European Association for the Development of Renewable Energies, Environment and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality
(ICREPQ'10)
Granada (Spain), 23th to 25th March, 2010

Off-Grid PV System to Supply a Rural School on DC Network

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Abstract.

This paper presents the development of a photovoltaic (PV) system to supply electric energy to a typical rural school in the countryside of the sunny Northern East of Brazil. The system is designed to supply a rural school for up to two days, even under minimum solar radiation conditions. The solar energy is captured by PV panels and stored in lead acid batteries. The solar battery charger (A boost converter) extracts the maximum power from the PV panels for any radiation. The load is supplied through a high gain boost converter (24 Vcc to 311 Vcc) and the entire system is controlled by a microcontroller, which runs the MPP algorithm, monitors the charge state of the batteries and controls the operation of the DC/DC boost converter according to the load demand.

Key words

PV, Isolated System, Rural Electrification, Lighting.

1. Introduction

This paper presents a pilot project of an off-grid PV system suitable for isolated areas where the cost to extend the electric utility is prohibitive. The system was designed to guarantee a safe supply of clean electric energy to rural loads, and also to demonstrate the technical and economic feasibility to supply the load in DC voltage.

The system is designed to supply a rural school for up to two days, even under poor solar radiation conditions. The solar energy is captured by PV panels and stored in lead acid batteries. The battery charger (a boost converter) extracts the maximum power from the PV panels at any solar radiation. The load is supplied through a high gain boost converter (24 Vdc to 311 Vdc) and the entire

system is controlled by a microcontroller, which runs a Maximum Power Point Tracker algorithm, monitors the charge state of the batteries and controls the operation of the DC/DC boost converters according to the load demand [2].

The system is composed by three parallel 130 Wp PV modules, a 24 V battery bank of four 150 Ah batteries (two strings in parallel and each string made up by two units connected in series), a battery charger of 600 W and a 500 W boost converter to supply the loads with the required voltage.

2. Stand-alone systems configurations

There are 3 kinds of combinations for stand-alone systems: simple DC system, system with DC/AC converter and system with DC/DC converter.

The simplest autonomic system is the one, where only one converter exists that loads the battery. After the batteries the load is directly connected. This means, that the loads have to be working with 12 or 24 Vdc, usually [4].

The system shown in Figure 1 has only the power loss in the first converter.

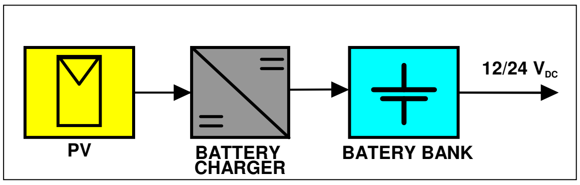

Fig. 1. Simple DC system, output: 12/24 Vdc.

To connect also AC loads a DC/AC converter behind the battery bank is needed, as shown in Figure 2. This is also the most commonly used system. With this converter, the system could one day be connected to the grid, if wished. Unfortunately, the DC/AC converter is not only expensive, but also shows a great power loss, which would mean, that the PV Panels and the Battery need to produce and store power just for the converter use [4].

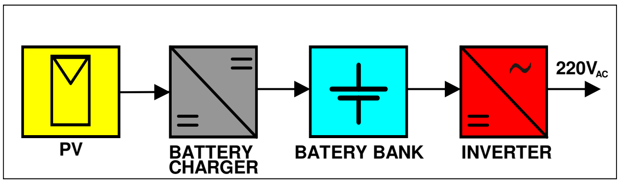

Fig. 2. System with DC/AC converter, output: 220 Vac.

Since in most rural areas in Brazil are unlikely to ever be connected to the grid, and good DC applications already exist, the DC/AC converter in comparison with the simple DC system is not advisable [4].

The big disadvantage of the simple system is the power needed for illumination. This problem can be avoided, by using energy saving lamps. Those need either 220 Vac or 311 Vdc to function. For this, a DC/DC converter boost can be installed as shown in Figure 3.

