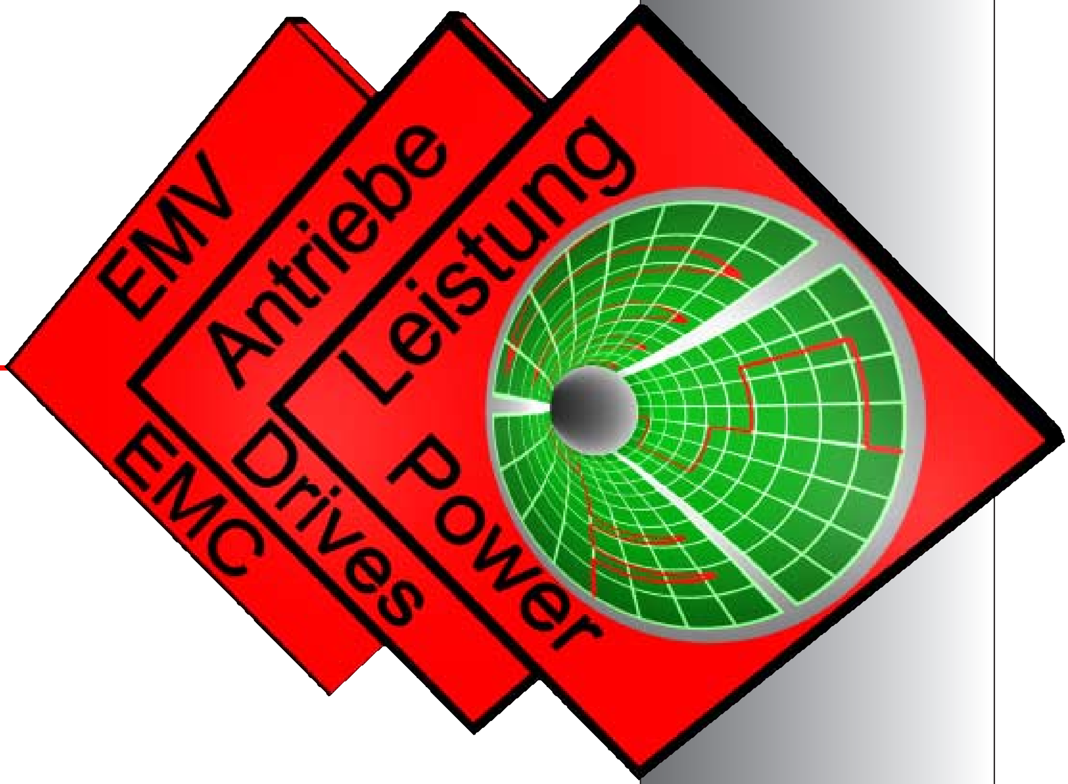
STEINBEIS-TRANSFERZENTRUM
FERTIGUNGSAUTOMATISIERUNG UND EMV
GEISLINGEN



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Demands for Power Measurement at Converters

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Demands for Power Measurement at Converters

by

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1. Abstract :

Independent on their output power, efficiency and other values in relation to energy become more and more important at converters and converter controlled appliances.

As modern semiconductors allow the development of converters with higher switching frequencies, much shorter risetimes, the measurement of values in relation to energy imposes extremely high require-ments on the instrumentation to be used.

Current and Voltage (True RMS), Active Power and Energy have to be measured independent on waveshape with a lot of harmonics and at floating potentials against ground.

To decide, if an instrument gives correct results at such applications, it is not enough to consider the standard specification of accuracy and frequency range only. Other specification, being in the back-ground up to now, must be evaluated.

It is the first target of this paper to explain such important requirements, like good Common Mode Rejection (CMR), or high Voltage-Frequency Product (VHz). Very different signal structures have to be analysed. By this reason a wide range of averaging time is necessary and different sampling methods are requested. Simultaneous measurement of all inputs and extremely low phaseshift between voltage and current input is the more important, the smaller powerfactor becomes.

It is the second target of this paper to show how these requirements are solved in a modern Power Analyzer with up to twelve channels. The completely menu controlled instrument can be configured in an optimal way for the measuring task at the foil keyboard or via interfaces and the very powerful software „POWER WIN“.

2. Floating Potential

In most measuring circuits earth/ground may be chosen as reference point. So it is possible, to connect an electronic instrument with the measuring circuitry in a correct way, the HI-terminal with high potential and the LO-terminal with earth/ground.

