The International Journal Of Engineering And Science (IJES)
|| Volume || 3 || Issue || 3 || Pages || 37-44 || 2014 ||
ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805

Llc Resonant Converter for Battery Charging Applications

[1]A.Sakul hameed, [2]S.Prabhu, [3]Dr.M.SathisKumar
[1&2]*PG Student, P.A.College of Engineering and Technology, Pollachi.*
[3]*Head of the Department, P.A.College of Engineering and Technology, Pollachi*

ABSTRACT
In this paper, sepic converter was used to improve battery performance without affecting the volume of charger by giving the constant output voltage when input voltages are low or high. The resonant tank was used to present better performance LLC multi resonant dc–dc converter in a two-stage smart battery charger for neighborhood electric vehicle applications. The performance characteristics and its multi resonant converter have been analyzed are implemented. It eliminates both high and low frequency current ripple on the battery.

INDEX TERMS—*Battery, LLC resonant converter, DC-DC converter*

Date of Submission: 26 February 2014 Date of Acceptance: 15 March 2014

I. INTRODUCTION

The efficiency plays a major role at present current global energy crisis is focus and electronic products are facing the daunting challenge to deliver high performance, at the same time as consuming less power. Various governmental agencies around the world have or are looking to increase their efficiency standards for numerous products in their respective specifications, as a result of this crisis. It will be difficult to meet these efficiency specifications with conventional hard switched converters. Power supply designers will require considering soft switching topologies to increase the efficiency as well as to allow for better frequency operation. Practical design considerations and resonant tank design procedure are offered for a better performance LLC multi resonant dc–dc converter in a two-stage smart battery charger for neighborhood electric vehicle applications.

The LLC resonant topology permits the zero voltage switching of the main switches thereby considerably lowering switching losses and improving efficiency. LLC resonant converters can be achieved with efficiencies of 93 to 96%. It will be illustrate the operation of the LLC resonant topology and show how such high efficiencies can be attained.

A smart charger is a battery charger that can act in response to the condition of a battery, and modify the battery charging actions compare to the battery algorithm. Conversely, a standard or simple battery charger supplies a pulsed dc or constant dc power source to a battery being charged. The charge on the battery and its output depends on time does not alter in a simple charger. Therefore, smart chargers are preferred for NEV battery charging application

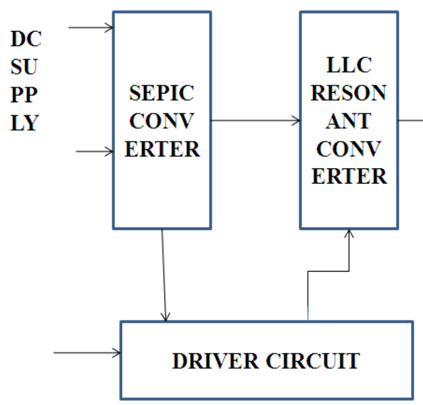

Fig 1: Block Diagram of LLC with SEPIC converter

II. SINGLE-ENDED PRIMARY-INDUCTOR CONVERTER

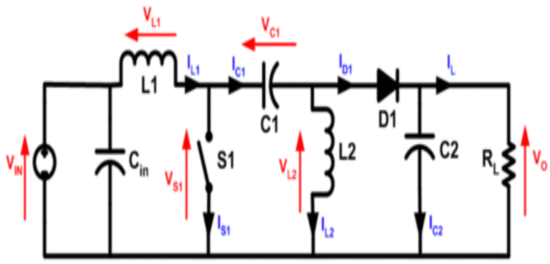

Fig 2: Schematic diagram of SEPIC.

Single-ended primary-inductor converter (SEPIC) is used for the conversion of a DC-DC and also for allowing the electrical voltage at its output to be less than or greater than or equal to that at its input; The duty cycle of the control transistor is used to control the output of SEPIC converter.

