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# DESIGN OF LEAD ACID ON-BOARD CHARGER FOR ELECTRIC VEHICLE

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## ABSTRACT

*This paper represents a new lead acid battery charging system. This system has the possibility in different applications (communications systems, electric vehicles, and low-Earth-orbit spacecraft) in order to minimize charging time using bidirectional dc-dc convert. Evolution of main parameters (battery voltage, current, switching stress and temperature) was recorded. Then, data obtained were processed and analyzed to determine the effects of fast-charging on Lead acid batteries. The simulation results are used to show main characteristics of charging process as a function of charging rate used. In this way, simulation results were taken to the application range of fast-charging in medium/high capacity Lead acid batteries can be reached. The design is verified by MATLAB simulation.*

***Index Terms—Bidirectional Dc-Dc Converters, Energy Storage Systems, Lead Acid Battery, Switching Stress***

## I INTRODUCTION

Recently, the generation system based on 12V battery has a limit to afford to increase electric components of eco-friendly. The alternative of the problem is development of new generation system based on a lead acid battery which is considered by many automotive companies, However, the lead acid system is not easy to apply to the fast charging because most of the batteries are designed to use with normal converter so more switching loss is occurred. For this reason, the bidirectional converter has been researched for compatibility of the new 12V electric components. Small size is expected to minimize the change of existing design of internal electric components. Also, the power converting loss 0design the bidirectional converter [1].

General cases of resonant converters, soft-switching range are limited by load conditions and, switching frequency as control component is variable. Thus state-space averaging method is not easy directly adaptive to resonant converters, not like PWM converter. It can be critical problems in vehicles when the converters are adapted [2][3] .

A resonant converter is suitable to solve problems which are switching loss of conventional PWM converter and the variable switching frequency of the resonant converter. The soft switching interleaved buck and boost converter has a combined configuration with a resonant induct or to non-isolated bidirectional interleaved converter for small size and high efficiency. The resonant induct or is used to make zero current switching (ZCS) tum-on and zero voltage switching (ZVS) turn-off conditions for all switches. Also, fixed switching frequency is used for control to minimize EMT problems. Because it is controlled by variable duty without variable switching frequency, analysis of the converter is easier than a conventional resonant converter. And, high efficiency can be accomplished in even in light load condition due to the wide soft-switching range, Application of input and output voltage source is suitable to the converter because of variable resonant current on switching conditions by duty ratio [4] [5].

The most common rechargeable battery that is commonly used on a daily basis is lead acid batteries because of their robust capacity to provide power and higher nominal voltages per cell compared to other secondary batteries. Lead-acid batteries have a low energy-to-weight ratio as well as the low energy-to-volume ratio which enable them to supply high surge currents while allowing the cells to maintain a large power-to-weight ratio. Because of these features, lead-acid batteries are used most exclusively for motor vehicles to provide high current for automobile [6]-[7]. Lead acid batteries are divided into two different types: starting lead-acid batteries and deep cycle batteries. The starting battery is designed to deliver quick bursts of energy (such as starting engines) and therefore has a greater plate count. The plates are thinner and have somewhat different material composition [8]. The deep cycle battery has less instant energy, but greater long-term energy delivery.

In this paper, bidirectional buck-boost converter is designed for 12V battery. To accomplish soft-switching on overall range of load, design and operation mode of the converter were mathematically analyzed depending on switching conditions, Also, the optimal design method of resonant inductance is proposed which are considering system capacity, input and output conditions.

The designed converter is compared with the conventional converter in loss analysis. The proposed design is verified using MATLAB/simulation.

## II LEAD ACID BATTERY CHARACTERISTICS

The lead-acid battery has been a successful marketable product is widely used as electrical energy storage in the locomotive field and other applications. Its advantages are its low cost, developed technology, relatively high power capability, and good cycle. These advantages are smart for its application in HEVs with high power is the first consideration. The materials complicated (lead, lead oxide, sulfuric acid) are moderately low in cost when associated to their more advanced equals. Lead-acid batteries also have several disadvantages. The energy density of lead-acid batteries is low, mostly because of the high molecular weight of lead. The temperature characteristics are poor. Below 10°C, its specific power, and specific energy are greatly reduced. This feature severely limits the application of lead-acid batteries for the traction of vehicles operating in cold climates.

