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LLC Resonant Converter with Capacitor – Diode Clamped Current Limiting Fundamental Harmonic Approximation

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Abstract: *The LLC Resonant converters with capacitor - diode clamping is used for limiting the current during overload conditions. LLC Resonant converters are widely used because of its high efficiency and simple structure. In the proposed converter one - leg of the full bridge diode rectifier is replaced with capacitor, so that it limits the fundamental harmonic approximation, minimizes the conduction losses, reduces the ripples and increases the current gain. The converter voltage gain and voltage-current characteristics under different overload conditions and operating frequencies are predicted in this model.*
Keywords: *Capacitor diode clamp; Current limiting; DC – DC converter; LLC converter*

I. Introduction

In today's world the converter is essential to deliver more power and to achieve high efficiency in wide load range. The term Converters are used to transform one form of electrical energy into another form of electrical energy, depending on the type of source and load it is categorized into four types, they are: AC-DC (Rectifiers), DC-DC (Choppers), DC-AC (Inverters), AC-AC (Voltage controllers). The resonant converters are based on resonant current oscillations it is a DC-DC converter or DC-AC PWM [8] inverter. It reduces the switching losses in the device. Resonant converters are of eight types, they areSeries resonant converters [13], Parallel resonant converters, Class E resonant converters, Class E resonant rectifiers, Zero voltage switching converters, Zero current switching converters, Two quadrant ZVS resonant converters and Resonant DC link inverters.

The LLC resonant converter is a (dc - dc) [6] series resonant converter. It is of high power density, high efficiency and has a good range switching frequencies. This has the soft switching property [1]i.e. it is switchedunder zero voltage (ZVS)or zero current (ZCS) [4], [15]. It has a wide range of operating frequencies wide input voltage and load ranges when it is operated under the series resonant frequency [9]which is also referred as load independent point (LIP). The frequency is operated to adjust the change in the input voltage with small changes to the frequency for the changes in load. Regrettably,it has a low impedance around the (LIP), because the flow of current may be excessive to the load under transient and overload condition hence the mechanism of current protection is included.

In LLC resonant converters current can be limited by (i) Reducing the conduction time of the MOSFET, (ii) Increasing the switching frequency, (iii) Operating at sub harmonic of the switching frequency, (iv) Changing the resonant frequency of the converter by switching in or out the resonant tank components [14]. During overload condition the switching frequency may increase the switching loss. Fundamental Harmonic Approximation (FHM) is most commonly used method in resonant converter analysis; this treats the current and voltage waveform as a pure sinusoidal wave at the fundamental frequency and neglects the other high-order harmonics. The LLC resonant converter is magnetically integrated [2] and it is used for designing DC-DC converter [11]. The LLC resonant converter is connected to a capacitor –diode clamp. Here, the current limit is done as soon as the overloading (current) occurs and it performs independently without the need of feedback mechanism. The use of clamping circuit is to split the capacitor and it fixes the clamping voltage to the input, the capacitor voltage is clamped to the output voltage of the transformer which allows the clamping voltage to be specified and hence it allows the desired current-limiting performance to be obtained. Thus the LLC resonant converter can handle an adjustable regulated output voltage using frequency control [5] even during the input voltage or output load variations applied to the converter. The theoretical analysis and comparisons of the proposed converters is discussed in the following chapters.

II. Capacitor – Diode clamped Half Bridge Rectifier

In this paper we have proposed a device which limits the current during overload condition. The device consists of half-bridge [7] LLC resonant converters with capacitor-diode clamp[3] in it. It consist of four main operational parts: 1) a DC chopper formed by two MOSFETS S_1 and S_2, 2) a resonant tank formed by inductors and capacitors L_p, L_s, C_c and C_s, L_p is magnetically connected to the transformer [16], 3) a transformer , bridge rectifierand output filter formed by the diodes D_1 -D_2 ,capacitor C_1-C_2 and C, 4) the clamp circuit formed by the diodes D_{c1} and D_{c2}which clamps the $V_c$voltage to the input voltage Vi as shown in fig (1). The switches S_1 and S_2 converts the input dc voltage into a square waveform, this waveform is passed through the resonant tank and produces AC waveform. When this waveform passes through (3) it gives an isolated DC output. Here the capacitor smoothens the wave, filters the noise, voltage is stabilized and also charges and discharges. D_{C1} and D_{C2} are used for current limiting purpose. During normal condition i.e., below the current limit the clamped diodes D_{c1} and D_{c2} do not conduct. Here the capacitor Cc is connected in parallel and series with C_s.