A SEPIC is similar to a usual buck-boost converter, but it has non-inverted output as a advantage (the input has the same voltage polarity with the output), with the help of a series capacitor to couple energy to the output from the input, and being able of true shutdown: when the switch is off, its output falls to 0 V, following a quite heavy transient dump of charge.

SEPICs are useful in applications in which a battery voltage can be below and above that of the regulator's intended output. For example, a single lithium ion battery usually discharges to 3 volts from 4.2 volts; if other component needs 3.3 volts, then the SEPIC would be effective.

Circuit operation

The SEPIC converter exchanges the energy between the inductors and capacitors to convert from one voltage to another. The switch S1 is used to control the amount of energy exchanged, which is usually a transistor such as a MOSFET; MOSFETs having an advantage of lower voltage drop and much higher input impedance when compare to bipolar junction transistors (BJTs), and also do not need biasing resistors.

Continuous mode

A SEPIC is said to be in (CCM) continuous-conduction mode ("continuous mode") if the current flows through the inductor L1 never goes to zero. The average voltage across capacitor C1 (V_{C1}) is equal to the input voltage (Vin), during a SEPIC's steady-state operation. Because capacitor C1 do not allows the direct current (DC), the average current across capacitor c1 (I_{C1}) is falls to zero, making inductor L2 the only source of load current. Therefore, the average load current is the same as the average current through inductor L2 (IL2) and hence input voltage is independent.

Looking at average voltages, the following equations can be written:

$$V_{IN} = V_{L1} + V_{C1} + V_{L2} \qquad (1)$$

Since the input voltage V_{IN} is equal to average voltage of V_{C1}, $V_{L1} = -V_{L2}$. Hence, the two inductors are wound on the same core. The effects of mutual inductance will be zero, Because of the voltages are the same in magnitude, assuming the polarity of the windings is correct and also the magnitudes of two inductor ripple currents will be equal.

The average currents can be summed as follows

$$I_{D1} = I_{L1} - I_{L2} \qquad (2)$$

When switch S1 is switched on, current I_{L1} increases and the current I_{L2} increases in the negative direction. (Mathematically, it decreases because of arrow direction.) The energy coming from the input source is used to increase the currentI_{L1}. Since S1 is a short when closed, and the instantaneous voltage V_{C1} is approximately V_{IN}, the voltage V_{L2} is approximately $-V_{IN}$.

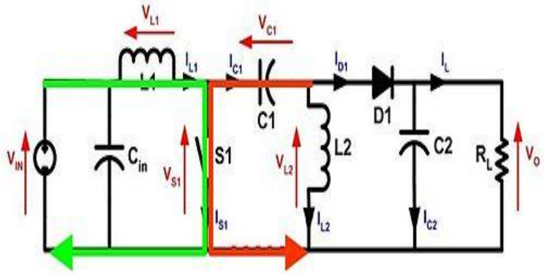

Fig 3: C1 discharges increasing current in L2 (red) and current increases through L1 (green) with S1 closed

Hence the capacitor C1 delivers the energy to maximize the magnitude of the current in I_{L2} and therefore increase the energy stored in inductor L2. Consider the bias voltages of the circuit in a d.c. state is the easiest way to visualize this, then close S1

When switch S1 is switched off, the current I_{C1} becomes the same as the current I_{L1}, for the reason that inductors do not allow any sudden changes in current. The current I_{L2} will continue in the negative direction, in fact it never reverses the current flow direction. It is shown in the diagram that a negative I_{L2} will add to the current I_{L1} to increase the current delivered to the load. Using Kirchhoff's Current Law, it can be shown that $I_{D1} = I_{C1} - I_{L2}$. It can be concluded then, that while S1 is switched off, power is supplied to the load from both the inductors L2 and L1. Capacitor C1, however is being charged with the help of L1 during this off cycle, and during the on cycle it will in turn recharge L2.