The situation at converters is different, nearly every point is floating against ground, that means the LO-input of an instrument has a potential U_c against ground too. This circumstance brings an additional error, named as Common Mode Influence (CMI).

2.1 Common Mode Influence

The Common Mode Influence (CMI) depends on the Common Mode Voltage U_c, its frequency f_c and internal design (C_i) and circuitry of the instrument. A very simplified blockdiagram of an electronic instrument is given in Fig. 1 and explains the reason for the CMI.

An instrument has distributed capacitance’s between electronic ground and housing (C_1), between the windings of transformer in the power supply (C_2) and between housing and ground (C_3). By this reason a current I_c is flowing, which produces a voltage drop on electronic ground and leads finally to an indication of the voltage ΔU_c, although no measuring voltage is applied between HI - LO inputs.

This current can be calculated as

$$I_c = k * U_c * 2\pi * f_c * C_i$$

2.2 Common Mode Rejection

By designing the instrument, C_i can be influenced only, to keep ΔU_c as small as possible, or to reject as much as possible the Common Mode Voltage U_c. This CMR is defined in dB as a logarithmic measure by the following formula :

$$\mathrm{CMR(dB)} = 20 * \lg \frac{\Delta U_c}{U_c}$$

The most successful way to enhance CMR is the Guard -Technology, as given in Fig. 2, shown on the example for current measurement. For current measurement by an electronic instrument always a Shunt is necessary, independent on internal or external construction.

By using such a Guard-Technology, the current I_c is flowing now over the guard against ground, not through electronic ground and does not influence the input voltage between HI and LO.

With this Guard-Technology we reach in our Power Analyzer a CMR of 160 dB (at 1kHz), which is an extremely high and unique value. In the example above, it gives a ΔUc and finally an error ΔU(%) of :

$$\Delta U_c = U_c * 10^{-\frac{dB}{20}} = 300 * 10^{-\frac{160}{20}} = 300 * 10^{-8} = 3 * 10^{-6} = 3\mu V$$

$$\Delta U(\%) = 100 * \frac{3 * 10^{-6}}{100 * 10^{-3}} = 0{,}003\%$$

It must not be forgotten, CMR (in dB) is a logarithmic measure, so CMR = 120 dB brings an additional error of 0,3 % already and it is senseless, to use an instrument which has declared limits of error of ± 0,1 %, if CMR is not at least 140 dB.

3. Current sensing

When measuring current at converters, a wide frequency range not only of voltage and current channel is necessary, also the current sensor has to be applicable for this task. Such a current sensor has to work sufficiently at DC, and from very low frequencies up to some hundred kilocycles.

A good amplitude accuracy is not enough for power measurement, the phase error and timeconstant (risetime) has to be very small, otherwise an additional phaseshift is produced and indicated power is wrong (see Fig. 3).

These specification have more and more influence with increasing frequency and decreasing powerfactor. Finally a small ratio L / R is responsible for lowest phase error in a wide frequency range. When considering a sinus waveshape (because easier to calculate) then the influence of Δφ at different powerfactor is given in Fig. 4.

Depending on the requirements different methods of current sensing may be used, but for each application the user must know what he is doing, advantages and disadvantages have to be weighted against each other.

3.1 Current sensing by Triaxial Shunts

Although it is a relative expensive solution, shunts are the best current sensing units for accurate current and power measurement at converters and LEM Norma has done a lot of development to design special shunts with high bandwidth, low phase error and load influence.

A Shunt with such requirements has to be a nearly ohmic resistance (L = 0 and C = 0). That can be reached only by a coaxial construction, which brings compensation of the electromagnetic field. For reaching a high CMR the guard (G) is implemented and leads finally to a Triaxial Shunt. In Fig. 5 the principle of such a Shunt is given.

Terminals for current and potential are separated (Kelvin principle). HI, LO and Guard are connected directly by a Triaxial plug as shown in Fig. 6 to the current channel of the Power Analyzer (at Plug-On-Shunts) or using a Triaxial cable (at External Shunts).

The resistance element has the shape of a tube, what brings a big surface and together with a special material an extremely low load coefficient of less than 1,5 * 10^{-6} %/A^2. We developed a wide range of shunts, covering all applications in R&D, testfield and maintenance.

