ANALYSIS OF TRANSIENT TRANSFER PROPERTIES OF CURRENT TRANSMITTERS. COMPUTATIONAL RESULTS

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Abstract

In this paper those results and their evaluation are presented, which were calculated based on the analytical and numerical methods worked out in [1] for the analysis of transient transfer properties of self-integrating and current-integrating type current transmitters operating based on the principle of magnetic voltage measurement. The calculations were made for different exciter signals (fault far from the generator, fault near to the generator, half-sine wave current, current signal of an inverter).

Keywords: current transmitters, current transformer, transient signal transmission.

1. Introduction

In current-integrating circuits, in the overwhelming majority of cases such a circuit is applied which is designed for $f_n = 50$ Hz, with a time constant of $T_i = 320$ ms, containing $R = 10000\ \Omega$ serial and $R_v = 2\ \mathrm{M}\Omega$ loss resistance and having a Q-factor of $a = \frac{R}{\omega \cdot L} = 100$. However, other circuits will be examined as well.

In self-integrating circuits such a transmitter is used for our examinations which is also designed for $f_n = 50$ Hz and has the same Q-factor ($b = \frac{\omega \cdot L}{R+R_a} = 100$), while the ratio of resistance is $R_a/R = 100$ and the loss resistance is $R_v = 2\ \mathrm{M}\Omega$. Regarding the two main parameters of this circuit (Q-factor and loss resistance), this circuit corresponds with current-integrating circuit, therefore these two kinds of current transmitters can be easier compared.

2. Fault Far from the Generator

Based on formula (13), the short circuit current is the sum of a sinusoidal term of constant amplitude and an exponentially damping DC term. Let us consider the steady state peak value of the short circuit current to be (I_m) unity. In the case of a 50 Hz network, the circular frequency of the voltage supplying the circuit is $\omega = 2 \cdot \pi \cdot f = 2 \cdot \pi \cdot 50 = 314$ rad/s. T_h is the time constant of the network (in the case of the high voltage network it is about 30 ms, while in a low voltage network it is about 10 ms), φ is the phase lag related to the voltage in the steady state of the short circuit.

Between the time constant (T_h) and phase shift (φ) of the circuit equation $\operatorname{tg}\varphi = \omega \cdot T_h$ is valid. The value of the switch-on angle (ψ) equals the phase angle of the voltage at the formation of the short circuit, its value can be arbitrary. Value of α is determined by ψ and φ, according to equation $\alpha = \psi - \varphi$.

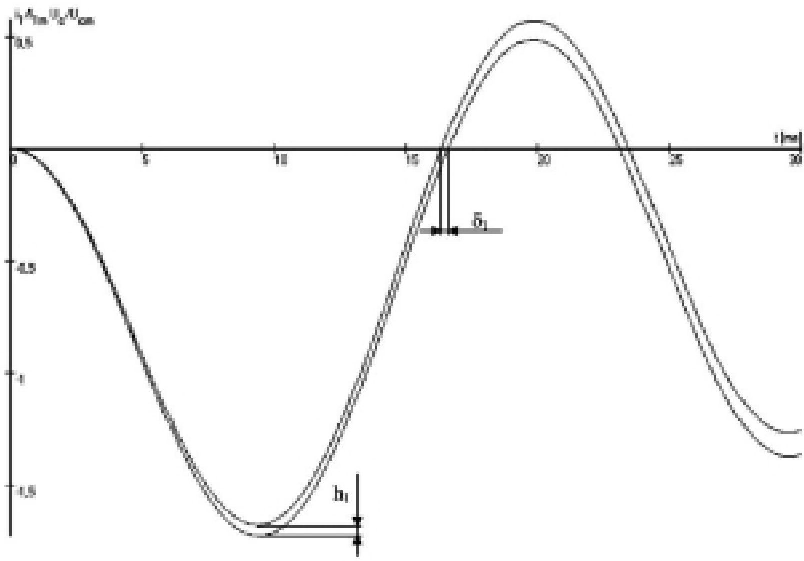

Fig. 1.

The difference between input and output signals is measured in two different situations. On the one hand, the relative value of the difference at the peak of the current (the error at the peak: h_1), on the other hand, the time difference at the current zero after this current peak, as an error of phase (δ_1) (*Fig. 1*).

First, the dependence of h_1 on the ψ or α parameter of the exciter signal will be examined (*Fig. 2*), then it will be analysed for δ_1 as well (*Fig. 3*).

Both parameters can have an arbitrary value in a 2π wide domain of angle. Based on (13), the transient component of the short circuit current is maximal at $\alpha = 0$ and at $\alpha = \pi$, while the transient component completely disappears from the signal at $\alpha = \pi/2$ and at $\alpha = -\pi/2$. Time functions in domain $\alpha = 0 - \pi$ and $\alpha = \pi - 2\pi$ are reversed functions of each other, therefore the analysis of the last ones gives no significant information. The maximal error (h_1 and δ_1) appears at switch-on angle $\psi = \pi/2$ and accordingly, at $\alpha = \pi/2 - \varphi$, ($h_1 = 1.455\%$, $\delta_1 = 4.3483$ crad), because the highest current peak can be found here. There is a breakpoint in the curves at $\alpha = \pi/2$ and $\alpha = -\pi/2$, resulted by the alternation of sign of the transient component and the highest peak.

Comparing the behaviour of two transmitters of similar parameters, it has

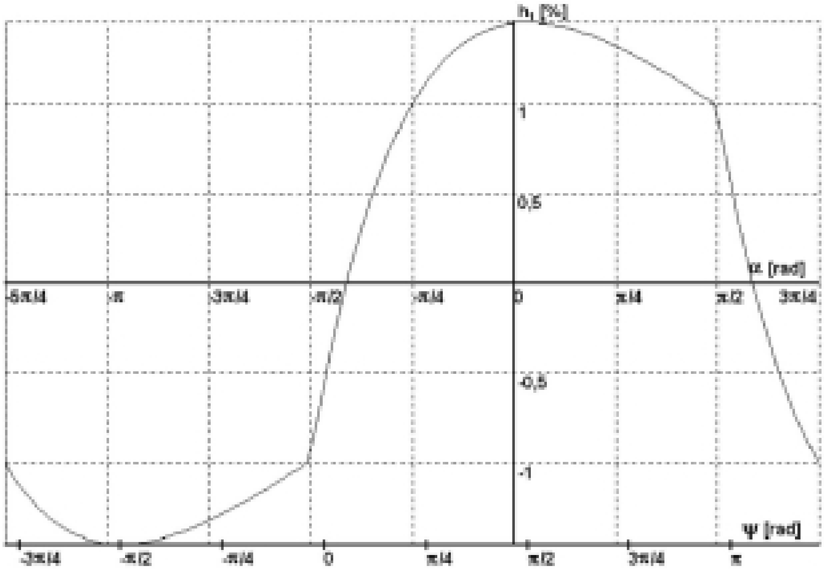

Fig. 2.

