# Analysis and simulation of LCTLC Resonant Inverter with Multifunction Output


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***Abstract*** **The paper deals with design analysis and simulation of power resonant inverter with integrated LCLC filter and VF transformer (LCTLC). The filter provides sinusoidal output voltage for sensitive loads with harmonic distortion roughly 5% in the whole range of the load (0-100%). The LCTLC filter is supplied from either single-phase voltage inverter in full- or half- bridge connection, or from simple DC/DC buck converter. The output can be considered as simply controlled AC HF power generator (power supply) or DC rectified output (DC power supply), or/and as AC LF source with variable frequency.**



***Keywords*** **LCLC resonant inverter, HF transformer, cycloconverter output voltage, Fourier analysis**


## I. Introduction

There are many applications when load has to be supplied by harmonic voltage with solid harmonic distortion smaller than 5 %. Also, many applications need to be supplied from DC/DC power supply with integrated HF transformer. A LCTLC Resonant Inverter can provide both types of AC or DC power supply functions. Other suitable types are LCC resonant converter or LCCLC converter [1], [2]. One of the novel types of converters are LCLCL converter [3] based on LLC resonant scheme, and LCTLC inverter [4], [5] consists of DC/DC buck converter, LCLC resonant filter and HF transformer (HV or normal MV). The HF transformer can also be connected after the LCLC filter, if necessary. The inverter (LCTLC) is usually used as power supply for either HV rectifiers [6] (vacuum displays and CRTs, or X-ray devices) or HF cycloconverters or matrix converters, for 2-phase motor applications [7], [8], respectively.

## II. Basic LCTLC Inverter Analysis

The basic scheme of LCTLC resonant inverter is shown in Fig. 1. It consists of DC/DC buck converter, LC series resonant filter (with parameters $L_{11}$, $R_{11}$, $C_1$), HF transformer (HV, MV or LV), and LC parallel resonant filter ($L_{22}$, $R_{22}$, $C_2$). The HF transformer can also be connected after the LCTLC filter, if it is necessary.

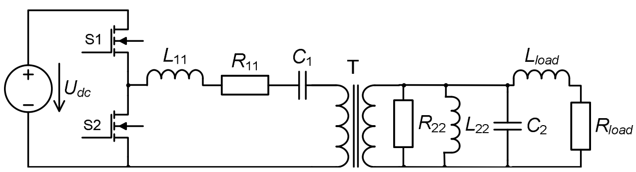


Fig. 1. Basic scheme of LCTLC resonant inverter

Based on works [4]-[6] one can create following equivalent scheme of the LCTLC circuit, Fig. 2. The equivalent parameters of the HF transformer ($L_\sigma$, $R_\sigma$, $L_m$, $R_{Fe}$) are included into resulting component parameters:

$$R_1 = R_{11} + R_\sigma \; ; \quad \frac{1}{R_2} = \frac{1}{R_{Fe}} + \frac{1}{R_{22}} \tag{1a}$$

$$L_1 = L_{11} + L_\sigma \; ; \quad \frac{1}{L_2} = \frac{1}{L_m} + \frac{1}{L_{22}} \tag{1b}$$

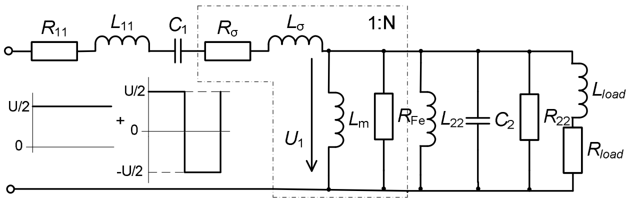


Fig. 2. Equivalent scheme of LCTLC circuit

The state-space equations for equivalent circuit with R-L load will be

$$\begin{aligned}
\frac{di_{L1}}{dt} &= \frac{1}{L_1}u(t) - \frac{R_1}{L_1}i_{L1} - \frac{1}{L_1}u_{C1} - \frac{1}{L_1}u_{C2} \\
\frac{di_{L2}}{dt} &= \frac{1}{L_2}u_{C2} \\
\frac{du_{C1}}{dt} &= \frac{1}{C_1}i_{L1} \\
\frac{du_{C2}}{dt} &= \frac{1}{C_1}i_{L1} - \frac{1}{C_2}i_{L2} - \frac{1}{C_2 \cdot R_2}u_{C2} - \frac{1}{C_2}i_L \\
\frac{di_L}{dt} &= \frac{1}{L_{load}}u_{C2} - \frac{R_{load}}{L_{load}}i_L
\end{aligned} \tag{2}$$

where

$i_{L1}$, $i_{L2}$ - currents through the inductors $L_1$ and $L_2$, respectively
$i_L$ - current through the load $R_{load}$, $L_{load}$
$u_{C1}$, $u_{C2}$ - capacitors voltages of $C_1$ and $C_2$, respectively
$u(t)$ - output voltage of the converter (filter input voltage)

## III. Design of LCLC components

Resonant frequency of $L_1C_1$ and $L_2C_2$ should be the same as basic fundamental frequency of the converter and is requested by load demands. So, based on Thomson relation

$$\omega_{res} = \sqrt{\frac{1}{L_1C_1}} = \sqrt{\frac{1}{L_2C_2}} \rightarrow$$
$$\rightarrow L_1\omega_{res} = \frac{1}{\omega_{res}C_1} = L_2\omega_{res} = \frac{1}{\omega_{res}C_2} \tag{3}$$

where
$\omega_{res} = 2\pi\omega_1$, $\omega_1$ is fundamental frequency of the converter.

