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An Llc Resonant Converter Design Forwide Output Voltage Range Of Battery Charging

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Abstract: This project consists of a LLC resonant converter with its features enhanced by including a resonant tank circuit design which reduces the harmonics considerably. By using this LLC Multi Resonant DC to DC Converter, we are able to reduce the harmonics and ripple frequency in a NEV battery charging system.By using this specific converter design, the battery charger can respond to the condition of a battery, and modify its charging actions according to the battery algorithm. Thus much more desirable output voltage can be achieved and due to this the Battery is able to charge faster and have a longer life cycle than when it is charged by other type of chargers.The Multi Resonant Converter has been analyzed and its performance characteristics are presented. It eliminates both low- and high frequency current ripple on the battery, thus maximizing battery life without penalizing the volume of the charger.This prototype unit converts 390V from the input dc link to an output voltage range of (48–72)V dc at 650 W. The prototype achieves a peak efficiency of 96%.

Keywords: LLC Multi Resonant; NEV battery; harmonics.

I. INTRODUCTION

Neighbourhood Electric Vehicles (NEV) Are Propelled by an electric motor that is supplied with power from a rechargeable battery. Presently, the performance characteristics required for many electric vehicle (EV) applications far exceed the storage capabilities of conventional battery systems. However, battery technology is improving and as this transition occurs, the charging of these batteries becomes very complicated due to the high voltages and currents involved in the system and the sophisticated charging algorithms. Quick charging of high capacity battery packs causes increased disturbances in the ac utility power system, thereby increasing the need for efficient, low-distortion smart chargers. A smart charger is a battery charger that can respond to the condition of a battery, and modify its charging actions according to the battery algorithm. Conversely, a standard or simple battery charger supplies a constant dc or pulsed dc power source to a battery being charged. A simple charger does not alter its output based on time or the charge on the battery. Therefore, smart chargers are preferred for NEV battery charging applications.

The proposed NEV battery charger power architecture includes an ac–dc converter with power factor correction (PFC), followed by an isolated dc–dc converter. This architecture virtually eliminates the low- and high-frequency current ripple charging the battery without using a bulky filter capacitor.

Instead, it uses a high-frequency transformer. The architecture maximizes battery life without penalizing the charger volume. In the work that follows, the front-end ac–dc PFC converter is a conventional continuous conduction mode (CCM) boost topology. The second-stage dc–dc converter is a half-bridge multiresonant LLC converter. The criteria for choosing these topologies include high reliability, high efficiency, and low component cost. The half-bridge resonant LLC converter is widely used in the telecom industry for its high efficiency at the resonant frequency and its ability to regulate the output voltage during the hold-up time, where the output voltage is constant and the input voltage might drop significantly.

Resonant converters have been used in many applications, including induction heating, and fuel cells. However, the wide output voltage range requirements for a battery charger are drastically different and challenging compared to telecom applications, which operate in a narrow output voltage range. It has four distinct operating modes: bulk, absorption, equalization and maintenance. In the bulk mode, the charger limits the maximum charging current to a preset IMAX value while monitoring the battery voltage. In the absorption mode, the charger elevates the voltage to VABS while monitoring the current. This voltage is just below the battery gassing voltage. When it has reached this point, the battery is between 70% and 90% state of charge (SOC). When the current decreases to a preset value, IOCT, the charger enters the equalization mode. When it has reached this point, the battery is at 100% SOC. Equalizing an overcharge performed on lead acid batteries after they have been fully charged. This function equalizes the cell voltages in a battery module. In the maintenance mode, the charging action is finished and the charger only supplies limited current to offset the internal soft discharge.

The battery voltage, at the dc–dc converter output, can vary from as low as 36 V to as high as 72 V. Therefore, the design requirements for selecting the resonant tank components are significantly different than those in telecom applications featuring a constant output voltage. The authors in addressed wide output range applications; however, the design procedures are given for resonant tank components using the first harmonic approximation proposed in and , which is only valid for frequencies close to the resonant frequencies. The resonant tank design guidelines utilize information from the lead acid battery V–I plane, provided. It illustrates the key design points and limitations on a 650-W charger for a 48-V system. This V–I plane dictates the design criteria for the half-bridge multiresonant LLC converter, in particular the resonant tank components, Lr, Lm, and Cr . The outer range of the operating plane is constrained by the constant voltage (CV), constant power (CP), constant current (CC), and short circuit limits, in addition to the maximum frequency of the LLC converter.