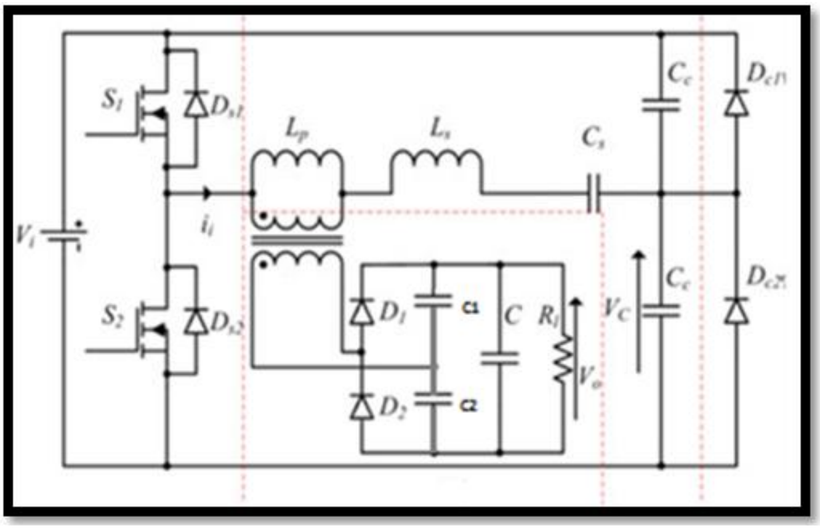

Fig. 1.

2.1 Modes of Operation

The circuit is operated under three modes: a) when S_1 and S_2 in off condition, b) when $S_1$is in on condition and c) when S_2 is in on condition.

a) S_1 and S_2 in off condition

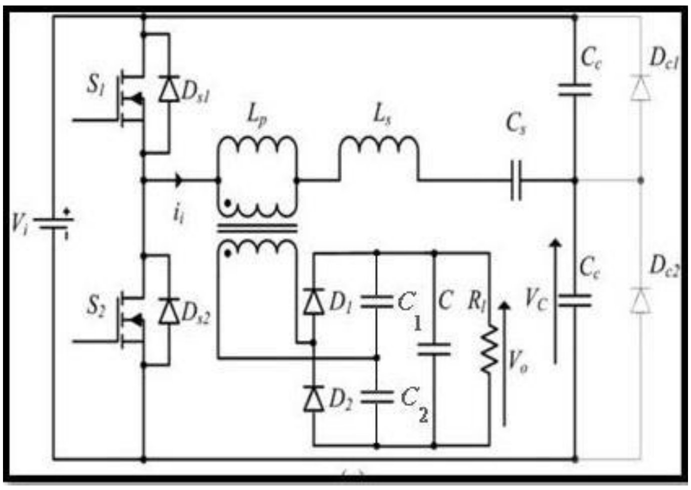

Fig. 2.

At normal condition i.e, below the current limit the voltage $V_c$operates between two clamping voltage levels 0 and V_i. The clamped voltage D_{c1} and D_{c2} do not conduct in this switching period.

b) when switch S_1 is on

When S_1 is kept under on condition, the DC source enters the circuit, the current moves in anticlockwise direction over the resonant circuit. At that time period the current moves in clockwise direction in half bridge rectifier.

