LLC Resonant Tank based Converter for EV Charging Application

S. Nagaraj, R. Ranihemamalini, L. Rajaji, K. Srividya, A. Mohandoss

Abstract: The aim of the article is to maximize the battery life using LLC resonant tank. LLC tank designing methodology and also the practical designing examination is introduced in LLC multi converter. Designed de- dc converter increases the battery life by eliminating low and high frequency current ripples. In addition, bridgeless cuk converter is used for power factor improvement. To achieve the better power factor and to reduce the conduction losses the cuk converter is aimed to function in discontinuous mode of conduction (DCM). DC output voltage ranging 42-24 V for 650 W is obtained from the modelling for battery charging application.

Keywords: Discontinuous conduction mode (DCM), LLC multi resonant converter, Bridgeless cuk converter.

I. INTRODUCTION

Rechargeable battery supplies power to electric motor to drive electric vehicle [1],[2]. Currently, the standard battery systems storage capability demand is increased. Even though battery technology is improved, the system requires high current and high voltage to charge these batteries. Nowadays the smart charger battery charging methodology becomes very difficult due to the advancement in charging algorithms [3]. A smart charger with low distortion is required because of increased disturbances in quick charging of excessive potential of battery packs. The proposed architecture block includes a bridgeless cuk converter, followed by a resonant converter as depicted in Fig 1 which rejects the current ripple charging energy storage system i.e., battery using a high frequency transformer.

The criterion for selecting discontinuous conduction mode topology includes natural protection against overload current, easy implementation of transformer isolation and less electromagnetic interference. Second section describes about chopper representing multi – resonant half – bridge power converter.

Though, the battery charger’s wide output voltage specifications are extremely challenging and varying while comparing to telecom applications that operates in a narrow range. DC-DC converter battery output voltage varies from 36 V to 72 V. Hence the designing specifications to choose the bridgeless cuk converter and LLC components are non-identical suits for telecommunication application under continuous voltage. LLC resonant tank converter is required to meet these specifications. To achieve high switching frequency and higher efficiency resonant tank is modeled for higher range of input voltage. Both zero voltage and zero current switching are achievable over the entire operating range. Chapter 2 tells about the working of bridgeless cuk converter. Chapter 3 follows the design of cuk converter and multi resonant LLC converter. Chapter 4 gives the simulation results. Chapter 5 shows the hardware results. Chapter 6 gives the conclusion.

II. BRIDGELESS CUK DC/DC CONVERTER

A. Proposed System

The operation of the system under study is as shown in Fig 2 is described. For attaining PFC, the inductor output current induce inductor iL1 and iL2 remains discontinuous while the input inductor current (iL1 and iL2) and the voltage across intermediate capacitors remains continuous.
Mode I: While \( S_1 \) is at first made on, the \( L_{o1} \) stores energy through \( D_p \) diode, hence the current \( i_{L1} \) through the inductor rises. Mode II: While \( S_1 \) is made off, \( i_{L1} \) inductor that discharging across the \( C_1 \) capacitor through \( D_1 \) and \( D_p \) diodes. Also, \( L_{o1} \) inductor’s stored energy is transferred to \( C_0 \) capacitor across DC-link. \( i_{L1} \) and \( i_{L01} \) currents across the inductors will start to degrade whereas the voltage across \( C_0 \) DC-link capacitor and \( C_1 \) capacitor rises. Mode III: In this mode, \( i_{L01} \) inductor’s current is zero. The capacitor \( C_1 \) voltage increases through inductor \( L_1 \).

![Fig. 3. Equivalent circuit of proposed method](image)

Ke < \( K_{e-cr} = \frac{1}{2(M+\sin{\omega_0}D)^2} \)  

Where, Ke is a dimensionless conduction parameter and is given by: 

\[
K_e = \frac{2Le}{R_c T_s}
\]

\[
K_{e-cr-min} = \frac{1}{2(M+1)^2} \quad \text{and} \quad K_{e-cr-min} = \frac{1}{2(0)^2}
\]

\[
\Delta i_{L1} < 10\% \quad \text{and} \quad \Delta V_{C1} < 5\%
\]

\[
\Delta I_{L1} = \frac{D}{F_x L_1}
\]

\[
\Delta I_{L2} = \frac{(1-D) V_e}{F_x L_2}
\]

\[
\Delta V_{C1} = \frac{D V_{ac} L_g}{V_C F_x}
\]

From the equations (5), (6), (7) the values of inductances and capacitances are given by:

\[
L_1 = L_2 = 300 \text{mH}, \quad L_{o1} = L_{o2} = 1 \text{mH}, \quad C_1 = C_2 = 2200 \mu \text{F}, \quad C_{out} = 2200 \mu \text{F}.
\]

The DC link voltage is given in equation (8).

\[
V_o = V_{ac} \frac{D}{(1-D)}
\]

Vac is the diode bridge rectifier output for a given AC input voltage (Vs).