II. DESIGN CALCULATION

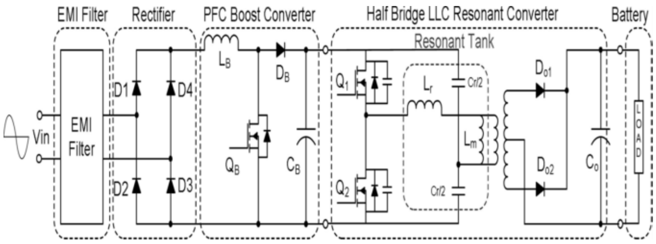

Fig.Circuit Diagram

The life and capacity of EV batteries depend on several factors, such as cycle count, charge mode, maintenance, temperature, and age. Among these factors, the charge mode has a significant impact on battery life and capacity. EV batteries should be charged with current and voltage levels with low ripple. In addition, the basic requirements for battery chargers are small size and high efficiency, which can be achieved using soft switching techniques. To reduce the switching losses that result from high-frequency operation, resonant power conversion can be used.

There are several publications and application notes in industry focusing on resonant circuit design. There are two major issues with the existing work:

1) The output voltage is considered constant (e.g. typical for telecom applications), which is not a valid assumption in battery charging.

2) The ratio of the transformer magnetizing inductance and the resonant inductance (including the leakage inductance) is given by some suggested values without considering the effect of the short circuit condition on the resonant network.

As a result, the sequence of designing the resonant network is different for battery charging applications. illustrates a family of typical dc gain characteristics for an LLC converter as a function of normalized switching frequency for seven different load conditions varying from no-load to short circuit. Resonance occurs at unity gain, where the resonant capacitors and series resonant inductor are tuned.

By design, this is the point where the converter is required to deliver maximum power, and it is marked as “Design Point fs .” A second resonance occurs at the peak of the bell shaped curves, which is the boundary between ZVS and ZCS. The maximum gain is achieved at the second resonant frequency, where the resonant capacitors are tuned with series resonant inductor and parallel magnetizing inductance. This point of maximum gain is labeled

as “Design Point Lm.”Achieving maximum efficiency requires operation close to frequencies where the resonant tank impedance is very low. Wide range for input and/or output operating voltages requires operation on the steep portion of the curve below resonance. In addition, maintaining ZVS operation while avoiding ZCS operation, requires operation in Region. Fast overload and short circuit protection circuitry is required in order to avoid possible ZCS operation in the capacitive Region .

Stage	Parameter	Designator	Value
Initial Design Parametrs	Input Votage Range	$V_{in\_min} \sim V_{in\_max}$	370 - 410 [V]
	Input Votage Nominal	V_{in_nom}	390 [V]
	Output Votage Range	$V_{o\_min} \sim V_{o\_max}$	36 - 72 [V]
	Output Votage Nominal	V_{o_nom}	48 [V]
	Output Power at 48 V	P_{o_nom}	650 [W]
	Switching Frequency	$f_{s\_min} \sim f_{s\_max}$	150 - 450 [kHz]
	Resonant Frequency	f_o	200 [kHz]
Resonant Tank Compomets	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 Constatnts	Resonant period	T_O	4.75 [μs]
	Maximum DC gain	M_{DC_max}	1.6
	Dead Time	t_{dead}	400 [ns]

Fig.Design Specifications

DESIGN CALCULATIONS:

1.Transformer Turns Ratio,

Nn = Vin(nom) / 2 (Vo(min) + Vd)

= 390 / [2 (36 + 13)]

Nn = 4 turns

2.Resonant Inductor,

Lr = [Nn . Vin(nom) . Vo(nom)] / [8fs max . Po]

= [4 * 390 * 48] / [8 * 450 * 103 * 650]

Lr = 32μH

3.Resonant Capacitor,

Cr = 1 / [(2πfo)2 . Lr(scc)]

= 1 / [(2 * 3.14 * 200 * 103) 2 . 35 * 10-6]

