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LLC Resonant Tank based Converter for EV Charging Application

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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 dc- 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 narrowed. 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.

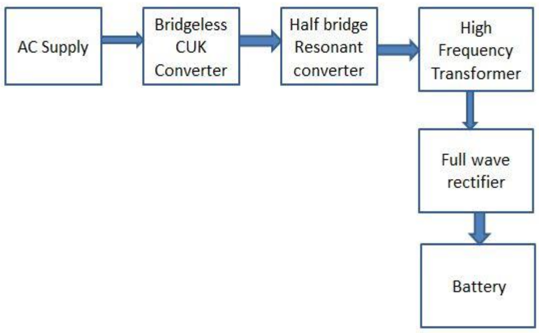

Fig. 1. Block Diagram of Proposed converter

II. BRIDGELESS CUK DC/DC CONVERTER

A. Proposed System

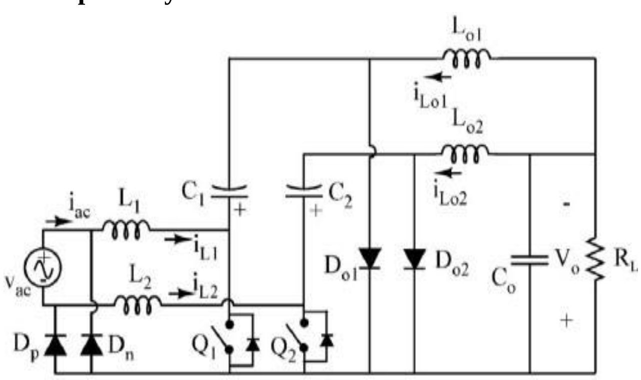

Fig.2. Bridgeless CUK Converter

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The operation of the system under study is as shown in Fig 2 is described. For attaining PFC, the inductor output current inductor i_Lo1 and i_Lo2 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_{01} 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_{Lo1} 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_{Lo1} inductor's current is zero. The capacitor C_1 voltage increases through inductor L1.