Plug-On-Shunts (directly plugged on the current channel have a range of 3 mA .... 100 A, while External Shunts run from 100 A up to 1400 A. Such External Shunts are located near the test object, voltage drop and guard are connected to the current channel with a shielded Triaxial cable. The following Fig. 7 and Fig. 8 show one representative of both constructions.

3.2 Current sensing by Passive Clamps

Passive Clamps or CT´s have a current output of mostly 1 A.. As they do not need auxiliary energy they are called passive clamps. Such clamps are suitable for AC only, their frequency range is limited with approx. 10 Hz .... 10 kHz. With special core material they reach an amplitude accuracy of ± 0,2 % and a phase error of ± 0,3 ° at technical frequencies (50 Hz .... 60 Hz) can be realised. But errors increase rapidly with frequency.

We offer for our Power Analyzer such a clamp with core material of a Ni-Fe-Alloy, which has above relative good specification. This clamp is delivered with an adapter for direct plugging on the current channel and reading without any further calculation. It is a relative cheep solution and mainly used at the mains-side of Converters.

3.3 Current sensing by Active Transducers

During last years relative accurate active transducers, based on the Hall-Effect had been developed, which are particularly suitable at such measurements, when demands to accuracy are not too high. Amplitue accuracy is quite well, but phase shift increases strong with frequency. Mostly the bandwidth is specified and looks first quite well, but -3 dB means an amplitude error of 30 % already and a phase shift of 45 degrees. Their advantage is current measurement without opening the circuit and working also for (AC+DC) signals.

Also clamps working by the Hall-Effect are on the market, but accuracy under these conditions is poor and not always defined, because of the airgap.

To find out the very big differences between the three sensing methods we made measurements and the results are given in Fig. 9, measured at a powerfactor 0,1.

4. Voltage - Frequency - Product

When an input signal has short rise times (like a PWM signal of a converter) and a higher voltage, than voltage and frequency can not be considered seperately. The voltage divider of the input circuitry is a network consisting of resistance’s and capacitors for linearisation, as shown in principle at Fig. 10.

Capacitor C_1 its the most loaded, because it is parallel to the highohmic part of the divider. Current I_1 is proportional to frequency and voltage, but is limited by its construction.

That means, the Voltage-Frequency-Product is a constant value (e.g. 1 * 10^8 VHz) and has to be specified in the datasheet of such an instrument. When Input Voltage is drawn in a diagram (depending on frequency), we receive a symmetrical hyperbolic curve, giving information, which maximal voltage at which frequency is allowed to apply. Such an interdependence is given in Fig. 11.

If square waves with short risetimes have to be measured, an equivalent frequency may be calculated, as given an example in Fig. 12.

5. Linearity

A high linearity in frequency and amplitude of the measuring channels is requested. Big influence to this demand has the high-ohmic part of the voltage divider in the input circuitry. High quality components (resistors, capacitors) have to be used.

By a special construction we reach these requirements, together with long time stability, responsible for a very long recalibration cycle of 24 months (2 years !) we confirm our customers. This construction with its exactly defined dimensions is shown in Fig. 13.

The resistance is a special Metalfilm resistor (2 Watt, 4,47 kV) with very small Temperature coefficient (< 5 ppm/K), lowest Voltage coefficient (< 0,1 ppm/V) and extremely low long-time drift (< 50 ppm/year). The capacitor C is a gas capacitor for 8,6 kV and 2 pF, very stable with lowest drift and frequency influence.

6. Digital Signal Processing

The digital Signal Processing in such a Power Analyzer has to follow also some higher demands as in most cases usual, otherwise results become irregular. Some of the most important points to be considered, are the following.

6.1 Simultaneous Measurement

In a modern electronic Power Analyzer the active power has to be calculated in a digital way by using the general definition as energy per time unit. The older classic definition P = U * I * cos phi is valid only for signals with sinus waveshape and not applicable at converters. The definition of active Power in W is energy (Ws) per time unit (s) and is written as in the expression below. To calculate active Power, three procedures have to be done, sampling voltage and current, multiplying them and averaging

$$P = \frac{1}{T} * \int_0^T u_{(t)} * i_{(t)}\, dt$$

That means finally, each quantity u(t) and i(t) has to be sampled strictly at same time t, no analog or digital time shift must be produced. A good Power Analyzer should have not more than 5 m° analog phase shift and each quantity has to be scanned in a synchronised way, no multiplexing must be done. Of course, it is more expensive when each channel has its own (and synchronised) A/D - Converter, but the only way to avoid irregular results.

