Implementation of an Universal Battery Charger with Wide Input and Output Voltage Ranges

Tiago Henrique Mateus, Bruno Cersar P. Ferreira, Danucha M. Marchesin, Pedro Eugênio M. J. Ribeiro, Gustavo dos Santos Pires, Gilberto Shimada Tatibana, Ruben Barros Godoy, João Onofre Pereira Pinto

Federal University of Mato Grosso do Sul
Dept. of Electrial Engineering
79070-900 Campo Grande, MS – BRAZIL

tiagoee@gmail.com, brunocesar85@gmail.com, danuchamm@gmail.com, pedro87@gmail.com, gustavo.pires.86@gmail.com, tatibana@nin.ufms.br, ruben@batlab.ufms.br, jpinto@nin.ufms.br

Abstract* –This paper describes the implementation of a wide input/output voltage ranges of an universal battery charger. It is wide input voltage range in the sense that it works for input voltage amplitude that varies from 95 to 270 Vrms and frequency that can varies from 48 to 440 Hz. On the output end it provides voltage from 2 up to 24 dc voltage. The universal does not only refers to the input/output voltage capabilities, but also to the fact that it can be used to charge the main commercial battery types, i. e., Lead-acid, Nickel-cadmium, Nickel-metal-hydride, and Lithium-ion batteries. Due to the output voltage range, different combination of battery cells may be charged. In this work, first, a brief introduction is done, in the sequence, the circuit is described, and finally, some experimental results, showing actual battery charge current and voltage profiles is given. The final paper will present equations, simulations results, details of the control circuit, and performance parameters of the battery charger.

I. Introduction

Nowadays, the demand for portable equipments is substantially increasing. It happens because these types of devices facilitate people's lifestyle, allowing them certain freedom of the electric grid, resulting in versatility for work and leisure activities. However, such tools are dependent of energy storage devices. Most of the times, these storage devices are batteries. The problem is that the great majority of these batteries are disposable, i. e., they are one time use type of battery. Since, in general, these batteries are made of aggressive materials, the dispose of the big volume of disposable batteries cause a negative environmental impact.

On the other hand, due to technological advances, in the last decade different types of rechargeable batteries had been developed, that is, batteries that can be recharged to be reused. The recharge process is done connecting the battery to the electric grid via an equipment called "battery charger". Today, the rechargeable batteries represent only about 8% of the European market of stacks and batteries, but the market is growing world-wide in a rate of 15% per year [1]. This grows is due to the increase of the use of stand-alone operation devices such as: notebooks, cellular telephones and other electronic products. Therefore, with the increasing use of rechargeable batteries, which can be recharged up to 1000 cycles, the expectation is that there will be a considerable decrease of the negative environmental impact caused by conventional batteries, therefore, reducing contamination and pollution.

Among the rechargeable batteries, nickel-cadmium (NiCd) has the biggest market share, which is about 70%, although nickel-metal-hydride (NiMH) is more technically and environmentally acceptable. However, the production cost of Ni-MH still is higher when compared with Ni-Cd. Despite the fact that NiCd batteries present ambient problems due to presence of cadmium, this type of battery still being widely used in products that cannot fail such as medical emergency and aviation equipments [2].

However, in order for this technology to consolidate it is important that aspects such as efficiency and durability of the batteries be guaranteed. Moreover, they must provide the maximum user autonomy, preventing constant recharge. As selection criteria for rechargeable batteries, the following aspects are relevant: dimensions, energy density, voltage, current, period of recharge, presence of memory effect and lifetime.

One very important issue that can help to spread out the use of rechargeable batteries is the availability in the market of better featured batteries chargers. Current batteries chargers are limited in their capability to attend the different type of batteries. In other words, there is a different battery charger for each different type of battery. Moreover, the commercially available battery chargers have limited input voltage range regarding amplitude and frequency. However, it is also very important to highlight good features of the available current batteries chargers such as high density power and efficiency.

The objective of this paper is to develop a universal battery charger. Here, the "universal" term relates to its capability to charge the four main types of battery in a very wide input/output voltage ranges.

II. Power Circuit Description

The solution for the proposed problem can be done using cascaded circuits doing all the steps necessary to permit the circuit work with the wide input/output voltage ranges required. Figure 1 shows the system configuration with all separated steps required to build a battery charger.

