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DESIGN OF HYBRID ELECTRIC VEHICLE CHARGER WITH LLC RESONANT CONVERTER

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Abstract:- In this paper a design of hybrid electric vehicle charger using inductor–inductor–capacitor (LLC) resonant converter is presented. The battery charger plays an important role in the development of electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs). A wide range of operation can be performed by LLC resonant converter which leads to high efficiency with low electromagnetic interference and obtains high power densities. The primary side zero voltage switching (ZVS) operations are analytically identified based closed loop sliding mode control techniques which reducing the switching losses and improves switching frequency. The converter achieves high efficiency and soft switching for the complete operation range, which is very essential for high voltage EV battery charger application. Finally, a design methodology is proposed and stimulated through experiments on a software tools matlab/simulink by converting 100 V from the input to an output voltage range of 250–450 V at 3.3 kW with high efficiency of 98.2%.

Keywords-hybrid vehicles ,sliding mode controller ZVS, Battery charger ,LLC resonant converter.

I INTRODUCTION

A plug-in hybrid electric vehicle (PHEV), plug-in hybrid vehicle (PHV), is a hybrid vehicle which utilizes rechargeable batteries, or another energy storage device, that can be restored to full charge by connecting a plug to an external electric power source (usually a normal electric wall socket). A PHEV shares the characteristics of both a conventional hybrid electric vehicle, having an electric motor and an internal combustion engine (ICE); and of an all-electric vehicle, having a plug to connect to the electrical grid. Most PHEVs on the road today are passenger cars, but there are also PHEV versions of commercial vehicles and vans, utility trucks, buses, trains, motorcycles, scooters, and military vehicles.The type of charger is mainly dependent on the dc–dc stage since the output voltage and current are regulated in this stage[1],[2].

Among different solutions, an inductor–inductor–capacitor (LLC) resonant converter becomes the most attractive topology due to its high efficiency, low electromagnetic interference (EMI) emissions, a wide operation range, and the ability to achieve high power density. Many design methodologies have been proposed for this type of converter in the past decades. Exact analysis of LLC resonant converters ensures accuracy but cannot be easily used to get a handy design procedure due to the complexity of the model. The methodologies based on sliding mode control technique are much simpler to handle. The SMC approach gives acceptable accurate results for operating points at and above the resonance frequency of the resonant tank[3]. Therefore, it has been widely used in constant output voltage applications where the LLC converter is designed to resonate at nominal condition. Designing a wide-output-range LLC resonant converter based on SMC is investigated and the expanded range is mainly designed in frequencies above the resonant frequency.

II BLOCK DIAGRAM OF PROPOSED SYSTEM

In proposed system design of hybrid electric vehicle battery charger using LLC resonant converter is implemented. Full bridge LLC resonant converter is preferred to improve the performance of the system and high efficiency. The SMC approach is introduced to gives acceptable accurate results for operating points at and above the resonance frequency of the resonant tank . Therefore, it has been widely used in constant output voltage applications where the LLC converter is designed to resonate at nominal condition. Designing a wide output range LLC resonant converter based on SMC is investigated in and the expanded range is mainly designed in frequencies above the resonant frequency. The block diagram of proposed system shown in fig 1.

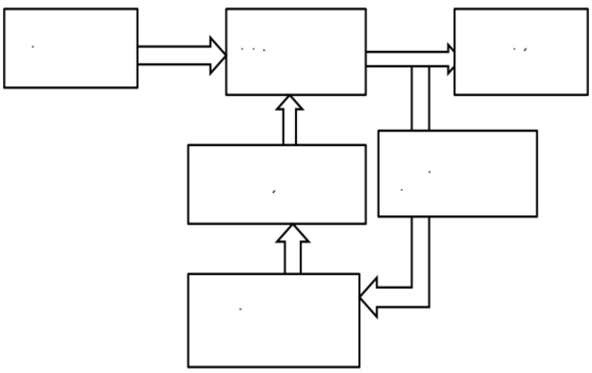

Fig1.Block diagram of proposed system

A. LLC FULL BRIDGE RESONANT CONVERTER OPERATION

The LLC topology can be implemented as a full-bridge type. The full-bridge type is preferable in PHEV charger applications due to its high power rating. The focus is on efficiency and electronic products are facing the approachable challenge of delivering high performance, while consuming less power[5]. The system consideration mainly based on soft switching topologies to improve the efficiency as well as to allow for higher frequency operation.

