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A New Design of Lead Acid Battery Charging System with Improved Efficiency

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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.

Key words: 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) turnoff 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.

Deep cycle batteries have denser plates and can survive a number of discharge cycles [8]. Starting batteries should not be used for deep cycle applications because the solvent plates are more prone to warping and pitting when discharged.Typically a lead-acid car battery consists of 6 individual cells that are used to for electrochemical reactions to produce electricity and power. Each individual cell’s voltage can range between 2.15V up to 1.85V. For a fully charged car battery, the nominal output voltage is around 13V while a fully discharged car battery has a nominal output voltage of 11V. Interior of a Deep Cycle Lead Acid Battery [10] there are two general rules of thumb to determine the amp hour ratings of a lead-acid car battery based upon the backup capacity (RC). The reserve capacity of a battery is defined as the number of minutes a fully charged battery at 80 ° F will expulsion 25 amps until the battery voltage drops below 10.5 volts [12]. Using the reserve capacity of a battery, the amp hours rating can be determined by either multiplying the RC value by 0.6 or dividing the RC value by 2 and adding 16 to that resultant value [12].

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.

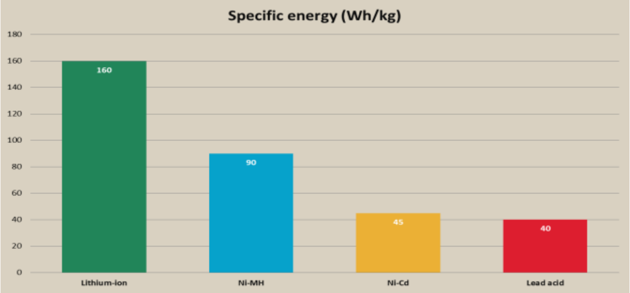

Fig. 1: Comparison of different battery types with W/kg

III. PROPOSED SYSTEM

The design is composed of interleaved boost converter and resonant tank with lead acid battery. The power is processed through two different stages of conversion in the dual-stage bidirectional converters. The two- stage methodology allows a wider range of output voltage and current in addition to the inferior voltage stress applied to the active components.

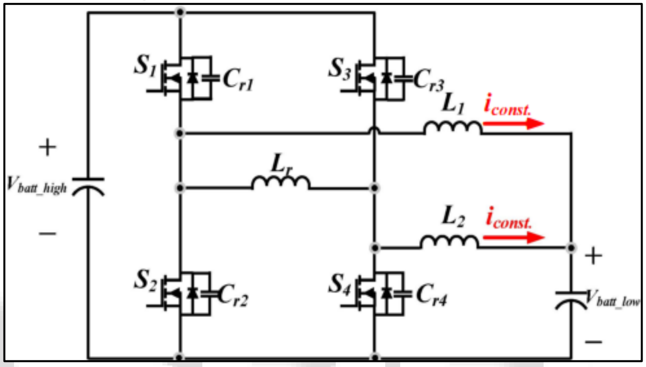

Fig. 2: Proposed Bidirectional buck-boosts converter with resonant tank

High-frequency switching method is forced to minimize the size in the case of a conventional bidirectional converter. However high switching frequency causes high switching loss in low voltage and high current converter applications consequently, the overall size is increased because of the necessity of bigger heat sink as well as reduced efficiency of the converter. To overcome the drawbacks, variable resonant converters have been researching for high efficiency and reduction of size.

The type of battery used for this system is Lead acid. The battery has a nominal voltage of 12 V and an initial state of charge (SOC) of 90 percent. The battery model used here is a detailed model available in Simulink block. The battery with a voltage factor of 116% and the nominal voltage of 12 V has a fully charged voltage of 12.25V. The battery charging technique used in this study is pulse charging [13].

As per simulation result, the efficiency is increased to 96.1 percentages when a battery is fully charged and the charging time also decreased. Simulation of the proposed converter explains the single phase supply is given to rectifier where the AC is converted to DC. Then the input supply is stepped down using the linear transformer as per the need of required battery voltage. The bidirectional converter converts the dc-dc voltage more efficiently with fast charging and obtaining more output voltage. The output voltage varies according to the input voltage. The simulation result shows the different output voltage waveform.

The controller used in the simulation is PID. It has the parameters like Kp is proportional gain, Ki is integral gain, and Kd is a derivative gain. PID has variable e is the tracking fault or the difference between the chosen reference value (r) and the actual output value (y). The controller takes this error signal and compares both its derivative and its integral values. The obtained signal which is sent to the actuator (u) is now equivalent to the proportional gain (Kp) times multiplied the magnitude of the error plus the integral gain (Ki) times multiplied the integral of the error plus the derivative gain (Kd) times the derivative of the error. From the desired output signal obtained from the PID controller is send to gate signals to control the switching operation.