6.2 Sampling

Output signals of a converter are instationary signals, all characteristic values (waveshape, frequency, spectrum) are changing more or less. Such a Power Analyzer should be able to change the sampling method, depending on the signals structure. The user may select between three methods, the adaptive sampling, the synchronised sampling and the sampling with fixed frequency.

Adaptive Sampling does not operate with a fixed frequency, frequency is adapted to the signal frequency in such a way, that (together with automatic averaging) the optimal way between measuring time and stability on display is reached. That means an averaging time of approx. 5 .... 8 signal periods is selected automatically. This method is set as a default method, because 90 % of all applications can be covered by this method. In this case a batch detector finds out, when sampling frequency becomes multiples of signal fundamental frequency, in this case sampling frequency has to be wobbled away.

Synchrony Sampling gives better results for short averaging intervals, because a synchronised interval allows even to average over one period only. No truncation error occurs, when multiples of signal periods are averaged. And this method is absolutely necessary, when Harmonic Analysis by Digital Fourier-Transformation (DFT) is done.

Fixed frequency sampling is mainly used, when sampled values shall be stored in the internal memory for receiving an equidistant time scale. In that case, sampling frequency is selected directly in kHz.

6.3 Averaging

Averaging is a central point at each measuring method, it does not matter, if it is an analog or digital method. And a general answer, valid in every case cannot be given. It depends on the application and what is requested to be seen during the measurement. Short averaging intervals bring unstable display, showing every change of the input signals. Long averaging intervals bring a stable display, but short peaks in the result are averaged too and might lead to wrong conclusions about the structure of the signals.

So we realised two levels of averaging intervals, a short one (called average A), and a longer one (called average B) which are selectable multiples of average A. Both of them can be displayed. In our Power Analyzer we realised averaging intervals from 20 ms up to 47 hours. This wide range covers all application, from detecting short time peaks, up to long-time measurements, like thermal capabilities.

7. Practical Measurements

A very comfortable system for complete testing of a convertercontrolled drive is shown in Fig. 14. It works with a 12-Channel-Analyzer, which has additional inputs for measuring torque and speed on the shaft of the motor. Simultaneous measurement has increasing importance the more channels are in operation, as results of such convertercontrolled drives are never stable.

All important components of such a drive can be tested exactly. With the wiring in Fig. 14 the total efficiency is calculated as well as partial efficiences of rectifier, inverter and motor. As ranges and coupling modes can be selected different in each channel, also exact measurements in the DC-circuitry can be done. Different interfaces and Software packages are available for full automatically test runs in production control.

One further circumstance has to be pointed out, when talking about the circuitry in Fig. 14. Power Measurement at the output of a Converter never should be done by Two-Wattmeter-Method. Although we have no Neutral (Threephase-Threewire-System), the condition for Two-Wattmeter-Method $\sum I = 0$ is not filled, because of the higher frequencies and distroyed capacitance’s a current is flowing through earth. Measurement at the input of a converter can be done by this method, as there is only mains frequency with limited harmonics.

A similar wiring for such a 12-Channel-Analyzer is used in many R&D departments of famous car manufacturers which are developing E-Mobiles. It is easy to understand, highest accuracy is requested in this case, as these companies are fighting for each 0,1 % more in efficiency, to increase the running time of such a car, before recharging its batteries.

As it was requested, we realised separately integration of active power to display +Wh and -Wh. So energy consumption during acceleration and energy generation during slow down can be displayed.

8. Summary

It was the target of this paper, to explain the very heavy demands for measurement of power and other deviated quantities at converters and to give hints, which specification have to be considered, when selecting an instrument for this purpose. The very important points of the analog signal pre-processing have been described.