B. RESONANT TANK OPERATION

The full bridge LLC resonant converter has only two possible operations within the switching cycle and each of the modes pointed out above may contain one or both of these operations. Power delivery operation, which occurs twice in a switching cycle . At first when the resonant tank is excited with a positive voltage, so the current resonates in the positive direction in the first half of the switching cycle, the equivalent circuit of this mode is shown in Figure 2 and second occurrence is when the resonant tank is excited with negative voltage.

Table I. Result of resonant tank parameters

S.no	Parameter(designator)	Calculated value	Measured value
1	Inductance ratio(l)	0.197	0.19
2	Critical voltage gain(Mcrit)	1.186	1.183
3	Maximum characteristics impedance(z)	25.52[Ω]	24.86[Ω]
4	Characteristics impedance(z_o)	25.51[Ω]	24.85[Ω]
5	Magnetizing inductance(l_m)	133.10[µF]	141.10[µF
6	Series resonant inductance(L_r)	26.25[µF]	26.50[µF]
7	Series resonant capacitance(C)	40.33[nF]	42.90[nF]
8	Transformer turns ratio(n)	1.56	1.57
9	Series resonant frequency(F)	154.70kHz	149.30kHz

so the current resonates in the negative direction in the second half of the switching cycle, the equivalent circuit of this mode is shown in Figure 3. During the power delivery operations, the magnetizing inductor voltage is the positive/negative reflected output voltage and the magnetizing current is charging/discharging respectively. The difference between the resonant current and the magnetizing current passes through the transformer and rectifier to the secondary side, and power is delivered to the load and table 1 shows the parameters of LLC resonant rank[7].

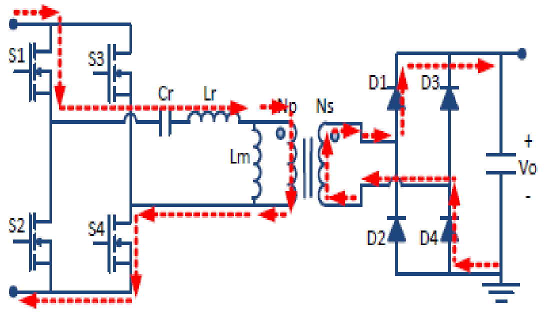

Fig .2 Equivalent circuit of resonant tank with positive direction

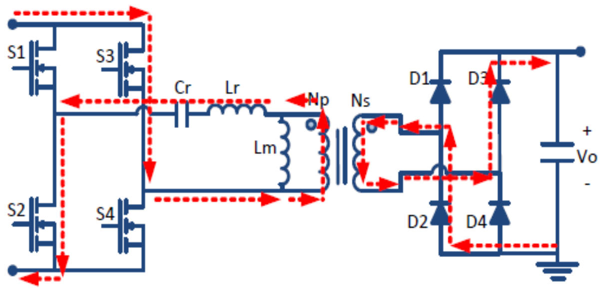

Fig .3 Equivalent circuit of resonant tank with negative direction

C. FREEWHEELING OPERATION

Freewheeling operation can occurs when the power delivery operation only if the resonant current reaches the transformer magnetizing current, this only happens when fs<fr, causing the transformer secondary current to reach zero and the secondary side rectifier to disconnect, consequently the magnetizing inductor will be free to enter the resonance with the resonant inductor and capacitor[7,8], the frequency of this second resonance is smaller than the original resonant frequency fr, especially at high values of m where Lm>>Lr, thus the primary current during the freewheeling operation will only changes lightly, and can be approximated to be unchanged for simplicity. The equivalent circuits of the freewheeling operation in of the switching cycle. The equivalent circuits of the freewheeling operation in of the switching cycle are shown in Figure 4.