IV. EFFECTIVE ANALYSIS

To compare efficiency with the proposed converter and a conventional converter, each loss analysis is held based using AUTRFS3107-7P MOSFET. Key parameters of the MOSFET are shown as Table 1.

Parameter	Value
Static Drain-to-Source On-Resistance (Rds)	2.1[mΩ]
Output capacitance(Coss)	850[pF]
Maximum Power Dissipation(PD)	370[W]
Drains-to- source voltage (V(BR)DSS)	75[V]

Table 1: Specific Characteristic of ORFS31 07-7P

A number of parameters distress switching performance, but the most are the gate-drain, gate-source, and drain-source capacitances, which generate switching losses in the circuit. The total power of a MOSFET, the gate charge will have a major effect on the switching act. To reduce switching losses new technologies such as drain thick bottom oxide are created to reducing the gate charge. Advanced technologies like SuperFET minimize conduction loss and rises switching performance by depressing drain-source resistance and gate charge to allow such MOSFETs to withstand both high-speed voltage and current switching transients, letting them operate reliably even at higher frequencies.

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 2: Simulation Parameter

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,so we generate the 20 kHz in the closed loop.

V. SIMULATION

The proposed converter designed with MATLAB simulation. The main inductor is 10 [uH] and the resonant inductor is design 1.0[uH]. This paper has described the experimental setup of the combination of 12V, 5-6 Ah lead acid battery with bidirectional dc-dc converter the specific parameters of the proposed converter are shown in Table 2. The simulation is held to various switching condition on bidirectional power converters. When supply is given the inductor L1 and Lr are charged, once the Lr value is increased then the switch S1 and S4 are switched on,the battery is charged and the capacitors across the switches are charged. When inductor L2 and Lr are charged then once the Lr value is increased then the switch S2 and S3 are switched on, the battery is charged.

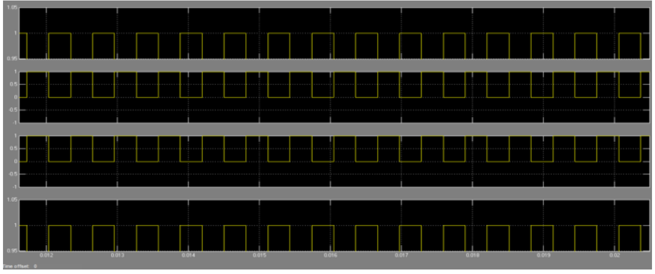

Fig. 3: Output waveform of switching operation

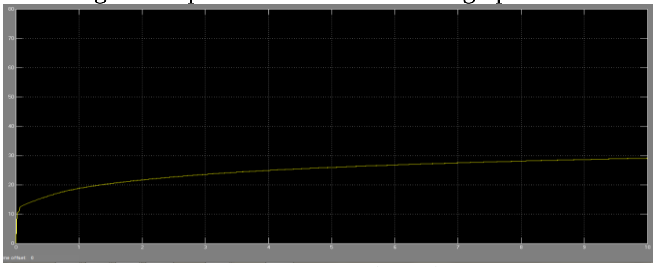

Fig. 4: Output voltage waveform for 15 V Input

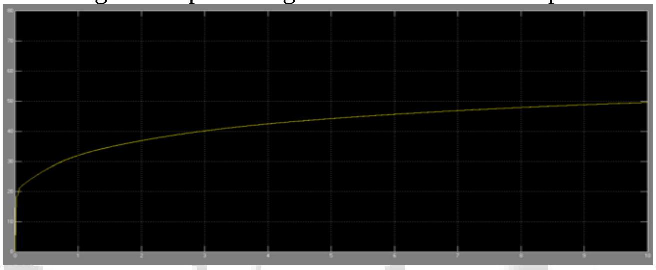

Fig. 5: Output voltage waveform for 25 V Input

Fig.3. shows the switching operation of proposed converter. Fig 4 and Fig 5 shows the output voltage of 15V and 25V respectively. The output voltage is constantly increased based on input voltage.

Based on the simulation parameters the design of proposed converter is made. The simulation results shown are different output voltage based on the different input voltage. Fig 6 and Fig 7 shows the output voltage of 35V and 45V respectively By constant increase in output voltage, the lead acid battery charged efficiently and charging time is reduced.