The presence of highly corrosive sulfuric acid is a potential safety hazard for vehicle occupants. Hydrogen released by the self-discharge reactions is another potential danger since this gas is extremely flammable smooth in tiny concentrations. Hydrogen discharge is also a problem for hermetically sealed batteries. Indeed, in order to provide a good level of protection against acid spills, it is necessary to seal the battery, thus trapping the parasitic gasses in the casing. As a result, pressure may build up in the battery, causing swelling and mechanical constraints on the casing and sealing. The lead in the electrodes is an environmental problem because of its toxicity. The emission of lead consecutive to the use of lead-acid batteries may occur during the fabrication of the batteries, in the case of a vehicle collision (spill of electrolyte through cracks), or during their disposal at the end of battery life.

Different lead-acid batteries with better performance are being developed for EVs and HEVs. Improvements of the sealed lead-acid batteries in specific energy over 40 Wh/kg, with the possibility of the rapid charge, have been attained. One of these advanced sealed lead-acid batteries is said to be Electrosource's Horizon battery. It adopts the lead wire woven horizontal plate and hence offers the competitive advantages of high specific energy (43 Wh/kg),high specific power (285 W/kg), long sequence life (over 600 cycles for on-road EV application), rapid recharge capability (50% capacity in 8 min and 100% in less than 30 min), low cost, mechanical roughness (robust structure of horizontal plate), maintenance-free conditions (sealed battery technology), and eco-friendly friendliness. Other advanced lead-acid battery technologies include bipolar designs and micro- tubular grid designs. Advanced lead-acid batteries have been developed to remedy these disadvantages. The specific energy has been improved through the reduction of inactive materials such as the casing material, current collector material separators, etc. The lifetime has been increased by over 50% — at the expense of cost, however..

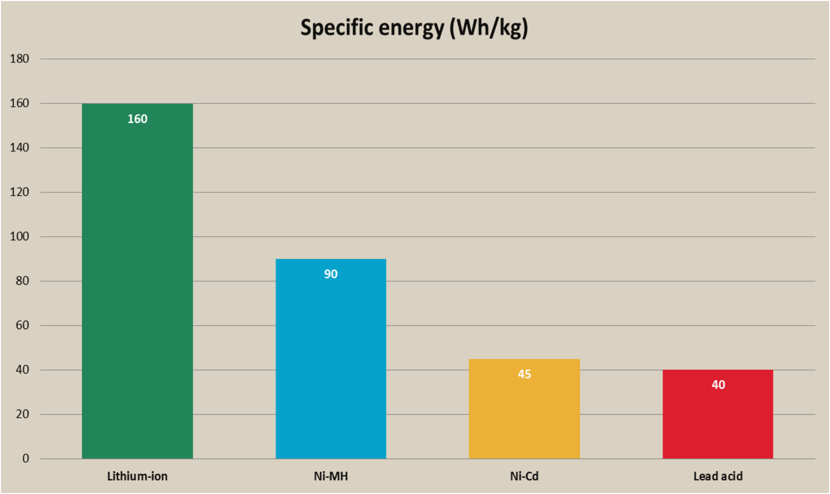


**Fig.1.Comparision of different battery types with W/kg**

## III PROPOSED SYSTEM

### 3.1 Battery

A theoretical study of the load is necessary to design the on-board charger. In addition, voltage and capacity have an influence on the kind of DC/DC converter which is used in the PFC. It's also needs to know how the battery has to be charged and, for the simulation, how batteries can be represented.

### 3.2 Characteristics

The battery voltage varies according to the kind of the plug-in hybrid vehicle. For a car, this voltage could for example be between 300V and 400V. The peak power is in the region of 50kW, and the energy density could be between 5 and 20kWh. For information, an electric car of ordinary size needs about 2kWh to cover 10km. The batteries can have about 1000 cycles of charge. These figures are rough values, and depending on the battery technology, the usage of the battery (small car, truck…) and other parameters.

