International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 18 (2015) pp 39458-39462

An Isolated Voltage regulator with boost circuit for Variable DC sources

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Abstract

This paper consist of an isolated DC/DC resonant converter with an unregulated LLC filter for variable DC Source applications. The wide variation of variable DC Source voltage is regulated by an LLC isolated voltage amplifier. By separating the functions, the unregulated LLC converter can be operated at an optimal switching condition, and the high-frequency operation of 300 kHz can be accomplished without introducing an excessive switching loss. The proto type converter with a 1-kW shows an efficiency of above 92% under a 24-V input and full load conditions. Boost circuit installed in the input stage to increase the level of input supply to the desired level.

Introduction

In the modern world, our atmosphere temperature has increased due to the reason of global warming, air pollution, depletion of ozone layer, disappearing of forests, and acid precipitation. It's become very worse by the combustion of fossil fuels. To prevent these effects, must reduce the consumption of fossil fuel by an eco friendly energy supplies.

Various Variables renewable DC Sources promising our future because there is no combustion from these Sources. Electricity can produces more efficiently than any other technology. Variable DC Sources that converts the input energy to chemical energy or physical energy then into electricity through various reaction. Hydrogen is one of the most common fuel, but hydrocarbons such as natural gas and alcohols like methanol are sometimes used. Variable renewable DC Sources are different from batteries in that they require a constant source of fuel or energy to run, but they can produce electricity continually for as long as these inputs are supplied.

Basic variable DC Sources running are free from pollution, giving off heat, water, and electricity. The ability of our variable DC Sources to provide nearly zero emissions has been a notable force in the development of the era of technology over the past years, and is capture the attention to the technology today. When compared to generators, variable DC Source has no moving part and thus these variable DC Sources making them more reliable. Power plants must be large in order to gain efficiency, but variable DC Sources can achieve higher efficiencies at any scale, making them perfect for residential, transportation, residential, and small generation of power. When go to the economical side, variable DC Sources represent a wise path to provide the country's electric power because of their quick installation, and are fuel flexible, and can be put in place incrementally, mitigating the need for more costly and sweeping changes.

Under variable load conditions, variable DC Sources shows a large variation in output voltage, and the voltage produced by the variable DC Source is low in magnitude. Moreover, the low variable DC Source voltage should be raised to the peak of a utility line voltage for power conditioning system design. Thus, it is necessary to design a high step-up converter with a wide line regulation performance to interface the variable DC Source to various loads. To achieve a high voltage gain, converters based on a transformer or coupled inductors have been considered. Compared with an isolation transformer, the coupled inductor has a simple and efficient structure, but its use is restricted to applications that do not require electrical isolation. To obtain not only a high voltage gain but also the electrical isolation, current-fed converters have been widely used. Fig. shows a two-inductor current-fed half-bridge converter.

The major drawbacks of this converter are hard-switching operation and turnoff voltage spikes. To alleviate these problems, a zero voltage switching (ZVS) technique using an active-clamp circuit can be used, but this active-clamp circuit increases the circuit complexity due to additional switch blocks. The number of magnetic elements that affect the circuit volume can be reduced by using the current-fed full bridge converter with two magnetic devices, which is shown in Fig. but the switch blocks are increased to five, including the active-clamp circuit. The circuit structure can be simplified using the current-fed push-pull converter, which is shown in Fig. but it has several disadvantages, such as the high voltage stress of the switches and low voltage conversion ratio.

Half Bridge Resonant LLC Converter

The DC characteristic of LLC resonant converter could be divided into ZVS Region and ZCS region.For this converter, there are two resonant frequencies. One is determined by the resonant components Lr and Cr. The other one is determined by Lm, Cr and load condition. As load getting heavier, the resonant frequency will shift to higher frequency. The two resonant frequencies are:

$$fr1 = \frac{1}{2\pi\sqrt{LrCr}}$$

$$fr2 = \frac{1}{2\pi\sqrt{(Lm + Lr)Cr}}$$

With this characteristic, for a 400V operation, it could be placed at the resonant frequency of fr1, which is a resonant frequency of series resonant tank of Cr and Lr. While input voltage drops, more gain can be achieved with lower switching frequency. With proper choose of resonant tank, the converter could operate within ZVS region for load and line variation. On the right side of fr1, this converter has same characteristic of SRC. On the left side of fr1, the image of PRC and SRC are fighting to be the dominant. At heavy load, SRC will dominant. When load get lighter, characteristic of PRC will floating to the top. With these interesting characteristics, we could design the converter working at the resonant frequency of SRC to achieve high efficiency. Then we are able to operate the converter at lower than resonant frequency of SRC still get ZVS because of the characteristic of PRC will dominant in that frequency range.