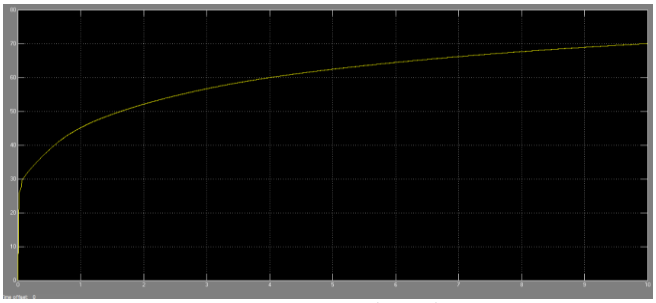

Fig. 6: Output voltage waveform for 35 V Input

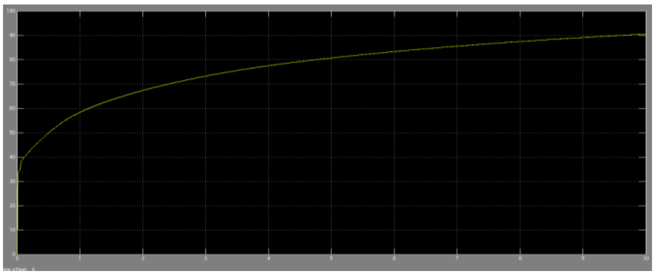

Fig. 7: Output voltage waveform for 45 V Input.

VI. 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 bidirectional DC-DC converter is explained. For the designed system, the efficiency above 99.5% 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.

REFERENCES

[1] Lee, Y. S. Lee and G. T. Cheng, "Quasi-Resonant Zero-Current-Switching Bidirectional Converter for Battery Equalization Applications," IEEE Trans. Power Electron.,vol, 21, no, 5, pp. 1213-1224, Sept 2006
[2] Chuang, Ying-Chun, et al. "A novel single-switch series resonant converter for low power DCIDC energy conversion applications." Power Electronics and Drive Systems (PEDS), 2015 IEEE 11th International Conference on. IEEE, 2015.
[3] Rathore, Akshay Kumar, and Udupi R. Prasanna. "Novel snubberless bidirectional ZCS/ZVS current-fed half-bridge isolated Dc/Dc converter for fuel cell vehicles." iECON 20II-37th Annual Conference on IEEE Industrial Electronics Society. IEEE, 2011.
[4] Jiang, Lei, et aL "A novel soft-switching bidirectional DC-DC converter with coupled inductors." Industry Applications, IEEE Transactions on 49,6 (2013): 27302740.
[5] Jung, Doo-Yong, et aL "Soft-switching bidirectional DC/DC converter with a LC series resonant circuit" Power Electronics, IEEE Transactions on 28.4 (2013): 1680-1690.
[6] J.Patel; H.Chandwani; V.Patel; H. Lakhani. "Bi-directional DC-DC converter for battery charging — Discharging applications using buck-boost switch," Electrical, Electronics and Computer Science (SCEECS), 2012 IEEE Students' Conference on , vol., no.13, pp.1,4, 1-2 March 2012
[7] Dong-Gyu, Nam-Ju Park, and Dong-Seok Hyun. "Soft-switching interleaved bidirectional DC-DC converter for advanced vehicle applications. "Power Electronics Specialists Conference, 2008. PESC 2008. IEEE. IEEE, 2008.
[8] M. Milanovic, A. Roskaric, and M. Auda, "Battery charger based on double-buck and boost converter," in ISIE '99. Proceedings of the IEEE International Symposium on Industrial Electronics (Cat. No.99TH8465), 2000, vol. 2, pp. 747– 752.
[9] Hsieh, Yao-Ching, Te-Chin Hsueh, and Hau-Chen Yen. "An interleaved boost converter with zero-voltage transition." Power Electronics, iEEE Transactions on 24.4 (2009): 973-978
[10] A. C. Hua and B. Z. Syue, "Charge and discharge characteristics of lead-acid battery and LiFePO4 battery," in The 2010 International Power Electronics Conference - ECCE ASIA -, 2010, no. 95, pp. 1478–1483.
[11] Tarascon, J-M., and Michel Armand. "Issues and challenges facing rechargeable lithium batteries." Nature 414, no. 6861 (2001): 359-367.RECHARGE aisbl. "Saftey of Lithium-ion Batteries" The European Association for Advanced Rechargeable Batteries. (2013)
[12] T. Feng, Q. Li, F. Wang, and W. Zhang, "Verification and implementation of the non-inverting buck-boost converter in energy-harvesting battery charger," in 2012 7th IEEE Conference on Industrial Electronics and Applications (ICIEA), 2012, pp. 855–859.
[13] C.C Hua and M.Y Lin, "A study of charging method control of lead acid battery for electric vehicles," IEEE Proc. of Ind. Electron., vol. 1, pp.135-140.
[14] Shukla, A. K, and Prem Kumar, T. "Materials for Next Generation Lithium Batteries.," Current Science Vol. 94 No. 3 (2008) pp 317-327.
[15] Kam, K. C. and Doeff, M. M. "Electrode Materials for Lithium Ion" Material Matters, Vol. 7, No. 4, (2012)Electronic Properties of Materials, 4th ed. Springer, NY, 2011, pp 110-111
[16] Stoeva, Z., Jager, B and et al "Crystal Chemistry and Electronic Structure of the Metallic Lithium Ion Conductor, LiNiN" JACS Vol. 129 No. 7 (2007)
[17] Leung, K "Electronic Structure Modeling of Electrochemical Reactions at Electrode/Electrolyte Interfaces in Lithium Ion Batteries" Sandia National Lab. , (2013)
[18] Inoue, N, and Zou, Y. "Electronic Structure and Lithium Ion Migration of La 4/3-yLi3yTi2O6 using Cluster Model" Solid State Ionics 176 (2005)
[19] C. Mikolajczak, M. Kahan, K. White, R. T. Long "Lithium-ion Batteries Hazard and Use Assessment: Final Report" The fire protection research foundation, July 2011
[20] Chuang, nYing-Chun, et al. "A novel single-switch series resonant converter for low power DCIDC energy conversion applications." Power Electronics and Drive Systems (PEDS), 2015 IEEE 11th International Conference on. IEEE, 2015.
[21] Rathore, Akshay Kumar, and Udupi R. Prasanna. "Novel snubberless bidirectional ZCS/ZVS current-fed half-bridge isolated Dc/Dc converter for fuel cell vehicles." iECON 20II-37th Annual Conference on IEEE Industrial Electronics Society. IEEE, 2011.
[22] Jiang, Lei, et aL "A novel soft-switching bidirectional DC¬-DC converter with coupled inductors." industry Applications, IEEE Transactions on 49,6 (2013): 2730-2740.

