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VIRTUAL POWER SOURCES

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Abstract: For the calibration of power meters, it is preferred to use virtual sources that supply voltage and current at their outputs with high accuracy and in a manner that the phase angle between the two electric quantities can be set to the desired value. Due to the direct calibration procedure, these sources are required to be stable and accurate as well. As a transformer is included in the voltage- and current amplification circuits, the inherent nonlinearity of transformers and the handling of problems due to the effect of diffuse parameters (stability, accuracy and distortion) become of great importance. The high accuracy requirements reawakened the mathematical- and physical models that describe the operation of transformers as a function of frequency, with various diffuse parameters also taken into account. In the implementation the dependence of various diffuse quantities (inductance, capacitance) and the iron losses on the signal level raises difficulties; in fact, these result in the alteration of the corner points in the transfer function as well as undesirable accentuation.

Keywords: high accuracy virtual sources, nonlinear transformer modelling

1 INTRODUCTION

The offices for measures of good reputation use virtual power sources for the calibration of power meters and kilowatt-hour meters. Under laboratory circumstances, the Device Under Test (DUT) and the source are completed by a current comparator based power bridge (NIST, NRC) [1,2] or a high precision multiplier (PTB) [3]. Under circumstances requiring lower accuracy, the source itself is capable of performing the calibration. In the virtual power source, all the source parameters including the phase angle between the voltage and current can be adjusted individually.

Virtual sources enable direct calibration to be implemented provided that the source fulfils the requirements in respect of accuracy, stability and traceability. In the case of three-phase measurements, the calibration can be expanded. At present, the voltage- and current signals are generated by using digital methods for the most part. Primarily in field applications, the synchronisation between the clock signal and the line frequency may be advantageous in order to eliminate the hovering and interference caused by the power line [4].

Further advantages of the digital signal generation consist in the possibility of control by using computers, various waveforms can be stored in the storage devices as well as the adjustment of phase angle between the voltage- and current signals is simplified. The analogue part has a fundamental influence on the accuracy of power calibration equipment; therefore it is of earmarked importance to deal with their signal transfer characteristics.

2 DESIGN ASPECTS

This paper presents the signal generation in the voltage- and current circuits. The signal of 0 to 5 V level produced by the generator shall be amplified. Due to the high level of output and high power (30 VA), power amplifiers combined with transformers shall be used.

The fulfilment of requirements in respect of accuracy and stability necessitates the detailed knowledge of signal transfer characteristics in the circuit as far as possible. From among the design aspects, those listed below are of the most importance. Considering that, for reasons of production technology, the data published in the literature and indicated in the data sheets show significant variance, it is reasonable to use measured data for planning. This iterative planning method is also important in order to take the transformer parameters into account that are difficult or unable to be calculated (i.e. leakage inductances and capacitances).

The general function of virtual signal sources requires the use of a frequency band as wide as possible. This may also influence the frequency response characteristics of the transformer; although the negative feedback used has a favourable influence on the increase in the bandwidth. However, in respect of integrating the transformer into the amplifier, the problem of stability is of extremely importance, which requires a special frequency response for the transformers in order to prevent high frequency oscillation from being induced. Problems may also arise due to the DC component introduced by various electronic components into the circuit, which results in the alteration of operating point of the transformer and, consequently, its operating characteristics. Using autotransformers can eliminate this; in fact, in this case, the DC loop remains closed.

In order to promote the required operation, the possibility of intervention within a given frequency range shall be ensured, thus ensures the proper AC performance of the system.

As the loading resistance can be considered to be of high value (R_t= 2500 Ω) in respect of frequency response characteristics, therefore, the stray capacitance C_s connected parallel to the load cannot be left out of consideration. The C_s stray capacitance - together with other parameters of the transformer - influence the high frequency characteristics of the transformer.