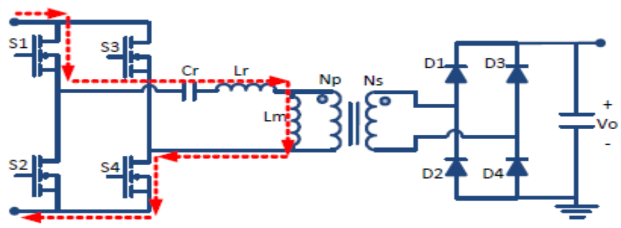

Fig .4 Equivalent circuit of freewheeling operation

D. SLIDING MODE CONTROLLER

Sliding Mode Control is used in nonlinear control scheme is especially well suited form Variable Structure System (VSS) like LLC resonant converters. The main advantage of SMC over common linear control schemes is its high robustness against line, load and parameter variations. A nonlinear control algorithm based on the theory of sliding mode control, with extensions in order to guarantee a constant switching frequency and to support different converter topologies and operating modes, has been proposed .The proposed controller architecture is effectively capable of regulating the output voltage of the LLC resonant converter with a dynamic performance and a small steady-state ripple.

The sliding mode control technique can be a possible option to control all kind of circuits . The use of sliding mode control enables to improve and even over-come the deficiency of the control method based on small signal models. In particular, sliding mode control improves the dynamic behavior of the system, and becomes very useful when the system is required to operate in the presence of significant unknown disturbances and plant uncertainties [12]. In order to obtain the desired response, the sliding mode technique changes the structure of the controller in response to the changing state of the system.

This is realized by the use of a high speed switching control forcing the trajectory of the system to move to and stay in a predetermined surface which is called sliding surface. In sliding mode a system's response remains insensitive to parameter variations and disturbances. Unlike other robust schemes, which are computationally intensive linear methods, analogue implementations or digital computation of sliding mode is simple. Fig .5 shows operation of sliding mode controller

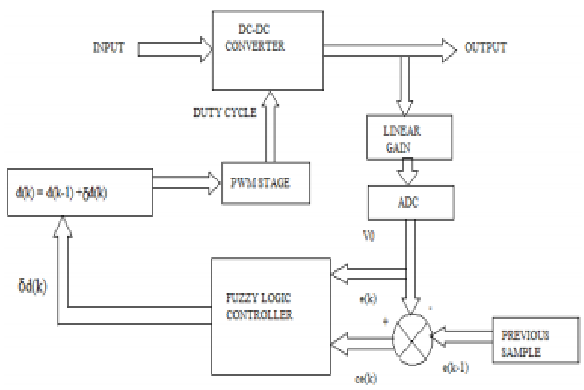

Fig .5 Operation of sliding mode controller

E. VOLTAGE AND CURRENT MEASUREMENT UNIT

The voltage measurement is used to obtain the actual and boosted voltage of the system. In sliding mode controller use to control the voltage and current values and also it control the PWM pulses.

III CIRCUIT DIAGRAM OF PROPOSED SYSTEM

In proposed system design of a Full-Bridge LLC resonant converter with Full Bridge rectifier is used for high power rating applications .The switching bridge generates a waveform to excite the LLC resonant tank ,which will output a resonant sinusoidal current that gets scaled and rectified by the transformer and rectifier circuit, the output capacitor filters the rectified current and outputs a DC voltage.A typical schematic of a full-bridge LLC multi resonant converter is shown in Fig. 6, where C_r is the resonant capacitor, L_m is the magnetizing inductor, and L_r is the leakage inductor reflected in the primary side. These reactive components form the resonant tank.