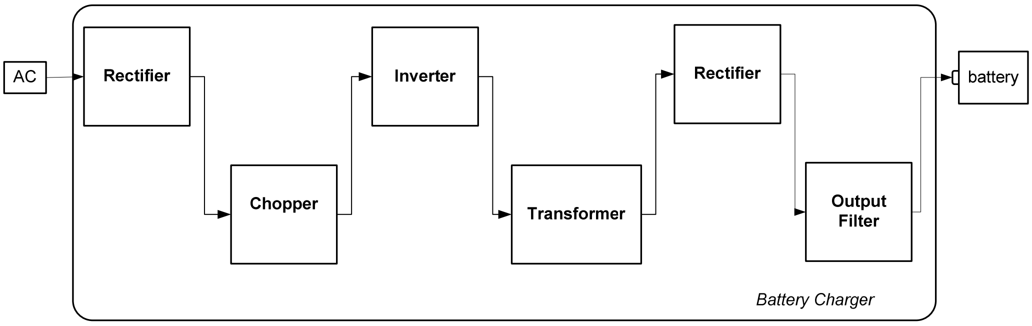

Fig. 1 – Universal Battery Charger Block Diagram Using Cascaded Converters

The front-end circuit is a rectifier to convert AC to DC voltage, and therefore to feed the second stage. The second stage is a chopper, and its job is to supply constant voltage to the following stage, independently of the input voltage characteristics (95-270 Vrms and 48 – 440 Hz). In order to provide galvanic isolation with a small size low weight transformer, in the third stage a high frequency inverter is necessary to do DC to AC conversion, and therefore to feed the high frequency transformer, which is the fourth stage. After the transformer, in the fifth stage, a diode rectifier is necessary to rectify the voltage back to DC, and after filtering it through an output filter, to feed the battery.

The problem with the system proposed in Figure 1, is the high number of stages in cascade, and therefore, the overall system efficiency will be very low, since it is the product of the efficiency of each stage individually. This is not the only drawback of such structure, issues such as robustness, size, cost and so on, must also be taken into consideration.

The system proposed in this paper is an evolution of the system given in Figure 1, where a main goal is to reduce the number of stages, through merging some stages, and elimination and/or substitution of others. Figure 2 shows the block diagram of the proposed system. In proposed system the first stage, still being the full bridge diode rectifier. Moving toward reducing stages, the high frequency inverter, the high frequency transformer and the rectifier blocks were replaced by a flyback converter [3]. The galvanic isolation could be obtained by one transformer that could work as coupled inductances and also stabilize the voltage, reducing the dimensions, the costs and increasing the global efficiency of the system [4]. Another advantage of this topology is that just one diode is necessary to rectify the high frequency DC pulsed secondary voltage. The implemented flyback has an input voltage range of 127 VDC to 400VDC and five stabilized outputs: one 30 VDC & 1A, three 15 VDC & 100mA and one 5 VDC & 200mA. Each output has different function: the 30V output, and the main one, is used to supply the next stage, the first 15V output supplies the flyback control integrated circuit (IC), the second one supplies the next stage control IC, and the third supplies the optoisolator that provides the power and the control isolation. The 5V output is destined to supply the others IC’s.

Finally, the last stage is a chopper, used to condition the flyback output voltage to the appropriate level to charge each different type of battery and cells configuration. The chosen topology was a buck converter. Current control was used in this stage in order to adequate the voltage to the batteries without compromising the battery lifetime. The schematic circuit of the proposed topology is shown in Figure 3.

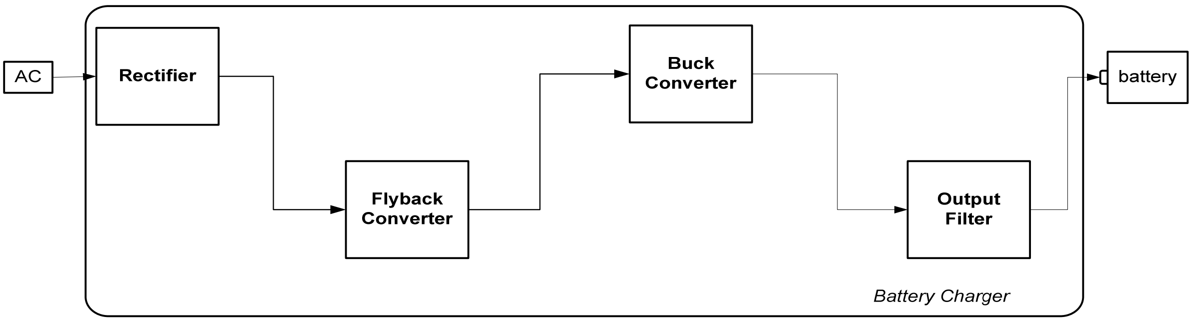

Fig. 2 – Universal Battery Charger Block Diagram Using Reduced Number of Converters.