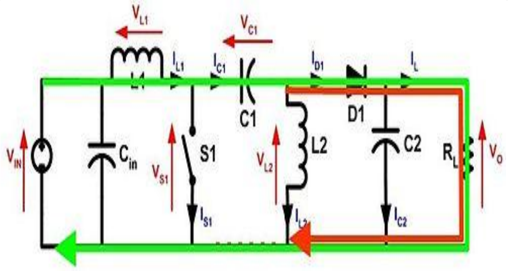

Fig 4: current through L2 (red) produce current through the load and current through L1 (green) with S1 is open

Since voltage across capacitor C1 may reverse direction each cycle, a non-polarized capacitor must be used. However, In some cases a polarized tantalum or electrolytic capacitor may be used, because the voltage across capacitor C1 will not change until the switch is closed long enough for a resonance half cycle with inductor L2, and the current in inductor L1 could be somewhat large by this time.

The capacitor C_{IN} is used to minimize the effects of the internal resistance and parasitic inductance of the power supply. The buck/boost capabilities of the SEPIC converter are possible due to inductor L2 and capacitor C1. The Inductor L1 and switch S1 create a standard boost converter, which generates a voltage (V_{S1}) that is higher than V_{IN}, whose magnitude is determined with the help of the duty cycle of the S1. Because, the average voltage across capacitor C1 is V_{IN}, the output voltage (V_O) is $V_{S1} - V_{IN}$. If V_{S1} is less than double V_{IN}, then the input voltage is greater than output voltage. If V_{S1} is greater than double V_{IN}, then the input voltage will be lesser than the output voltage. In SEPIC converter, two inductors coupled together to develop the switched-power supplies.

Discontinuous mode

A SEPIC is operated in discontinuous-conduction mode (DCM) if the current flows through the inductor L1 is allowed to go down to zero

Reliability and efficiency

The switching time of diode D1 and potential drop is critical to a SEPIC's efficiency and reliability. The high voltage spikes across the inductors should not be generated, whereas the diode's switching time requires being extremely fast, which could cause injure to components. Schottky diodes or fast conventional diodes may be used.

The effects on the converter efficiency and ripple are large is depends upon the resistances in the capacitors and the inductors. The lower series resistance in inductors is allowing less heat energy will be dissipated, resulting in better efficiency (a larger portion of the input power being transferred to the load). Capacitors with low equivalent series resistance (ESR) should also be used for capacitor C1 and C2 to reduce ripple and avoid heat production, especially in capacitor C1 where the current is changing direction often.

III. LLC RESONANT CONVERTER

The LLC resonant converters advantages with LCC over is that the 2 physical inductors can be often be integrated into one physical component, including both the series inductance Lr, and T/F magnetizing inductance Lm. The LLC converter has additional benefits are over conventional converters. 1. It can regulate the O/P over wide line and load variations with relatively small variation of switching frequency while maintaining excellent efficiency. 2. To achieve ZVs over entire operating range. The LLC resonant converter schematically looks very similar to the series resonant converter. The main difference is that in the series resonant converter the primary inductance of the transformer was so great as to not factor in the characteristics of the resonant network. However, in the LLC converter the primary inductance of the transformer is reduced in value such that it now impacts the resonant network. In fact, an LLC resonant converter has two resonant frequencies.

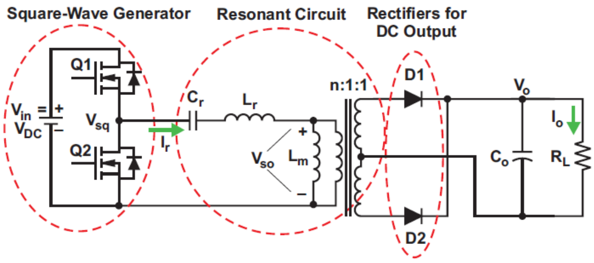

Fig 5: Circuit Diagram of LLC resonant converter

SQUARE WAVE GENERATOR: It produces square wave voltage, vd by driving switches, Q1 and Q2 with alternating 50% duty cycle for each switch

RESONANT CONVERTER: It consists of LLC. The current lags the voltage applied to resonant network which allows the MOSFET's to be turned on with zero voltage.