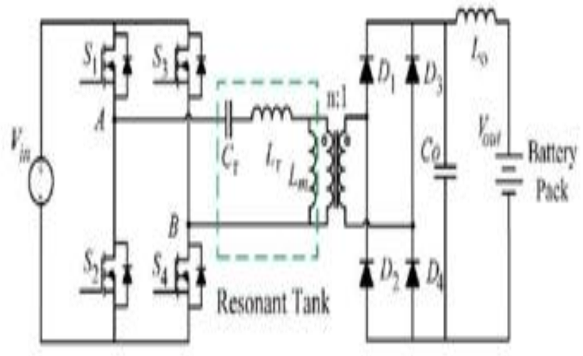

Fig .6 Full bridge LLC resonant converter

IV DESIGNING PROCESS OF LLC RESONANT CONVERTER

A. SELECTING THE Q MAX VALUE

Quality factor depends on the load current. Heavy load conditions operate at high Q values while lighter loads have lower Q values. It is important to set a value for the Q max associated with the maximum load point. To illustrate the effect of the Q value on voltage regulation.

B. SELECTING M VALVE

M is a static parameter that we have to start the design by optimizing its value, therefore it's important to understand the impact of the m ratio on the converter operation. It is obvious that lower values of m can achieve higher boost gain.

C. LOW M VALUE

- Higher boost gain.
- Narrower frequency range.

D. HIGH M VALUE

- Higher magnetizing inductance.
- Lower magnetizing circulating current.
- Higher efficiency.

E. FINDING THE NORMALIZED SWITCHED FREQUENCY

After selecting a value for Q max and an initial value form, we need to find the minimum normalized switching frequency that will guarantee inductive operation for the Q max (maxload) condition ,this minimum frequency will also guarantee inductive operation for all other loads. The minimum normalized switching frequency occurs at the peak gain of the Q max curve .

F. VOLTAGE GAIN VERIFICATION

This step is to verify that the maximum gain K max reached during maximum load by the selected m value is adequate.

G. CALCULATING RESONANT COMPONENTS VALUES

After few iterations of the design flow and reaching the optimum m value, we can proceed to calculating the resonant tank components values .Table 2 shows the designing parameter of LLC resonant converters.

Table.II Designing parameter of LLC resonant converters

S.No	**parameters**	**designator**	**value**
1	Input voltage range	$V_{in,}$	100 [v]
2	output voltage range	V_{out}	250[v]
3	Maximum output power	p_{out}	3.3[KW]
4	Resonant frequency	f_r	150[KHZ]
5	Maximum resonant frequency	$F_{s\ max}$	220[KHZ]
6	Expected efficiency	η	98%

V SIMULINK RESULTS

Simulation results of full bridge LLC resonant converter is obtain with respective to the different results like, input voltage waveform, input current waveform ,input v actual output voltage, boosted output voltage, output PFC waveform and the efficiency wave forms. Here the power factor correction gets improved up to the range of 0.97. Sliding mode controller is used to control the voltage at all operating conditions .LLC resonant converter consists of resonant tank which is used to boost up the voltage range upto 200-250v. The waveform of converter input voltage shown in the figure 7.Here the input supply voltage is measured as100V.

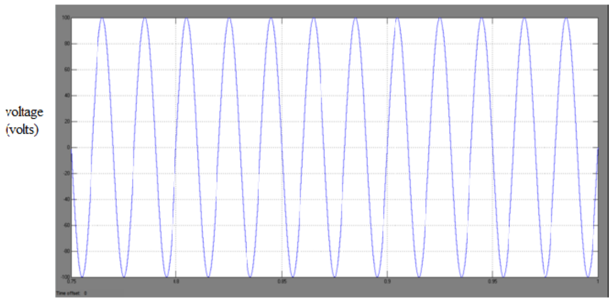

Fig.7 Waveform of converter input voltage

The output waveform of power factor correction shown in the figure.8. Here the real power and reactive power is calculated by using of SMC and the PFC get increasing from .97 to .99.