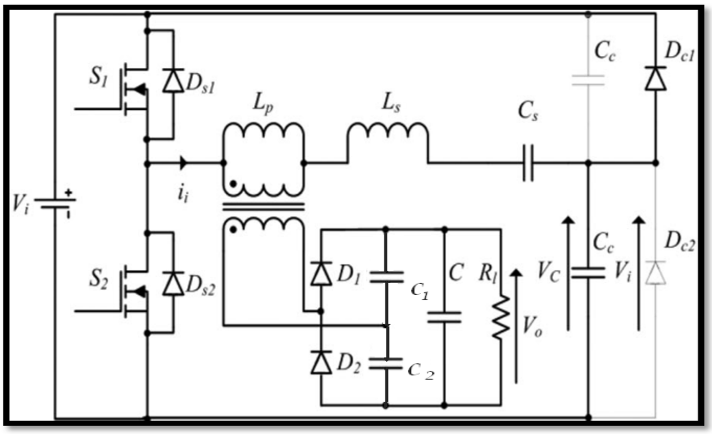

Fig. 3.

c) when switch S_2 is on

When S_2 is kept under on condition, the DC source enters the circuit, the current moves in anticlockwise direction over the half bridge rectifier. At that time period the current moves clockwise direction in resonant circuit.

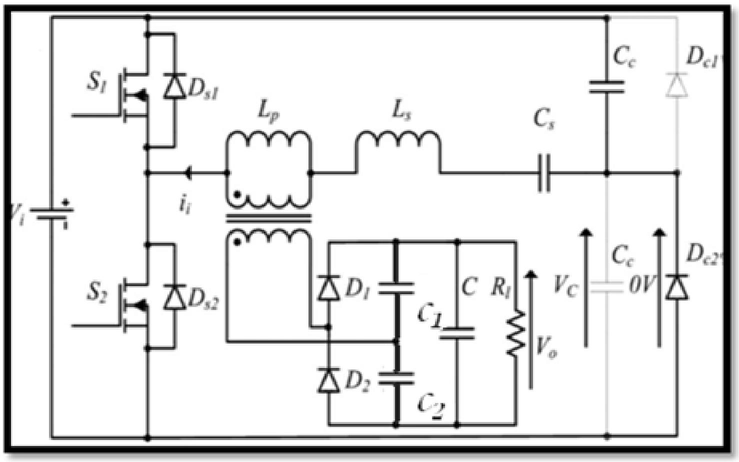

Fig. 4.

During overload condition i.e., when the load increases, V_c rice above the input voltage for some section of the switching period which makes the D_{c1} and D_{c2} to conduct thus clamps the Vc to the input voltage. At the time of clamping Vc remains constant and the capacitor C_c will not be a part of resonance because it creates a FHA that will be equal to the rise in capacitor values. This is done to reduce the resonant frequency of the tank so that there will be a increase in switching frequency to the resonant frequency ratio thus it reduces the flow of current in the circuit.

The condition of the diode is :

- D_{c1} conducts when $V_c > V_i$, clamps the V_c to V_i
- D_{c2} conducts when $V_c < 0V$, clamps the V_c to 0V

2.2 Graphical Representation of Voltage

During normal condition the voltage V_c level will be between two clamped voltage levels i.e, 0 and V_i.

During overload condition the wave form formed is quasi cosine-sine waveform, thus the current is limited.

The two condition briefs that the clamping diode terminates the conduction when the input current I_i of a resonant circuit is 0A. assuming that the resonant circuit is sinusoidal hence V_c takes a cosinusoidal shape.