Nowadays, the batteries that are most used in the hybrid vehicles are the NiMH (nickel-metal hydride) technology. An advantage of this technology is that NiMH batteries are not very sensitive to the memory effect, moreover they have a good energy to weight ratio and are safe. The drawbacks are that overload has a negative effect, and that it is difficult to detect the end loading. However, in a near future, this technology will be surpassed by the Lithium-ion technology. This technology has advantages like not to be effect by memory effect, very good energy to weight and energy to size ratios. The drawbacks are these batteries are less safe than NiMH, they are a higher cost, and a lower load and discharge current.

### 3.3 Charge

The charge of a NiMH battery can be divided into two parts. The first part, the battery is discharged; it needs a constant current to be charged. During this phase, the battery voltage is increasing. This phase stops when the battery reaches its rated voltage. The second phase consists in charge the battery with a constant voltage. The voltage doesn't increase but on the other hand the energy density is increasing. This phase stops when the battery is fully loaded; it doesn't take any current more. The best method to detect the end load is the ΔV method. In effect, when a NiMH battery is full, if the charger continues to supply it, the polarity voltage is reversing (5). If we can detect this inversion, we can know when the battery is full. A charger can be safer by the use of a resettable fuse which opens if the current or temperature is too high.

### 3.4 Non-isolated dc-dc converters

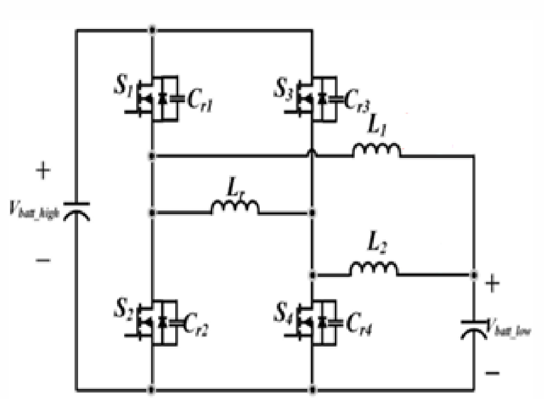


**Figure.2 Circuit diagram of non isolated dc-dc converter**

This converter can be obtained by cascading the buck converter with the boost converter. This topology operates in all quadrants (4 quadrant converter). It means that it is capable of step-down and step-up operations in both directions. Figure .2 Cascading buck-boost BDC is the most flexible topology. But it has several drawbacks: increasing the number of power switches and, as a consequence, a more complex control system and control algorithms and higher turn-on losses caused by reverse recovery problem of transistors body diodes.

### 3.5 Isolated dc-dc converters

In terms of the full-bridge topology, the operation is quite straightforward. As the figure. 3 shows, there are four active switches which make an ac signal that is carried to the transformer T, the signal is transformed on the secondary side and then rectified by the four diodes into a dc signal again

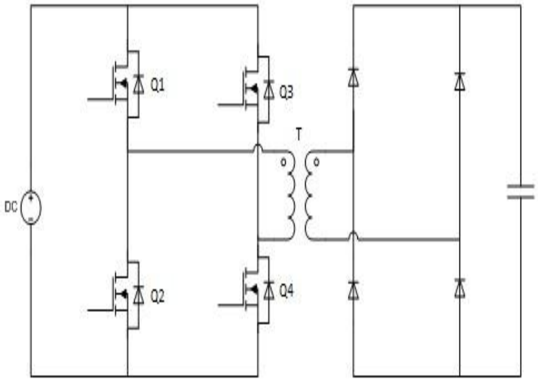


**Figure .3 Circuit diagram of non isolated dc-dc converter**

## IV SIMULATION WORK

The simulation realized was the full bridge converter. The power part was also made with IGBTs, snubbers were designed. The control part realized is the phase shift control method. This one is realized by a unipolar voltage switching control. This converter controls the value of the current in the battery in order to load this one with a constant current.