2.1 Equivalent T-network of the transformer

The stability tests require that the transfer characteristics of transformers are considered in detail. It was reasonable to perform the analysis and planning necessary for the task by means of the equivalent T-network of the transformer (Figure 1) (The secondary elements were reduced to the primary side). The network components are: *L*: main field inductance, R_v: iron losses, R_1 and R_2': copper resistance, L_1 and L_2': leakage inductances (as two-port network describing the function); *ü=N2/N1* the turns ratio of the ideal transformer, R_t: load resistance, C_s: stray capacitance (as a load), as well as an external R_b-C_b network influencing the amplitude/phase characteristics. *L* and R_v are nonlinear elements, their values are dependent on the frequency and voltage level. The two elements can be modelled in the range where the effect of stray capacitance is still absent. The C_p is an auxiliary capacitance, which helps to identify C_s. The R_b, C_b and C_s do not belong to the equivalent T-network of the transformer, so in the Figure 1. they are indicated by dotted line.

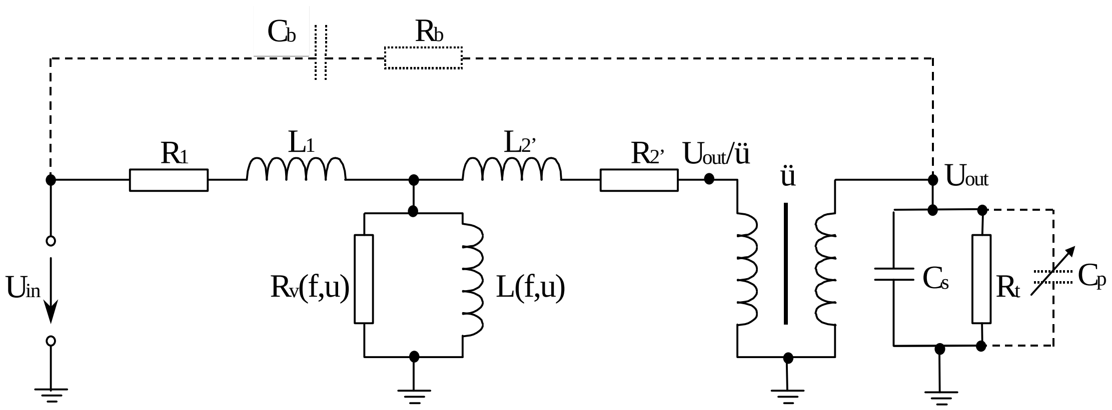

Figure 1. Equivalent T-network of the transformer

A further problem consists in the estimation of the stray capacitance; in fact, its value is unable to be determined in a direct way. In order to simplify the modelling, its value was assumed to be equivalent to a capacitance of concentrated parameter connected parallel to the output impedance; although, in reality, it is an element of distributed parameters which is frequency dependent as a result of capacitance between windings. The value of C_s can be estimated on the basis of frequency response of idle input impedance. The resonance frequency of the transformer can be easily diagnosable by a constant excitation current, C_p and in no-load mode. The measured absolute value and the phase and calculated idle input impedance can be comparable by modifying the C_s value in the model parameters. (Figure 2.)

It is very difficult to observe the behaviour the two nonlinear elements in the crossbranch of the transformer and give the value of *L* and R_v in closed mathematical form, because the measured result is correlated by C_s. Here it is worthy of note, that only such measured frequency points are useful which are far from the resonance frequency.

By using the measured data, a definite formula can be written by using three-point matching for the two nonlinear elements over the coordinate plane U_{in} vs. *f*. The two formulas are as follows:

$$L = A_0 f^a u_{in}^b \quad (1)$$

$$G_v = B_0 f^c u_{in}^d \quad (2)$$

where A_0,B_0, a, b, c and d are constants, f: frequency, U_{in}: the primary input voltage.

