PHOTOVOLTAIC INVERTER CONTROLLER FOR PUBLIC LIGHTING SYSTEMS

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Abstract - **In this paper, the development, implementation and test results of the conditioning and advantageous use of PV energy in public lightening systems is presented. Such a system is composed by a charge and discharge controller, a photocell and an inverter. Solar energy is transformed into electricity by means of a photovoltaic module that charges a battery. The charge and discharge controller verifies the battery's voltage level connecting it or not to the panel and/or load, thus assuring its life term. At night, the inverter push-pull type is started by the photocell energizing a compact fluorescent lamp. The controller, transistors' switching and photocell circuits were designed with operational amplifiers using hysteresis loop configurations, Schmitt trigger NAND gates and type-D flip-flops. Implementation strategies and characteristics are described and a comparison with commercial systems, concerning its simplicity, easy building and relative low cost, is also done. A prototype test is used to evaluate the project's performance.**

KEYWORDS

Public lighting; photovoltaic energy; low cost inverter.

I. INTRODUCTION

Public lighting in downtown is a very important service which contributes greatly for welfare, and it is so present in the city that it became almost common place. But when applied to countryside isolated areas which population has seldom access to electric energy, it turns out to be relevant, not as novelty, but mainly because it contributes to the improvement of the social dimension and quality of life of those communities.

Solar photovoltaic technologies appear as leading alternatives in supplying energy for almost isolated rural populations, once it is abundant, predictable, renewable and not pollutant.

Therefore, the main barrier for the diffusion of that technology is the equipments and replace parts high price. In that context, the developing of a technology envisaging the use of solar photovoltaic energy at fair reduced costs together with improved performance, has induced several researchers to work on the topic.

As to improve the performance of public lighting photovoltaic frames, several papers have been issued, such as: a lighting system with inverter and battery charger that seeks for the maximum power point based upon a micro-controller [1]; a charge controller and an inverter for compact fluorescent lamps with MOSFET[2] based symmetrical sinoidal waveform; a high frequencies E-class resonant inverter for fluorescent lamps [3]; and the implementation of a system that includes a battery controller that seeks the maximum power point.[4]

The aim of this study is to report the implementation and tests results of a project composed by the battery's charge and discharge controller, the photocell and the inverter for square wave generation, applied to public lighting with compact fluorescent lamps, PL. The implementation strategy and its characteristics faced with commercial systems are described, as well as its easy building, simplicity and relative low cost. The project performance is evaluated by means of a set of prototype tests.

The paper is organized as follows: first, the lighting photovoltaic system is overviewed. Next, the proposed project idea is developed. Finally, experimental results for validation, economical viability analysis and conclusions, are presented.

II. PHOTOVOLTAIC SYSTEM FOR PUBLIC LIGHTING

A typical public lighting photovoltaic system (Fig.1) is composed by the following parts. 1 – Solar Module; 2 – Batteries; 3 – Battery's charge and discharge controller; 4 - Photocell; 5 – Lamps; 6- Lamp-post (not shown).

All the components cited above are commercially available. However, some of them (as for example the controller, the inverter and the photocell) were not designed specifically to be used in public lighting. So, their characteristics go beyond the ones needed for that effect, fact for which its price is higher.

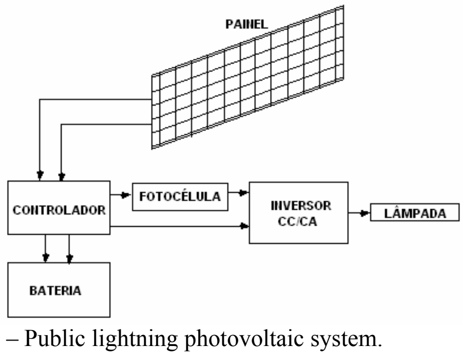

Fig. 1 – Public lightning photovoltaic system.

A. *The Proposed System*

A monoblock equivalent system - in bold lines in Fig. 2 - including a controller, an inverter and a photocell, henceforth dubbed kit, in this paper. Fig. 3 shows the kit's architecture inside the dotted line.

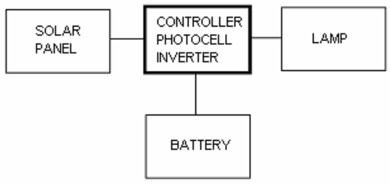

Fig. 2 - Proposed Public Lighting Photovoltaic System.

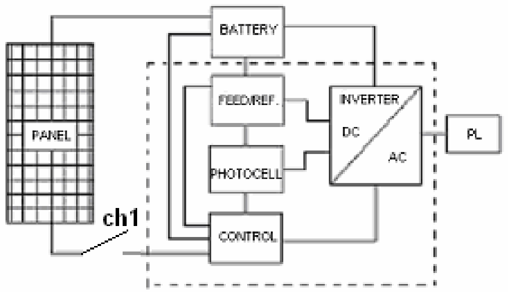

Fig. 3 - Kit's Functional block inside the dotted lines.

III. IMPLEMENTATION STRATEGY

The selected strategy has allowed the implementation of some functions such as: hysteresis loop, switching, square wave (two, with 180º gap between them), logic control and a reference voltage.

