A ZERO-VOLTAGE SWITCHING FULL-BRIDGE DC-DC CONVERTER ON-BOARD CHARGER FOR PLUG-IN HYBRID ELECTRIC VEHICLE BATTERY

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ABSTRACT

This paper represents a new lead acid battery charging system. This system has the possibility in different applications in order to minimize charging time using isolated 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 and hardware results are used to show main characteristics of charging process as a function of charging rate used. In this way, simulation and hardware results were taken to the application range of fast-charging in medium/high capacity Lead acid batteries can be reached. The design is carried out by MATLAB simulation.

Keywords: Bidirectional Dc-Dc Converters, Isolated Dc-Dc Converter Energy Storage Systems, Lead Acid Battery, Switching Stress.

I INTRODUCTION

A battery charger is a device used to put energy into a cell or (rechargeable) battery by forcing an electric current through it. Lead-acid battery chargers typically have two tasks to accomplish. The first is to restore capacity, often as quickly as practical. The second is to maintain capacity by compensating for self discharge. In both instances optimum operation requires accurate sensing of battery voltage. When a typical lead-acid cell is charged, lead sulphate is converted to lead on the battery's negative plate and lead dioxide on the positive plate. Over-charge reactions begin when the majority of lead sulphate has been converted, typically resulting in the generation of hydrogen and oxygen gas. At moderate charge rates, most of the hydrogen and oxygen will recombine in sealed batteries. In unsealed batteries however, dehydration will occur[1].

The onset of over-charge can be detected by monitoring battery voltage. The figure on the next page shows battery voltage verses percent of previous discharge capacity returned at various charge rates. Over charge reactions are

indicated by the sharp rise in cell voltage. The point at which over-charge reactions begin is dependent on charge rate, and as charge rate is increased, the percentage of returned capacity at the onset of over-charge diminishes. For overcharge to coincide with 100% return of capacity, the charge rate must typically be less than C/100 (1/100 amps of its amp- hour capacity). At high charge rates, controlled over-charging is typically as quickly as possible. To maintain capacity on a fully charged battery, a constant voltage is applied. The voltage must be high enough to compensate for self-discharge, yet not too high as to cause excessive over-charging[2][3].

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 dc-dc converter is designed for 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.

Energy storage capacity of current PHEV batteries may fall in the range of 15-20 kWh for a 60 km all electric driving range. PHEV batteries are required to have high power capability and high energy density. Typical battery requirements for PHEV applications are shown in Table 1 Table 1.PHEV battery requirement A. Nickel Metal Hybrid Battery A five cars field test, performed by EPRI, have proven that Nickel Metal Hybrid (NiMH) batteries lifetimes exceed five years and are expected to meet the 130,000 – 150,000 mile vehicle life time requirements due to improvements in charge acceptance and retention at high temperatures. however, NiMH technologies still faces significant challenges before reaching large scale deployment due to the battery relatively large weight and volume and insufficient power/energy performance compared with alternative solutions. B. Lithium Ion Battery For the same specifications, Li-Ion batteries are considerably lighter than NiMH ones. But, although Li-Ion batteries meet the requirements of PHEV batteries, deep cycling capabilities of these batteries are yet to be proven. The major challenges with Li-Ion batteries are high capital cost, energy and temperature management, and, at this stage of development, absence of field validation data proving deep cycle capabilities. There are different levels of battery chargers depending on the application and the connection. Charger types include residential charger (typically single-phase or phase-tophase) and rapid charger. The latter allows unidirectional power flow and will not be discussed further in this work. Table.2 displays operating electrical range of different types of PHEV battery chargers. For residential charger applications, full charge is to be achieved within 6 hours. However, for higher energy capacity batteries, longer periods may be required. The charger must be safe, convenient and efficient. Table 3. Summarizes the residential charger requirements. Operational requirements include battery temperature management, cooling, converter control, communication means, diagnostic capabilities.