RECFITIER NETWORK: It is used for AC to DC conversion.

IV. BATTERY

It is an electro-chemical device, which delivers electric energy by chemical reaction. If numbers of cells are grouped together is called as battery or cell. The classifications of battery or cells are 1.primary cells. 2. Secondary cells.

a. Primary Cell

A Cell which can't be recharged is called primary cell. It converts chemical energy into electrical energy.

Eg: Dry cell, Voltaic cell

b. Secondary Cell

The cell which can be recharged and brought back to the original state is called secondary cell.

Eg: lead-acid cells, alkaline cell.

c. Methods of charging

D.C. supply is used for charging. There are 2 methods

1. Constant current method
2. Constant Voltage method

Constant current method

The charging current is maintained throughout the charging process by adjusting the series rheostat.

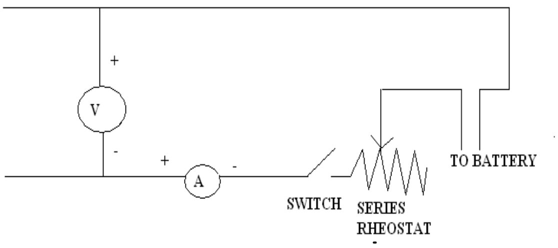

Fig 6: Circuit Diagram of Constant Current Method

The specified value of current is maintained constant till the cells are gassing. Normally the cells starts gassing the charging current are reduced

Constant voltage method

The batteries to be charged are connected in parallel across the supply. The charging voltage in maintained at constant throughout the charging process

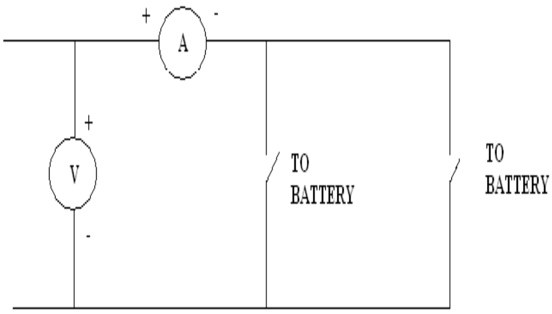

Fig 7: circuit diagram of constant voltage method

.

The charging current is high in the beginning and it is gradually reduced as battery pickup charge resulting in increased backemf. This method is mostly used in battery charging shops due to high initial charging current, the life of the battery is reduces.

Indication of fully charged cell

- Voltage ⟶ Checked with the help of tester
- Gassing ⟶ H2 increase in cathode, O2 decrease in anode.
- Specific gravity of electrolyte is increases
- Colour of plates ⟶ +ve plate ⟶ dark brown
  -ve plate ⟶ grey

Battery capacity

It is expressed in Ampere-hour (AH) and depends upon 1.temperature 2.size and no. of plates 3. Rate of discharge

AH= no. of specified discharge current in ampere and no. of hours battery discharged

Battery efficiency AH %=   Ampere-hour output/ Ampere-hour input *100

Battery efficiency= ((Discharge current *time of discharge)/ (Charging current*time of charge))*100

V. SIMULATION STUDIES

It is an efficient way for designer to learn how a circuit and its control are working. It is normally much cheaper to do a thorough analysis than to build the actual circuit in which component stresses are measured. A simulation can discover the possible problems and determine optimal parameters, increasing the possibility of getting the prototype. New circuit concepts and parameter variations are easily tested. Destructive tests that cannot be done in the lab, either because of safety or because of costs involved, can easily be simulated. Response to faults and abnormal conditions can also be thoroughly analyzed. The software tool used for the simulation studies is MATLAB/Simulink. MATLAB is a high performance language used for technical computing. It integrates calculation, visualization, and program in an easy to use environment where solutions and problems are expressed in well-known mathematical notation. MATLAB is an interactive system does not require dimensioning whose basic data element is an array. MATLAB is used for analysis and development. MATLAB features a family of join application-specific solutions called toolboxes. Toolboxes are complete collections of MATLAB functions to solve particular classes of problems that extend the MATLAB environment. Areas in which toolboxes are available include signal processing, control systems, neural networks, fuzzy logic, wavelets, and simulation. The MATLAB version used here is 7.5.0.