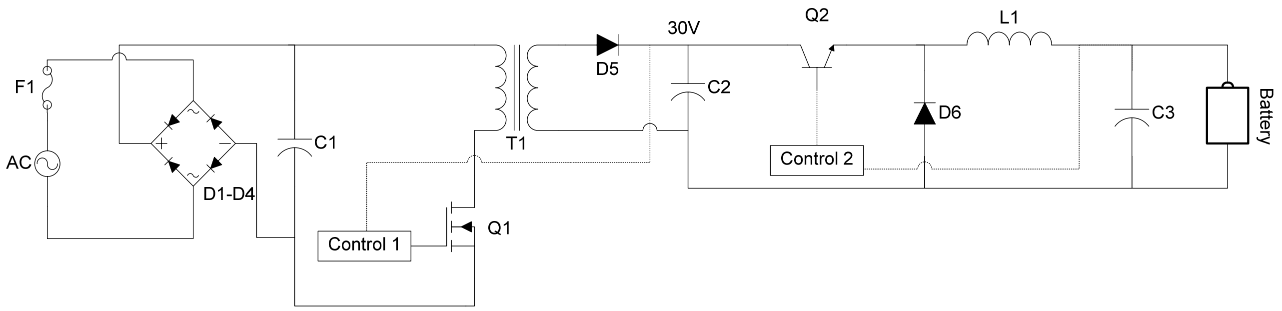

Fig. 3 – Topology of Universal Battery Charger Using Reduced Number of Converters.

III. Battery Identification

In order to efficiently and safely charge the batteries, it is important to correctly identify the battery type and cells configuration [5]. This type of information helps to define the voltage and/or current used by the control as reference inputs. So, aiming to find an algorithm to do battery identification, analysis of charging characteristics was done, as well as some experimental data was generated in order to validate the algorithm. The developed algorithm is proposed in another work, and goes beyond the scope of this paper[6].

IV. Control Strategy

The control subsystem was developed to do two basic actions: i) control the flyback converter to maintain constant voltage at its output; ii) control the buck in order to provide either constant output current or constant output voltage depending the battery charging strategy and cells configuration [7].

The implemented flyback used a control philosophy that operates the circuit with two distinct modes: PWM (Pulse Wide Modulation) and FM (Frequency Modulation). Although the PWM is a simple and effective way to control a flyback, the wide input voltage range requires also FM in order to keep the desired output voltage. For instance, at a operation point where the flyback input voltage in minimum, i. e., 127 VDC, and the output voltage is maximum, then the control operates in pre-define maximum frequency (around 80kHz) and also with the maximum duty-cycle (48%). As the input voltage increases, the pulse width diminishes until the moment that its reduction is not anymore sufficient to maintain the output voltage in the desired levels. At this operation point, the frequency starts to decrease. Also, considering the necessity of more than one output for the flyback, it was used one cross feedback loop, which guarantees control the voltage for the next stage, as well as the voltage to feed the control circuits [4].

In its turn, the control of the buck converter was done to provide two different type of control, voltage control or current control [5]. In both case, the controller was a hysteresis-band type controller. In this way, depending on the battery charging strategy, any of the two control options can be chose.

V. Experimental Results

The proposed system, given in Figure 3, was implemented. This section presents the currents and voltages profiles during the charging process of three types of battery, NiCd, Sealed Lead-Acid (SLA) and lithium-ion. The charging process of the NiMH was not shown because it is similar to NiCd.

Figure 4 shows the flyback's 30V output voltage at full load, supplying 1A to the buck stage.

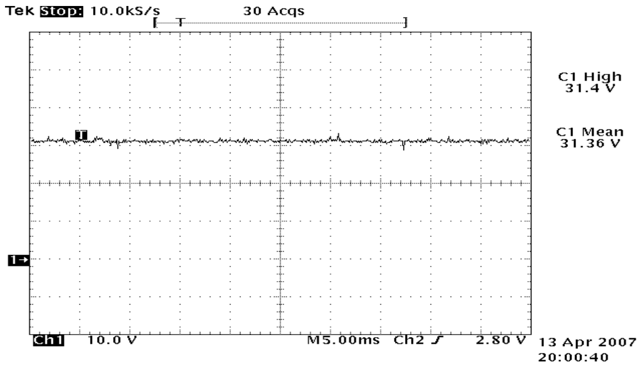

Fig. 4. – 30V Output Voltage at Full Load.

The scope time scale shows that the voltage regulation do not present ripple.

During the project development the ringing on the drain of the MOSFET was a problem as shown in figure 5 below.