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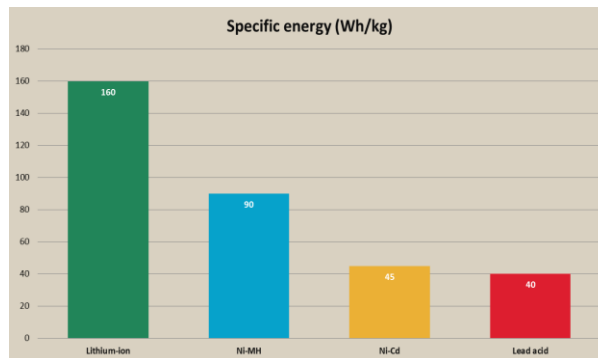
Fig.1.Comparision of different battery types with W/kg

III PROPOSED SYSTEM

i. 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.

ii. 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 Lead acid (nickel-metal hydride) technology. An advantage of this technology is that Lead acid 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 Lead acid, they are a higher cost, and a lower load and discharge current.

iii. Charge

The charge of a Lead acid 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 Lead acid 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.

iv.   Non-isolateddc-dc converters
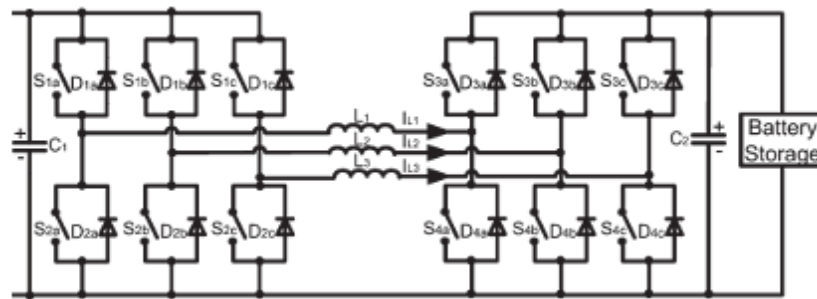
Figure.2 Circuit diagram of non isolated dc-dc converter

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.

v.   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
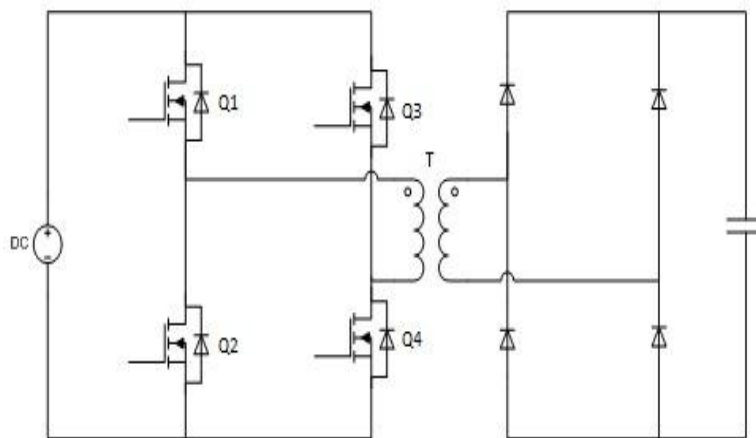