9. Figures

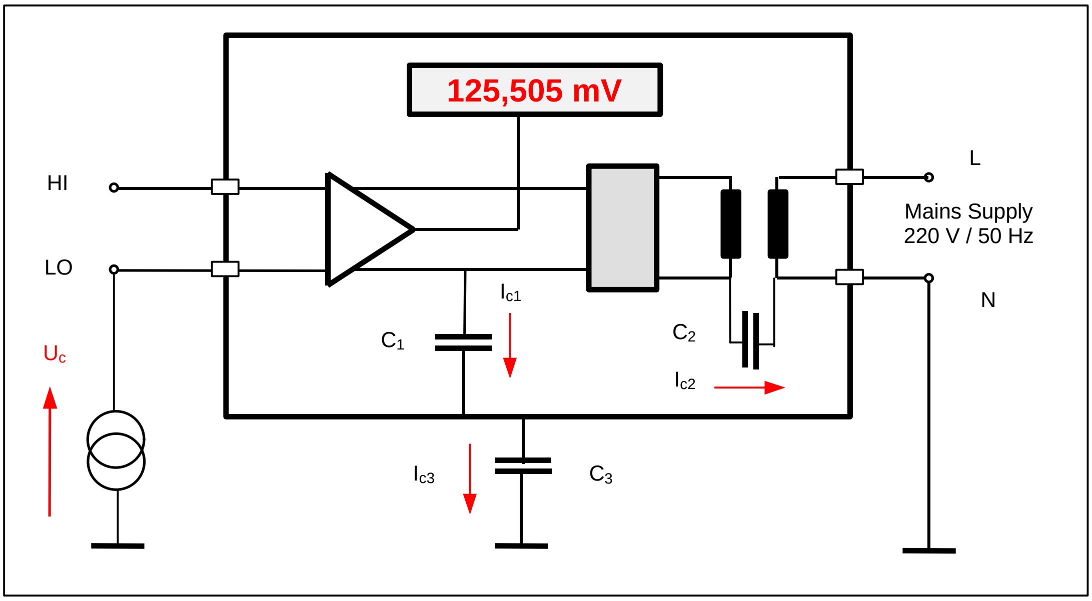

Fig. 1 : Reason for Common Mode-Influence

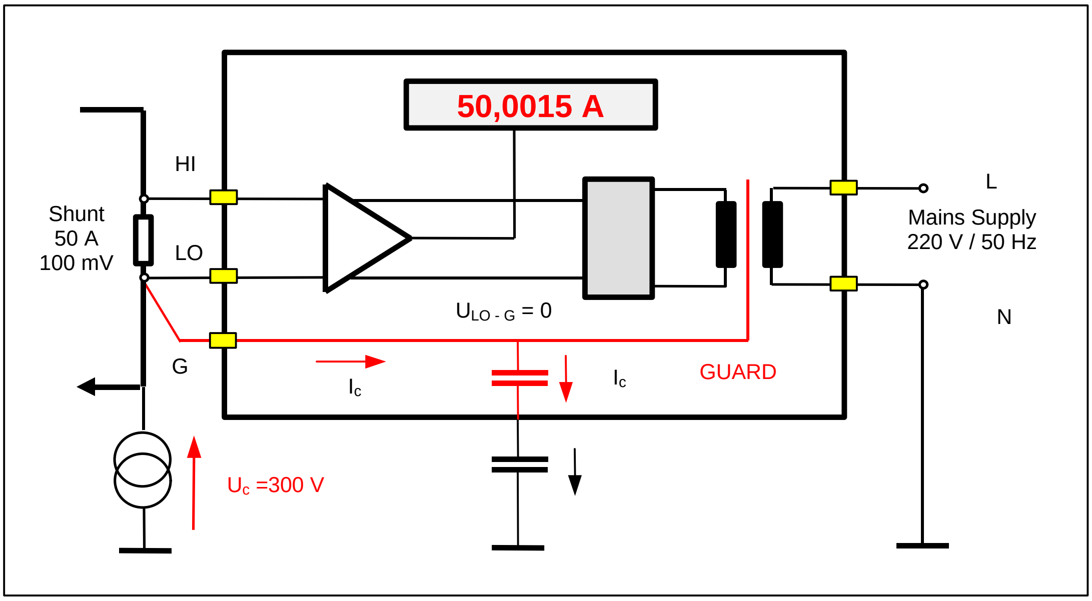

Fig. 2 : Enhancement of CMR by Guard Technology

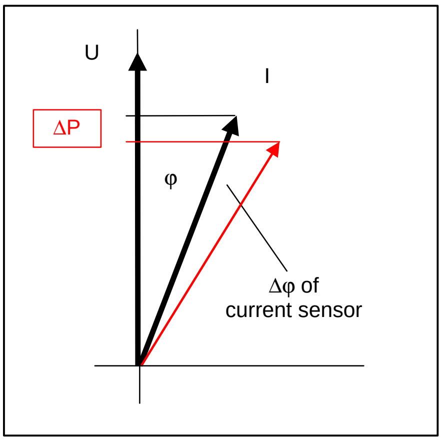

Fig. 3 : Vectordiagram with Delta Phi of a Sensor

Influence of Delta Phi from a Sensor :					
Delta Phi of Sensor (°) :	0,2				
Cos Phi :	1,00	0,50	0,20	0,10	0,05
Error in % of rdg.:	0,001	0,605	1,711	3,474	6,973