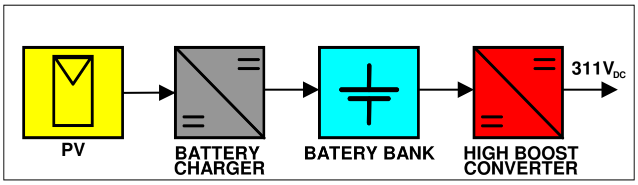

Fig. 3. System with DC/DC converter, output: 311 Vdc.

3. The proposed solar home system

The proposed system is shown in Figure 4, and is able to supply a rural unit with the following loads: 6 electronic lamps of 23 W each, a television set of 48 W, a parabolic antenna of 20 W for long distance TV signal, a portable sound system of 10 W, a DVD of 20 W, and a mobile phone charger of 10W.

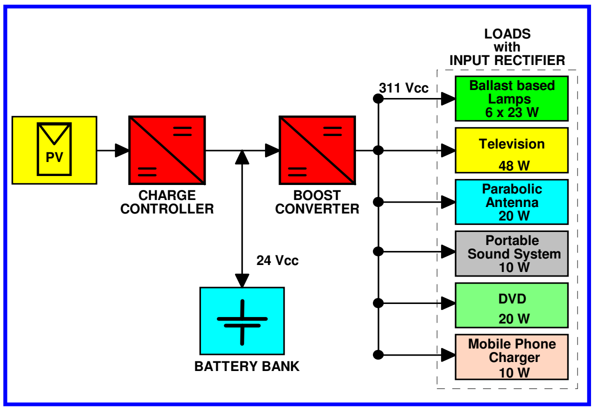

Fig. 4. The proposed system.

4. The battery charger

The battery charger has the function of providing energy to a battery bank under controlled voltage and current, in order to improve the service lifetime of the battery bank. This energy is provided by solar panels which are capable of converting solar radiation into electricity [1].

Aiming to reduce the initial investment cost, it is important to draw the maximum power of the panel. The energy produced by the panels depends on the ambient temperature, solar radiation intensity and also on the characteristics of its load. If one or more of these parameters are modified, the produced power can be significantly changed. So, it is necessary to use a control system in order to adjust the dynamic electric impedance of the battery bank to the best operation point of the PV panels (MPP) [1]. In the implemented prototype, a microcontroller was used to control the battery charger and to implement the MPP algorithm.

The battery charger is composed by a digitally controlled boost converter. The battery bank can be considered as a fixed voltage source. This characteristic allows the system to achieve the maximum MPP operation by just observing the current of the battery bank [1]. The electric circuit of the proposed battery charger is shown in Figure 5. A photograph of the implemented prototype is shown in Figure 6.

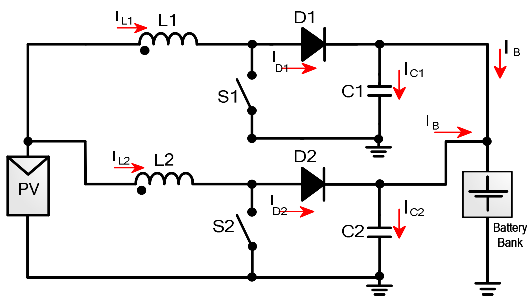

Fig. 5. Basic electric schematic of the battery charger.

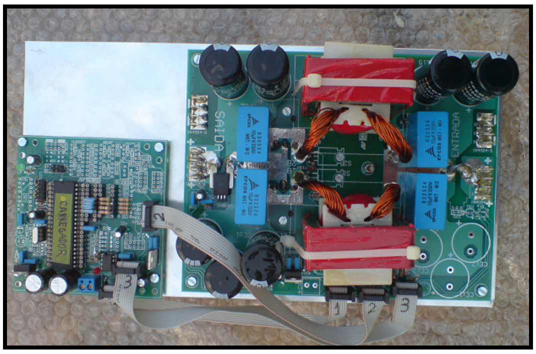

Fig. 6. Battery charger prototype.

5. The boost converter

The boost converter has the function to boost the 24 Vdc from the battery bank to 311 Vdc, which is required by the loads. Several topologies of boost converters are presented in the technical literature. However, when a high voltage gain is required (in this case, more than 13 times), most of the topologies are prohibitive, due to switching losses and poor utilization of the power switches (i.e., combination of high current and high voltage) [5].