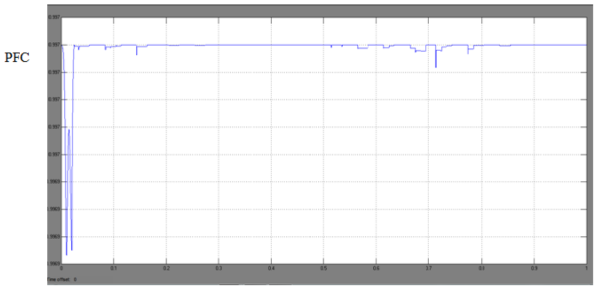

Fig .8 Output waveform of PFC

The actual output voltage of resonant converter shown in figure 9.The output of the converter is get increased by using of transformer and the voltage is obtained up to 210V from the input supply of 100V.

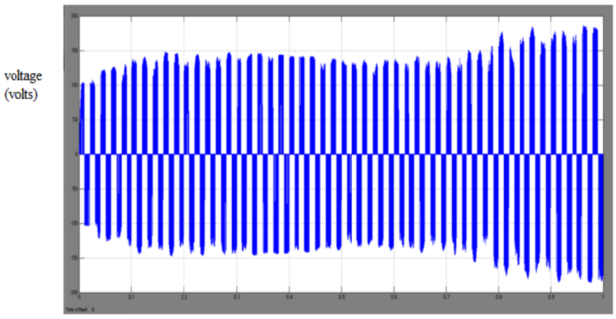

Fig. 9 Actual output voltage waveform of resonant converter

The boosted output voltage of resonant tank shown in the figure 10.The resonant tank consist of passive element used for charging and discharging process. Here the voltage is boosted upto 240V .

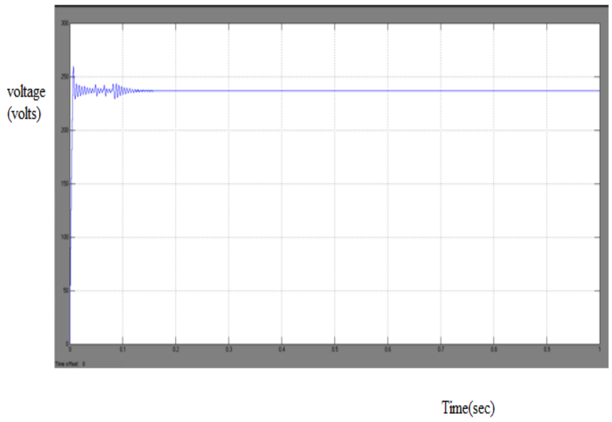

Fig 10. Boosted output voltage waveform of resonant tank

The waveform of efficiency vs voltage of LLC resonant converter shown in the figure 11.Here the efficiency gets improved upto 98% with the voltage range from 250-420v.

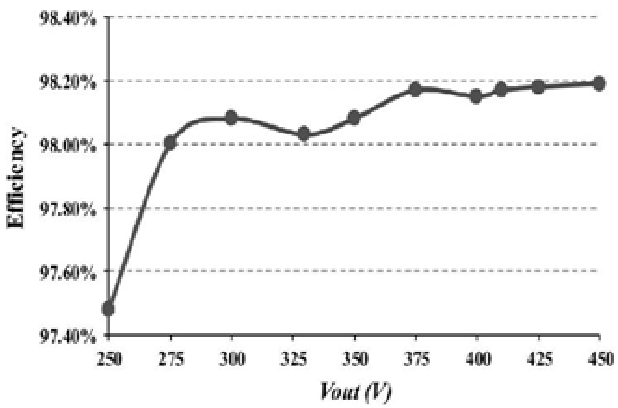

Fig. 11 Efficiency vs voltage of resonant converter

VI CONCLUSION

In this paper a full bridge LLC resonant converter is implemented which is used for high power rating and obtain high power density with high rating applications ,and it is applicable for all type of linear loads and non linear loads .LLC resonant converter is a emerging technology in plug in hybrid electric vehicles and electric vehicles. A new approach of sliding mode technique is introduces which improves the switching operation in all resonant frequencies and increases peak efficiency up to 98% .LLC resonant converter can be applicable for very light load to full load, when the switching frequency is almost unchanged, power switch can also achieve zero voltage switching, reduce the power switch losses, and generally it improve the power factor correction and effectively improve the efficiency. The resonant frequency control significantly reduces electromagnetic interference.

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