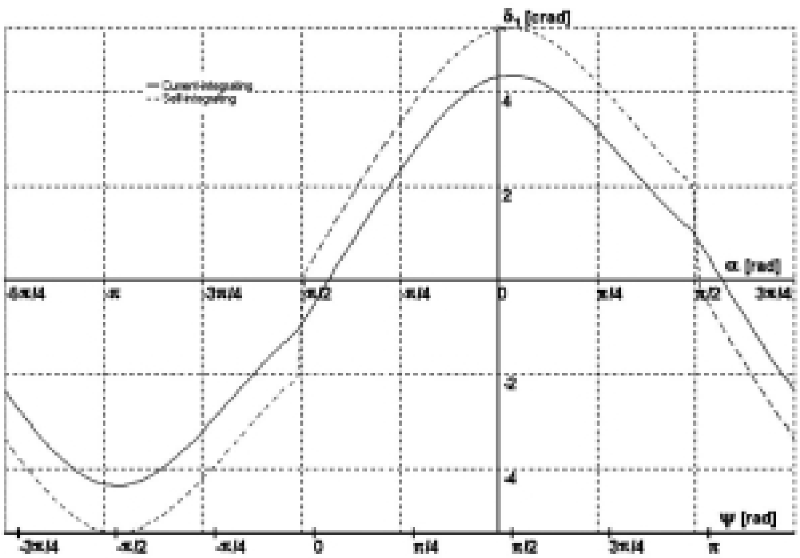

Fig. 3.

been found that h_1 is the same in each circuit at any ψ (*Fig.* 2), while δ_1 is different by a constant value (*Fig.* 3), thus the disadvantage of self-integrating circuit is that it has a higher absolute error. The value of this difference equals the error of angle (δ) belonging to the steady-state value of the excitation in the self-integrating circuit, where tg $\delta = 1/b$.

The reason of the two breakpoints (at $\alpha = \pi/2$ and at $\alpha = -\pi/2$) is that the DC component of the excitation alternates its sign here, as well as the highest current peak. Thus, at these points the measurement of error starts from a different zero point. Regardless of (δ_1), the constant difference of the angle errors, the switch-on angle of the fault transient signal (ψ) influences the errors just as with the current-integrating case.

These results are important for further examinations, because switch-on angle (ψ) – and therefore α as well – is arbitrary, and its value depends on the phase angle of the source voltage of the circuit of fault, at the moment of the formation of the fault. Therefore it is suitable to examine the effect of any other parameters in such a way that we get the maximal possible errors. This situation is at switch-on angle $\psi = \pi/2$, therefore this will be supposed in the following.

The frequency transmission features of the two kinds of current transmitters are significantly different. Examining how the transmitters – designed for $f_n =$ 50 Hz – behave for other (f) frequency signals (changing the frequency, the Q-factor also changes), the following can be experienced. Taking a glance at the error, measured at the peak (h_1), the two types of current transmitters provide equivalent transmission at lower frequencies (2–3 times f_n). But increasing the frequency, the error h_1 decreases monotonously by the self-integrating type, while in the case of current-integrating type, it increases again after a certain minimal value (*Fig.* 4). The position of this minimum value is determined first by the parameters of the transmitter, but the features of the fault also have a small effect. (Increasing the switch-on angle, the value of the frequency belonging to the minimal error increases, but, for example, the time constant of the network does not modify this value.)

The frequency dependence of the angle error (δ_1) shows similar properties (*Fig.* 5). In this case, there is no similarity, even at smaller frequencies, because even at nominal frequency (f_n) the two values differ by δ and this difference increases with the frequency. For higher frequencies, the errors have different sign, because the angle error of the current-integrating circuit has an alternation as a function of the frequency, while the angle error of the self-integrating circuit decreases monotonously, as the frequency increases. An advantage of the current-integrating circuit is that comparing to the self-integrating circuit, it has a smaller angle error in the relevant frequency domain, in addition, there is a frequency, where angle error (δ_1) equals zero. This value of angle is strongly influenced by the switch-on angle (*Fig.* 6). At nominal frequency the highest angle error (δ_1) appears at switch-on angle $\psi = \pi/2$, but this condition can be unfulfilled for frequencies higher than the nominal one. (Above a given frequency the maximal error appears at $\psi = 0$.) Because of the switch-on angle dependence of the zero point, it is impossible to create such a transmitter for a given circuit, which transfers the transient signal without angle error at a given frequency. Weighting the certain switch-on angles by their probability, supposing equal (probabilistic) frequency, the expected value

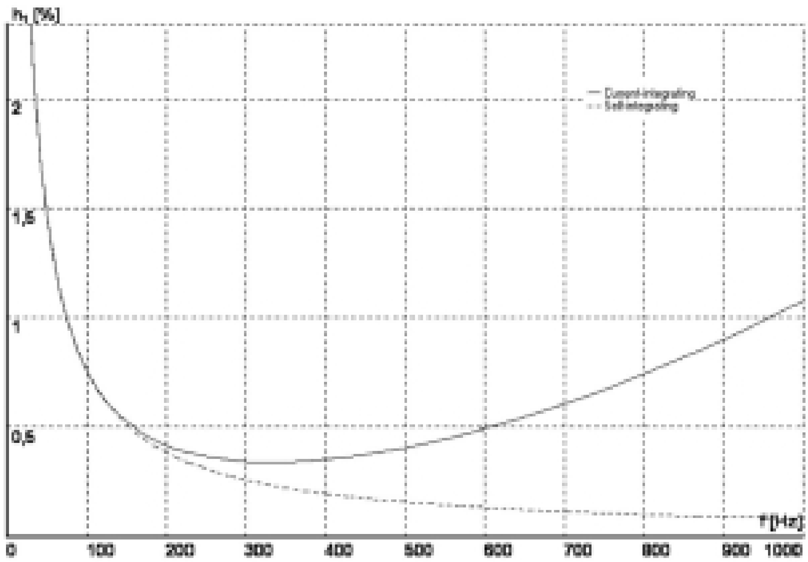

Fig. 4.

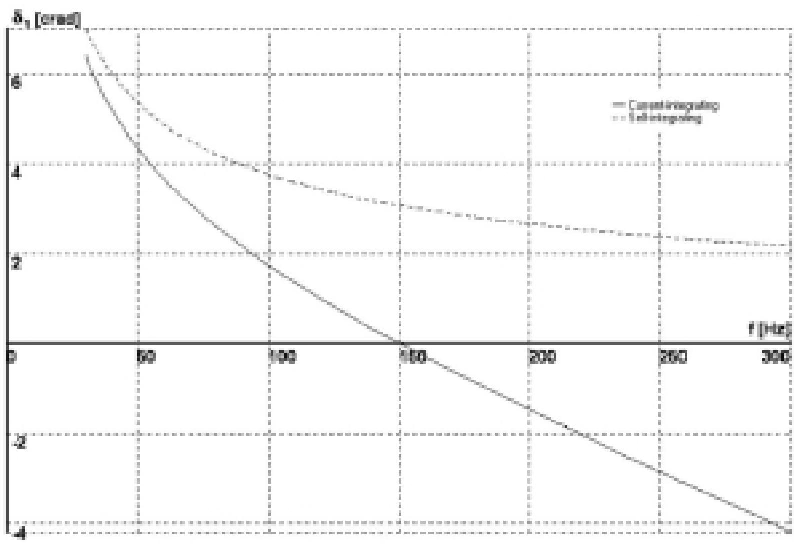

Fig. 5.

of angle error (δ_1) can be determined for every frequency. The expected value of the angle error of a transmitter designed for 50 Hz is minimal somewhere around

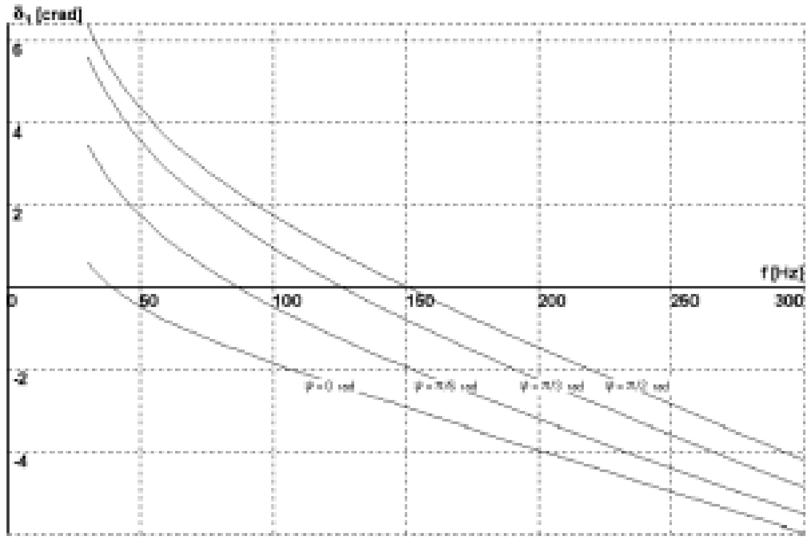

Fig. 6.

