An Investigation on a Transformer Converter of AC Current to AC Voltage

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One of the most precise way of converting AC current to AC voltage is by Compensated Current Transformer (CCT). What is offered in the present paper is: recommendations and investigation on the selection of a measuring transformer and the circuit for an electronic compensation that goes along with it.

All transformer converters suggest the following problems :

1. Non-linear distortions caused by the hysteric relation between B(t) and H(t) and non-linear form of the initial magnetisation curve.

2. Loses caused by hysteresis, eddy currents and leakage-heat in windings.

3. Existence of magnetic-leakage.

The initial magnetic curve of each ferromagnetic material can be divided in four sections according to the existence and type of two related mechanisms. The first of these is that the domain walls move under the influence of an applied field in such a way that favourably aligned domains grow at the expense of unfavourably aligned domains. The second mechanism involves rotation of aligned moments within as domain rotation. In the first section of the initial magnetisation curve the magnetisation is reversible and is produced by :

1) a reversible movement of favourably aligned domains toward the applied field;

2) a reversible merging of domain boundary only of those domains having mutual orthogonal self-magnetisation.

Its linearity and a lack of energy-leakage define the first section of the initial magnetisation curve as the most suitable one for the purposes of the conversion in question : H(t) -> B(t).

Having in mind the chosen section of the initial magnetisation curve the following criteria for selection of a magnetic material are suggested :

1) high initial magnetic permeability μ_i - a determining criterion. Weak magnetic field is introduced in the magnetic core;

2) small losses caused by eddy currents;

3) B_r, H_c, μ_{max} are not essential, due to the selection of the working section.

The high initial permeability suggests permalloy ($\mu_i \in$[2000 - 40 000]) or alsifer (μ_i ~35 000) to be picked up. The experience says that more suitable for a CCT are multiple ferrites like $(MnO.ZnO).Fe_2O_3$ and $(NiO.ZnO).Fe_2O_3$. They are less costly, have high ($\mu_i \in$[1000 - 10 000]) and temperature constant initial permeability.

In the theory of transformer it is always assumed that :

1) the resultant magnetic flux is a superposition of all separate magnetic fluxes. That is true if the electromagnetic field is homogeneous;

2) discarding the influence of leakage-magnetic.

These assumptions match most with toroids.

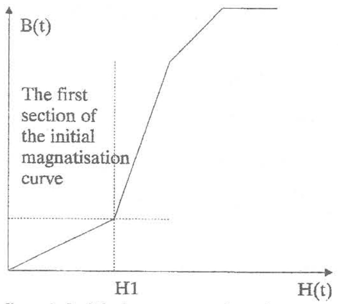

fig. 1 Initial magnetisation curve

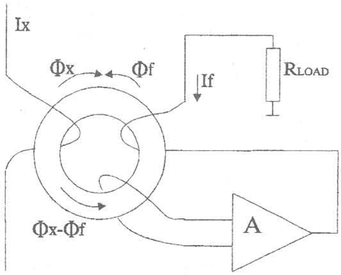

fig. 2 Structure circuit of the converter

A structure circuit of the converter (fig. 2)

The magnetic core physical and geometric parameters define the induced within it magnetic flux caused by the input current Ix. A reduction of the total magnetic flux is achieved by introducing a magnetic flux feedback. It is done by a compensating current If that flows through a compensating winding nf. The induced by the total magnetic flux Φx-Φf electromotive voltage in the secondary winding n2 is amplified by a feedback amplifier. In its output the compensating winding and a precise resistor R_{LOAD} are in series. The output voltage Uout is taken from R_{LOAD}.

The equivalent principle circuit of the converter in question without inductive connections is shown on fig. 3.

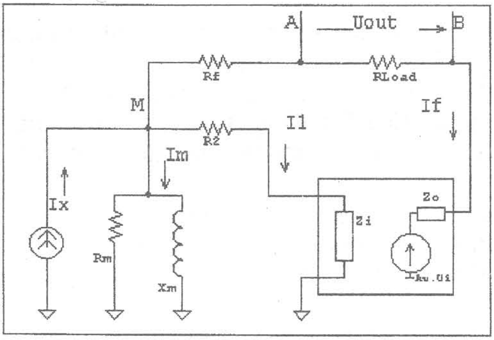

fig. 3

The selected coil form allows discarding the flux of magnetic leakage. The following equations are true :

(1) $\dot{I}_x = \dot{I}_M + \dot{I}_F + \dot{I}_i$ — $\dot{I}_x$ - not-know current;

(2) $\dot{A}_{UF}\dot{U}_M = (R_{LOAD} + r_F)\dot{I}_{OUT}$ — $\dot{I}_M$ - magnetic current;

(3) $\dot{I}_M = \dot{U}_M / Z_M$ — $\dot{I}_F$ compensating (feedback) current;

(4) $\dot{I}_i = \dot{U}_M / (R_i + r_2)$ — $\dot{A}_{UF}$ - amplification of op amp

These equations lead to a statement for $\dot{I}_F$ (5) :

$$\dot{I}_F = 1/[1 + \frac{R_{LOAD} + r_F}{\dot{A}_{UF}.Z_M} + \frac{R_{LOAD} + r_F}{\dot{A}_{UF}.(Z_i + r_2)}]\dot{I}_x \approx [1 - \frac{R_{LOAD} + r_F}{\dot{A}_{UF}.Z_M} - \frac{R_{LOAD} + r_F}{\dot{A}_{UF}.(Z_i + r_2)}]\dot{I}_x = (1 - \frac{\dot{I}_M}{\dot{I}_x} - \frac{\dot{I}_i}{\dot{I}_x})\dot{I}_x$$

The statement (5) is a current balance in a node M. It is shown in fig. 4.