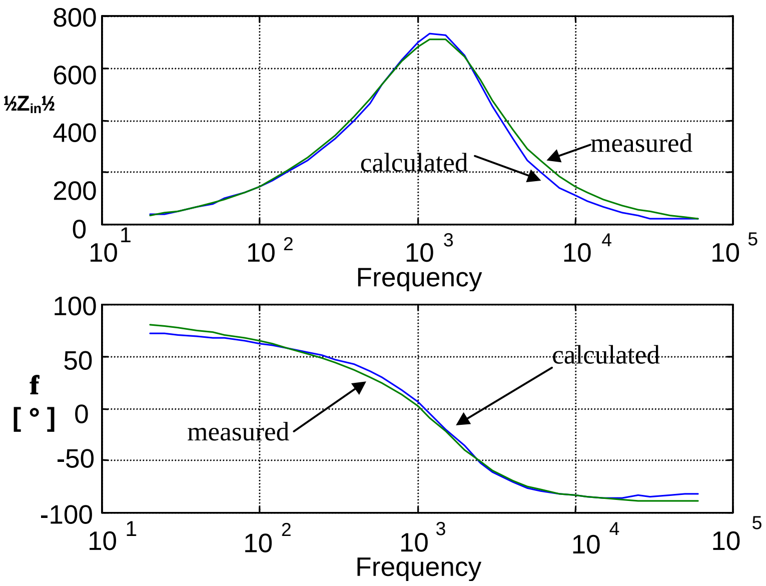

Figure 2. Measured and calculated (with C_s) value of the idle input impedance

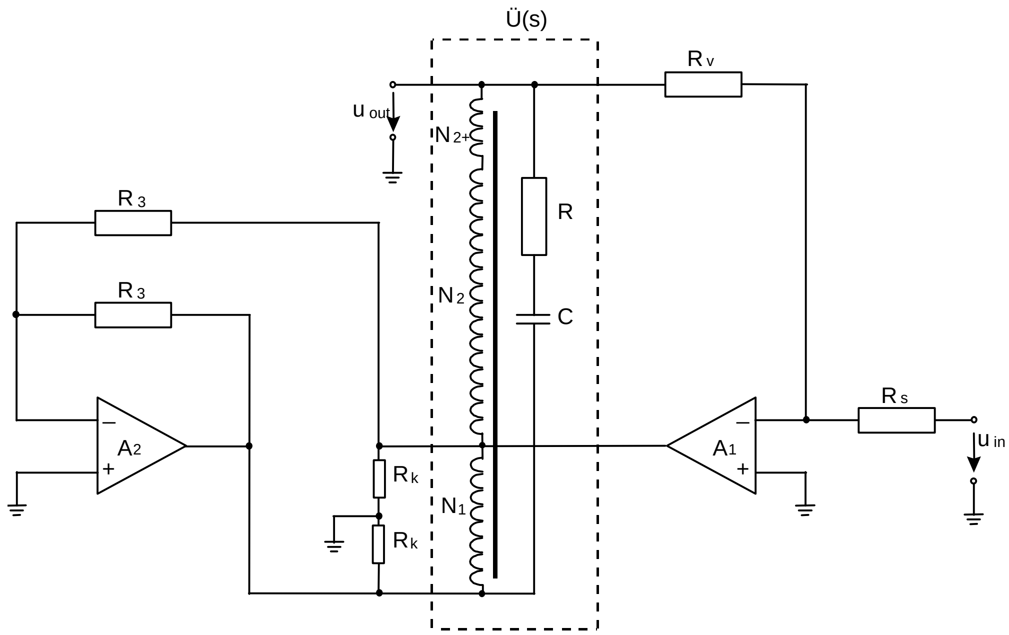

Figure 3. Circuit diagram of the voltage circuit

For reasons of stability, it was reasonable to modify the frequency response of the transformer in order that the amplitude approaches a finite value even in high frequency mode, and, in addition, to make the characteristics independent of the possible uncertainties and changes in the *L1* and *L2* leakage inductances and the C_s stray capacitance. The R_b-C_b network connected in parallel to the transformer forms a shunt circuit to the transformer in the high frequency range, thus enabling the amplitude characteristic to be influenced by using external means. Optimum results were obtained with resistance and capacitance values, which resulted in an accuracy of Ia class in the amplitude characteristic, without any effect in the range of 50 to 60 Hz.