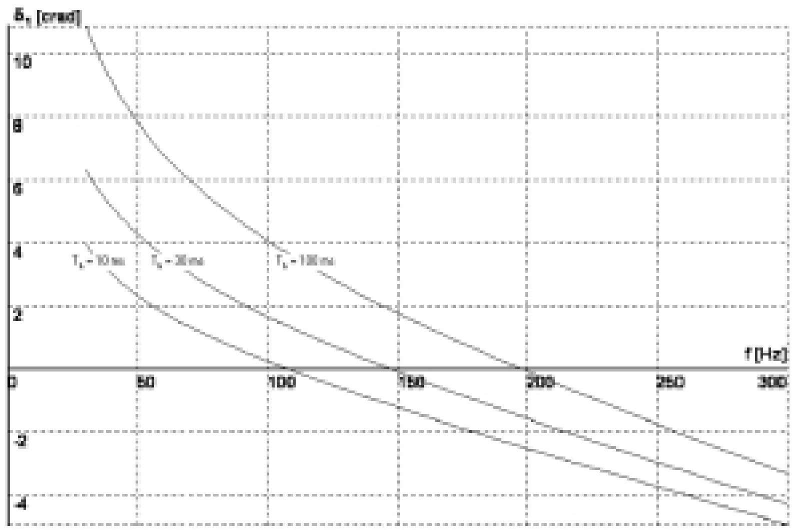

Fig. 7.

100 Hz. If we are searching for the minimum of the absolute value of angle error, then in can be seen that it will be minimal at around 100 Hz as well (at 50 Hz, $\delta_1 = 4.348$ crad; at 100 Hz, $\delta_1 = 1.846$ crad; at 150 Hz, $\delta_1 = 2.927$ crad,). At this frequency, angle error values belonging to $\psi = \pi/2$ and $\psi = 0$ are the same,

below that the minimal error appears at $\psi = \pi/2$, above that it appears at $\psi = 0$. Note that beyond the parameters of the transmitter and the switch-on angle, the results are significantly modified by the change of the time constant of the network (T_h). Increasing the time constant, the curves of the angle error are shifted towards higher frequencies (*Fig. 7*). In spite of that, such a conclusion can be drawn that the transient signal transmission features of transmitters designed for 50 Hz are optimal at a frequency, which is higher than the nominal one. From that a further conclusion is that it is possible to create such a transmitter for a given fault circuit, which is designed for $f_n < 50$ Hz and its maximal angle error (δ_1) will be minimal at 50 Hz.

From the aforesaid facts it can be seen that increasing the time constant of the network (T_h) the errors increase. The error measured at the peak (h_1) is independent of this parameter above a certain value, but angle error (d_1) increases significantly. (*Fig. 8*). The reason of that is that increasing time constant (T_h), the damping of the DC component is smaller, therefore the zero point, which follows the highest peak will be close to another peak. Here, on the one hand, the current zero will be uncertain and, on the other hand, a small difference between the two signals can result in a large difference in the angle (because of the small tangent of the functions). In the case of real networks the time constant of network (T_h) is in the 10–50 ms range, therefore the angle error (δ_1) has an acceptable value.

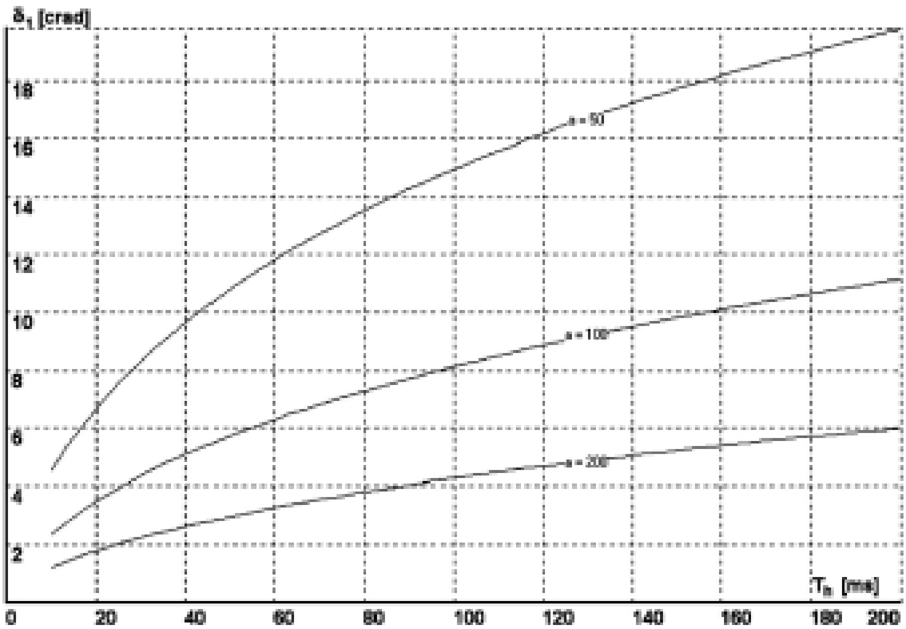

Fig. 8.

From the parameters of the transmitters (at nominal frequency) there are two parameters, which determine the transfer characteristics. The first one is the Q-factor (a, b), the second is the loss resistance (R_v). Increasing the Q-factor (a, b), the error measured at the peak (h_1) as well as the angle error (δ_1) strictly monotonously decrease and converge to zero (*Fig.9*). In the case of large Q-factors (T_i integrating time constant is high) even the signals containing larger time constant DC component can be transferred with a relatively small error.

Parallel resistance (R_v) decreases significantly the transient characteristics, if its order of magnitude is near to the value of series resistances.

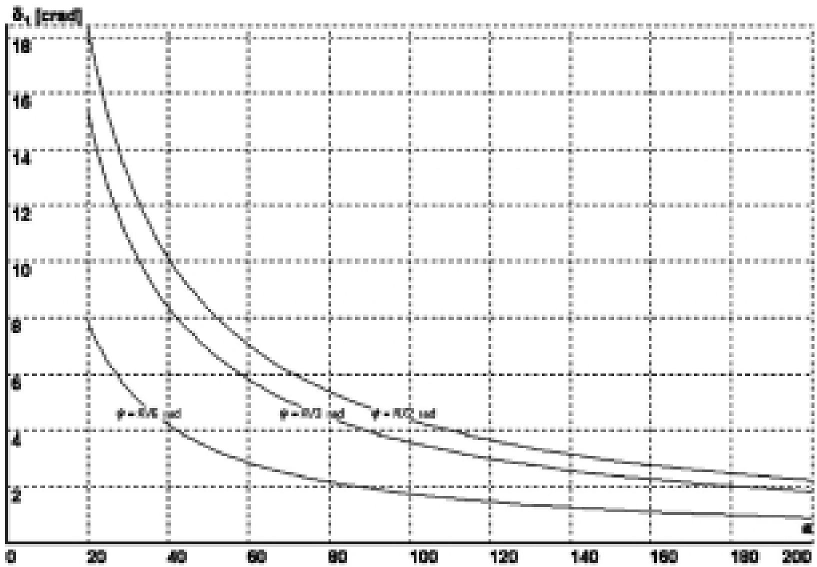

Fig. 9.