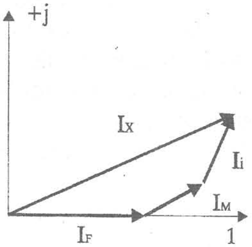

fig. 4

It is apparent that when the vector $\dot{I}_M + \dot{I}_i$ is small enough only its module applies to the amplitude and phase difference between $\dot{I}_x$ and $\dot{I}_F$. (5) also suggests that if $\dot{A}_{UF}$ is great enough the amplitude and phase errors of converter in question may be reduced beyond an initial set-up value. It can also be suggested that there are certain values for $\dot{A}_{UF}$ which zeros either an amplitude or phase error.

The feedback amplifier may be in inverting circuit with parallel feedback. The influence of the different elements can be evaluated when Tevenen's theorem is applied for nodes A and B. The converter is transformed in am active two-poles block with an equivalent voltage generator $\dot{U}_0$ and impedance Z_e. In fig. 3 the feedback op amp. is substituted with an equivalent macromodel compound of an input Z_i and output Z_O impedances and voltage controlled generator. It can be written $\dot{I}_F = \dot{U}_0/(Z_e + R_{LOAD})$.

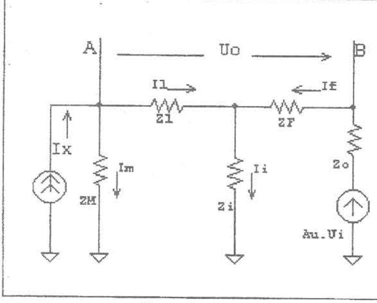

fig. 5

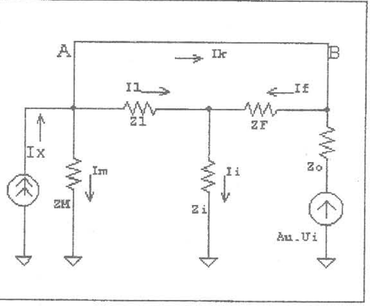

fig. 6

The voltage of the equivalent two-poles block is given by

(6) $$\dot{U}_O = \frac{Z_0.Z_1 + Z_1.Z_F - (\dot{A}_U - 1).(Z_1 + Z_F).Z_i}{(Z_0 + Z_F).(Z_1 + Z_i + Z_M) - (\dot{A}_U - 1).(Z_1 + Z_M).Z_i}.Z_M \dot{I}_x$$

The equivalent impedance Z_e while counting the dependent sources is given by $Z_e = \dot{U}_0/\dot{I}_K$ where $\dot{I}_k$ is the short current between nodes A and B.

(7) $$\dot{I}_K = \frac{Z_0.Z_1 + Z_1.Z_F - (\dot{A}_U - 1).(Z_1 + Z_F).Z_i}{Z_0.Z_M.(Z_1 + Z_F) + Z_1.Z_F.(Z_0 + Z_M) + [Z_0 - (\dot{A}_U - 1).Z_M].(Z_1 + Z_F).Z_i}.Z_M \dot{I}_x$$

The presence of a deep feedback suggests $Z_i \to \infty$ u $Z_O \to 0$. Then

(9) $$\lim_{Z_O \to 0, Z_i \to \infty} Z_e = \frac{(\dot{A}_U - 1).(Z_1 + Z_F)}{(\dot{A}_U - 1).(Z_1 + Z_M) - Z_F}.Z_M = F(z)$$

(10) $$\lim_{Z_O \to 0, Z_i \to \infty} U_O = \frac{(\dot{A}_U - 1).(Z_1 + Z_F)}{(\dot{A}_U - 1).(Z_1 + Z_M) - Z_F}.Z_M \dot{I}_x = F(z)\dot{I}_x$$

Then according with Tevenen's theorem

$$(11)\quad \dot{I}_F = \frac{\dot{U}_0}{Z_e + R_{LOAD}} = \frac{F(z)}{F(z)+R_{LOAD}}\dot{I}_x \approx (1 - R_{LOAD}/F(z))\dot{I}_x$$

The approximation is true if $R_{LOAD}/F(z) \to 0$. This condition suggests $Z_1 = -Z_M$. The last equation defines the capacitive type of the input impedance of the compensating feedback circuit and also suggests an existence of a negative active resistence in the input of the op amp.

Based on the above electrical analyses of the transformer converter, the following conclusions may be made :

1. The amplitude and phase errors are function and synonymous defined by the feedback amplifier parameters. The error is minimal when the stated conditions are applied.

2. Further reduction of the error can be searched by simulating a negative active resistence in the input of the feedback amplifier.

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