2.2 Signal transfer of the voltage circuit

The circuit diagram of the voltage circuit is shown in Figure 3. The amplifier *A2* repeats the output of amplifier *A1* with phase conversion and, together with the amplifier A1, excites the coil *N1* of the transformer. As a result of supply used, the center tap of coil *N1* is a virtual earthing terminal, the accurate setting of which can be ensured by earthing the connection point between the two identical R_k resistors. The turns ratio of the transformer was defined in the form of *ü=N2/N1*; however, the selection of the two amplifiers and the excitation modifies this ratio in respect of the ground. This is corrected by means of the coil *N2+* (*N2+=N1/2*). The set of amplitude and phase characteristics of the voltage circuit is shown in Figure 4-5. For the purpose of comparison, a curve obtained by calculation using linear elements is also shown. As shown, the frequency difference is significant in the range of low frequencies. The same figure also shows the phase margin that is decisive in respect of stability. The amplitude and phase characteristic of the closed voltage circuit is shown in Figure 6-7.

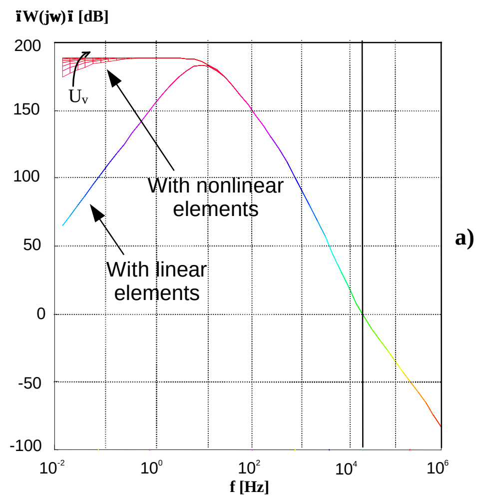

Figure 4. Amplitude characteristics of the voltage circuit