Figure .3 Circuit diagram of non-isolated– dc-dc converter

IV. EXPERIMENTAL &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.
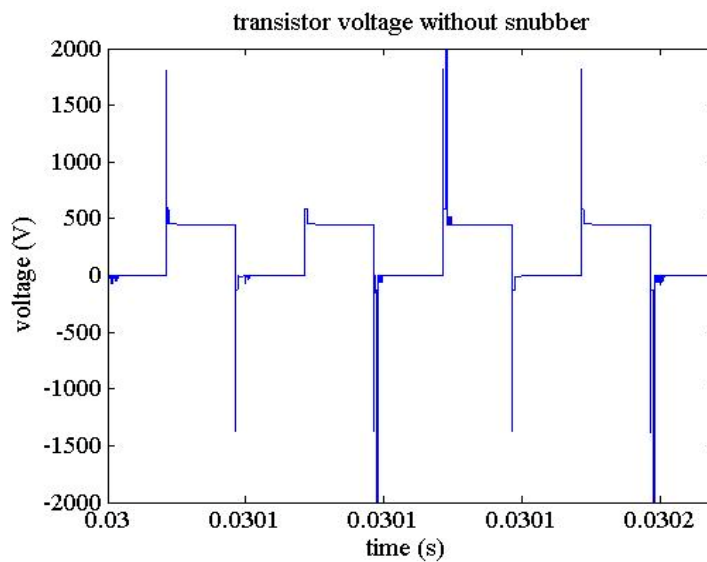

Figure.4 Mosfet voltage without snubber

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.
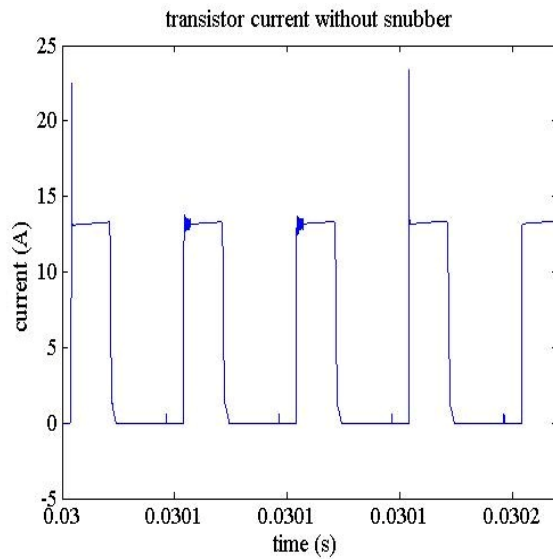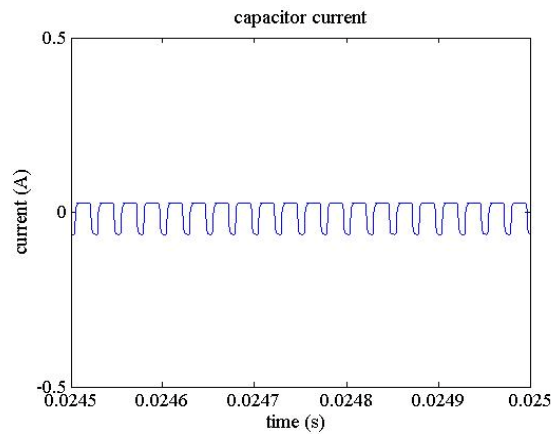
Figure5. Mosfet current without snubber

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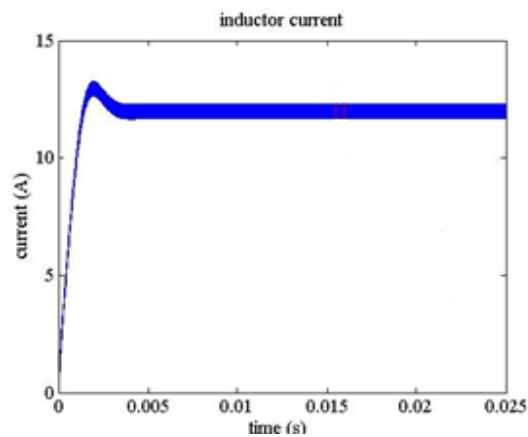

TheFigure.6Thecurrentintheinductorfilter

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).
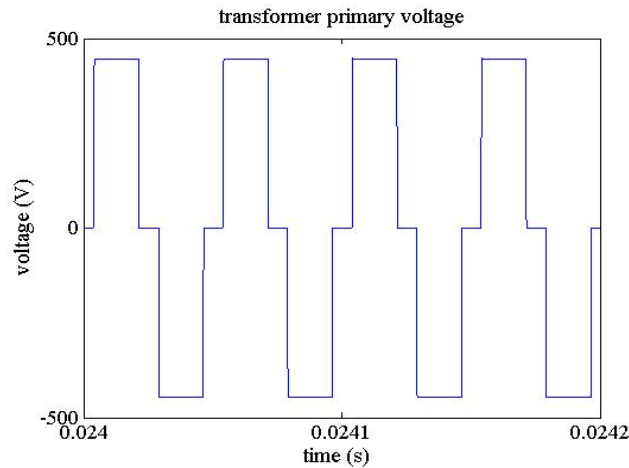