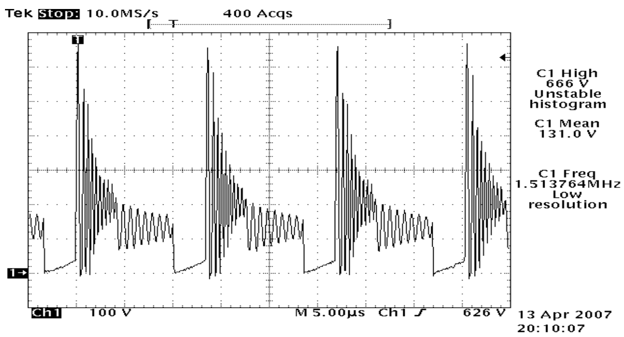

Fig. 5. – Switch Voltage on the MOSFET.

The minimum input voltage could barely be achieved. So a RC snubber across the MOSFET was implemented.

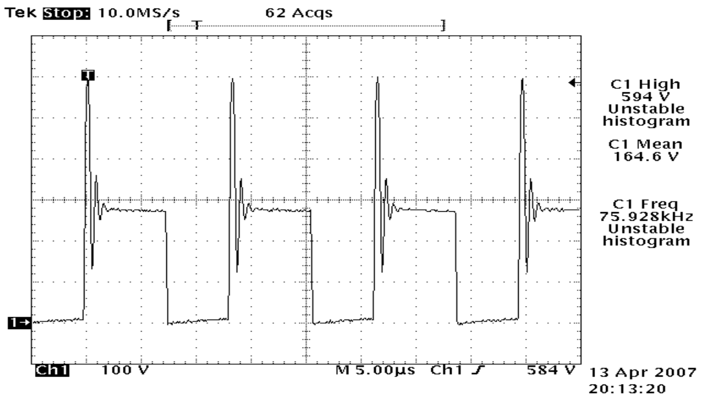

Fig. 5. – Switch Voltage on the MOSFET with RC Snubber

The RC snubber damped the ringing and clamped the voltage peak on the switch. Also was developed a manner to estimate the leakage inductance to design the snubber.

Figure 7 shows the current and voltage profiles during the charge process of a NiCd battery. Basically, as can be seen in the figure, the current was kept constant from the begining of the charge process in around 0.5 amperes. The voltage starts to slowly increase, until about one and half hour later, when it reaches its peak value and starts to decrease. At this point, the battery was considered charged and the charging process ended.

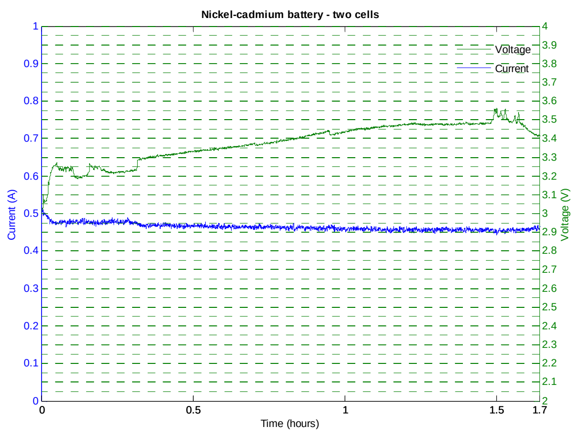

Fig. 7. – Current and Voltage Charging Profiles of a NiCd Battery.

Figure 8 shows the current and voltage profiles during the charge process of a SLA battery. From the figure it is possible to see that during the first 1.5 hour, a constant current of 1.3 amperes was applied to the battery and the voltage starts to increase until it reaches approximately 7.3 volts, beyond this point the voltage was kept constant and the current starts to decrease. After about 2.5 hour, the current reached less than 0.2 amperes, and at this point the battery was considered charged and the process stopped.

Figure 9 shows the current and voltage profiles during the charge process of a lithium-ion. Similar to Figure 7 and 8, it is possible to clearly observe the charging strategy.