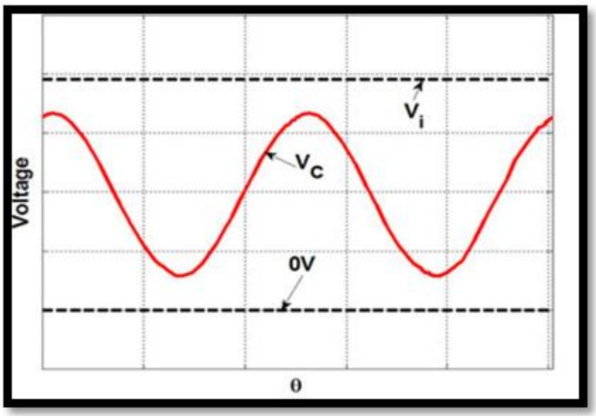

Fig. 5. During Normal Condition

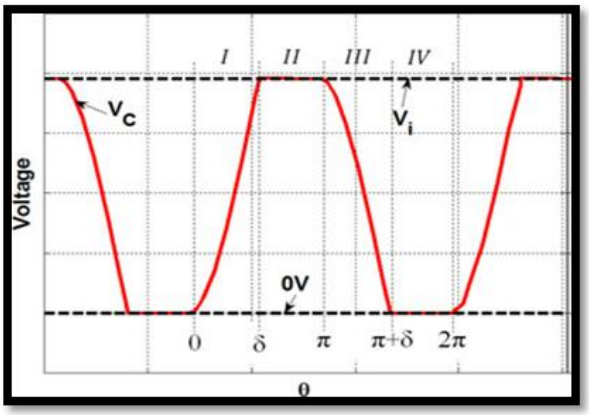

Fig. 6. During Overload condition

III. Simulation Result

The simulation is done using matlab version 7.10.0.499 (R2010a), 64bit, designed especially for evaluation and to display graphically for the numerical data. It develops data which gives improved design and decision.

The dc current enters the circuit through Vi, S_1 is turned on and within the fraction of seconds S2 is turned on. The dc current is converted to ac current, when passed through LLC resonant converters [10], [12]. Through mutual inductance and the capacitor C filters the wave and then given to the load. During overload condition D_{c1} and D_{c2} is activated and the current is limited. The capacitor-diode clamp is designed in such a way that it becomes active only when the load current exceeds the maximum rated load current, till then the converter will be treated as standard LLC resonant converter.

