September 10 - 12, 2003
Pilsen, Czech Republic

LOW – FREQUENCY CURRENTS IN INTERMEDIATE DC CIRCUIT OF VOLTAGE INVERTER

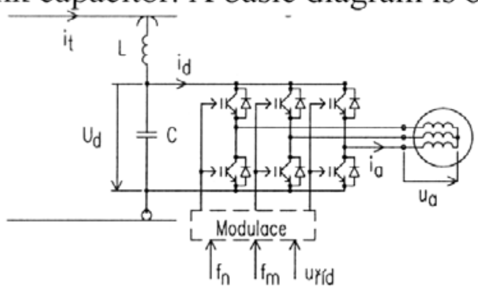
DOC. ING. JIŘI DANZER, CSC.[1]

Abstract: The work deals with circumstances of generation of low – frequency currents in DC link of voltage fed inverters with asynchronous modulation at DC traction vehicles. These frequencies are insufficiently attenuated by input LC filter and eventually they can correspond to its natural frequency. An analysis if their generation is performed and magnitudes and frequencies are introduced on particular example. An impact of different modulations is also considered.

Keywords: inverter, harmonics, modulation, analysis

1 Analysis

The DC traction vehicles with voltage fed asynchronous traction motors are often fed from line through input filter, the capacitor of which is herewith a DC link capacitor. A basic diagram is on picture 1.



Picture.1 A diagram and quantities

If the vehicle is in traction mode, the inverter takes-off from DC link a steady component of the current i_d and at the same time generates currents of different frequencies and magnitudes. These currents close partly through the capacitor, partly they flow through the filter choke, contact line and rails (current i_l). The frequencies of this AC components of the inverter current i_d are

[1] Západočeská univerzita Plzeň, e-mail: jiri.danzer@skoda.cz

given by basic frequency f_m of the motor voltage, carrying frequency of the inverter f_n (at PWM) and used modulation ($u_{řid}$).

The magnitudes of AC components of the line current are given by magnitude of the current i_d and by value of natural frequency of LC filter. AC line currents i_t are attenuated by the input filter the more efficiently, the lower is its natural frequency. However with lowering the natural frequency a mass (size, price, losses) of the filter grow. Therefore it is necessary to optimize its parameters. The most dangerous phenomenon is an interference of ATC systems, which operate at low frequencies (50 Hz and 75 Hz at ČD).

An operation of asynchronous traction motors in run requires motor frequencies from level of slip frequencies (in order of 0.1 Hz). A danger that some AC component will correspond to the ATC working frequency or natural frequency of the filter is real.

Further we pay attention to the **frequencies and magnitudes of AC currents** in range up to 100 Hz in dependence on used modulation. All considerations are concerning to **the steady values of AC currents generated by the inverter**. A principal method is **harmonic analysis** of the currents.

As the modulation we consider a way of generating of the AC voltage u_a of asynchronous motor from the DC link voltage U_d, where the AC voltage u_a is of requested magnitude and frequency of the basic harmonic. As **basic** harmonic we find such component of the motor voltages and currents, which generate real power. Used modulations can be divided in two basic groups:

- **synchronous,** where a course of the voltage is identical in each period of basic harmonic (rectangular modulation, a modulation with inserted commutations)
- **asynchronous** in all other cases.

By synchronous modulation the period for harmonic analysis is always identical with the basic harmonic of the motor voltage. This is the case we will not deal with.

By **asynchronous** modulation the inverter works with constant carrying frequency f_n and in the most frequent case control of the inverter is deduced from coincidence of the triangular voltage of the frequency f_n with periodical control voltage $u_{řid}$. The control voltage can be of sinusoidal or more complicated waveform with basic frequency f_m. This modulation is used for drive-away or for drives with small power often in whole range of the vehicle speed. With respect to the character of this modulation it is necessary to use other (longer) period for the harmonic analysis. This period must contain integrated multiple of periods T_n and T_m which correspond to the frequencies f_n and f_m. For quotient f_n/f_m we can write:

Eq. 1 $$\frac{f_n}{f_m} = \frac{i}{j} \Rightarrow \quad \Delta f = \frac{f_n}{i} = \frac{f_m}{j} \qquad T = \frac{1}{\Delta f}$$ where i, j are integer numbers.

On the period T even by the asynchronous modulation all AC values are periodical with the **basic harmonic of the frequency** Δf and corresponding higher harmonics. The frequency Δf is evidently in general **lower** that the motor one. Therefore the current in the DC link can contain also AC components with low frequencies.

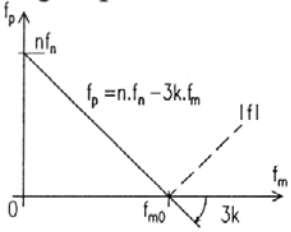
In work [1] there was numerically verified a hypothesis, that by asynchronous modulation in the DC link frequencies (if we formally permit also negative frequencies f_m) according to formula

Eq. 2

$$f_p(n,k) = n.f_n - 3.k.f_m \quad n = 0, 2, 4, 6, 8.\,(\text{even}).\ k = \ldots -5, -3, -1, +1, +3, +5, \ldots(\text{even})$$

$$n = 1, 3, 5, 7, \ldots.(\text{odd}) \quad k = \ldots. -4, -2, 0, +2, +4, +6\ldots.. \ (\text{odd})$$

appear. These frequencies we identify as "side frequencies". Generally, a dependence of the frequency f_p on the frequency f_m can be visualized by line according to picture 2.