Vac and Vs are related as:

\[
V_{ac} = 2\sqrt{2} \frac{V_s}{
\]

B. Design of Resonant Converter

The parameter required to design the converter are to be specified. The parameters like maximum output power, input voltage range, resonant frequency and output voltage range are to be cited. At DC link capacitor using PFC bus the dc-dc input voltage is determined. The dc-dc output voltage range will vary from 24 to 43 V. The existing output voltage 43 v is described for the maximum power of 650 W. The LLC resonant equivalent circuit is shown in figure 4.
The above Figure 6 shows the battery charging characteristics. The battery state of charge is 50% and the battery charges with output voltage of 42 V and current of 16 A. Magnetizing inductance (maximum), \( L_m(\text{ZVS}) \), as given by Equation 13. \( L_m(\text{max}) \) is the max gain attained while the switching frequency is min, given by equation (14).

\[
L_m(\text{ZVS}) = \frac{\tau_{\text{dead}} N_n V_o(\text{min})/V_o(\text{nom})}{C_H B V \text{in}(\text{max})}
\]

(13)

\[
L_m(\text{max}) = \frac{L_r(\text{sec}) n^2}{4 \left( 1 - \frac{L_m(\text{min})}{L_m(\text{sec})} \right)}
\]

(14)

At last, the total inductance value is given by Equations 15 and 16.

\[
\frac{1}{2} \left( L_m(\text{min}) + L_r(\text{sec}) \right) = \frac{1}{2} C_H V_o(\text{in}(\text{max})^2
\]

(15)

\[
L_m = \frac{N_n V_o(\text{min}) T_s}{4 L_m}
\]

(16)

IV. RESULTS AND DISCUSSIONS

The presented work is simulated in MATLAB platform. The performance such as power facto and total harmonics distortion are discussed. The proposed method has better performance than the conventional method. The power has increased as 0.98 and harmonics has been reduced by 4.07 percentage.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional</th>
<th>Proposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power factor</td>
<td>0.91</td>
<td>0.98</td>
</tr>
<tr>
<td>THD of Input current</td>
<td>46.27%</td>
<td>4.07%</td>
</tr>
</tbody>
</table>

There exist numerous factors need to be considered while designing for the purpose of achieving max output voltage. Also, for studying the changing the factors.

V. HARDWARE RESULTS

![Fig.7. Hardware Setup](image-url)
The above Figure 7 shows the prototype of proposed converter which consists of Bridgeless CUK converter, LLC Resonant converter, Pulse generating circuit. The battery state of charge is 45% and the battery charges with output voltage of 40 V and current of 16 A.

VI. CONCLUSION

To increase the battery life the wide output voltage range LLC based tank methodology and also practical way of designing examination is conferred. By the use of LLC multi resonant tank circuit under low and high frequency current ripples are eliminated for electric vehicles. To attain unity power factor Bridgeless CUK converter is employed and power factor is improved by 0.99. The dc output voltage of 42-24 V for 672 W is obtained from the modelling for EV application

REFERENCES


AUTHORS PROFILE

R. Rani Hemamalini, she is serving in the field of teaching for the past 27 years at various levels. Presently she is working as Professor and Head, Department of Electrical and Electronics Engineering at St. Peter’s Institute of Higher Education and Research, Avadi, Chennai, India. Her area of research includes Process controls and Instrumentation, Embedded System and VLSI. She has published more than 80 papers in the national/international journals and conferences.

L. Rajaji, is a Professor in the Department of Electrical Engineering, ARM College of Engineering & Technology, Chennai, India. He received Bachelor of Engineering from Madras University in 1997 and Master of Engineering from The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat, India in 2000. He has received Ph.D in the year 2010 from Sathyabama University, Chennai, India. His area of interest includes Distributed Power Generation, Power Electronics and Drives.

K. Srividiya, she received her Bachelor of Engineering degree in Electronics and Communication Engineering and her Master Engineering degree in Applied Electronics in 2005 and 2009 respectively from Anna University, Chennai, India. Her current research interest includes Power Electronics Converters. She is presently working as Assistant Professor at Sri Sairam Engineering College, Chennai, India.

A. Mohandoss, he received Bachelor of Engineering degree in Electrical and Electronics Engineering Master of Engineering degree in Electrical Drives and Embedded Control in 2013 and 2015 respectively from Anna University, Chennai, India. He is presently working as an Assistant Professor in P.B.College of Engineering. His current research interest includes Power Electronics Converters and drive system.

S. Nagaraj, he received Bachelor of Engineering degree in Electrical and Electronics Engineering from Bharathiar University, India in 2004 and his Master of Engineering degree in Applied Electronics from Anna University, Chennai, India, in 2009. He is pursuing Ph.D. degree at St. Peter’s Institute of Higher Education and Research, Chennai, India and also working as an Assistant Professor in P.B.College of Engineering. His current research interest includes Power Electronics and Drives.