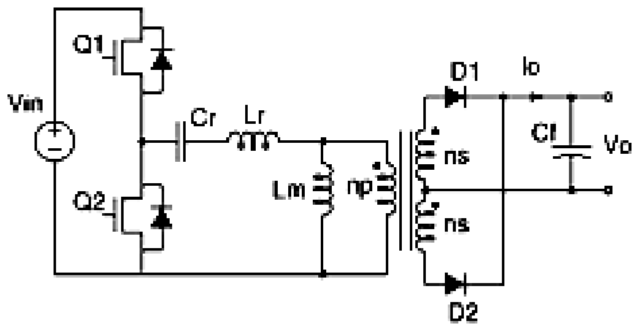


Fig.1.Half bridge LLC resonant converter

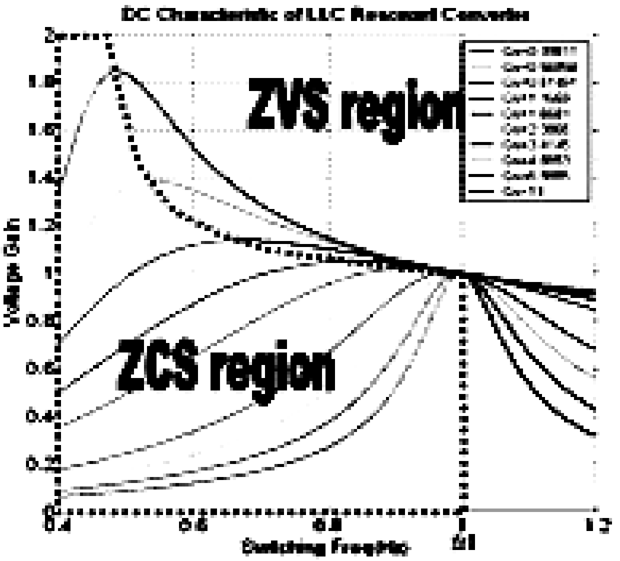


Fig.2.DC Characteristics of LLC resonant converter

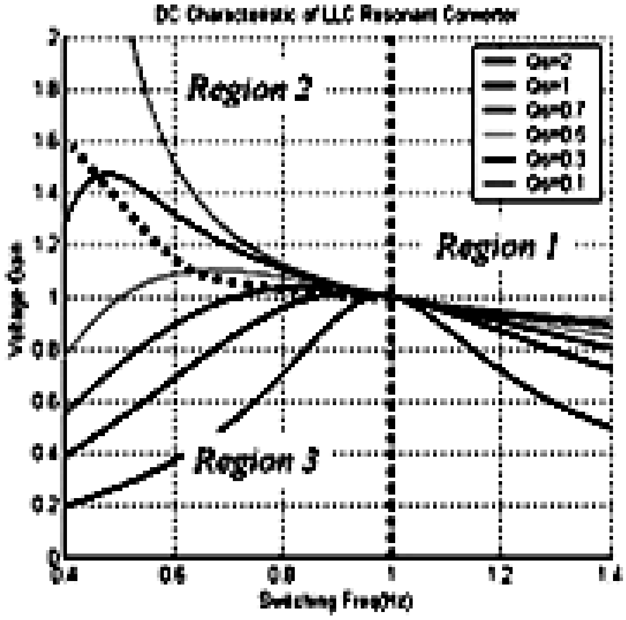


Fig.3.Three operating region of LLC resonant converter

By changing the frequency of input voltage, the impedance of resonant tank will change. This impedance will divide the input voltage with load. Since it is a voltage divider, the DC gain of SRC is always lesser than 1. At resonant frequency, the impedance of series resonant tank will be very small and all the input voltage will drop on the load. So, for series resonant converter, the maximum gain happens at resonant frequency.

The DC characteristic of LLC resonant converter could be also divided into three regions according to different mode of operation as shown in Fig. Our designed operating regions are region 1 and region 2. Region 3 is ZCS region. The converter should be prevented from entering region 3. The simulation waveform for region 1 and region 2 are shown in Figure 2 and Figure 3. In fact, there are many other operating modes for LLC resonant converter as load changes.