The topology adopted in this work is based on a coupled inductors, what makes it possible to reach a high step up voltage without stressing the power switches; this is a key point to achieve high efficiency and robustness of the converter, characteristics that are of major importance when processing electric energy for renewable energy sources, mainly from a PV conversion [3],[7].

The basic electric circuit schematic of the proposed boost converter is shown in Figure 7 and a photo of the implemented prototype is at Figure 8.

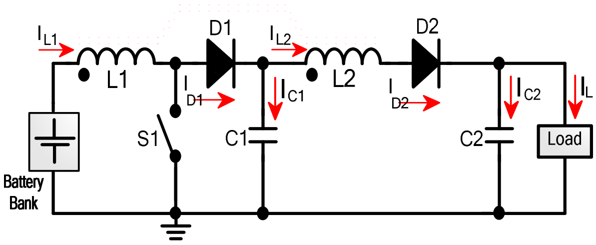

Fig. 7. Electric schematic of the boost converter.

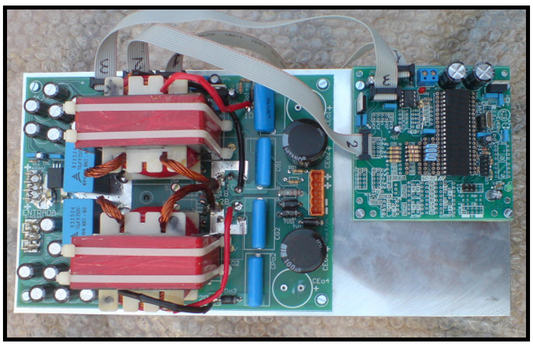

Fig. 8. Boost converter prototype.

6. Experimental results

A photograph of the implemented laboratory converter is shown in Figure 9. The results of the preliminary test of the prototype (with a 330W load) are presented in this topic.

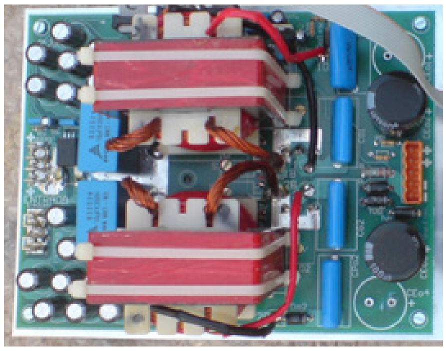

Fig. 9. Top view of the boost high-gain.

The voltage waveform across the power switch for the converter operating with load is shown in Figure 10.

When the converter operates with load, the voltage across the power switch presents some overshoot when it is switched off. This voltage overshoot is due to the sudden charge of the snubber capacitor, which occurs due to the dispersion inductance of the coupled inductor.

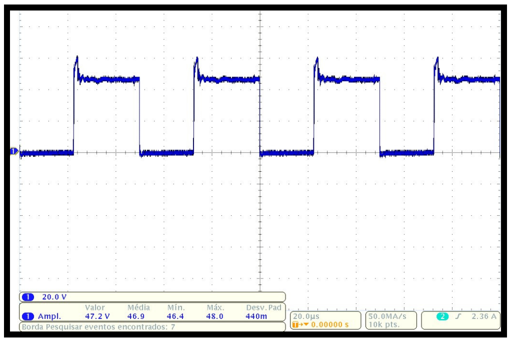

Fig. 10. Voltage across the power switch (with load) (20V/div).

Figure 11 shows the current through L1 and the voltage across the power switch. It can be noticed that the variation of the inductor current is almost linear

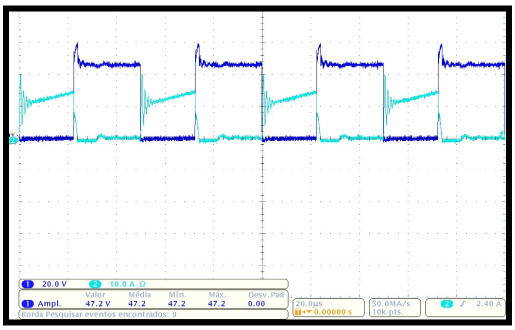

Fig. 11. Current through L1 (CH2) and voltage across the power switch (CH1). (20V/div), (10A/div)

The voltage across the power switch, the current through L1 and the current across inductor L2 are shown in Figure 12. As expected, it is possible to notice that I_{L2} is discontinuous. It can also be seen the linear variation of I_{L2} during the second operation cycle (discharge of the coupled inductor).