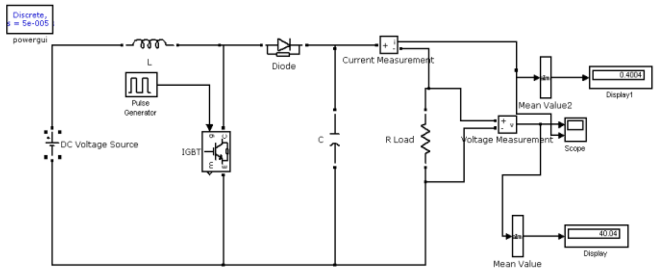

Fig 8: Sepic converter simulink design

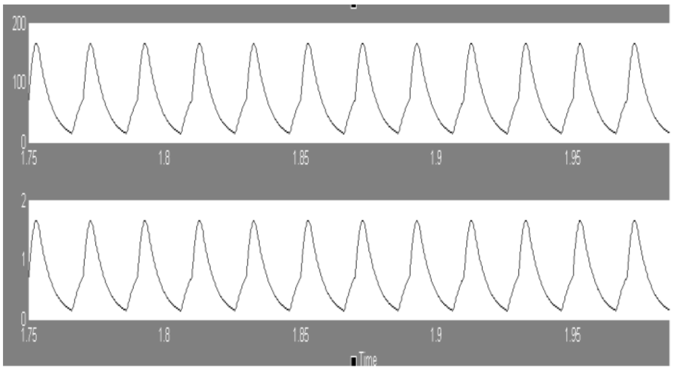

Fig 9: Output waveform of SEPIC converter

This simulation result has shown the improved performance of battery life and improving the efficiency as 98%. This shows the improved battery performance and life time of battery charger without affecting volume of charger. This battery presents stable output voltage at 70V.

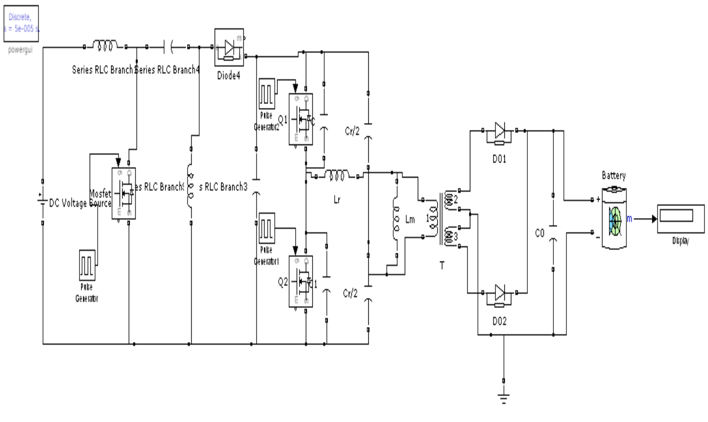

Fig 10: LLC resonant converter with battery simulink design

VI. CONCLUSION

Sepic converter provides a stable output voltage with the range of 36-72v for this application. The simulation result show improved voltage and performance of battery using LLC resonant converter and boost converter. This ensures higher life time of battery without affecting the volume of charger. This will improve performance of charger system. The LLC resonant type converter will reduce the switched losses with improving the efficiency. Thus, with small switching frequency variations, compensation of the load variations and adjustment of the regulated output voltage in a wide range has been achieved. Soft switching is achieved for all power devices under all operating conditions. Due to this feature, switching losses and EMI noises have been reduced effectively, and the converter size has been reduced by increasing the switching frequency.

