Abstract
The resonant inverter in half-bridge scheme operation with increased circuit frequency relative to resonance in the same circuit is investigated.

Keywords
Frequency, resonance inverter.

Introduction
Investigation of coil’s insulation must be realized at impact of high voltage stresses. Such a voltage can be generated in load circuit of resonance inverter operating in resonant case at supply from rather low level DC voltage [1, 2]. Therefore it is essential to calculate appropriate values of voltage applied to the investigated coil. Calculations are connected with investigation of resonant converter operation regimes. Normal operation of resonance inverter can be provided only in case when parameters of load circuit accord to the oscillating processes in load circuit, i.e., in accordance with relation

\[ \frac{1}{LC} > \left( \frac{R}{2L} \right)^2 = \delta^2 \]  

(1)

where \( \delta \) is damping parameter for LCR load.

Frequency of self oscillations for load’s circuit is

\[ \omega = \sqrt{\frac{1}{LC} - \delta^2} \]  

(2)

Correct calculation of resonance inverters is difficult task because oscillation process is developing from one switching cycle to the next one and in the steady-state condition of converter the magnitude value of capacitor’s voltage is much bigger than voltage of the DC supply [2]. Therefore in this article is presented a simplified method for calculations which allows calculate processes with rather good approximation.
Inductance of load circuit RLC can decrease at damages of coil in respect to the meaning \( L \) at resonant case and as result the load circuit oscillation frequency

\[ \omega_{ld} > \omega_v. \]

If

\[ \omega_v < \omega_{ld} \leq 2 \omega_v, \]

then processes can be illustrated with diagrams on Fig 1b.

The relation

\[ \omega_{ld} \leq 2 \omega_v \]

means, that inductance \( L \) can decrease in four time relative to resonant case.

When switch S1 is turned-on, current \( i \) from negative value starts to change to positive value and in the moment when \( i=0 \) voltage value across the capacitor is at maximum negative value \( U_{m0} \). In the moments, when current has extreme values minus \( I_{m0} \) and positive \( I_{m0} \), voltage on capacitor practically is minus \( 0,5U_d \).

Similar, when switch S2 is turned on, the current changes from positive values to negative, but at maximum points of current voltage \( U = \frac{U_d}{2} \).

In the ranges between

\[ -\frac{U_d}{2} \leq U_c \leq \frac{U_d}{2} \]

capacitor voltage changes practically in linear way. This is the reason why we can write that

\[ I_{av}(0.5T_v - 0.5T_0) = CU_d, \quad (3) \]

where \( I_{av} \) is an average value of current in interval \((0.5T_v-0.5T_0)\), where \( T_v \) is period for control of the switches, but \( T_v \approx 2 \pi \sqrt{L_0C_v} \) is load’s self-oscillations period \((T_0<T_v)\) at decreased value of inductance \( L \).

This average value of current can be calculated as

\[ I_{av} = \frac{4}{T_v - T_0} \int_{T_0}^{T_v} \frac{0.25 (T_v - T_0)}{I_m \cos \omega_0 t} dt \]

\[ = \frac{4I_m}{(T_v - T_0) \omega_0} \sin(\omega_0 \frac{T_v - T_0}{4}) \quad (4) \]

As we can see from the picture Fig. 1b when current \( i \) decreases from \( I_{m0} \) to zero as \( I_m \cos \omega_0 t \) then voltage \( u_c \) increases from 0,5\( U_d \) to \( U_{m0} \). The changes of voltage can be described as

\[ u_c = \frac{I_{m0}}{\omega_0 C} \sin \omega_0 t + 0.5U_d \quad (5) \]

Here from when \( \omega_0 t = \frac{\pi}{2} \) then \( u_c = U_{m0} \) and

\[ U_{m0} = 0.5U_d + I_{m0} \sqrt{\frac{L_0}{C_v}}. \quad (6) \]

Using the obtained previous expressions the magnitude value of current can be calculate as

\[ I_{m0} = \frac{\sqrt{\frac{C_v}{L_0}} U_d}{2 \sin \frac{\pi}{2} \left( \sqrt{\frac{L_v}{L_0}} - 1 \right)} \quad (7) \]

and the magnitude value of capacitor’s voltage - as

\[ U_{m0} = 0.5U_d \left[ 1 + \frac{1}{\sin \frac{\pi}{2} \left( \sqrt{\frac{L_v}{L_0}} - 1 \right)} \right] \quad (8) \]

Here with index „\( v \)“ are presented load parameters in the case of resonance.