Picture 2. A dependence of f_p on f_m for given n, k

With exception of occurrences for $k=0$ the line intersect f_m axis in frequency f_{m0}. In surround of this intersection the side frequencies drop to zero and then again increase (dash line for absolute value of the frequency f_p). According to Eq. 2 is:

Eq. 3 $f_{m0} = \dfrac{n.f_n}{3.k}$

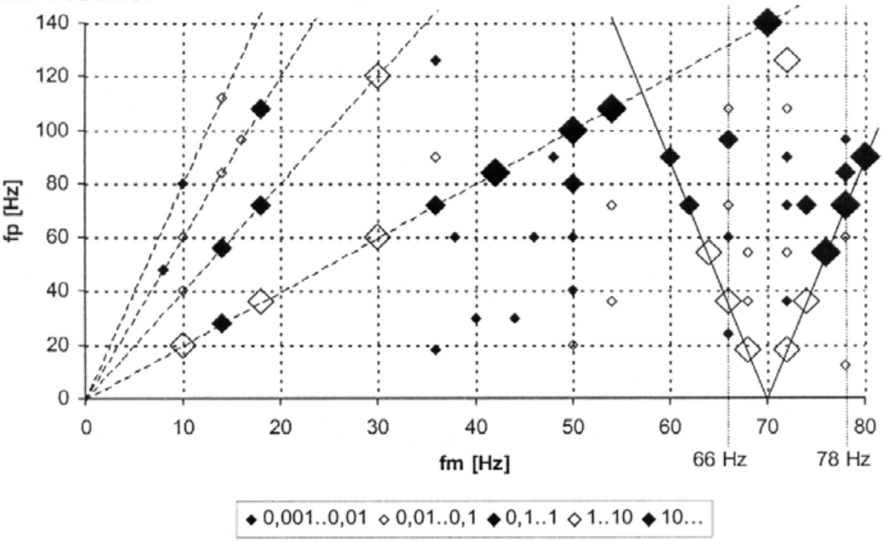
As we are interested in conditions for low frequencies, it is convenient to work in surround of the frequencies f_{m0}. There can be concentrated frequencies corresponding to diverse "lines" i.e. to diverse further couples of numbers n_1, k_1, which are integrated multiples of numbers n, k. Through each „point“ $\boldsymbol{f_{m0}}$ **a volume of lines** passes. A slope of these lines is according to Eq.2 equal to $-3*k$.

In surround of the points $\boldsymbol{f_{m0}}$ a huge amount of side harmonics from various multiples of the carrying frequency is concentrated. From aspect of this work these frequencies are the most important.

2 Application

Parameters of the traction motor ML 4144 K/6 - 500 kW were used for computation. Further carrying frequency 630 Hz was chosen, because it offers most "integer" values of the frequencies f_{m0}, which substantially shortens time of the computation. The computations were performed for control sinusoidal wave (marked as "sin") as well as for sinusoidal wave with 15% content of 3rd harmonic (marked as "sin3").

From Eq. 3 the most important frequencies are f_{m0} =70, 42, 30 Hz for f_n = *630 Hz*. The computation was performed with step 2 Hz for f_m in range from 2 Hz to 80 Hz. A general overview is on picture 3 for modulation „sin3" and currents higher than 1 mA. Size and shape of marks distinguish an order of particular results.



Picture 3.

In picture 3 there are marked frequencies and currents corresponding to n=1, k=3 according to the Eq.2. Also points corresponding to further couples *n, k* can be easily traced. Currents for modulation "sin" are of 1-2 orders lower for identical cases.

Besides, in picture 3 there appear further distinct currents with the frequencies, to which particular couple of numbers *n, k* cannot be simply assigned. Dependencies $f_p=2*f_m$, $f_p=4*f_m$, $f_p=6*f_m$, $f_p=8*f_m$ corresponding to significant currents are line – marked. From them only dependency $f_p=6*f_m$ corresponds to the side frequencies for *n=0, k=2*. As similar "anomaly" on certain values of f_m is appearance of a set of currents with frequencies in multiples. It is well evident on frequencies f_m=50, 66 and 78 Hz. For explication of this phenomenon a situation on aside frequencies $\pm 1\,Hz$ were computed. In all cases magnitudes of the currents are below 1 μA.

In these cases it concerns to the currents, which probably appear only at certain exact combination of frequencies $\boldsymbol{f_n}$ and $\boldsymbol{f_m}$. Therefore these currents were operatively marked as "combinative". Although the magnitudes of these currents can be considerable, in fact they represent in their sum only "noise". In practice the motor frequency f_m and conditions for generating of these currents change fast and randomly, despite of the currents on side frequencies, which continuously change their magnitudes and frequencies with continuous change of f_m.

References -

[1] Danzer J.: Harmonics in voltage fed inverter. Research report No. 211-8-00 ZČU FEL Plzeň, September 2000