3. Fault Near to the Generator

Based on formula (16) the exciter signal consists of three components: subtransient, transient and DC part. All of them can be described by two parameters, by the magnitude and the time constant. The effect of a given component can be analysed in such a way that the others are neglected, this is the best way to separate the different effects. Let's suppose the steady-state value of the fault current $(\underline{I}_z)$ to be unity. Previously defined errors are applied in this case too (*Fig.1*).

The behaviour of the self-integrating circuit is the same as it was in the case of a fault far from the generator, regardless of the angle error (δ) belonging to the steady state. Comparing the time functions it can be experienced that the signals accord with each other at the peaks, in any period of the exciter signal (thus not only at the

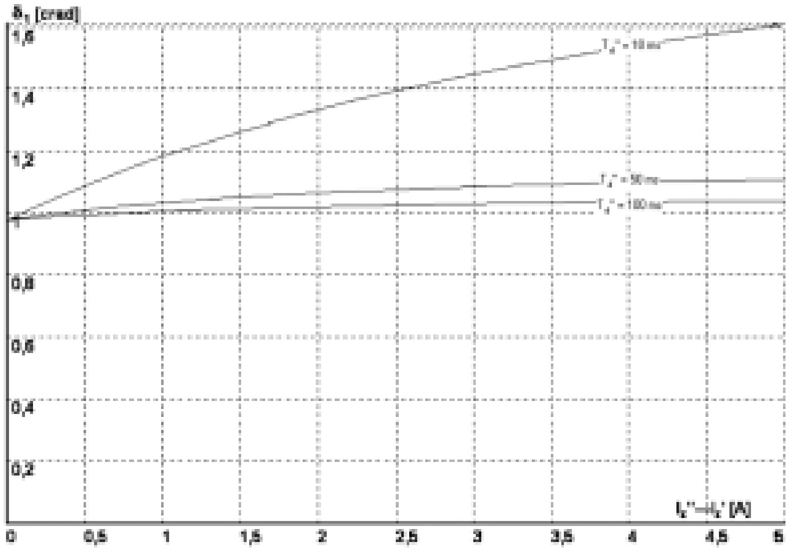

Fig. 10.

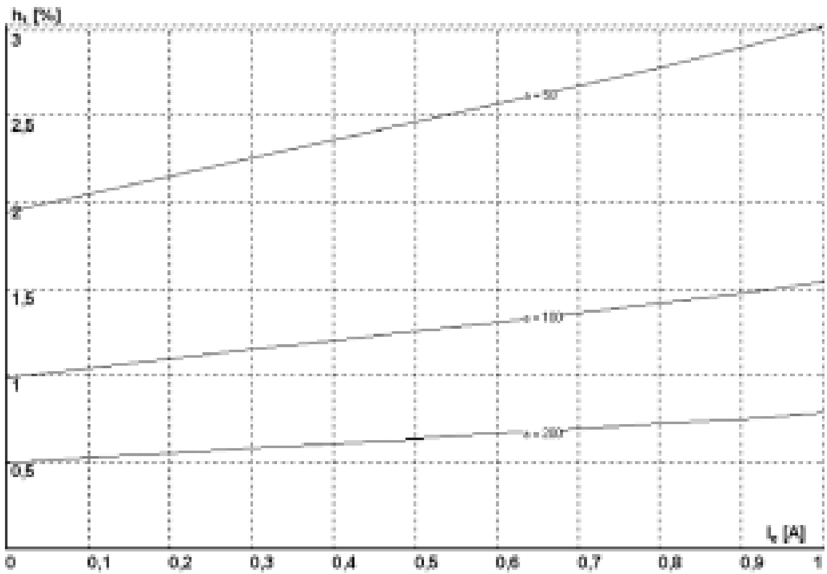

Fig. 11.

first peak). It follows from the foregoing that the error measured at the peak (h_1) is always the same, as it is in the current-integrating case having similar parameters.

In the case of the error angle (d_1), it can be said that the difference between the results from the two circuits is constant and its value equals the angle error (δ) belonging to the steady state. Therefore it is enough to examine the characteristics of the current-integrating circuit, because the features of the self-integrating circuit with similar parameters can be easily determined from them.

Examining the effect of the subtransient component it can be established that the value of the error measured at the peak (h_1) is not influenced significantly by the magnitude and the time constant of the subtransient component ($I_z'' - I_z'$ and T_d''). A small effect can be revealed only at smaller values of the time constant, where the transmission became worse. In the case of the angle error (δ_1) these effects are stronger (*Fig. 10*).

Neither the magnitude of the transient component ($I_z' - I_z$) nor its time constant (T_d') takes any effect on the examined errors. Its explanation is that supposing a 50 Hz signal, the first peak and the subsequent zero point (where errors h_1 and a δ_1 are measured) appears after some ms and in such a short time domain the transient component is practically constant.

Also that is the reason, why time constant of the DC component (T_S') does not influence the errors defined by me, but its magnitude (I_e) has a significant effect on those. As I_e is increasing, the error measured at the peak (h_1) increases linearly (*Fig. 11*), while the angle error (δ_1) increases rapidly (*Fig. 12*).

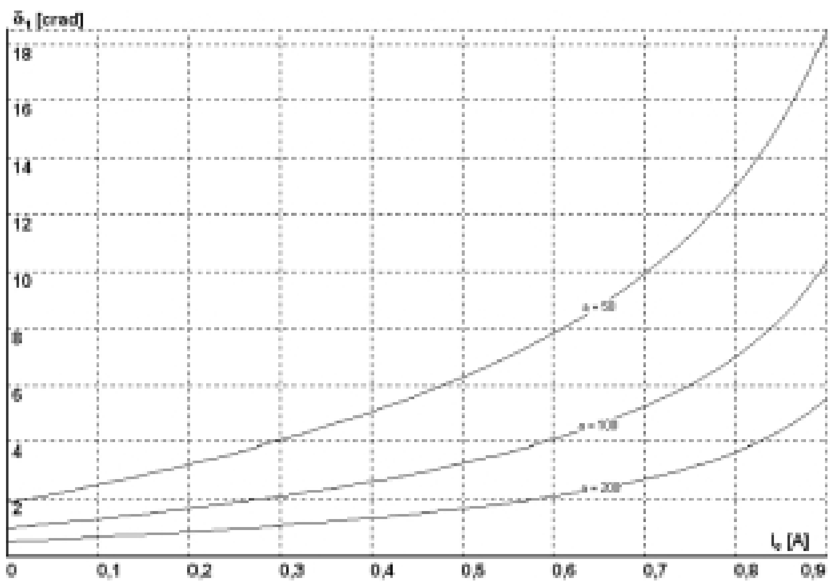

Fig. 12.