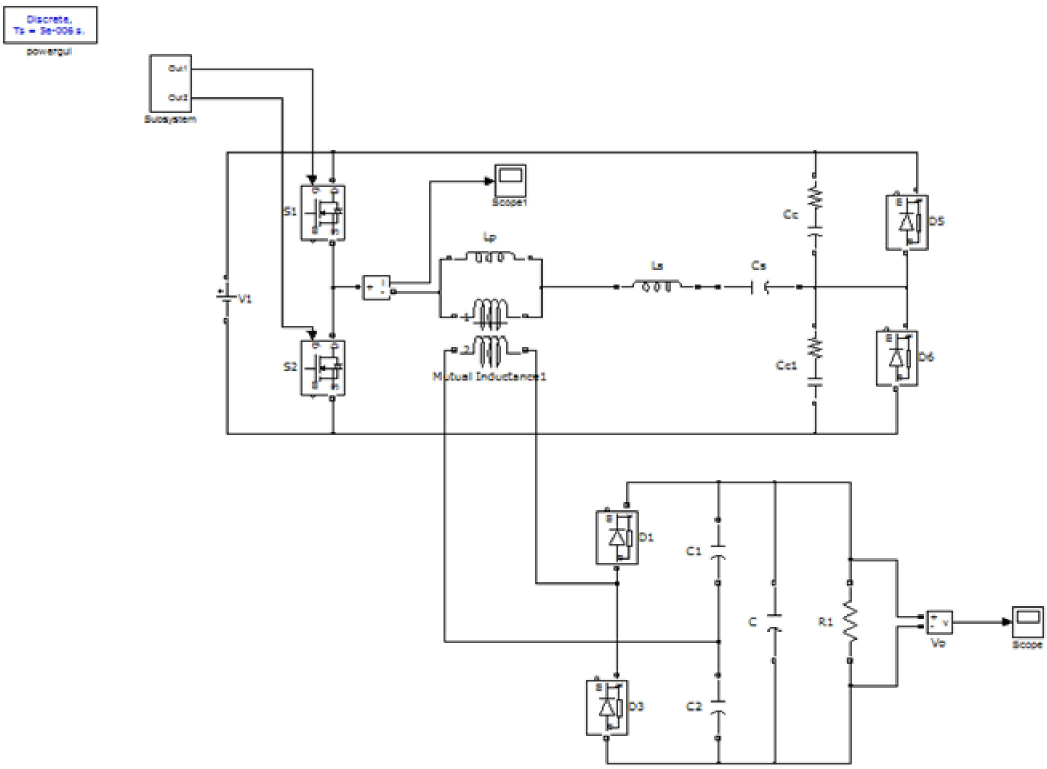

Fig. 7. Simulation Diagram of Capacitor – Diode clamped Half Bridge Rectifier

For a common input current of 390 V, The fig 8 & fig 9 shows the comparative results in graphical format with more ripples and disturbances when bridge is simply diode clamped and the ripples were reduced and conduction loss is minimized when it is capacitor – diode clamped.

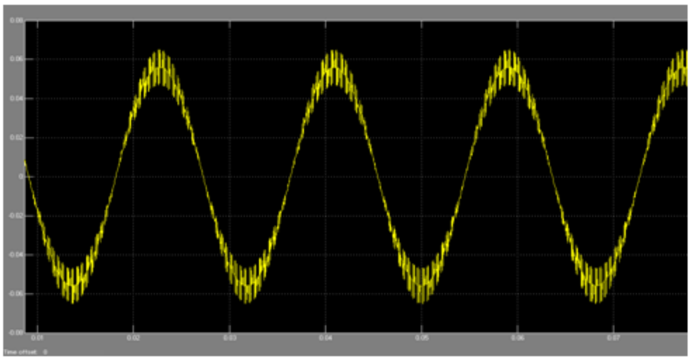

Fig. 8. Formation of ripples in Diode clamped rectifier

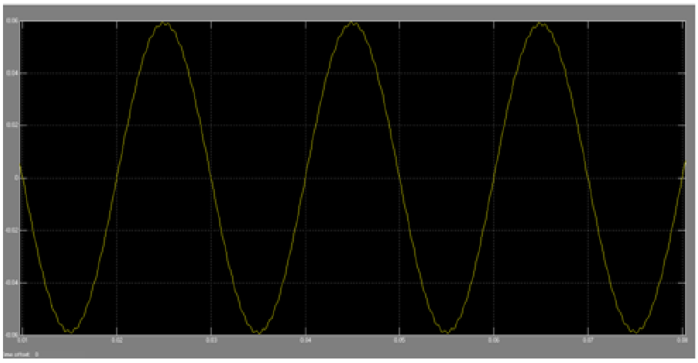

Fig. 9. Formation of ripples in Capacitor - Diode clamped rectifier

The current gain and the output waveform for diode clamped rectifier is shown in fig 10 and the Capacitor – Diode clamped rectifier is shown in fig 11.