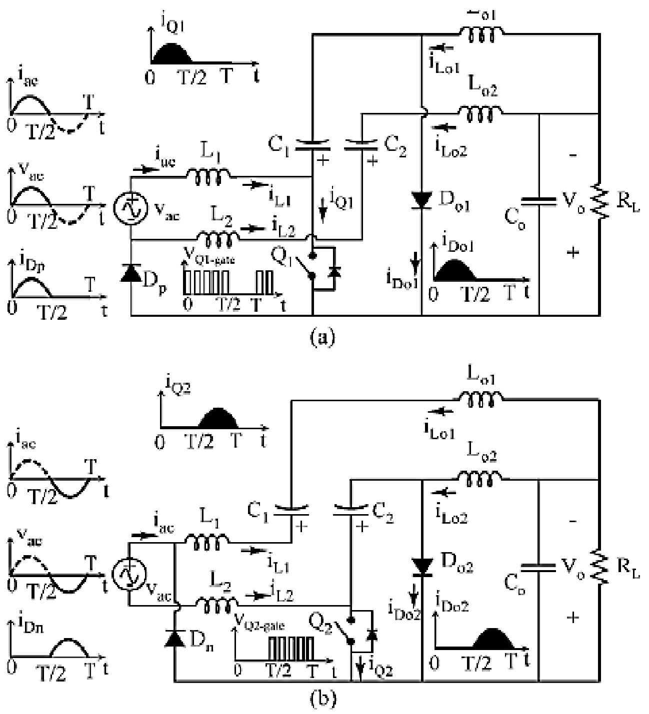

Fig.3. Equivalent circuit of proposed method

Fig. 3 depicts the working principle of system for both half cycles of the alternating current supply. Through the (+ve) period of the cycle of the AC voltage V_{ac}, S1 switch is in conduction through i_{L1} and Dp. The capacitor C1 transfers energy over L_{01} and D_{01}. Likewise, for (-ve) period of the cycle of AC voltage, S_2 switch is conducting over i_{L2} and D_n. Different modes of operation of cuk converter during positive half cycle is given by Mode I: While S_1 is at first made on, the L_{01} stores energy through D_p diode, hence the current i_{L1} through the inductor rises. The stored energy in C_1 capacitor present intermediate is discharged to C_0, DC link capacitor and $L_{o1,}$ output inductor. As a result, i_{Lo1} and V_{dc}, voltage across the DC-link are increasing and V_{C1}, voltage arises in the capacitor present intermediately reduces and i_{L1} current in rises, however the C_0 capacitor across the DC-link delivers the necessary energy, hence there is a reduction of V_{dc} voltage appears in mode III operation.

III. DESIGN OF CONVERTER

A.Design of bridgeless cuk converter

The design of the converter is framed under certain mathematical presumption. The operation of a DCM is acquired under the following condition.

$$Ke < Ke_{crit} = \frac{1}{2(M+\sin(\omega t))^2} \quad (1)$$

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

$$Ke = \frac{2Le}{R_L\, Ts} \quad (2)$$

$$K_{e\text{-}cr\text{-}min} = \frac{1}{2(M+1)^2} \text{ and } K_{e\text{-}crit\text{-}min} \frac{1}{2(M)^2} \quad (3)$$

$$\Delta i_{L1} < 10\%\, I_{L1} \text{ and } \Delta V_{c1} < 5\% \quad (4)$$

$$\Delta I_{L1} = \frac{D.Vin}{F_S.L1} \quad (5)$$

$$\Delta I_{L2} = \frac{(1-D).Vo}{F_S.L2} \quad (6)$$

$$\Delta V_{C1} = \frac{D.V_d.I_d}{V.C.F_S} \quad (7)$$

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

L_1= L_2=300mH, L_{01}=L_{02}=1mH, C_1=C_2=2200µF, C_{out}=2200µF.

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

$$V_o = V_{ac} \frac{D}{(1-D)} \quad (8)$$

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

Vac and Vs are related as:

$$V_{ac} = 2\sqrt{2}\,\frac{Vs}{\pi} \quad (9)$$

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.

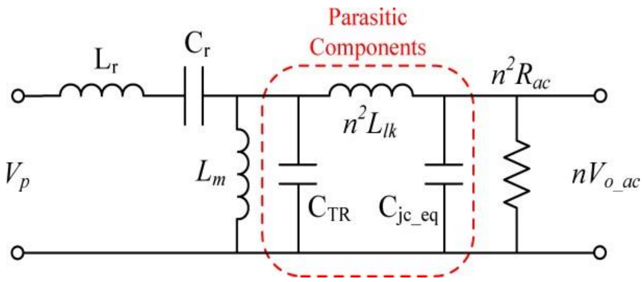

Fig.4. LLC resonant converter equivalent circuit

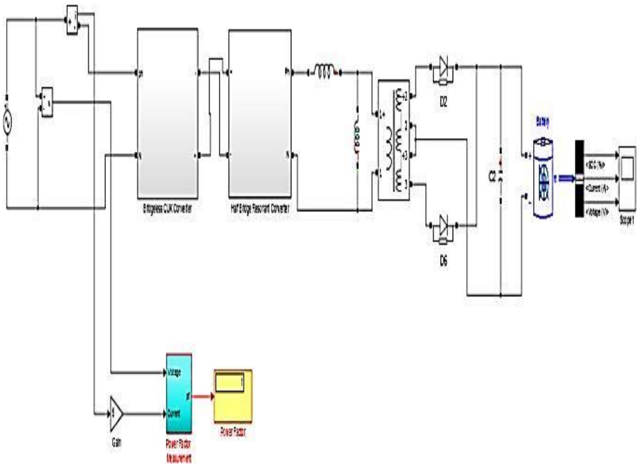

Fig.5. proposed Simulation Circuit

In Figure.5 it shows the complete MATLAB Simulation circuit of Proposed Converter. At unity gain, the TTR for the resonant frequency is selected and it is calculated using Equation 10, where V_d denotes the rectifier's diode output voltage drop