In this converter, the interesting signals are the signals in the transistors, in the transformer, and in the output filter and the battery. These signals can be viewed below.

The snubber reduces stresses during the turn off phases and turn on phases, for the current and the voltage. The snubber reduces switching losses and improves quality of the signals in the on-board charger.

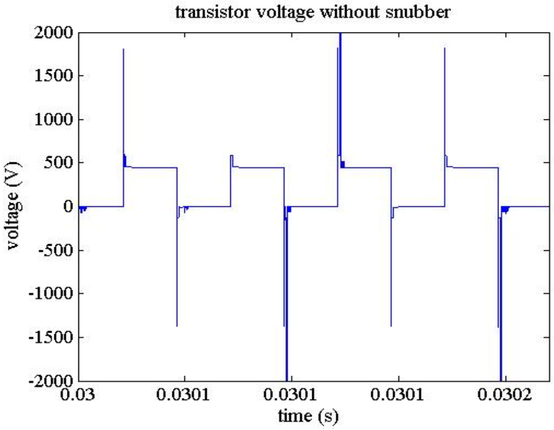


**Figure.4 MOSFET voltage without snubber**

The Figure.6 shows the current in the mosfet 1, with or without snubber. A pure capacitor can't be the only component of this snubber because simulink models the transistor as a current source. The addition of a resistor is needed. The Figure.5 shows the voltage in the mosfet 1 in both cases, with or without snubber role of the snubber on the transistor current.

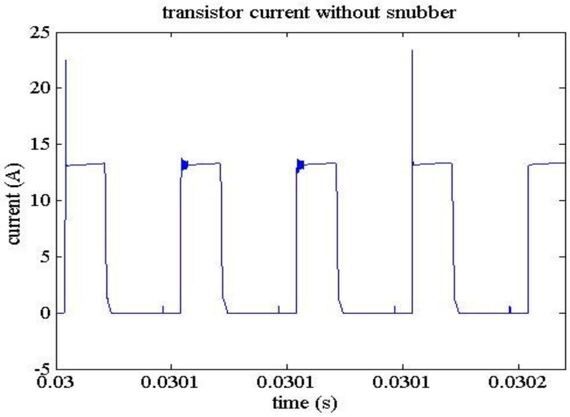
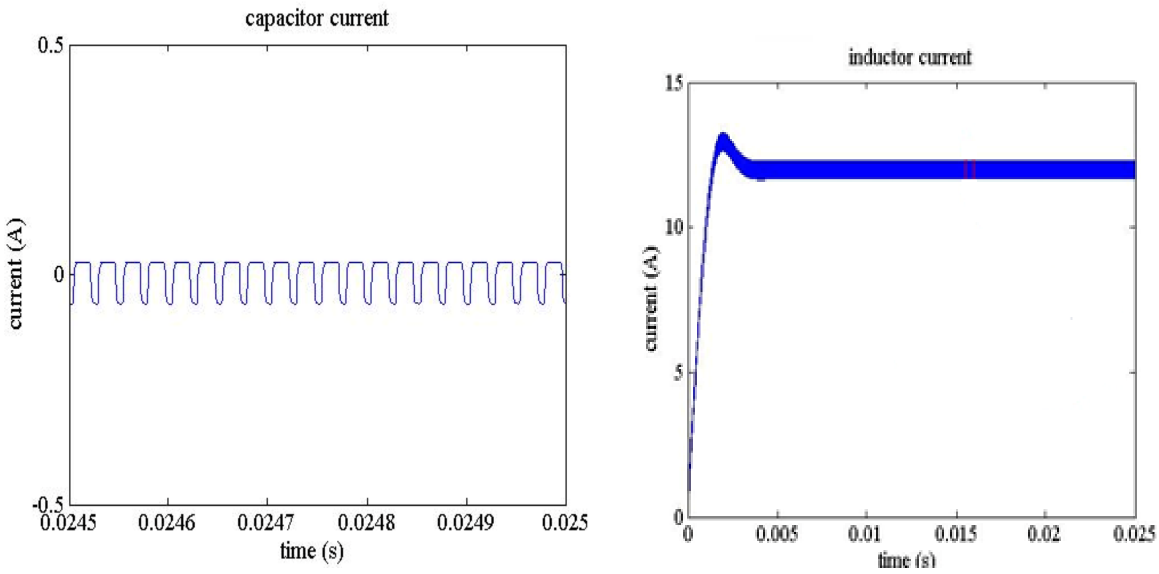