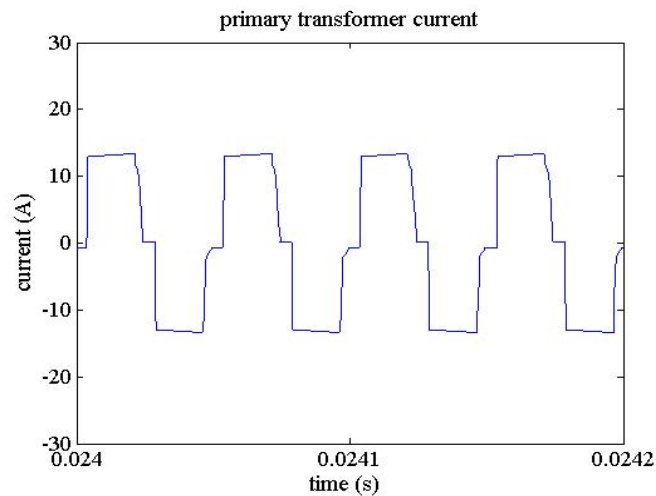Figure.8.The transformer primary voltage

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.
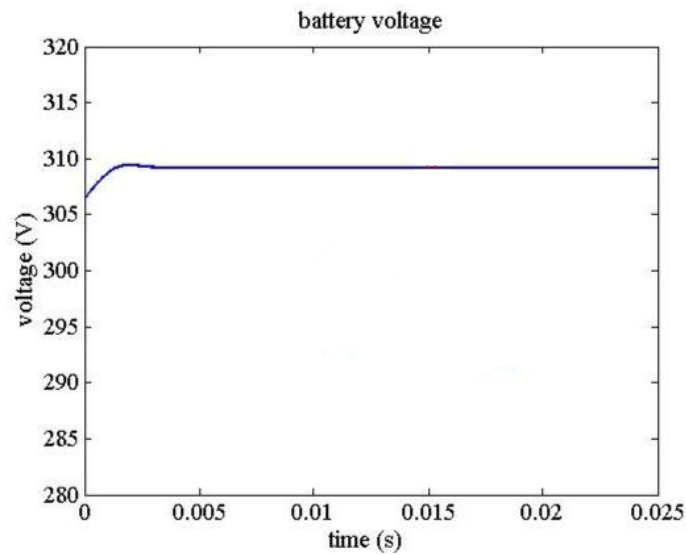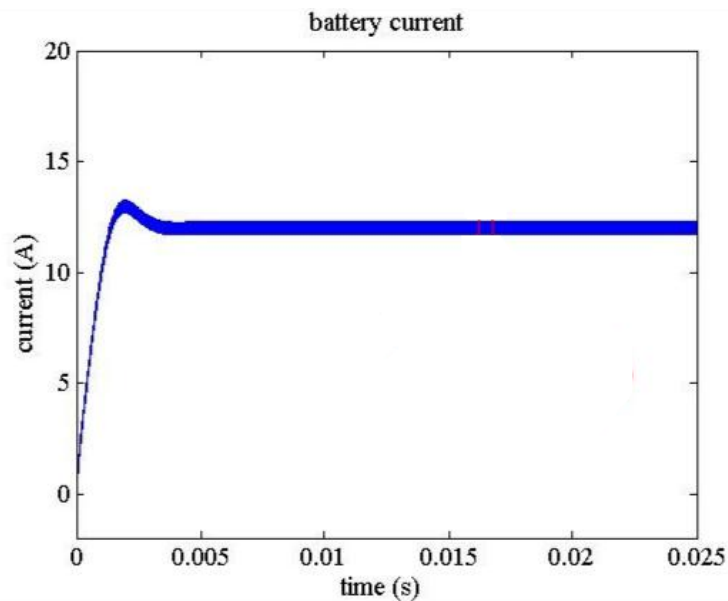
Figure .10 Voltage in the battery

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]