[23] Jung,Doo-Yong,et aL "Soft-switching bidirectional DC/DC converter with a LC series resonant circuit" Power Electronics, IEEE Transactions on 28.4 (2013): 1680-1690.
[24] Chuang, Ying-Chun, et al. "A novel single-switch series resonant converter for low power DCIDC energy conversion applications." Power Electronics and Drive Systems (PEDS), 2015 IEEE 11th International Conference on. IEEE, 2015.
[25] Rathore, Akshay Kumar, and Udupi R. Prasanna. "Novel snubberless bidirectional ZCS/ZVS current-fed half-bridge isolated Dc/Dc converter for fuel cell vehicles." iECON 20II-37th Annual Conference on IEEE Industrial Electronics Society. IEEE, 2011.
[26] Jiang, Lei, et aL"A novel soft-switching bidirectional DC¬ DC converter with coupled inductors." industry Applications, IEEE Transactions on 49,6 (2013): 2730-2740.
[27] Jung,Doo-Yong, et aL "Soft-switching bidirectional DC/DC converter with a LC series resonant circuit" Power Electronics, IEEE Transactions on 28.4 (2013): 1680-1690.
[28] Nadia M. L. Tan; Takahiro Abe; Hirofumi Akagi, “A 6-kW, 2-kWh Lithium-Ion Battery Energy Storage
[29] System Using a Bidirectional Isolated DC-DC Converter, "in Power Electronics Conference (IPEC), 2010 International in 2010 PP 46 - 5.
[30] Bong-Yeon Choi; Soon-Ryung Lee; Jong-Young Lee; Seung-Ho Baek; Chung-Yuen,” Design of Soft-Switching Interleaved Buck and Boost Converter for vehicle application,” in IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific) in 2016, PP 290 - 295.
[31] S. G. Abeyratne; P. S. N. Perera; H. S. Jayakody; S. M. K. B. Samarakoon; R. R. S. De Bulathge,” Soft Switching Fast Charger for Batteries used in Renewable Energy Applications and Electric Vehicles,” in IEEE International Conference on Industrial and Information Systems (ICIIS) in 2012,PP 1 – 6.