Fig.

A. Reference voltage and power supplying

Control circuits as well as the inverter and the load (PL lamp) are powered by the batteries, which voltage varies according to the charge/discharge cycling.

To cope with it, a voltage reference, Vref, was implemented, as shown in Fig. 4. Thus, the control circuit responses are not affected by the Vbat (battery voltage) fluctuations.

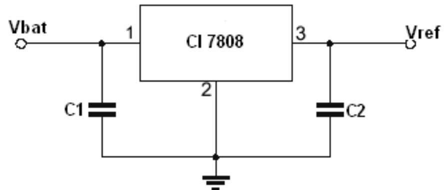

Fig. 4 - Power suppling and reference voltage.

B. *Charge and discharge controller*

The charge and discharge controller, Fig.5, is directly responsible by the battery's life term duration. Its function is to check the voltage level and from there on connect or disconnect it to the PV module and load (lamp). The circuit operation is based upon comparison with hysteresis loop, using operational amplifiers.

The hysteresis loop shown in Fig. 6 are summarized the controller operation principle. It works by switching a MOSFET which turns on or not the solar module when the voltage in the battery reaches 13,7V, re-switching it only when the voltage is 12,5V. It also turns off the inverter (and thus the lamp) disabling the oscillator whenever the battery voltage is less than 11V, only resetting the system when the voltage resumes to 12V. This procedure increases the battery's life term, avoiding its overcharging or full discharging.

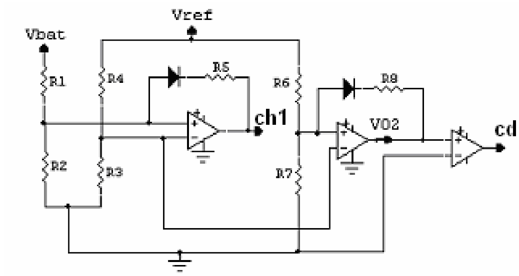

Fig. 5 - Controller's charge and discharge circuit.
- ch1: charge controller
- cd : discharge controller

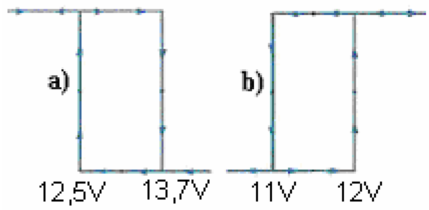

Fig. 6 - Hysteresis loop: a) for charge control; b) for discharge control.

C. Photocell

In Fig.7 is shown the photocell circuit, implemented with a photodiode, replacing the traditional, and more expensive, LDR based system, This circuit, acting together with the discharge controller, lets the lamp be energized only when the battery is charged, and it is limited to the evenings and dawns, that is between 6h PM. and 6h AM. Table I shows the lamp's state in accordance with the signals sent by the controller and the photocell.

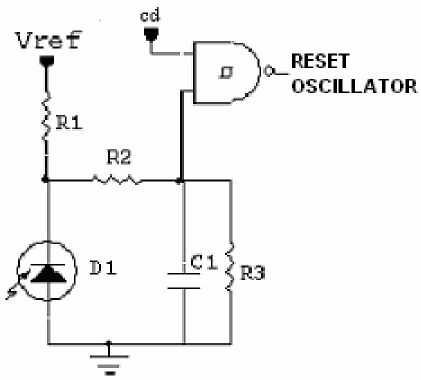

Fig. 7 - Photocell circuit.
- cd : discharge controller.

Table I
Lamp state in accordance with the signals sent by the controller and photocell.

Period	Battery	Disable	Lamp
Day	Charged	1	Turn off
Day	Discharged.	1	Turn off
Evening	Charged	0	Turn on
Evening	Discharged.	1	Turn off

D. The Inverter and its working principle

In order to implement the inverter it was selected the push-pull technology with low frequency switching, Fig. 8, as for its simplicity and economy. Its functioning is based upon the alternate closing/opening operation of the S1 and S2 switches, generating an AC voltage in the transformer's output coil primary (the primary coil).

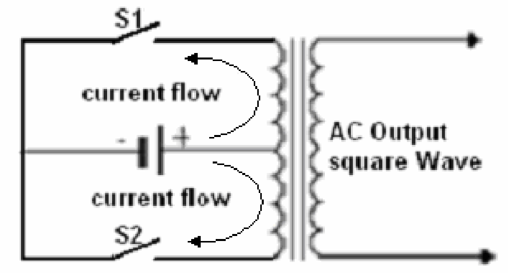

Fig. 8 - Push-pull scheme.

Switches S1 and S2 were implemented with field effect transistors, FET, due to their reduced loss level by Joule effect. The switches' control was implemented with NAND and D-FFs logic circuits, generating two square waves with 180º phase shift between them. Fig. 9 shows the simplified inverter diagram with the oscillator circuit.

An important characteristic of the implemented inverter is its ability to be applied to conventional fluorescent lamps as well as to the ones containing PL embedded electronic ballast, as opposed to the ones used only with 4 screw PL lamps. Besides that, it can readily be used with a commercial voltage transformer available in the electronic market.