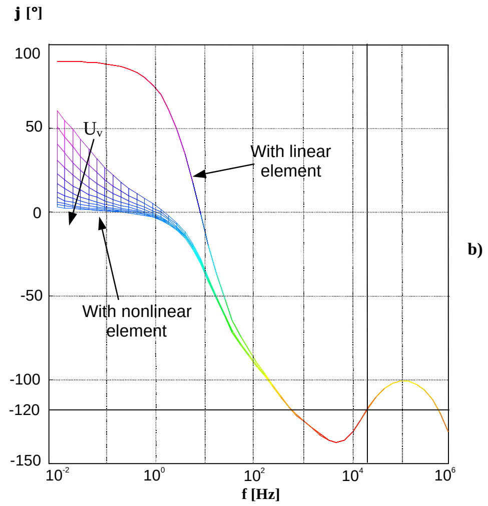

Figure 5. Phase characteristics of the voltage circuit

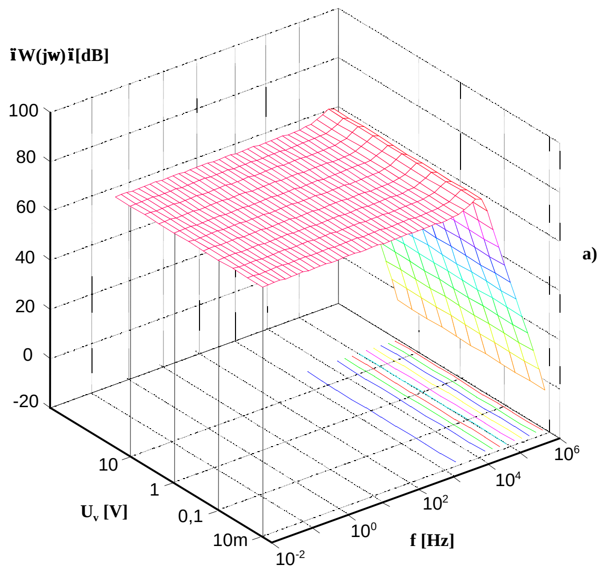

Figure 6. Amplitude characteristic of the closed voltage circuit

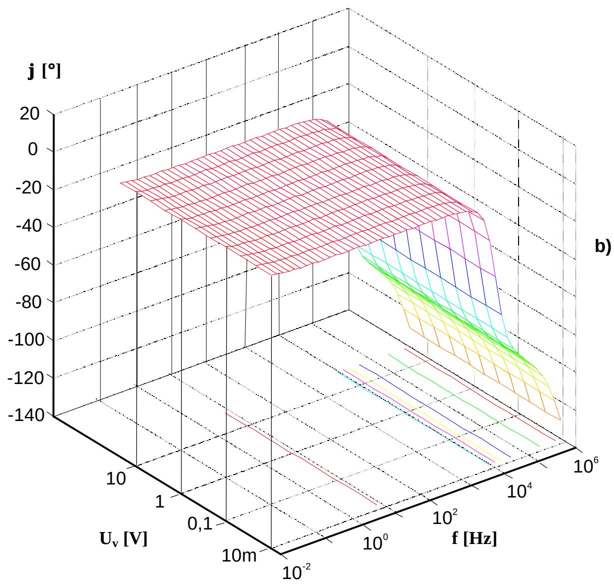

Figure 7. Phase Characteristic of the closed voltage circuit

3 TRANSFER CHARACTERISTICS OF THE CURRENT CIRCUIT

As in the case of voltage circuit, the high power also makes the use of a transformer indispensable. The simplified circuit diagram of the current circuit is shown in Fig. 8. The forward branch includes a summing amplifier, a transformer which forms a voltage/current converter; while the feedback branch includes a standard resistor and a differential amplifier. As a result of the three active components, the description of the dynamic behavior is more difficult as compared to the voltage circuit; each amplifier is fed back in itself; their stability shall be arranged for separately. The block diagram of the current circuit for the calculation of frequence response is shown in Fig. 9.

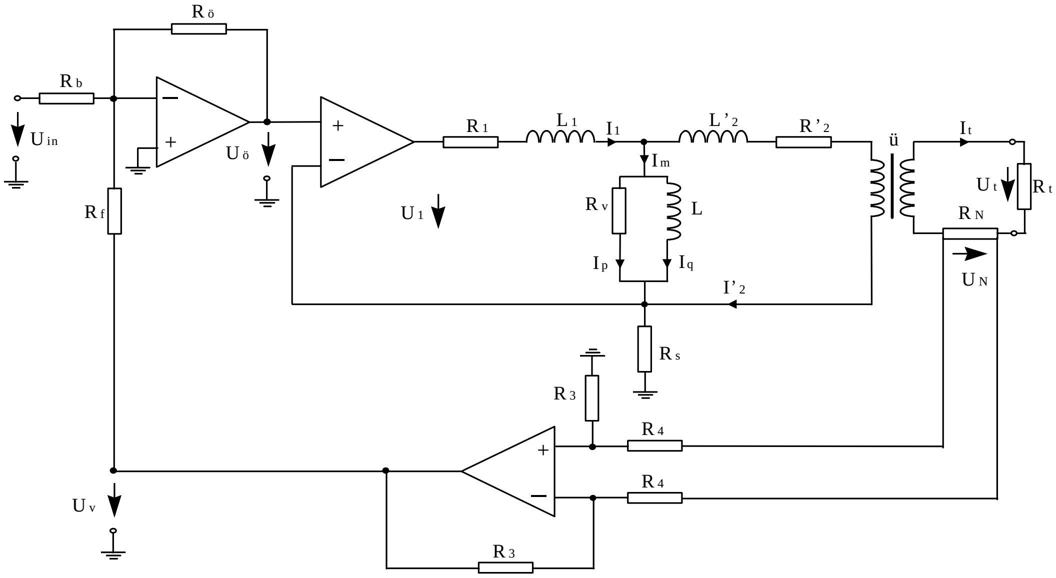

Figure 8. Simplified circuit diagram of the current circuit

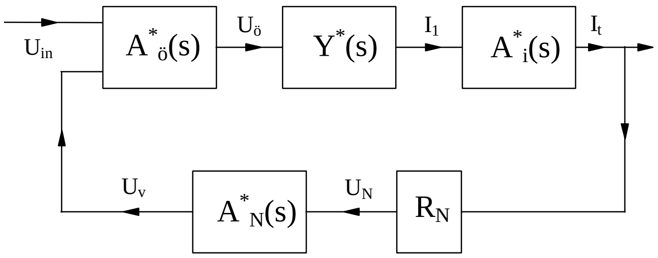

Figure 9. Block diagram of the current circuit

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