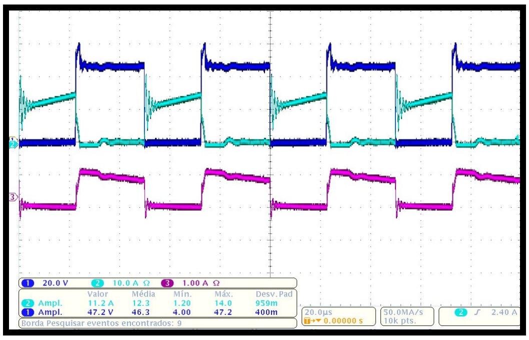

Fig. 12. Current through L1 (CH2), L2 (CH3) and voltage across the power switch (CH1). (20V/div), (10A/div and 1A/div).

Figure 13 shows the input current, in the other words, the current in batteries. Can see that the current is practically constant.

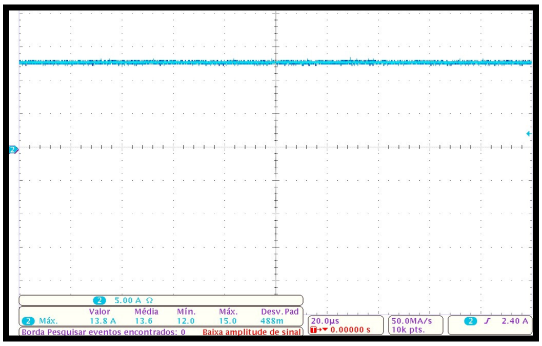

Fig. 13. Input current (into the battery) (5A/div).

The Figure 14 shows the output voltage, where it can be seen it is around 311V and its ripple is low

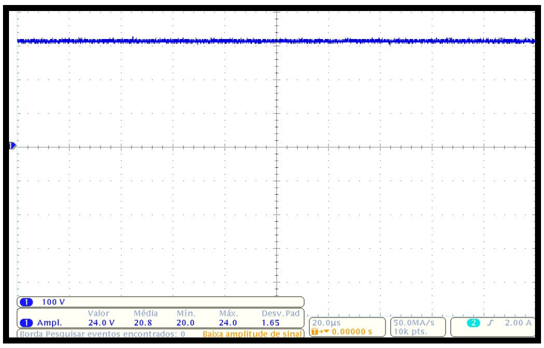

Fig. 14. High gain boost converter output voltage (100V/div).

Finally, Figure 15 shows the converter efficiency, where the value average of this efficiency is 93%.

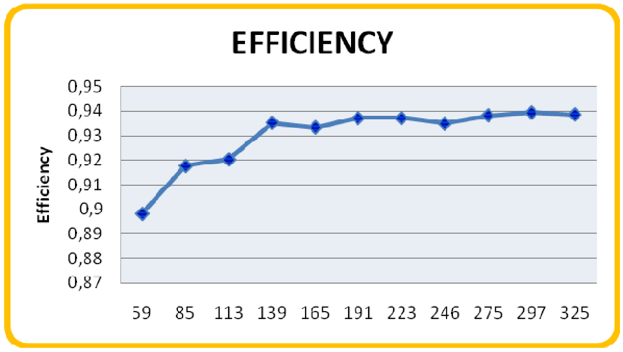

Fig. 15. High gain boost converter efficiency.

7. Conclusion

The proposed system presents high efficiency and has lower cost when compared with other solar home systems. In addition, its simplicity and robustness make it suitable for applications in rural consumers of low power demand. This is the case of most houses in remote areas in the Northeast of Brazil.

The experimental results with the converter were quite satisfactory (average efficiency of 93%). The load was limited to 330W, because the tests were performed to simulate the energy consumption of the rural community.

The next tests will be conducted with the complete system, with an expected higher efficiency because the converters were built to supply power to a load of 600W.

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