In region 1, the converter works very similar to SRC. In this region, Lm never resonates with resonant capacitor Cr; it is clamped by output voltage and acts as the load of the series resonant tank. With this passive load, LLC resonant converter is able to operate at no load condition without the penalty of very high switching frequency. Also, with passive load Lm, ZVS could be ensured for any load condition. Here the operation will not be discussed in detail. There are several other modes of operation for light load condition. In region 2, the operation of LLC resonant converter is more complex and interesting. The waveforms could be divided into clearly two time intervals. In first time interval, Lr resonant with Cr. Lm is clamped by output voltage. When Lr current resonant back to same level as Lm current, the resonant of Lr and Cr is stopped, instead, now Lm will participate into the resonant and the second time interval begins. During this time interval, the resonant components will change to Cr and Lm in series with Lr, which is shown in the waveforms as a flat region. In fact, that is a part of the resonant process between Lm+Lr with Cr. From this aspect, LLC resonant converter is a multi resonant converter since the resonant frequency at different time interval is different. Because of the resonant between Lm and Cr, a peak on the gain appears at resonant frequency of Lm+Lr and Cr.

Parallel Resonant Converter

The schematic of parallel resonant converter is shown in Fig.

Its DC characteristic is shown in Figure 4.5. For parallel resonant converter, the resonant tank is still in series. It is called parallel resonant converter because in this case the load is in parallel with the resonant capacitor. More accurately, this converter should be called series resonant converter with parallel load. Since transformer primary side is a capacitor, an inductor is added on the secondary side to match the impedance.

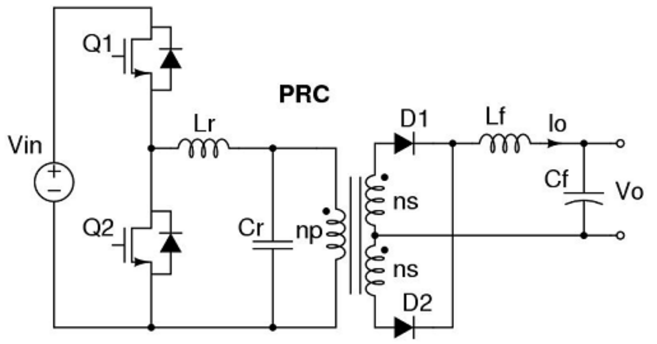


Fig.4 Half bridge parallel resonant converter

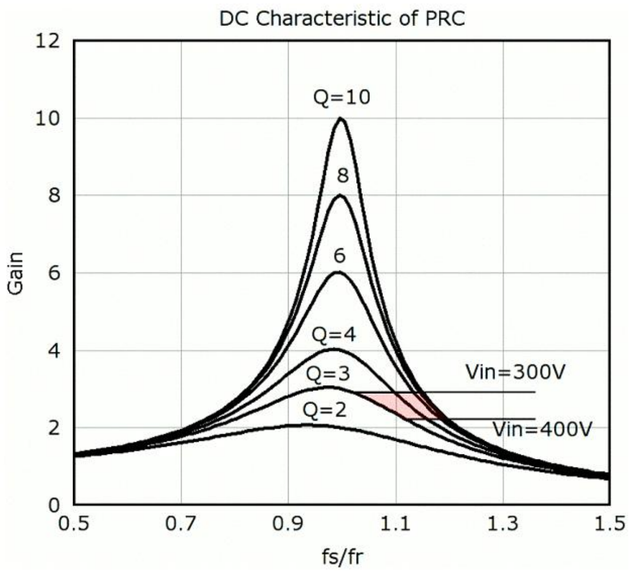


Fig.5.DC characteristic and operating region of PRC

The range of Q for this converter is 3 (Full load) to ∞ (No load). The operating region of PRC is shown in Fig.5 as shaded area. Simulation waveform is shown in Fig.6.From the operating region graph and simulation waveforms, several things could be observed:

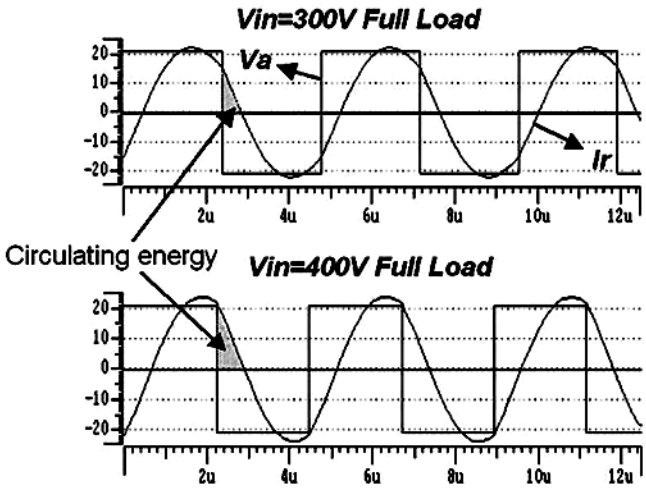


Fig.6.Simulation waveforms of PRC

Proposed Converter

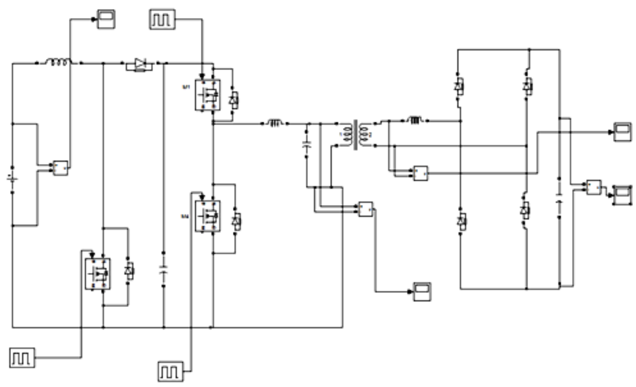


Fig.7. Circuit Diagram of proposed converter

The life of the variable DC Source is depends the pulsating output. The proposed converter consists of a Boost regulator and a LLC converter. Fig.7 Shows the LLC converter with a boost regulator. The circuit consists of boost application components; Dc input source, half bridge converter, LLC resonant converter, high frequency transformer full bridge rectifier, filter etc. The DC input voltage is fed to a boost converter for the step up application and it givens to parallel LLC Resonant converter. The boost converter directly controls a final output voltage and the ripple current generated at the input can be alleviated through the boost inductor. The DC input voltage is inverted by means of high frequency AC using MOSFET half bridge inverter. The primary of the transformer is connected to the inverter thro LLC resonant tank circuit. The transformer secondary voltage is rectified using diode bridge rectifier then filter circuit and load. The resonant frequency fr is determined by

$$f_r = \frac{1}{2\pi\sqrt{L_{lk}C_{eq}}}$$

The input-to-output relationship of the proposed converter is the product of those of the boost converter and the *LLC* converter, and it can be written as

$$\frac{V_b}{V_{\text{in}}}\times\frac{V_o}{V_b} = \left(\frac{1}{1-D}\right) \times\left[\frac{n}{2}\sqrt{\left[1+\frac{1}{k}\left(1-\left(\frac{f_r}{f_{\text{sL}}}\right)^2\right)\right]^2+\left[\frac{\pi^2}{8}Q\left(\frac{f_r}{f_{\text{sL}}}-\frac{f_{\text{sL}}}{f_r}\right)\right]^2}\right]^{-1} \quad (1)$$

where $Q = \pi^2 n^2\sqrt{L_r/C_r}/(8R_o)$, $k = L_m/L_r$, and $f_r = 1/(2\pi\sqrt{L_r C_r})$. If the LLC converter switching frequency f_{sL} is selected with the same value as the resonant frequency f_r to reduce the switching loss, it can be simplified by

$$\frac{V_o}{V_{\text{in}}} = \frac{V_b}{V_{\text{in}}}\times\frac{V_o}{V_b} = \frac{1}{(1-D)}\times\frac{n}{2} \quad (2)$$

where D means the duty-ratio of the boost converter.

State Space Representation

ON-State:

$$i1R1 + l1\frac{di1}{dt} + i1R2 + Vc = Vi$$

$$\frac{di1}{dt} = \dot{x1}, Vc = x3$$

$$R1x1 + l1\dot{x1} + R2x1 + x3 = U$$

OFF-State:

$$x2R1 + L1x2 + \dot{x2}R3 = U$$

$$\begin{matrix}\dot{x1}\\ \dot{x2}\\ \dot{x3}\end{matrix} = \begin{bmatrix}-(R1+R2)/L1 & 0 & -1/L1\\ 0 & -(R1+R3)/L1 & 0\\ 1/C & 0 & 0\end{bmatrix}\begin{bmatrix}x1\\ x2\\ x3\end{bmatrix} + \begin{bmatrix}1/L1\\ 1/L1\\ 0\end{bmatrix}U$$

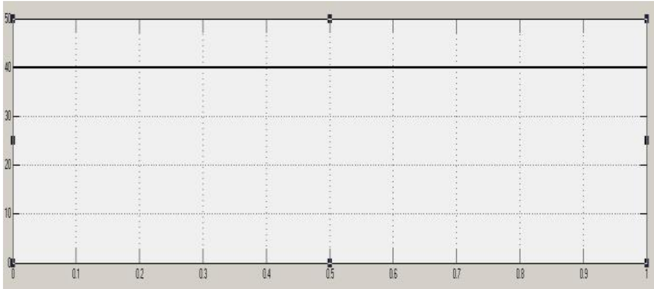
$$y1 = Vc = x3$$

$$y1 = \begin{bmatrix}0 & 0 & 1\end{bmatrix}\begin{bmatrix}x1\\ x2\\ x3\end{bmatrix}$$