**Figure 5. MOSFET current without snubber**

The Figure.6 shows the current in the inductor filter and the Figure.7 the current in the capacitor filter.



**The Figure .6 The current in the inductor filter Figure .7 the current in the capacitor filter.**

The transformer primary current is shown on the Figure.9. The transformer ratio being equal to one, and the transformer being almost perfect in the simulation, the secondary current has the same waveforms as the primary current. This explains that the secondary voltage of the transformer has the same waveform as the primary voltage (Figure 8).

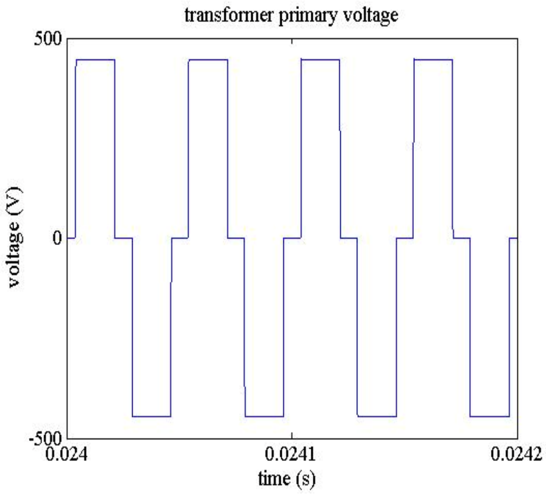


**Figure.8.The transformer primary voltage**

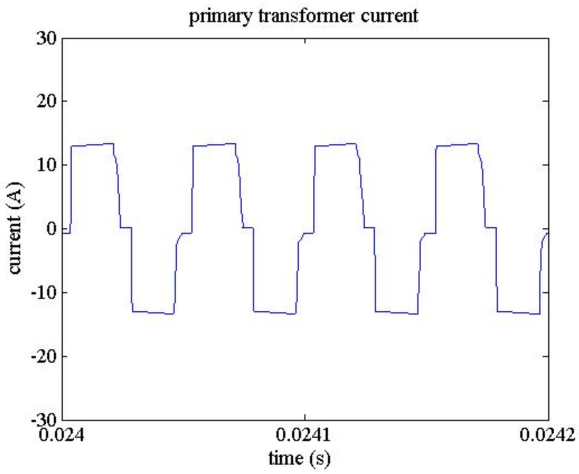


**Figure .9 The transformer primary current**

The current level close to zero should be equal to zero; the difference is due to the transformer inductor. The voltage waveform has the square form which was attending. The variation of the time length of the zero level allows controlling the primary transformer mean voltage.

The current in the filter capacitor is too small. This capacitor current should be the ripple current of the inductor. If the inductor current ripple doesn't go in the capacitor that means that this current will flow in the battery. This battery current can be viewed on the Figure .10.

