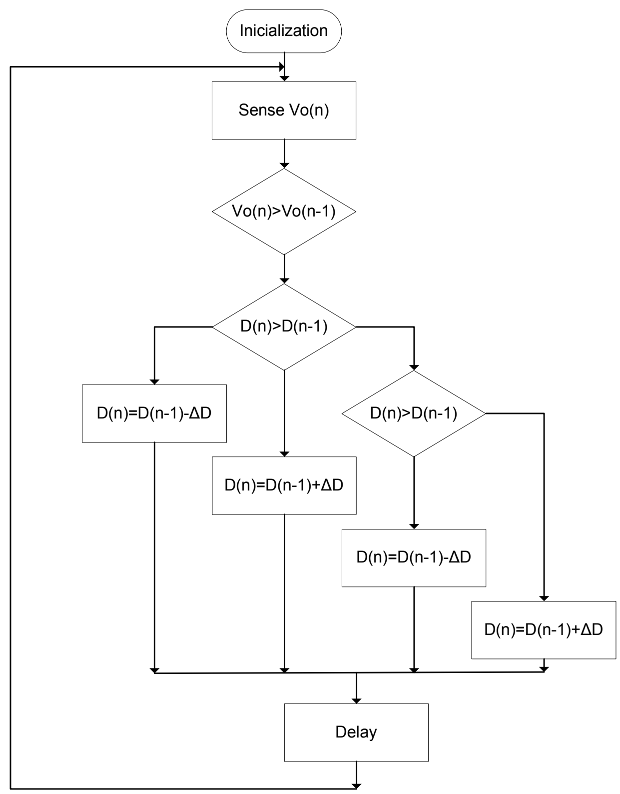

Fig. 8. The P&O algorithm flowchart.

C. DC-AC converter

On the second stage, a full-bridge inverter is used. The control is simple, and its works switching on the pair of IGBT1/IGBT3 or IGBT2/IGBT4 during a shorter period of time that half commutation period. The theoretical wave forms of the inverter are showed on the Fig. 9.

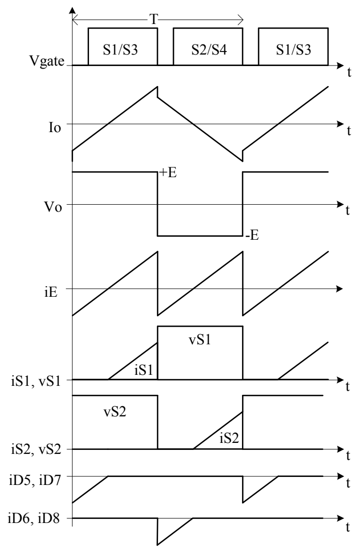

Fig. 6. Theoretical wave forms of the dc-ac converter.

Due to the inductive characteristic of the pump is necessary the use of capacitors to supply the reactive energy to them. Hence, is connected a capacitor bank on the link DC, in this manner, the inverter processes all apparent power of the pump.

IV. EXPERIMENTAL RESULTS

The experimental results show relevant currents and voltages on main points of the circuit. It also shows the global efficiency curve of the system (Boost + Inverter). A prototype was developed on laboratory to validate the efficiency of the system proposed.

A. Specifications

The basic converter specifications to the project are on the table II.

TABLE II
Specifications of the converters

Specifications			
Boost Converter		**Inverter**	
Po = 400W	Output power	Po = 400W	Output power
Vin = 34V	Input Voltage	Vin = 220V	Input Voltage
Vo = 220V	Output Voltage	Vo = 220V	Output Voltage
f = 25KHz	Commutation frequency	f = 60Hz	Commutation frequency

B. Waveforms

On the Fig. 10 is presented the input voltage Vin and the current drained from the photovoltaic panels where a 60Hz ripple is noticed. The input voltage and the inductor current can be viewed on Fig 11. On this same picture a 20% inductor current ripple is presented. The Fig 12 presents the bus voltage and the input current of the inverter where the negative parcel of this current corresponds to a reactive current due to the inductive load. The Fig. 13 shows the output voltage of the inverter Vo and the current Io on the pump and the symmetry for each semi-cycle can be observed.

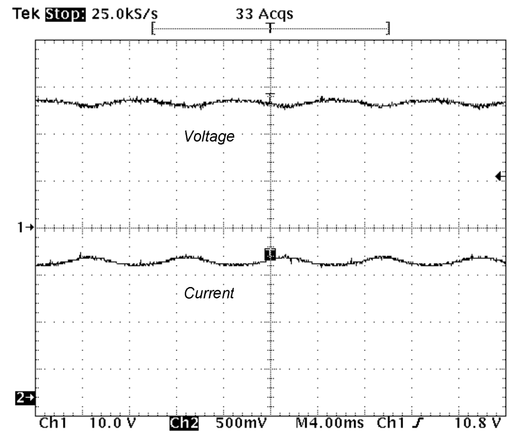

Fig. 10. Voltage and current of the PV array. (10V/div.; 5A/div.; 4ms/div.)