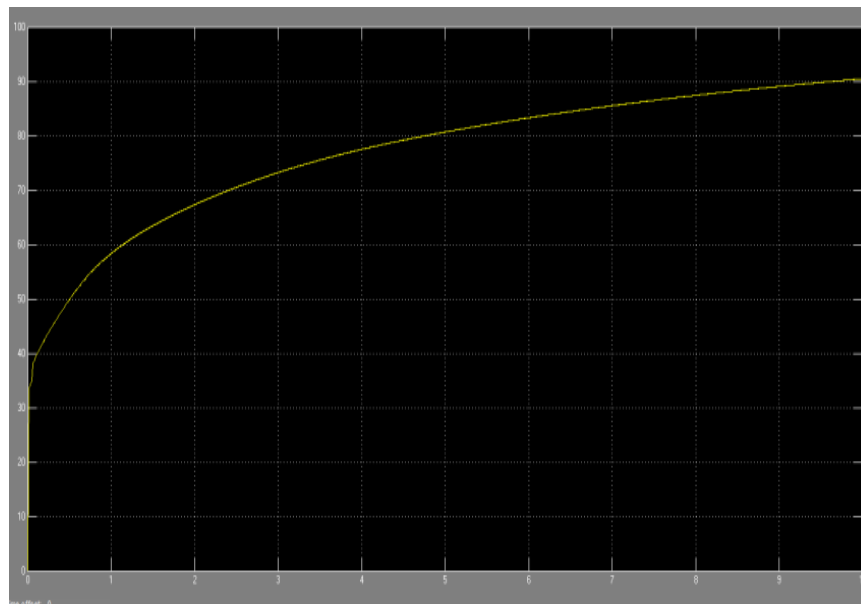Table 1. Simulation parameter of isolated dc-dc converterof the on board charger for lead acid battery.

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

Figure.12. shows the 90V output voltage ofisolated dc-dc converter. An On-Board charger experimentally developed to verify the operational modes is shown in Figure 13.. The analog-to-digital converter and pulse width modulation switching rates are kept at 10 kHz. The performance of the rectifier is evaluated at different charging conditions. The experimental results how that the rectifier operates at 97% efficiency. The operation of the dc/dc converter at the switching instants is observed in the experimental results.
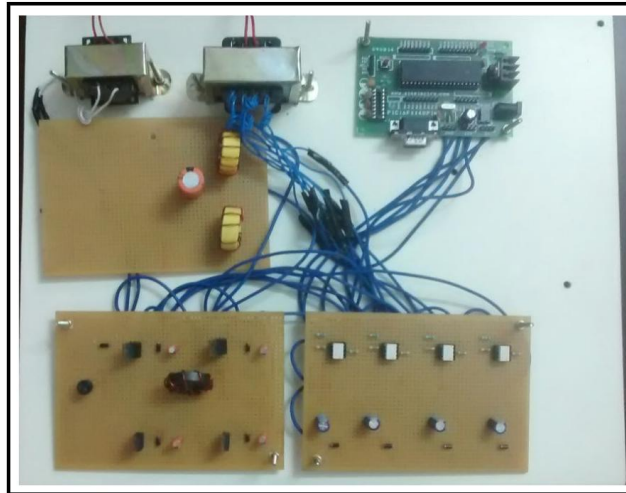
Figure.13 Experimental setup

TABLE 2 EFFICIENCY COMPARISION

	Efficiency (%)	Non isolated dc-dc converter	Isolated dc-dc converter
Input current 16 A	Disloaded	93,37	94,95
	Loaded	94,53	96,13
	Average Loaded	93,95	95,54
Input current 10A	Disloaded	94,48	96,14
	Loaded	95,37	97,02
	Average loaded	94,93	96,5

Table 2.Shows the efficiency Comparision of Isolated and Non- isolated dc-dc converter

TABLE 3 COMPARISION OF DC-DC CONVERTER

Parameter	Non isolated dc-dc converter	Bidirectional DC-DC Converter Charger
Charging Time	5h 30min	2h 30min
Output voltage	320V	90V
Input bridge rectifier diode loss	16 W	25W
Boost MOSFET loss	48W,4W	60W,6W
Boost diode loss	20W,4W	40W,8W

Table 3.Shows the Output Comparision of dc-dc converter

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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