Cr = 18 nF

4.Characteristic Impedance,

$$Z_o = [L_r(scc) / C_r(res)]^{1\backslash 2}$$

$$= [(32 * 10^{-6}) / (18 * 10^{-9})]^{1/2}$$

$$Z_o = 42.16 \text{ ohms}$$

5.Magnetizing Inductance,

$$L_m = \frac{t_{dead} . N_n . V_o(min) . [(1/ 4f_{smax}) - (t_{dead} /2)]}{C_{HB} . V_{in}(max)}$$

$$L_m = \frac{400 * 10^{-9} * 4 * 36 * [(1 / (4 * 450 * 10^3) - ((400 * 10^{-9}) / 2)]}{0.001 * 10^9 * 410}$$

$$L_m = 105\ \mu H$$

III. ALGORITHM

The PIC Microcontroller is programmed using MPLAB software. The program is similar to "C" program.

Step 1: Start the process

Step 2: Configure the IC.

Step 3: Configure I/P and O/P.

Step 4: Set PWM Period by writing to the PR2 register.

Step 5: Set the PWM duty cycle by writing to the CCPR1L and CCP1CON register.

Step 6: Make CCP1 pin an output by clearing the TRISC2.

Step 7: Set the TMR2 prescale value and enable timer2 by writing to T2CON.

Step 8: Configure CCP1 module for PWM operation.

Step 9: On the timer.

Step 10: Stop.

IV. PROGRAM

```
include<pic.h>

delay(unsigned int value);

int main()

    {
```

```
unsigned char   dc,i=0xFF;

TRISC = 0 ;

PORTC = 0 ;

PR2 = 0x7c ;

T2CON = 0x05 ;

CCP1CON = 0x0c;

CCP2CON = 0x3c ;

for(;;)

            {

CCPR1L = i ;

CCPR2L = ~(i) ;

delay(10) ;

CCPR1L = ~(i) ;

CCPR2L = i;

delay(10) ;

          }

}
```

V. SIMULATION AND HARDWARE OUTPUT

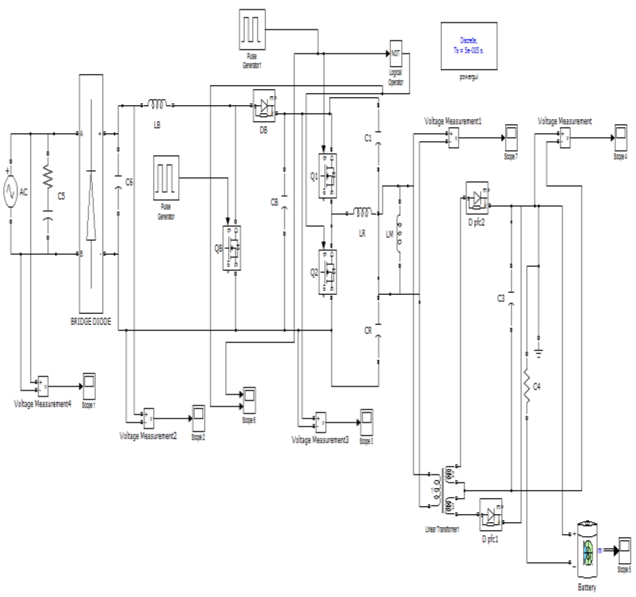

Fig. Simulation Model

When you measure a current using a Current Measurement block, the positive direction of current is indicated on the block icon (positive current flowing from + terminal to – terminal). Similarly, when you measure a voltage using a Voltage Measurement block, the measured voltage is the voltage of the + terminal with respect to the – terminal. However, when voltages and currents of blocks from the Elements library are measured using the Multimeter block, the voltage and current polarities are not immediately obvious because blocks might have been rotated and there are no signs indicating polarities on the block icons.