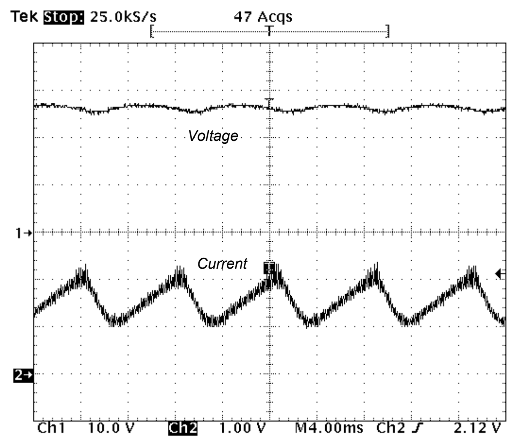

Fig. 11. Voltage and current of the input boost. (10V/div.; 10A/div.; 4ms/div.)

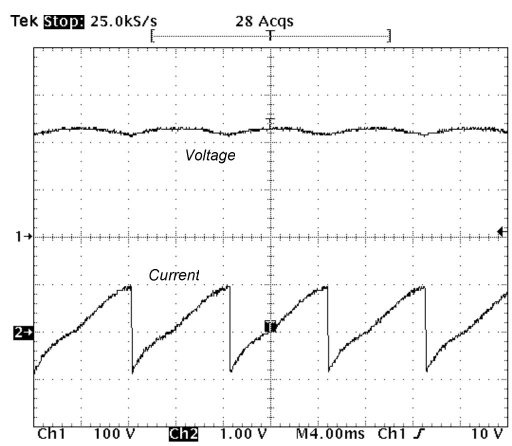

Fig. 12. Voltage and current of the input inverter. (100V/div.; 10A/div.; 4ms/div.)

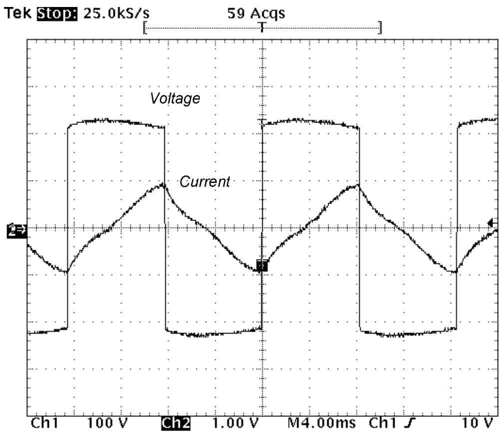

Fig. 13. Voltage and current of the pump. (100V/div.; 10A/div.; 4ms/div.)

The Fig 14 shows the converter efficiency curve (boost + inverter) in function of the output power using the vibratory pump as load. This curve was drawn to different levels of radiation.

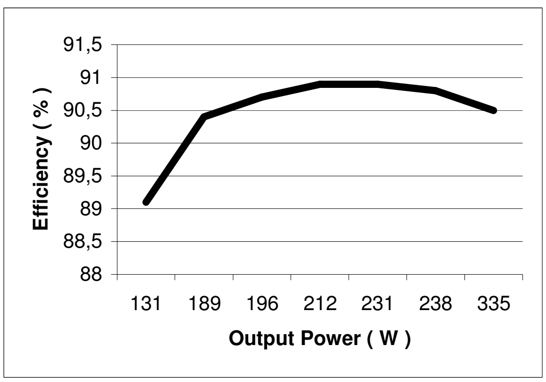

Fig. 14. Efficiency curve.

B. Components

The main components used on the prototype are listed on the table III. The freewheels diodes of the inverter are inside on the IGBT's.

TABLE III
Components used in prototype.

Boost Converter	
Mosfet's (M1, M2)	IRFP260
Diodes (D1, D2, D3, D4)	15ETH06
Commutation Frequency	25KHz
Inductor (L)	100µH NEE-42/21/15 NL=24 turns
Transformer	turns ratio = 1 NEE-42/20
Input Capacitor (Cin)	10mF/100V
Output Capacitor (C1, C2, C3)	220µF/250V
Inverter	
IGBT's (S1, S2, S3, S4)	GP50B60PD1
Frequency	60Hz
Input Capacitor (C4, C5)	680µF/400V
Diodes (D5, D6, D7, D8)	Inside IGBT's

V. CONCLUSION

On this paper was proposed a cc-ca converter to supply a vibratory pump from photovoltaic panels, contributing on this way, as the solution to water catering on remotes communities without any electrical network. This system can be used to pumping water on artesian shafts and than stock on reservatories to human consummation or irrigation.

The vibratory submerged pump was chose because its advantages: it is common on the market, cheap, has a good durability and it is well adapted to this kind of work.

The use of magnetic elements on high frequencies, inductors and transformers, leads the converter to 90% efficiency on average. The output power of the photovoltaic panels is maximized using an algorithm of MPPT control that try to keep a maximum voltage on the pump terminals.

The most important disadvantage on the pumping through the photovoltaic generation, principally on countries in development resides on the high initial cost. On this system, the high initial cost of photovoltaic panels can be compensated by its very low cost of the maintenance, reliability and robustness.

ACKNOWLEDGEMENT

We are thankful to FUNCAP (Fundação de apoio a pesquisa) by the financial support and also GPEC (Grupo de Processamento de Energia e Controle) laboratory of the Departamento de Engenharia Elétrica-UFC for the components, equipments and support.

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