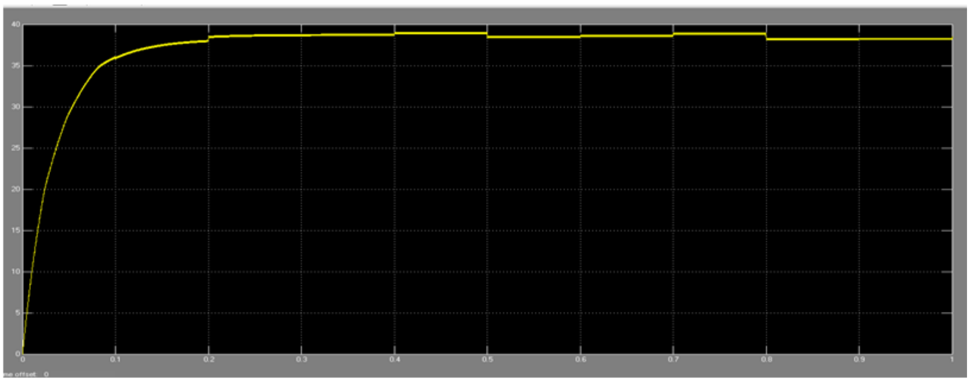

Fig. 10. Output voltage waveform for Diode clamped rectifier

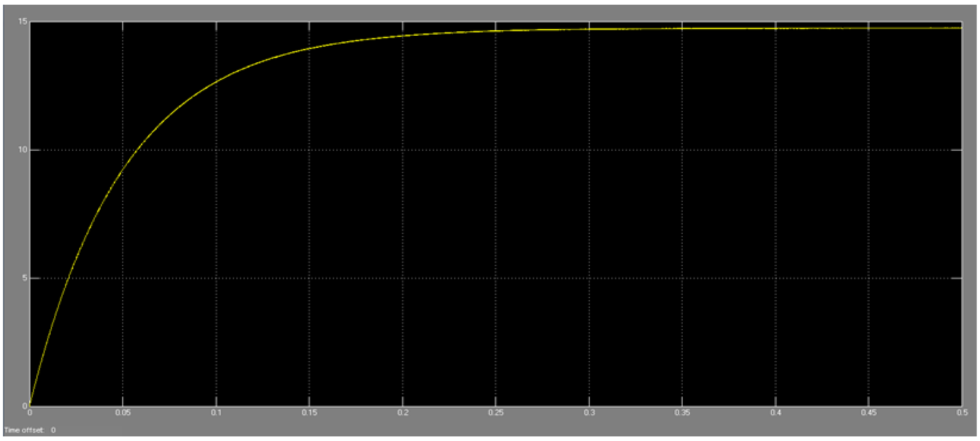

Fig. 11. Output voltage waveform for Capacitor - Diode clamped rectifier

The difference in Total Harmonic Distortion (THD) value is observed using FFT analysis when compared with diode clamped and Capacitor – Diode clamped is shown in fig 12 & fig 13.

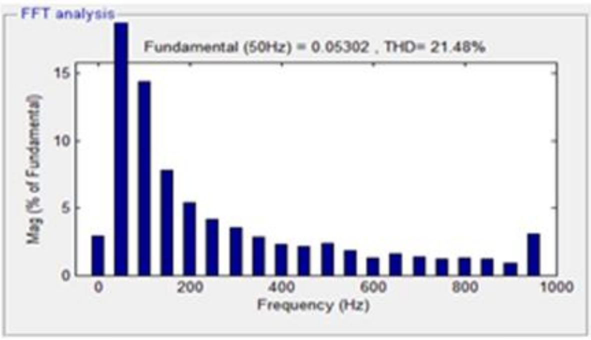

Fig. 12.FFT analysis for Diode clamped

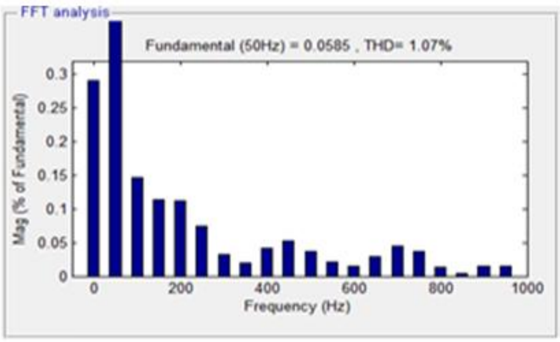

Fig. 13. FFT analysis for Capacitor - Diode clamped

From the above graphs it is clear that the THD value of Diode clamped rectifier is 21.48 % but in Capacitor – Diode clamped it gets reduced to 1.07 %

IV. Conclusion

In this paper a new half bridge rectifier is proposed in non-clamped circuit. One side of the rectifiers is replaced by capacitors. Thus the use of LLC resonant converter with capacitor-diode clamp circuit limits the current during overload condition. The clamped circuit is constructed in such a way that it limits the current as soon as the overloading occurs. The resonant capacitors C_c of the clamped circuit is selected in such a way that it starts to operate as soon as the maximum load current under the minimum voltage exceeds. Hence the resonant frequency is used for sharing the load thus reduces the conduction loss. The usage of capacitor in half bridge rectifier stabilizes the voltage and gives reduced ripples, increase in current gain, minimized conduction loss and harmonics is reduced.

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