For Low pass D=0

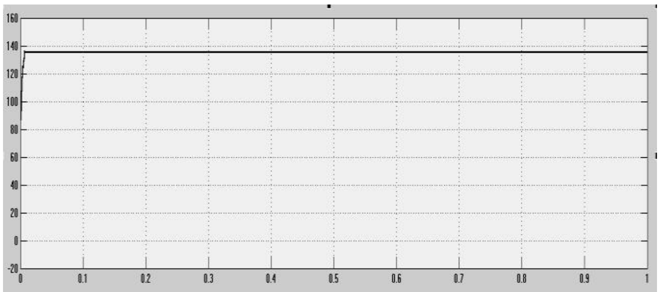
Simulation Results

The Half bridge LLC parallel boost resonant converter for variable DC Source is simulated using Mat lab and the results are presented.



Voltage(1div =10V) Vs Time

Fig.8 Input Voltage of proposed conv.



Voltage(1 div=20V) Vs Time

Fig.9 Output voltage of proposed converter.

Output voltage and current waveforms are shown in Fig. 8 and Fig.9 respectively. From the results, it is clear that the output voltage increased very much as a result of boost converter & parallel LLC combination. Thus the efficiency of the circuit is Increased and also provide a smooth and ripple free output.

$$V_{in}^{\min} = \sqrt{V_{O.PFC}^{\;2} - \frac{2P_{in}T_{HU}}{C_{DL}}}$$

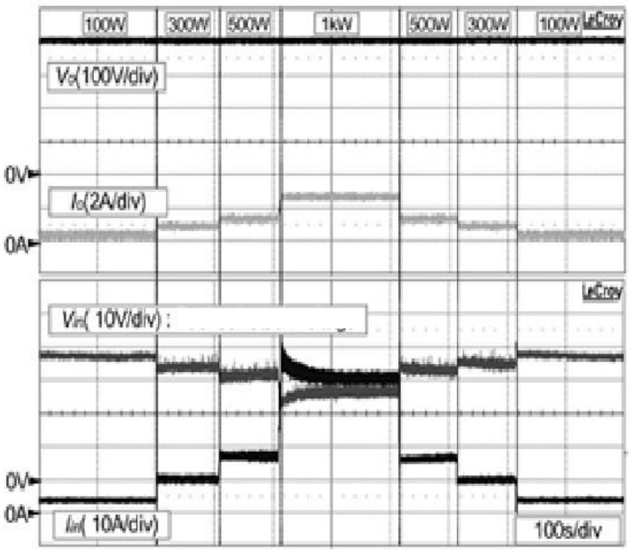


Fig.10.Test results with variable DC Source prototype

Prototype of Hardware

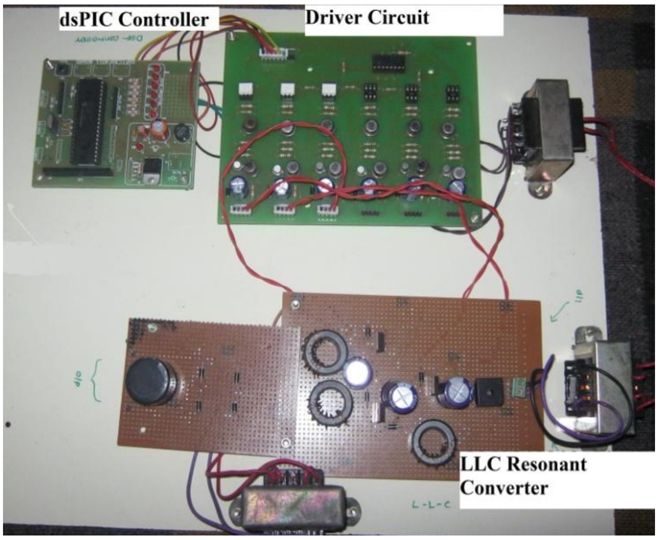


Fig.11 Photograph of proposed converter

Conclusion

In this paper, ZVS based high frequency converter with voltage amplification has been proposed. It is composed of the boost converter for output voltage regulation and the isolated voltage amplifier using the LLC converter, are simulated using MATLAB simulink and the results are presented In the results we can see that the output voltage wave is very much increased with smooth and ripple free. High efficiency is achieved with a constant output voltage. Resonant converter topologies can be used to increase circuit switching speeds, improved power factor and reduced switching losses. From analysis and test, LLC resonant converter is proved to be able to improve the performance of front end DC/DC converter significantly.

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