2 Examination of the results

Example 1. Let’s take \( U_d=10 \) V, \( C_v=0.374 \) \( \mu F \), \( L_0=6 \) mH, which provide \( \omega_0 = 2.111 \cdot 10^4 \) s\(^{-1} \). Accepted switching period at \( L_v=8.7 \) mH is

\[ T_v = \frac{1}{2791} \text{s}. \]

By calculations the magnitude of current \( I_{m0} = 0.124 \) A, but capacitor voltage amplitude \( U_{m0} = 21 \) V. As it’s seen in computer simulation diagrams, coincidence is an excellent (Fig. 2). In addition here is taken in model that \( R=0.1 \) \( \Omega \).

Fig. 2. Diagrams of computer modelling for ex. 1

Example 2. Take \( U_d=100 \) V, \( C_v=10 \) \( \mu F \), \( L_0=0.5 \) mH, which provide \( \omega_0 = 14142 \) s\(^{-1} \). The switching period at \( L_v=1.618 \) mH is

\[ T_v = \frac{1}{1252} \text{s}. \]
By calculations $I_{m0} = 7.4\text{A}$, but capacitor voltage amplitude $U_{m0} = 103\text{V}$, which perfectly coincides with diagrams from computer simulation (Fig. 3). In addition here is taken in model that $R=0.5\ \Omega$.

**Experiment 1**

When $U_d=10\text{V}$ (see above) the both calculated and experimental values of capacitor voltage at $L_0$ are practically the same:

$U_{m0} = 21\text{V} : I_{m0} = 0.124\text{A}$.

At resonance case with $R=0.1$ calculated value of $U_{mv}$

$U_{mv} = \frac{20 \cdot 10^6}{\pi \cdot 0.1 \cdot 2\pi \cdot 2791 \cdot 0.374} = 9.717\text{kV} \quad ;$

$I_{mv} = \frac{20}{\pi \cdot 0.1} = 63.7\text{A}$

Ratio

$\frac{U_{mv}}{U_{m0}} = \frac{1620}{103} = 15.8$ \\
In this case here is very good match of results as a result of increased source voltage as in the first experiment.

As it’s seen if will be higher ratio of load wave impedance $\rho_v$ and resistance $R$ then also will be higher voltage changes in the case of coil’s puncture.

In the same $\frac{\rho_v}{R}$ ratio voltage decrease will be higher if decreasing of inductance will be more, i.e., higher ratio $L/L_0$.

Ratio of the calculated results:

$\frac{U_{mv}}{U_{m0}} = \frac{9717}{21} = 465.5 \text{ times}.$

The experimental values from computer model are

$U_{mve} = 7.01\text{kV}$ ;

$I_{mve} = 46\text{A}$.

Comparing these results with calculated results, we can conclude that at low voltage of source

1. results at resonance can be affected by switches;
2. approximate calculation gives significant error.

**Experiment 2**

At $U_d=100\text{V} \ \text{calculated and experimental value of voltage at lowered L is } U_{mv}=103 \text{V}$. At resonance with $R=0.5 \ \Omega$ calculated value of voltage is

$U_{mv} = \frac{200 \cdot 10^6}{\pi \cdot 0.5 \cdot 2\pi \cdot 1252 \cdot 10} = 1.62\text{kV}$ ;

$I_{mv} = \frac{200}{\pi \cdot 0.5} = 127.4\text{A}$

The experimental values are

$U_{mve} = 1.61\text{kV} \ : \ I_{mve} = 127\text{A}$.
Conclusions

1. Processes in scheme of resonant inverter connected in the half-bridge scheme at resonant frequency of load higher as switching frequency effected by control can be described sufficiently good using approximate approach of processes assuming zero value of load’s resistance.

2. When tuned on resonance load circuit change its parameters to decreasing of inductance then oscillation of load frequency became faster then control frequency and this processes characterises with decreasing of voltages and currents in load circuit.

3. If higher is relation between load’s wave impedance and coil’s resistance then higher is ration of voltage decreasing in respect to the resonant case.

References