These values of error can be expected, but the fact must not to be ignored that those values are measured after some ms related to the formation of the signal, where the transmission error of the transmitter is not too high. But in the total time

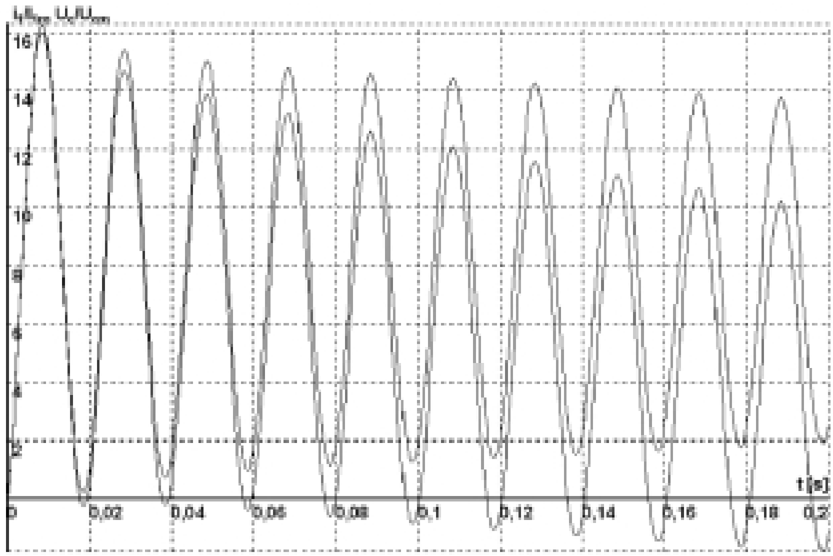

Fig. 13.

domain, the functions of the exciter and the response signal can be significantly different, as it can be seen in the figure (*Fig. 13*), where a DC component having a time constant of 7.7 ms is added to the AC signals. The DC component of the excitation is damping determined by the DC time constant (T_S'), but the same component of the response signal is damping determined by the integrating time constant (T_i). This phenomenon can be eliminated in such a way that we choose T_i to be in the same order of magnitude as T_S'.

4. Sinusoidal Half Wave Current to Test Circuit Breaker

This input signal is simple (17, 18). In practice 500 Hz current signal is used for the tests of circuit breakers. In this case 50 Hz signals will be examined, to keep the main parameters of the transmitters. Thus it will be easier to evaluate results, because of the comparability.

The following quantities are examined (*Fig. 14*):

1. Error measured at the peak (h_1).
   The relative difference of input and output signals at maximal magnitude.
2. Angle error (δ_1).
   Phase angle difference between the output and input signals at zero point ($t = \pi/\omega$).
3. Remaining voltage (u_1).
   The relative voltage remaining on the switches a $t = \pi/\omega$.

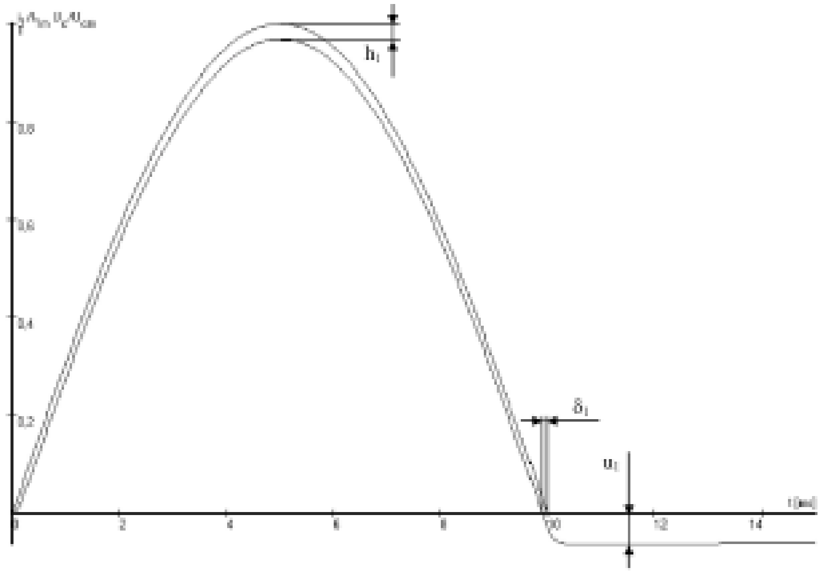

Fig. 14.

At $t = \pi/\omega$ the excitation ends, but the output of the measuring circuit has a remaining voltage because of the energy-storing elements. This voltage disappears after a certain time, determined by the time constant of the circuit. It can be disturbing in the case of high time constants, because at the switch-on of a new signal there can be energies in the measuring circuit.

Changing the frequency of the excitation influences the value of h_1 significantly. The transmission is similar to the results got in the case of the fault far from the generator. In the case of the current-integrating circuit the error measured at the peak (h_1) decreases as the frequency is increasing, then it reaches a minimum at a given frequency which equals some times the nominal one, and after that it increases unlimitedly. The position of the minimal value depends on the parameters of the transmitter. In self-integrating circuit increasing the frequency, the error decreases monotonously.

Frequency dependence of the angle error (δ_1) is also similar to the fault far from the generator. In current-integrating circuit it became zero at a given frequency, which is higher than the nominal one, and after that it keeps to infinity after its sign has changed (*Fig. 15*). This point of intersection is independent of the Q-factor (a), but depends on the nominal frequency (f_n).

The frequency dependence of the remaining voltage (u_1) is very similar, what is not surprising, because the relationship between the angle error and the remaining voltage is nearly linear, therefore their sign and points of intersection must be the same.

The alternation of the sign of u_1 and δ_1 originates from the fact that the delay

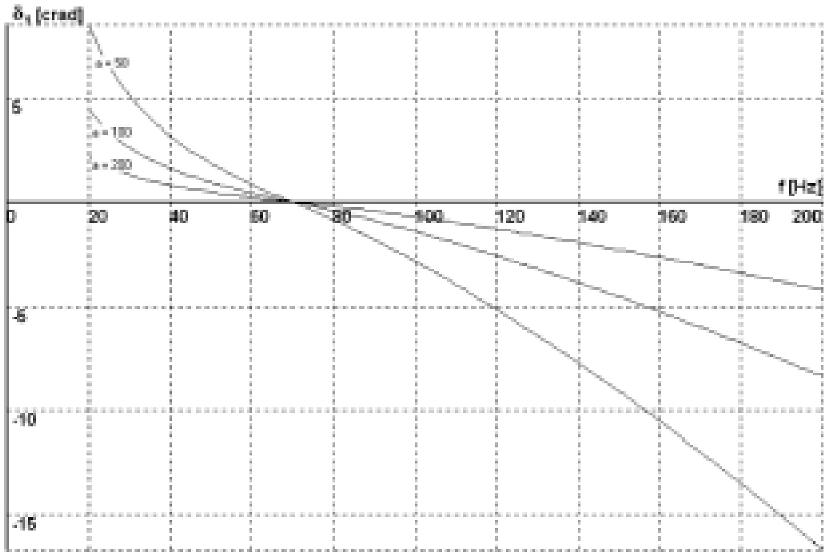

Fig. 15.

of the response signal related to the excitation becomes larger and larger as the frequency increases.