Appendix

Stage	Parameter	Designator	Value
Initial Design Parameters	Input voltage range	V_{in_min}~ V_{in_max}	370-410 [V]
	Input voltagenominal	V_{in_nom}	390 [V]
	Output voltage range	V_{o_min}~ V_{o_max}	36-72 [V]
	Output voltagenominal	V_{o_nom}	48 [V]
	Output power at 48v	$P_{o\text{-}nom}$	650 [W]
	Switching frequency	$f_{s\text{-}min}$~ $f_{s\text{-}max}$	150-450[kHz]
	Resonant frequency	f_o	200 [kHz]
Resonant tank components	Transformer Ratio	N_n	4:1:1
	Resonant Inductor	L_r	35 [μH]
	Resonant capacitor	C_r	2×8.2 [nF]
	Magnetizing inductance	L_m	105[μH]
Design constants	Resonant period	T_o	4.75 [μs]
	Maximum DC gain	M_{DC_max}	1.6
	Dead time	t_{dead}	400 [μs]

Fig 11: Design Parameters

Stage	*Component*	*Manufacturer*	*Part #*
Power Train Components	MOSFET	*STMicroelectronics*	STB23NM60ND
	Diode Rectifiers	*STMicroelectronics*	STTH2002C
	Resonant Film Capacitor	*EPCOS MKP*	2×8.2 [nF]
	Resonant Inductor	*EPCOS*	RM12 - N97
	Magnetizing Inductance	*EPCOS*	RM14 - N97
	Output Film Capacitors	*EPCOS MKT*	3×3.3 [μF]
	Controller IC	*On Semiconductor*	NCP1395

Fig 12: Components used in prototype converter

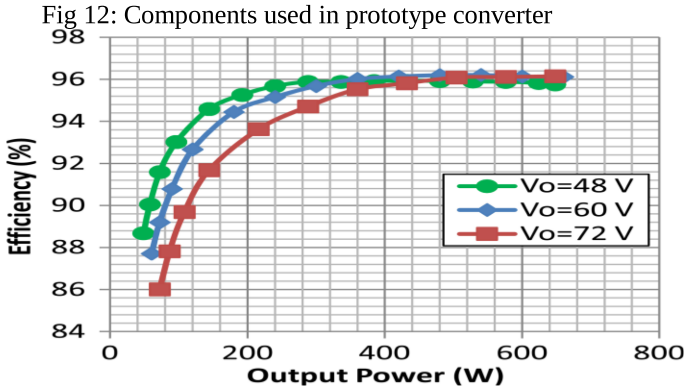

Fig 13: Characteristics curve between efficiency and output power

Measured efficiency versus output power at *Vo* = 48 V and *f*sw =211 kHz, *Vo* = 60 V and *f*sw = 170 kHz, *Vo* = 72 V and *f*sw = 152 kHz.Curves of the efficiency of the converter as a function of load are given in Fig. 8 for output voltages of 48, 60, and 72 V. These measurements were taken with the output relay, common mode EMI inductor, and output fuse included.

REFERENCES

[1] D.W. Gao, C. Mi, and A. Emadi, "Modeling and simulation of electricand hybrid vehicles," *Proc. IEEE, vol. 95, no. 4, pp. 729–745, Apr. 2007.*

[2] A. Emadi, S. Williamson, and A. Khaligh, "Power electronic intensive solutions for advanced electric, hybrid electric, and fuel cell vehicular power systems," *IEEE Trans. Power Electron., vol. 21, no. 3, pp. 567*–577, May 2006.

[3] A. M. Rahimi, "A lithium-ion battery charger for charging up to eight cells," in *Proc. IEEE Conf. Vehicle Power Propulsion, 2005, pp. 131–136.*

[4] B. Singh, B. N. Singh, A. Chandra, K. Al-Haddad, A. Pandey, and D. P. Kothari, "A review of single-phase improved power quality AC-DC converters," *IEEE Trans. Ind. Electron., vol. 50, no. 5, pp. 962–981,*

[5] L. Petersen and M. Andersen, "Two-stage power factor corrected power supplies: The low component-stress approach," in *Proc. IEEE Appl.Power Electron. Conf. Expo., 2002, vol. 2, pp. 1195–1201.*