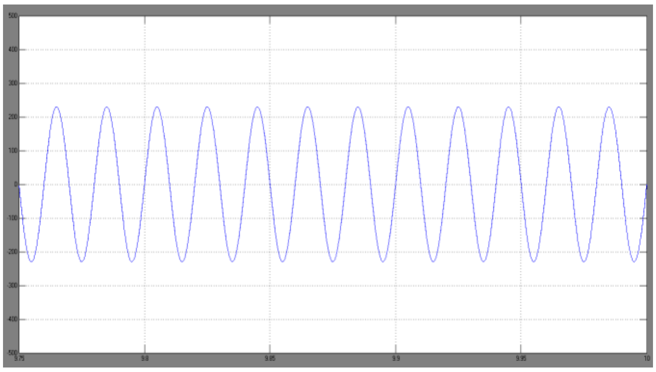

Fig. Input Voltage

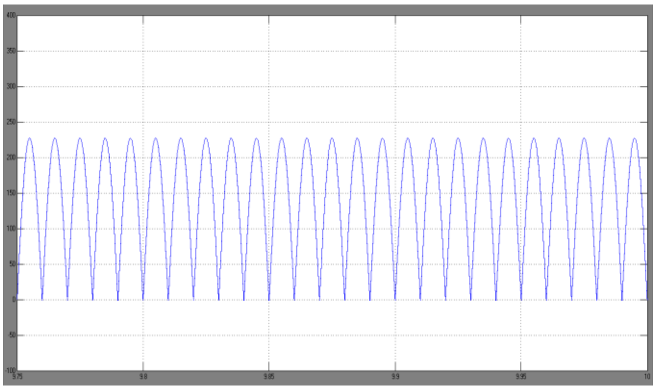

Fig. Rectifier Output

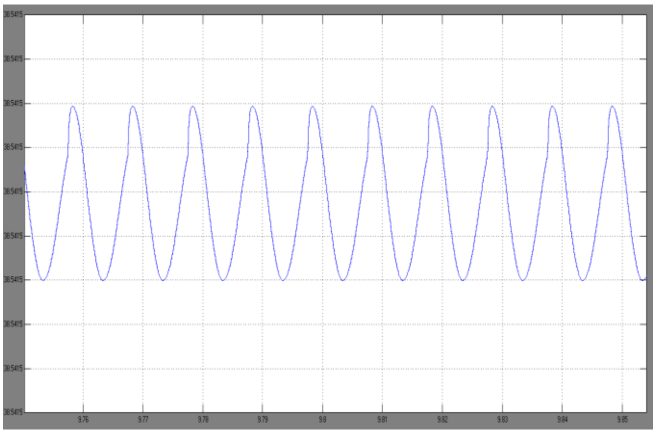

Fig. LLC Resonant Converter Output

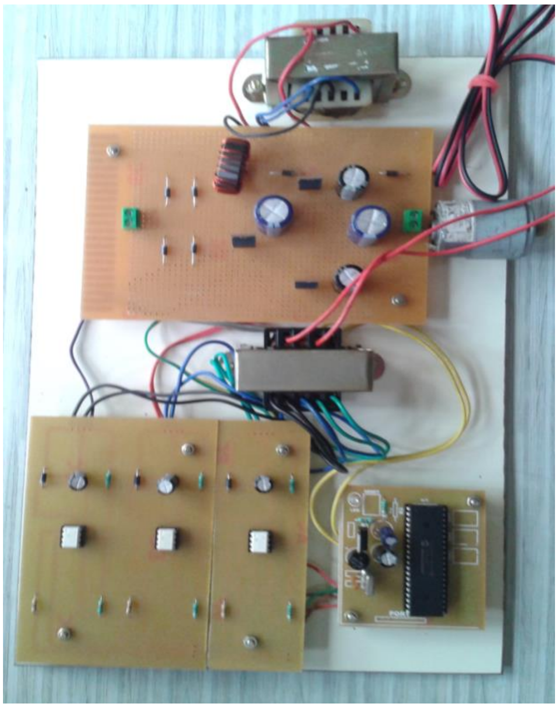

Fig. Hardware

VI. CONCLUSION

A resonant tank design procedure and practical design considerations were presented for a high performance LLC multiresonant dc–dc converter in a two stage wide output voltage range smart battery charger for NEV applications.Themultiresonant converter has been analyzed and its performance characteristics presented. It eliminates both low- and high-frequency current ripple on the battery, thus maximizing battery life without penalizing the volume of the charger. Experimental results were presented for a prototype unit converting 390V from the input dc link to an output voltage range of (48–72)V dc at 650W. The prototype achieves a peak efficiency of 96%.

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