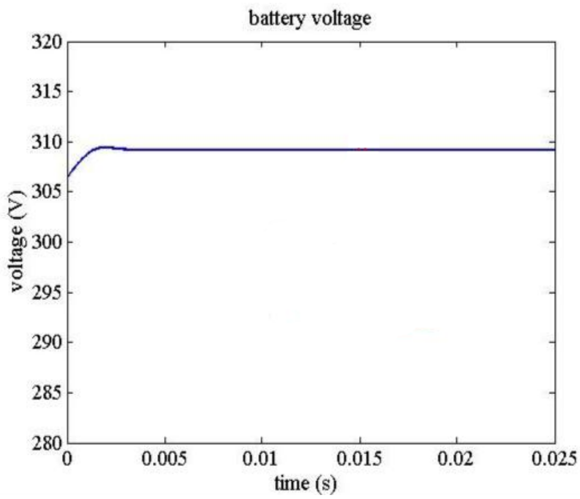


**Figure .10 Voltage in the battery**

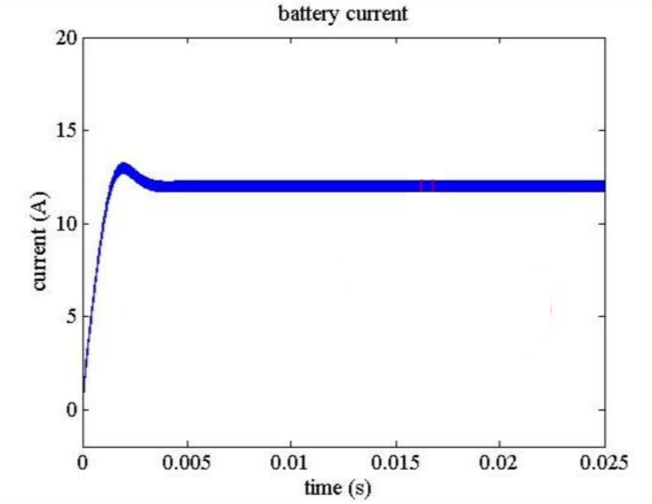


**Figure .11 Current in the battery**

This figure 11. confirms that the inductor ripple current is flowing in the battery. An EMI filter cab be added to reduce this ripple current but the battery can accept it. The steady state of the battery current is reached after 5 milliseconds.

The switching frequency is calculated as when the frequency is f=1/t as per the pulse scope the pulse total time is 0.00005,then generate the 20 kHz in the closed loop.

**TABLE 1**

**SIMULATION PARAMETER**

| Parameter | Value |
|---|---|
| Input voltage | 45[V] |
| Output voltage | 90[V] |
| Resonance inductance | 400[µH] |

| | |
|---|---|
| Resonance capacitance | 1[ρF] |
| Main inductor | 1000[mH] |
| Switching frequency | 100[Khz] |

Table 1. Simulation parameter of isolated dc-dc converter of the on board charger for lead acid battery.

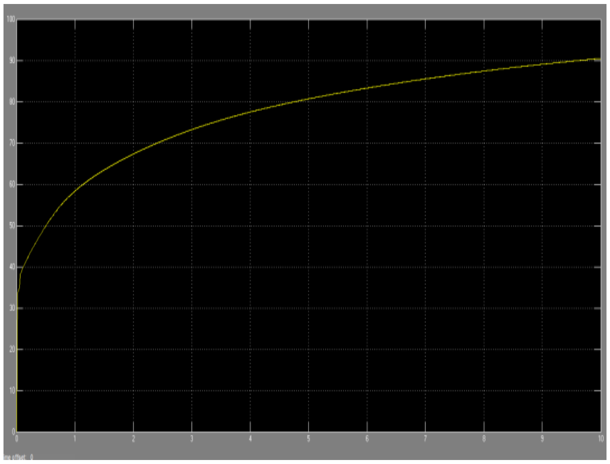


**Figure .12. Output voltage waveform for 45 V Input.**

Figure.12. shows the output voltage 90 V Non isolated dc-dc converter output voltage.

## V CONCLUSION

In this paper, a concept for lead acid battery charging system is simulated. The converter is based on a split DC input voltage and utilizes a boundary operation mode to achieve soft switching as well as interleaving for reduction of the output current ripple. Besides the operating principle and the control of the isolated DC-DC converter is explained. For the designed system, the efficiency above 98.5% can be achieved over a wide operating range and the relative current ripple amplitude at the output is below 2%. Simulations shows that when compared to a standard buck boost converter, the losses and charging time can be reduced by more than 40% if optimized MOSFETs are used for the proposed concept.

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