Fig. 4 : Influence of a Sensor´s Delta Phi

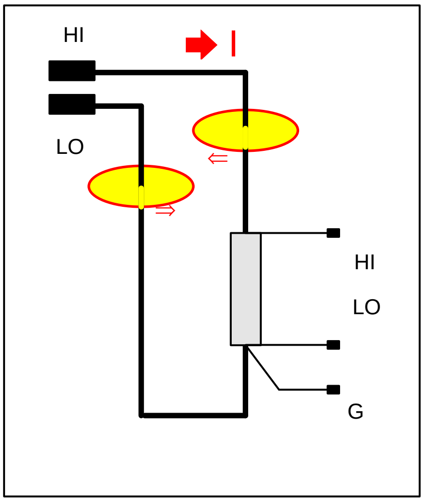

Fig. 5 : Principle of a Triaxial Shunt

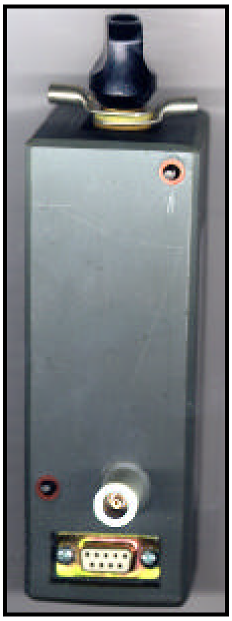

Fig. 6 : Plug-On Shunt with Triaxial Plug

Fig. 7 : External Shunt 100 A / 30 mV

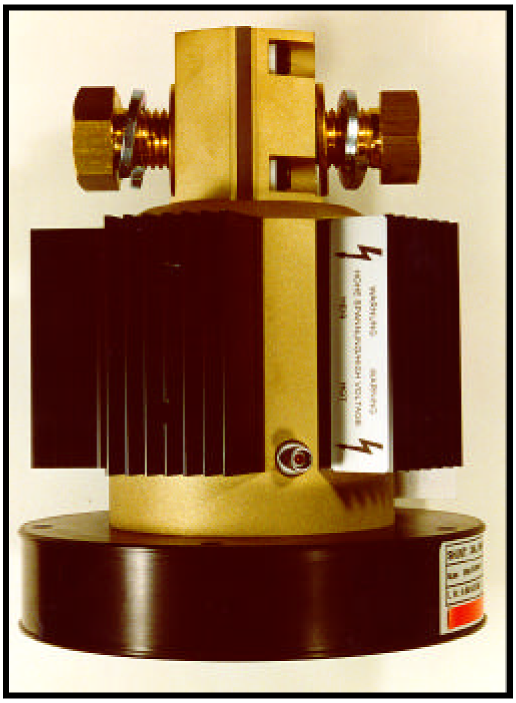