In the case of nominal frequency the two waves are absolutely symmetrical, the positions of their peaks are the same in time. At such a situation the angle error (δ_1) originates from the fact that the response signal is below the excitation by a small value, therefore its zero point appears earlier. Increasing the frequency, the delay of the peak of response signal becomes larger and larger (and its magnitude increases to a certain limit, this is the reason why h_1 is smaller and smaller as the frequency is increasing), therefore its zero point is getting closer and closer to the zero point of the excitation. At a given frequency the two points of intersection will be at the same time, where no angle error is zero and no charge remains on the capacitance. The further increase of the frequency results in higher delay, at such a situation at $t = \pi/\omega$ the voltage of the capacitance will have a positive sign, but the current of the inductance charges it to a voltage having opposite polarity, so it damps like the voltage of a damped resonance circuit containing two energy storing elements.

5. Current Signal of an Inverter

Because the formation of the stationary transient current of an impulse-operating inverter depends on the starting circumstances of the inverter, therefore only the stationary transient state will be examined and transients appearing during the running-up of the inverters will not be taken into consideration. After a certain pause, the length of which depends on the switching-in time ratio (β), the signal is repeating continuously. Considering that the exciter signal is not continuous, but it has constant length interruptions (stationary transient state), a problem arises, because a certain amount of charge remains in the capacitance of the transmitter during the time of the interruptions, which approximately discharges during a time determined by the integrating time constant (T_i). Its voltage value is small, but it does not disappear until the start of the next cycle, so the transmitter will have initial voltage in the further cycles, therefore it starts from a non energy free state.

This initial voltage having the negative sign increases the remaining voltage until the end of the next cycle (because it has the negative sign also), thus the transmitter will have a higher initial voltage in the next cycle. Of course, this process is not divergent, but it is a convergent one and after some cycles the initial voltage of the transmitter reaches a certain value (after 1000 cycles the value of the initial voltage practically does not change, therefore it can be supposed as the value belonging to the steady state, and the dependence of the initial voltage on the number of cycles can be determined related to that. It can be experienced that the difference of the initial voltage related to the steady state (1000 cycles) is $3.5 \cdot 10^{-6}\%$ at 100 cycles, 0.19% at 50 cycles and 28.5% at 10 cycles. Based on that we can draw the following conclusion: 100 cycles describe the steady state with appropriate accuracy.

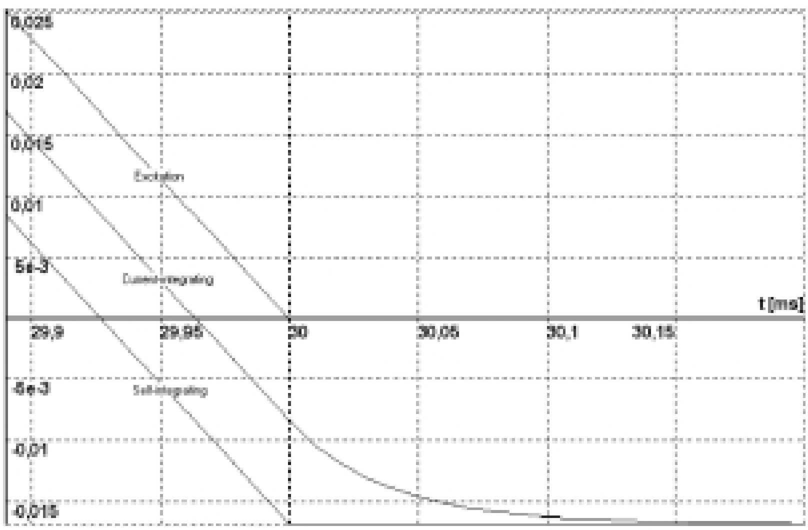

Fig. 16.

Regarding that the self-integrating circuit also contains an energy-storing element (inductance), therefore there will be a remaining voltage on the output in the interruptions between the cycles. This remaining voltage is caused by the

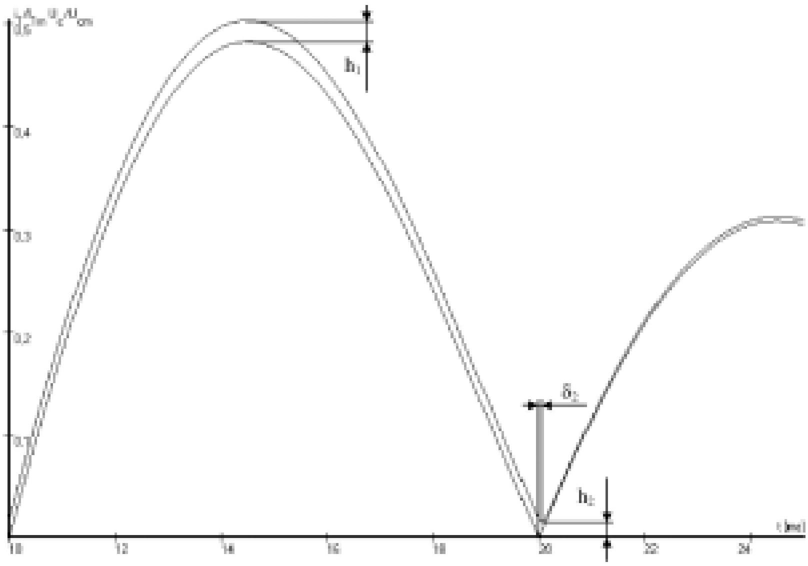

Fig. 17.

current of the inductance (i_2). However, in the case of the same exciter signal, if the Q-factors (a and b) and the loss resistances (R_v) of the current transmitters are the same, then the magnitude of this voltage equals the voltage, which can be measured in the current-integrating circuit. Magnifying the time functions of the end of the cycle (*Fig. 16*), it can be seen that after a short time the time functions of the output signals (output voltages) are the same, then they are damping by a higher time constant. The switch-on time ratio (β) determines the start of the next cycle, so the time between the two cycles. Usually it is much smaller than the time constant of the circuit, therefore at the start of the next cycle there will be an initial voltage. Its value is the same for the two circuits.

The transmission is described by the following errors (*Fig. 17*). Error measured at the peak (h_1), which gives the magnitude of the difference measured at the second peak (the first one is positive) in percentage. The 'valley' between the second and third peak, where the excitation has no zero point, touches zero only at one point. In this section the response signal can be various. The most frequent case is that the response signal is always above the excitation, therefore it does not reach value zero, it will have a positive minimum, which value in percentage (the basis of the comparison is the magnitude of the peak before the 'valley') is signed by h_2-. In the case of extreme parameters it can occur that this minimum point reaches value zero, it can be negative indeed. We will come back to the possible cases later. The position of this minimum point in time is not the same as it is by the exciter signal, therefore an angle error (δ_2) can be defined. As the fourth error, initial voltage is examined and signed by h_0-.

In spite of the difference of the time functions of the output signals in both circuits, they are overlapped at the examined peak, therefore the error measured at the peak (h_1) is always the same (supposing the same exciter signal and circuits having similar parameters). Based on that, the initial voltage (h_0) and the error measured at the peak (h_1) need to be examined only in one of the circuits.

From the parameters of the exciter signal phase constant ($\cos\varphi$) has a strong influence on the examined errors. Representing the steady state and the starting cycle in the same diagram (*Fig. 18*) it can be shown well that increasing the number of cycles, the error measured at the peak (h_1) decreases, and in steady state it will be nearly half as big as it is in the first cycle. The reason of that is that the initial voltage is negative and becomes larger and larger in every cycle, but the error measured at the peak is positive (the response signal is higher than the excitation) and the negative initial voltage 'shifts down' the diagram of the response signal, decreasing the error. Increasing $\cos\varphi$, the error increases, because the magnitude of the second peak decreases (the curve becomes flatter), therefore the difference increases – not absolutely, but relatively.