Theoretically, $L_1\omega_{res}$ and other members of (3) can be chosen from wide set. Not to exceed nominal voltages and currents of the accumulative elements we take value of the nominal load. Then

$$L_1 = \frac{U_1^2}{\omega_1 P_1} \cdot q = L_2 ; \quad C_1 = \frac{P_1}{\omega_1 U_1^2} \cdot \frac{1}{q} = C_2 \tag{4}$$

where

$q$ - quality factor is ratio of component's impedance $L_1$, $L_2$, $C_1$ and $C_2$ to load impedance.

## IV. Simulation Results

Using suitable numerical method or directly Matlab functions allow (2) the time waveforms of the quantities of LCTLC inverter can be obtained. Simulation results of the quantities of LCTLC inverter with full width of pulse is depicted Fig. 3, where output voltage of LCTLC inverter is high quality (THD ~ 5 %) in steady-state.

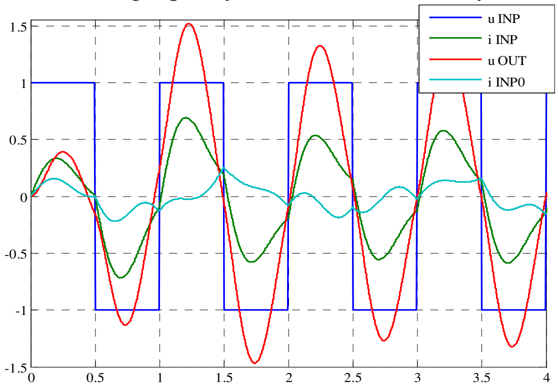


Fig. 3. Basic simulated waveform of LCTLC inverter with full width of pulses

Other system consists of high frequency LCTLC inverter and 2-phase high frequency cycloconverter or matrix converter, respectively. Simulation results of the output quantities of LCTLC inverter and five-pulse cycloconverter is depicted Fig. 4.

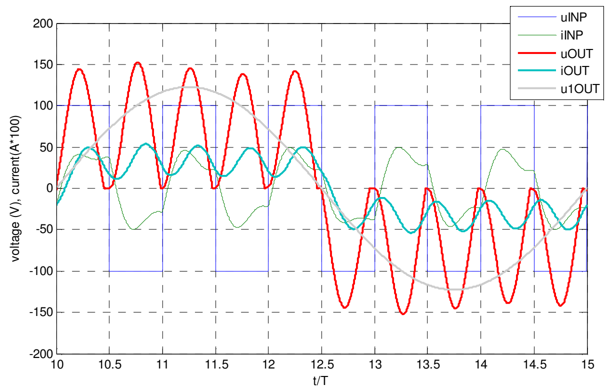


Fig. 4. Simulation results of the output quantities of LCTLC inverter and five-pulse cycloconverter

For output voltage of five-pulse cycloconverter, Fig.4, connecting to output of the LCTLC inverter the fundamental harmonics can be calculated [9] using term

$$\sin(5\omega t) \cdot \sin(\omega t) = (1/2)[\cos(5\omega t - \omega t) - \cos(5\omega t + \omega t)] \tag{5}$$

After integration the result is $U_{5\max(1.h)}$ = 0,8164 $U_{amp}$ $\rightarrow$ 81,46% . The fundamental voltage harmonics of multi-pulse cycloconverter are in Fig.5.

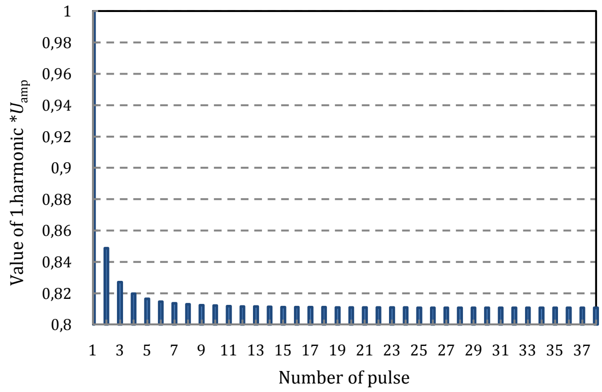


Fig. 4. Calculated fundamental harmonics of the output voltage of multi-pulse cycloconverter

## V. Conclusion

Design analysis of high frequency LCTLC inverter has been presented. It can be declare from the simulation and experimental results that output voltage of LCTLC inverter is high quality (THD ~ 5 %), output voltage is nearly constant in whole range of the load, frequency of the voltage is constant.

Output quantity of such a type of inverter can be used for second stage presented by half-bridge converters or matrix converter, respectively.

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