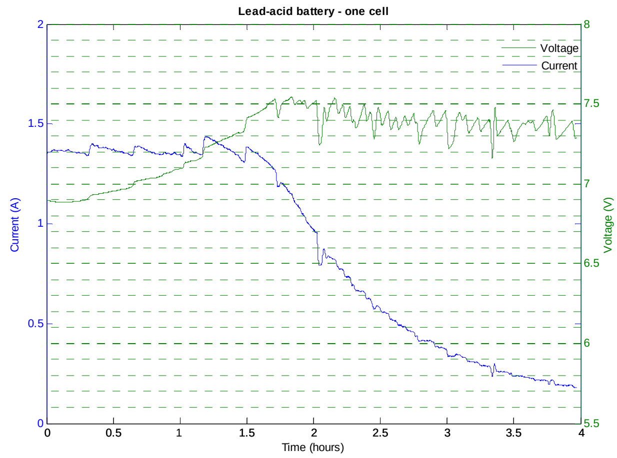

Fig. 8. Current and Voltage Charging Profiles of a SLA Battery

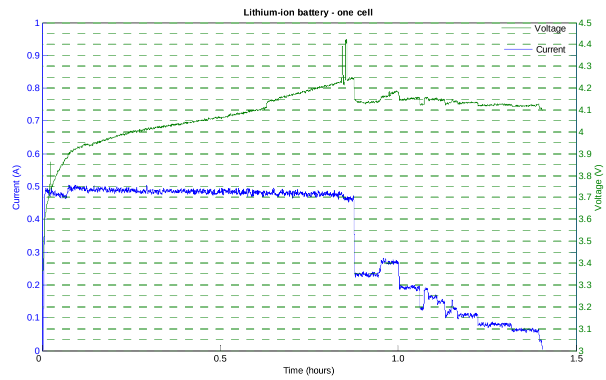

Fig. 9. Current and Voltage Charging Profiles of a Lithium-Ion Battery.

VI. Conclusions and Final Considerations

This paper presented the implementation of a wide input/output voltage ranges universal battery charger. The input voltage of the implemented converter may ranges from 95 Vrms to 270 Vrms and from 48Hz to 440 Hz. In its turn, the dc output voltage may ranges from 2 V to 24 V. Furthermore, the charger can charge the four main battery types, namely: Lead-acid (SLA), Nickel-cadmium (NiCd), Nickel-metal-hydride (NiMH), and Lithium-ion. It was provided current and voltage profiles of charging process only of the NiCd, SLA and lithium-ion battery because the NiMH is similar to the NiCd. Further work is being done, to improve the circuit and search for higher efficiency, achieve better power factor, decrease costs, and reduces weight and volume.

Acknowledgment

The authors would like to thank BATLAB-IFEC Team, Alexandre Ataíde Carniato, Helder Santini Petraroli, Elvey Tessaro Andrade, Lislei Vendas Urban, Lucas de Oliveira

Silva, Marcel Henrique de Almeida, Renan Gonçalves e Rubens Gazineu Neto for help in development of this project.

REFERENCES

[1] The EPBA two step plan – Internet site: http://www.epba-urope.org/docs/tech01.htm

[2] PUTOIS, “F. Market for nickel-cadmium batteries”, in *Journal of Power Sources*, pp. 67-70, 1995.

[3] V. Fernão Pires, J. Fernando Silva, "A Single Phase Two-Switch Buck-Boost Type AC-DC Converter with a High Power Factor and Sinusoidal Source Current", in *IEEE Power Electronics Specialists Conference (PESC'99)*, vol. 1, pp 230-237, June/July 1999.

[4] Haas, R.M., “Transformer design for low cost battery chargers”, in *Electrical Electronics Insulation Conference and Electrical Manufacturing & Coil Winding Conference*, Proceedings. Chicago '93 EEIC/ICWA Exposition, 4-7 pp. 713 – 718, Oct. 1993.

[5] Chu, Y.S.; Chen, R.Y.; Liang, T.J.; Changchien, S.K.; Chen, J.F. “Positive/negative pulse battery charger with energy feedback and power factor correction” in *Applied Power Electronics Conference and Exposition, 2005*, APEC Twentieth Annual IEEE vol.2, pp. 986-990, 6-10 March 2005.

[6] R. B Godoy, E. T. Andrade, H. S. Petraroli, M. H. De Almeida, J. O. P. Pinto, “Battery Identification Algorithm For Universal Low Power Battery Charger”, in Proc. of COBEP, 2007.

[7] Maksimovic, D.; Zane, R.; Erickson, R, “Impact of digital control in power electronics” *Power Semiconductor Devices and ICs.* Proceedings. ISPSD '04. The 16th International Symposium on, pp. 13 – 22, 24-27 May 2004.

[8] Sang-Hwa Jung; Young-Jin Woo; Nam-In Kim; Gyu-Hyeong Cho, “Analog-digital switching mixed mode low ripple-high efficiency Li-ion battery charger”, *Industry Applications Conference, 2001*. Thirty-Sixth IAS Annual Meeting. Conference Record of the 2001 IEEE, vol. 4, pp. 2473 - 2477 , Sept/Oct 2001.

[9] V. Fernão Pires, J. Fernando Silva, "Sliding Mode Controller for Single Phase AC/DC Buck-Boost Converter", *8th European Conference on Power Electronics and Applications (EPE'99)*, pp 1-10, Lausanne, Suiça, September, 1999.