Fig. 8 : High-Current Shunt 1500 A / 20 mV

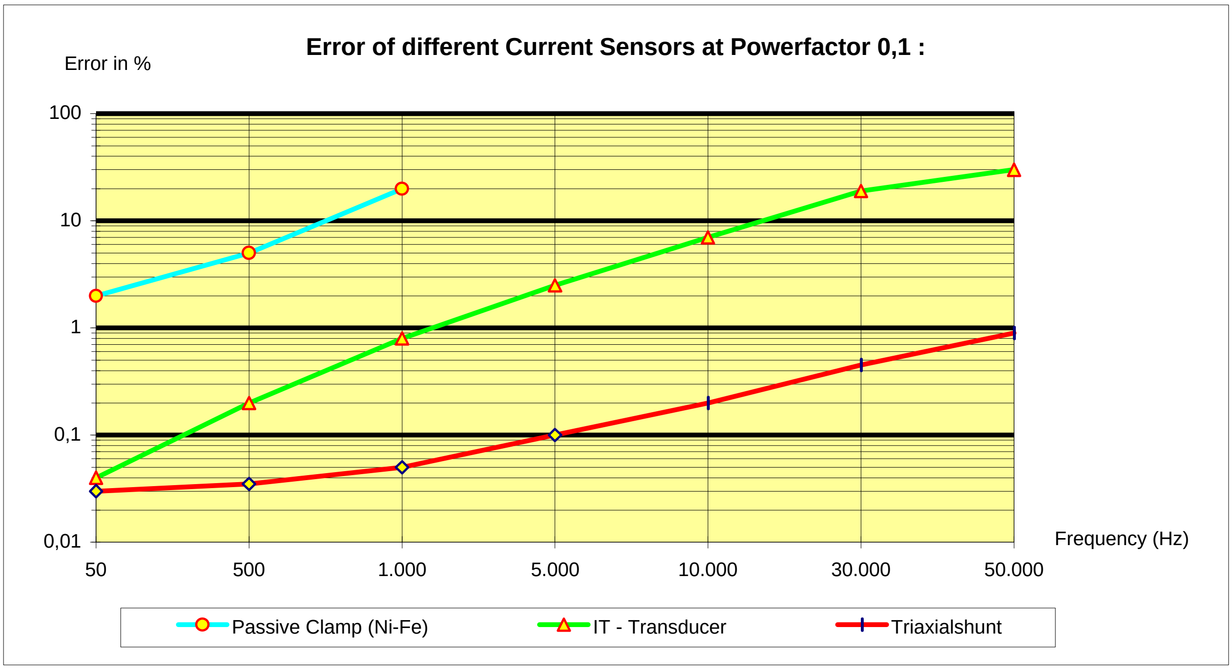

Fig 9 : Errors of different Sensors at Powerfactor 0,1

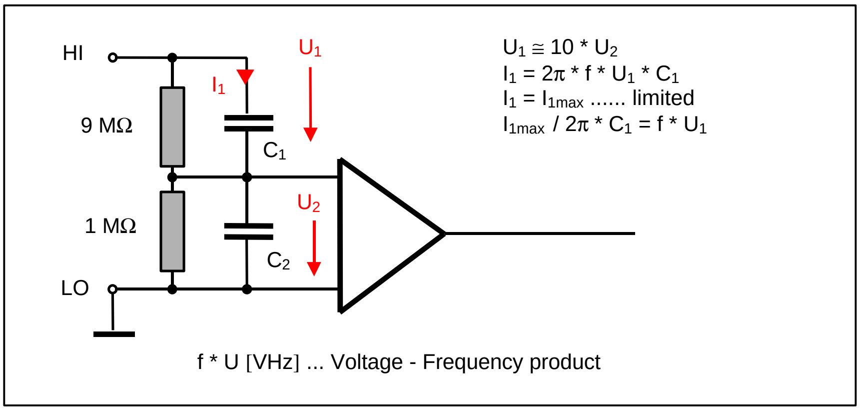

Fig. 10 : Diagram of an Input Circuit

Fehler! Keine gültige Verknüpfung.