$$Nn = \frac{Vin(nom)}{2(Vo(\min) + Vd)} \quad (10)$$

The minimum inductance is given by Equation 11

$$Lr(scc) = \frac{Nn.Vin(nom).Vo(nom)}{8.fs\_max.Po} \quad (11)$$

Resonant capacitor value is given by equation (12)

$$Cr(res) = \frac{1}{(2\pi fo)2Lr(scc)} \quad (12)$$

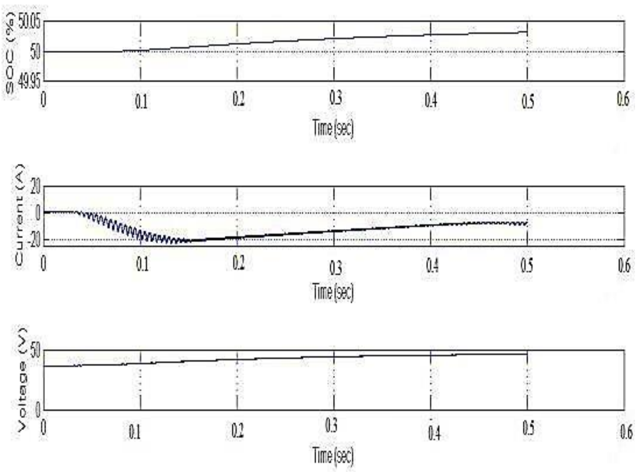

Fig.6. Battery Output Voltage Vo = 42V and Output current Io= 16A and SOC%=50%

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 16A. Magnetizing inductance (maximum), $L_{m\,(ZVS)}$, as given by Equation 13. Lm (max) is the max gain attained while the switching frequency is min, given by equation (14)

$$L_{m(zvs)} = \frac{t_{dead} N_n . V_{o(min)} . \left(\frac{1}{4 f_{smax}} - \frac{t_{dead}}{2}\right)}{C_{HB} V_{in(max)}} \quad (13)$$

$$L_{m(max)} = L_{r(scc)} \frac{\pi^2}{4} \frac{\frac{f_o}{f_{s\_min}} - 1}{1 - \frac{1}{M_{dc\_max}}} \quad (14)$$

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

$$\frac{1}{2}\left(L_{m(min)} + L_{r(scc)}\right) I_{m-pk}^2 > \frac{1}{2} C_{HB} V_{in(max)}^2 \quad (15)$$

$$I_{m\_pk} = \frac{N_n . V_{o(min)} T_o}{4 L_m} \quad (16)$$

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 1. Performance comparison

Parameter	Conventional	Proposed
Power factor	0.91	0.98
THD of Input current	46.27%	4.07%

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

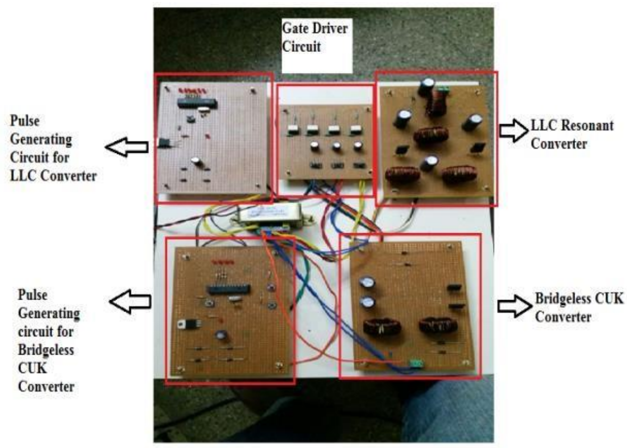

Fig.7. Hardware Setup

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 16A.

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

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