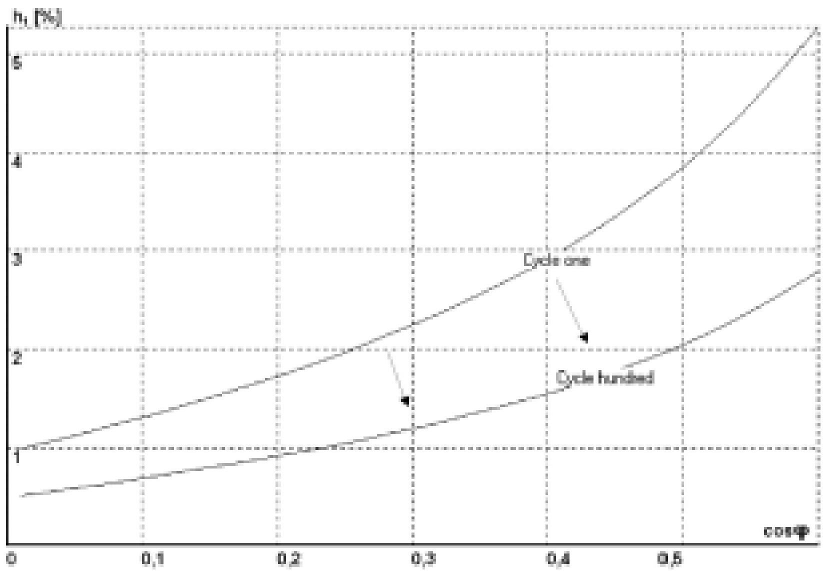

Fig. 18.

The minimum value measured in the 'valley' (h_2) will be similar. The only difference is that the error can be zero at a very small $\cos\varphi$, and it can be negative as well. In this case the minimum of the response signal is in the negative domain. However, the minimum measured in the 'valley' (h_2) differs from the current-integrating case. Comparing the $\cos\varphi$ dependence of the current-integrating and the self-integrating circuits (*Fig. 19*) it can be seen that we get a smaller value in the case of the self-integrating circuit, mainly in the steady state, between $\cos\varphi = 0.2 - 0.3$,

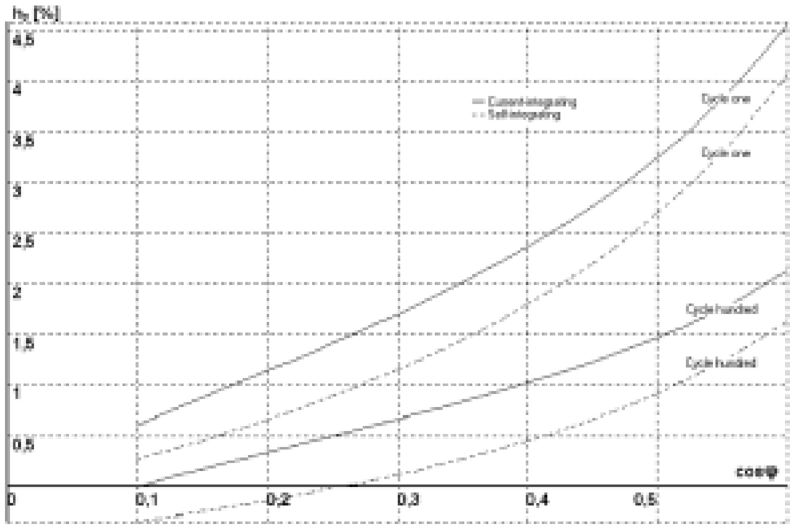

Fig. 19.

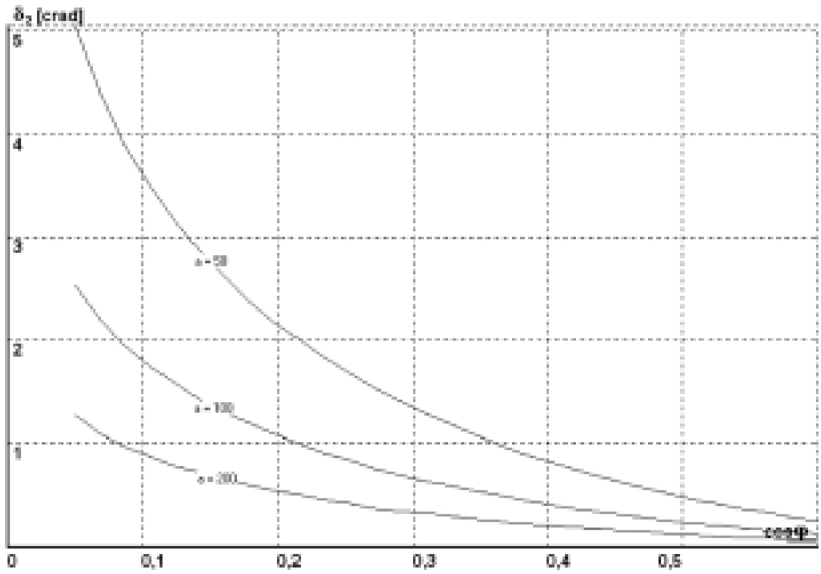

Fig. 20.

where error (h_2) alternates its sign. In this domain h_2 measurable in the steady state is only a portion of that of current-integrating circuits. A further feature of the self-integrating circuit is that the two minimum points (the minimum of the exciter signal and the response signal) are not different in time, so the angle error measured in the ‘valley’ (δ_2) is zero. For current-integrating circuit it is not true, but remaining voltage and its convergence do not influence the position of the minimum point in time (value of δ_2 does not change during the running-up of the inverter). This value of angle is decreasing as a function of $\cos\varphi$ (*Fig. 20*).

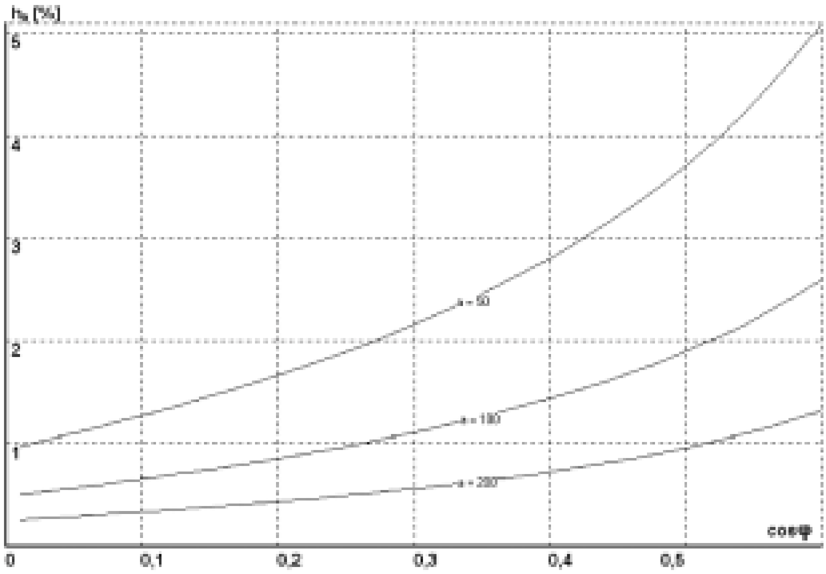

Fig. 21.

Examining the initial voltage (h_0) the first period is meaningless to examine, because at the start of the first cycle (at $t = 0$) the transmitter is free of energy, therefore there is no initial voltage. Increasing $\cos\varphi$ the initial voltage (h_0) relatively increases (*Fig. 21*), but its main reason is that the peak value, which is the basis of the comparison (the second peak) decreases continuously. However, it is clearly seen from that and from the previous curves, that the Q-factor (a) modifies every difference in an advantageous way, as it can be seen more clearly in what follows.