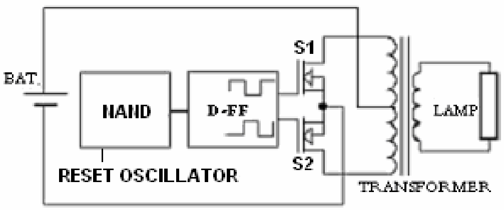

Fig. 9 - Simplified Inverter Diagram.

IV. EXPERIMENTAL RESULTS

The developed prototype was submitted to a severe set of tests and measurements in field and laboratory, such as:

- Charge and discharge controller performance tests;
- Inverter and photocell performance tests.

The charge and discharge test of the controller was done at the laboratory by using either a variable voltage source (which simulates a photovoltaic module) and a lead-acid battery. The controller responded according to Fig. 6 transition points. Field tests were done with a 75Wp, Vmax=21.7V, Isc=4.8A solar module, and 45Ah lead-acid battery, proving, in this case, the lab results. In Fig.10, it is shown the lab inverter's test diagram

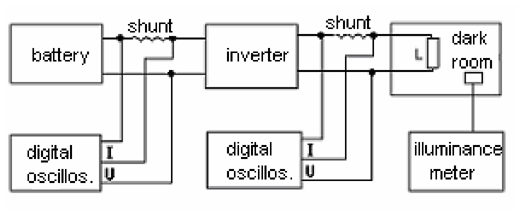

Fig. 10 - Inverter Test Diagram.

Measurements and analysis of battery current and voltage were done. The same was done with the inverter current and voltage output, connected to a compact fluorescent 15W lamp. Luminance tests were also done.

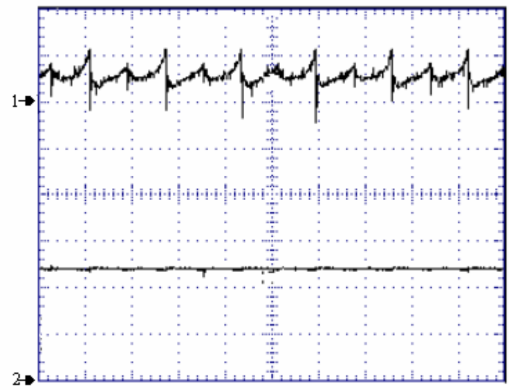

Fig. 11 - Current and voltage Battery wave form
- 1: CH1 2,27A/DIV 10ms
- 2: CH2 5V/DIV 10ms

Fig.11 shows the battery's current and voltage wave form. Current spikes are clearly noticeable followed by the consequent ripple coming up in the voltage; problem that could cause battery heating, embarrassing its life term [5]. Nevertheless, once it is the case of a low power inverter, the observed spikes were of the order of only 3 Ap-p.

In Fig. 12, is shown the inverter's fully symmetrical wave form. No spikes and overshoots are observed, fact that does not alter the lamp life term.

In general, the lamp positive ions (mercury molecules) pose higher momentum than the electrons. This produces damage in the negative potential lead, which becomes visible by the appearing of a black shadow in the lamp just by the side of the referred terminal. In the case of a symmetrical waveform the damage due to over voltages is equally shared by the lamp filaments. Nevertheless, when the wave form is asymmetrical, one of the filaments is much more affected than the other, thus reducing the lamp's useful life. [6]

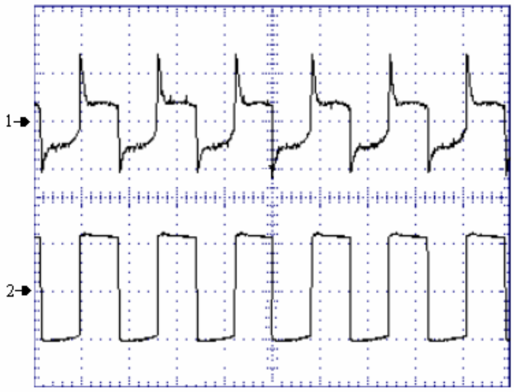

Fig. 12 – Output of current and voltage inverter wave form.
- 1: CH1 100mA/DIV 10ms
- 2: CH2 200V/DIV 10ms

The luminance efficacy (LUX/ W) was done with a compact fluorescent 15W lamp, either by using the inverter or the utility energy. As a result the inverter showed a 90% luminance efficacy, when compared with the one got by means of the area utility.

Photocell and inverter set, after passing laboratory test, is under field evaluation for about six months, meeting satisfactorily its functions with an 11W fluorescent compact lamp. This kit is settled and maintained by the Núcleo de Energias Alternativas (NEA) in the yard of the Centro de Ciências Exatas e Tecnologia, Universidade Federal do Maranhão.

V. CONCLUSIONS

The Project implementation became very simple due to the strategy that implied the using of only 4 ICs and some passive components, easily found in the market. This leads to a compact kit relatively cheap, close to 85% (not included the circuit board and the conditioning box), when compared with commercial similar. In addition, the luminance efficacy of about 90% is just worth full because of the own transformer efficiency is also about 90%.

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