Fig. 11 : Interdependence of Frequency and Input Voltage

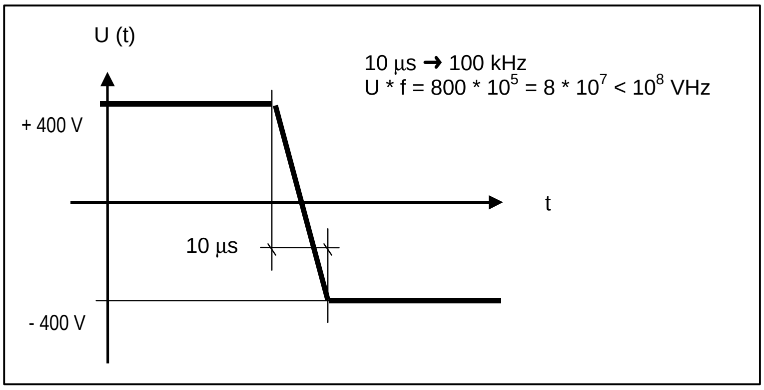

Fig. 12 : Risetime and Voltage - Frequency Product

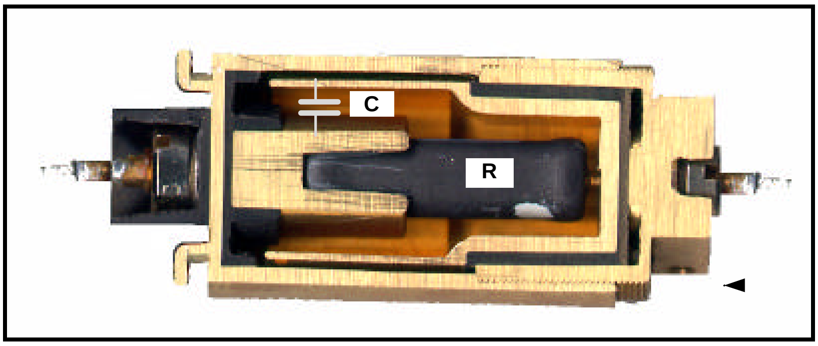

Fig. 13 : High Quality Voltage Divider

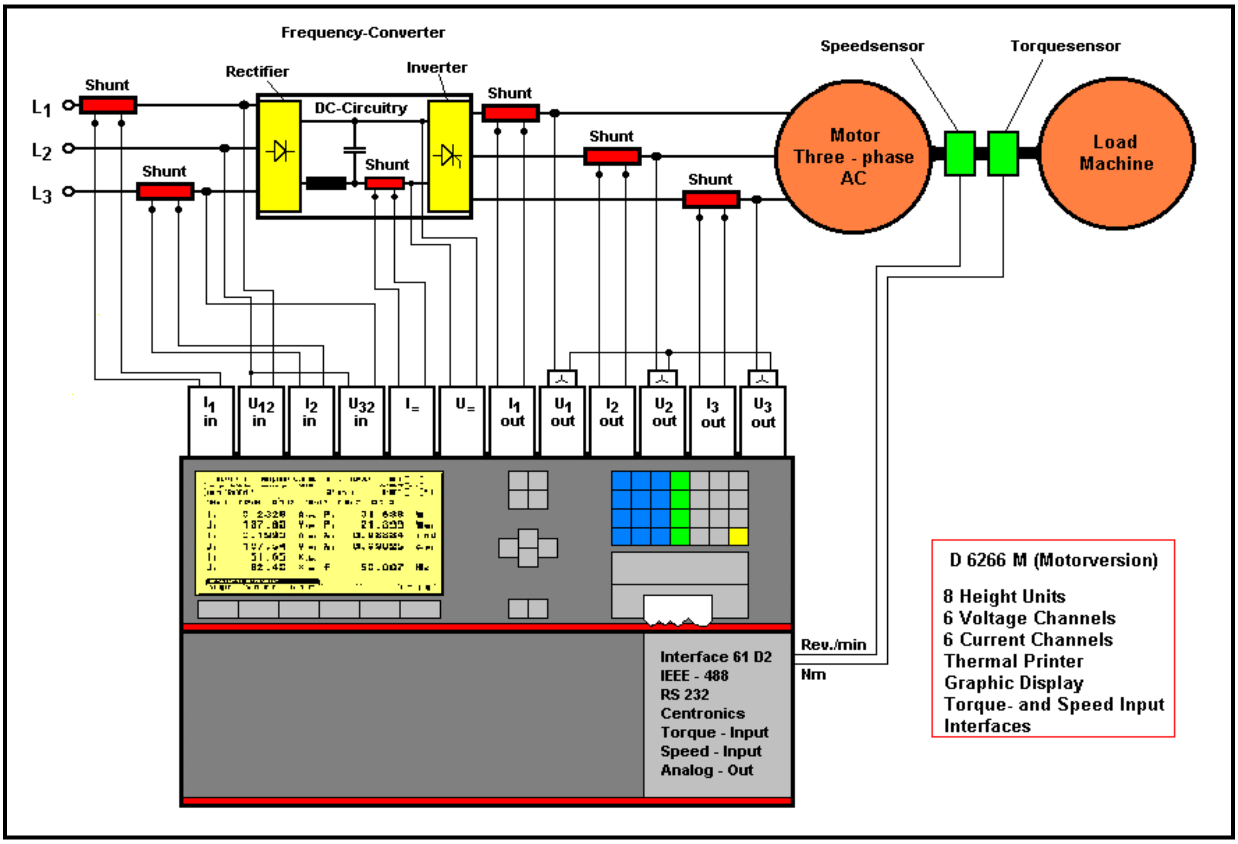

Fig. 14 : Testing a complete converter controlled drive