The switch-on time ratio (β) does not change the shape of the time function, but it increases the interruptions between certain cycles. Therefore the formation of the first cycle won’t be examined, because the first cycle is not preceded by an interruption.

Increasing the switch-on time ratio (β) the error measured at the peak (h_1) increases (*Fig. 22*), which was expected, because during longer interruptions the energy storing elements of the transmitters discharge better, therefore the initial voltage will be smaller on the output, which fact increases the error measured at the peak (the initial voltage ‘draws the curve down’, that is advantageous). The value of the error converges to the value measured in the first cycle. Changing the switch-on time ratio, the behaviour of both circuits is the same, but self-integrating circuits show smaller h_2 error.

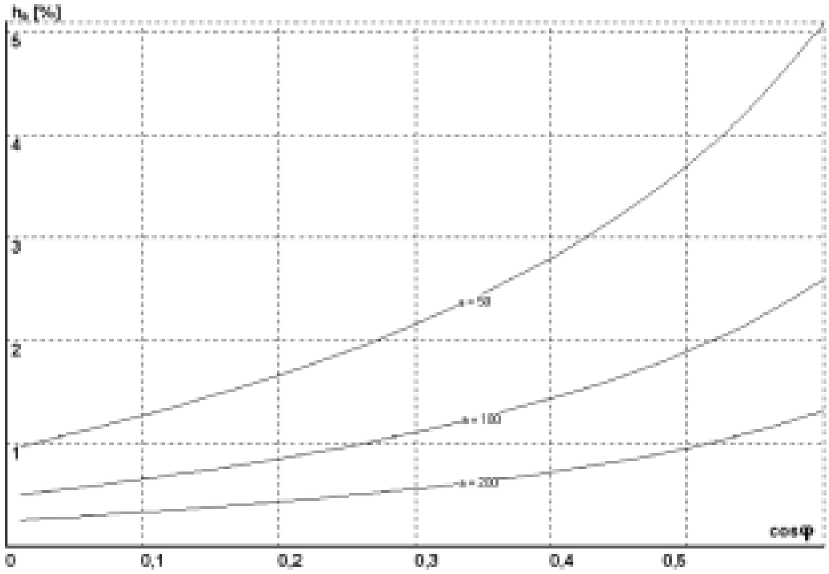
h [%]
5
4
3
2
1
0
0,1
0,2
0,3
0,4
0,5
cos φ

Fig. 22.

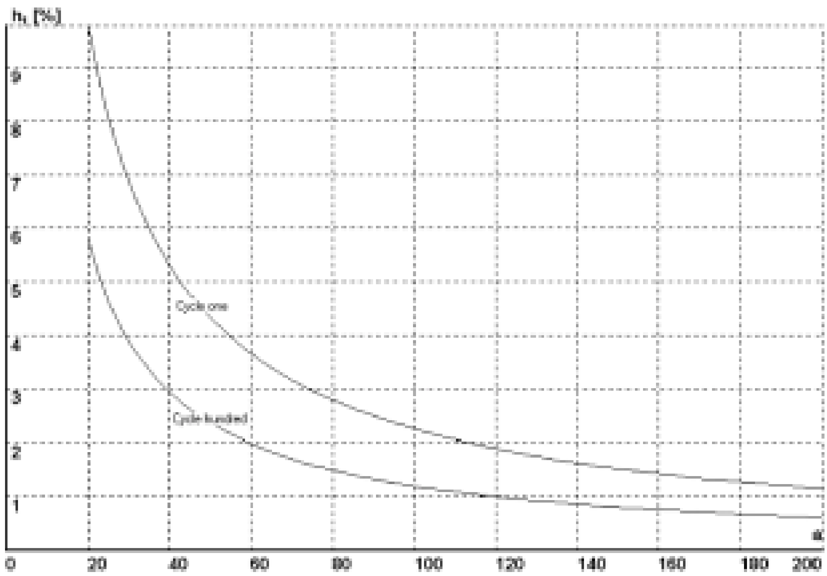
h [%]
9
8
7
6
5
4
3
2
1
0
20
40
60
80
100
120
140
160
180
200
Cycle one

Fig. 23.

The angle error of the minimum measured in the 'valley' (δ_2) is independent of the switch-on time ratio (β), which is expectable, because it was established earlier that this error is independent of the initial voltage. However, it has an influence on the initial voltage (h_0), because it affects the error measured at the peak (h_1) and the minimum measured in the 'valley' (h_2). The initial voltage converges exponentially to zero as the switch-on time ratio increases.

Analysing the effect of the Q-factor (a) we get that as it increases, the examined errors are all decreasing. There is no lower bound for the decreasing, so the value of the errors converges to zero (*Fig.* 23).

6. Summary

In the case of an appropriate design current-integrating and self-integrating type current transmitters transfer the signal to measure conformally and with high accuracy. Theoretically the accuracy can be increased by increasing the Q-factor (a, b), but in practice it has limits, which are strongly influenced by the frequency. In the case of self-integrating circuits the upper limit of the transferable frequency is determined by the interturn-capacitance, while the lower limit of the frequency is defined by the sensitivity, so using such a measuring circuit only such currents can be measured, frequency of which is $f > 10$ kHz.

With the new type of current-integrating circuits it became possible to produce such current transmitters, which can be created in the practice and which make possible the measurement of network frequency currents. Based on our examinations such a conclusion can be drawn that in the case of equal Q-factors (and same excitation and same input resistance connected in parallel) the output signals of both circuits are nearly the same. The reason of it is that the angle error (δ_1) of the self-integrating circuit computed at the zero point is higher by an additive value (δ) than it is in the appropriate self-integrating circuit. It is valid for the steady state and for the previously examined transient state as well. The constant difference is equal to the angle error (δ) measurable in the steady state of self-integrating circuits.

Another difference between the output signals of both circuits can be found in the transfer of the current signal of the inverter. Here the self-integrating type provided more accurate transmission in the 'valley' between two peaks of the exciter signal.

In conclusion both of the circuits provide accurate measurement, but current-integrating type is more advantageous than the self-integrating type having similar parameters.

If the exciter signal contains high time constant DC component, the difference between the exciter and the response signal can be high. Only one possible way exists to prevent that, choosing the integrating time constant (T_i) high enough. Of course, it can be problematic, because of physical limits.

Based on the results it can be said that the dependence of the errors on the certain parameters is a kind of monotonous function-relationship in most cases.

Therefore it has to be taken into consideration during the design that the change of a certain parameter (e.g. Q-factor) reduces the errors significantly only until a given limit and after that not so effectively.

If we would like to use the current transmitter to measure transient signals, it has to be taken into consideration during the design period. A current-integrating transmitter having zero angle error and zero transfer error in steady state will have an angle error and a transfer error in the case of transient excitation. The transmitter has to be designed for that, the diagrams presented here provide help in it.

If we would like to use a transmitter only to measure transient signals, then further decrease of transfer errors is possible by 'mistuning' (the frequency of the excitation is not equal to the nominal frequency of the transmitter). It is important to emphasise that in this case the angle error and the transfer error of the transmitter in steady state will not be zero, but the transfer errors measurable in the transient state will be smaller.

References

[1] BURUZS, T. – KOLLER, L.: Analysis of Transient Transfer Properties of Current Transmitters. Computational Methods. *Periodica Polytechnica Ser. El. Eng.*, **43**, pp. 263–276.