ADAPTIVE CURRENT MEASURING CIRCUIT FOR ELECTRIC POWER METERS

Žarko ČUČEJ, Tomaž ROMIH and Jože MOHORKO
University of Maribor, Faculty of electrical engineering and computer science, Maribor, Slovenia

Keywords: physics, electrotechnics, electric power measurement, electric power meters, measuring circuits, Hall sensors, Hall generators, electric current sensors, accuracy classes, measuring ranges, dynamic ranges, accuracy assurance

Abstract: This article presents the current measuring circuit for usage in power meters. The circuit provides a measurement class in a dynamic range over 120 dB with the use of the standard analog-to-digital and digital-to-analog devices. This large dynamic range is achieved with the appropriate setting of the excitation current of the Hall sensor. Experimental results show that the proposed measuring circuit exceeds the requirements for accuracy and the dynamics that are defined by the IEC687 standard.

Adaptiven tokovni merilnik za števce električne moči

Ključne besede: fizika, elektrotehnika, merjenje moči električne, merilniki moči električne, vezja merilna, Hall senzorji, Hall generatorji, senzorji toka električnega, razredi točnosti, območja merilna, območja dinamična, zagotavljanje točnosti

Povzetek: V članku je predstavljen tokovni merilnik za uporabo v števcih električne enrgije. Merilnik zagotavlja merilni razred v dinamičnem obsegu več kot 120 dB z uporabo standardnih analogno-digitalnih pretvornikov. Tako veliko dinamiko dosega z primerno nastavitvijo vzbujalnega toka Hall-ovega senzorja. Eksperimentalni rezultati kažejo, da predlagan merilnik presega zahteve po natančnosti in dinamiki, podane v standardu IEC687.

1 Introduction

Besides the accuracy in the dynamic range over 100 dB, modern power meters are also expected to measure the power in harmonic components. Only digital instruments can manage this. In the measurement of the flow of energy through the network, the change in the voltage amplitude is relatively small. The specified working range for an instrument in the class 0.2, defined by the standard IEC687, is 10% of the reference voltage, but the changes in the current are larger. According to the standard IEC687, an instrument in the class 0.2 must measure power for currents from 0.1% of the nominal current to 120%. Digital instruments for this amplitude range must have at least 20 bits of AD conversion to achieve the measurement range and to provide the declared class of the instrument for the whole measurement range. In that case, the dynamic of the AD converter is 120.4 dB. Because the high resolution AD converters that work on the sigma-delta principle usually have a SNR relation worse than its dynamic, it is necessary to take AD converters with a higher bit resolution. Again, they do not have such attractive prices and the instruments can not be competitive on the market. The natural solution to this problem is the introduction of current sensors with changeable sensitivity. This can be achieved in two ways:

- with the use of fast PGA circuits, for which the gain is based on the measurement strategy,
- with the use of Hall sensors, for which the gain is set according to the excitation current.

In this article the new adaptive current measuring circuit for electric power meters with a Hall sensor is described. Its gain is set according to the amplitude of the measured current to ensure the accuracy class of the measuring circuit. The circuit measures currents of all shapes in a wide measurement range. The setting is formed digitally in the back-loop of the measuring range regulator. That way the measuring circuit reduces the dynamic of the measured values and achieves the ordered accuracy with fewer bits of the AD converter. It is useful in measuring electric power and energy, and in all measuring instruments which measure the electric current with ordered accuracy in a wide measuring range and galvanic separation of the measuring circuit from the measuring current.

The article is divided into five chapters. The introduction is in the first chapter, the summary on the power measuring circuit and Hall sensors follows in the second chapter, and the third chapter describes the measuring circuit. The results of testing the measuring circuit prototype are shown in chapter four and the conclusion is in chapter five.

2 Measurement of electric power and use of the Hall sensors

Electric power meters use current transformers, shunt resistors or Hall sensors to measure current. Because of its many beneficial properties, the use of the Hall sensors is very wide-ranging. The electric power meter MT300 from the manufacturer Iskra Emeco is very similar. The measuring circuit contains a Hall sensor integrated with the circuit for power calculation into the monolithic circuit; that way, better resistance to the climatic influence is achieved. The measuring circuit meets the international recommendation IEC1036 for class 1 and 2 of the electric power meters. The accuracy of the electric power measuring circuit also depends on the frequencies of the voltage and current. Thus the standard IEC1036 defines the standard reference frequency of the voltage, current and the permitted deviation of 5%, within which the measuring circuit must meet the demands for accuracy. In definite cases, electric power must be measured in a wider frequency band and with larger dynamics (from 3mW to the 1.5kW) [1,2]. Those demands are fulfilled most easily by the use of the Hall sensors [3].

3 Current measuring circuit with Hall sensor

New technology makes it possible to build adaptive current measuring circuits, which are capable of accommodating the measuring range for the flow of the measured signal. From that the amplitude dynamic is enlarged. In [4] is described the solution of the adaptive measuring circuit that uses the model of the measured system to predict the input of the sensor from the known input of the measured system. Calculation of the model requires high calculating power, therefore an efficient digital signal processor is required. A simpler solution is to change the gain of the sensor by setting the excitation current (some measuring circuits for electric power measurement use this current to directly measure power). In [4] the use of the excitation current for this purpose is omitted because of the increased influence of the noise in smaller gains. However, the new technology of the Hall sensors makes it possible to reduce the influence of the noise and offset voltage [5,6] so that this solution is promising again.

3.1 How the Hall sensor works

The principle of how the Hall sensor works is generally known, therefore the only properties that are summarized are those that are used in the proposed measuring circuit.

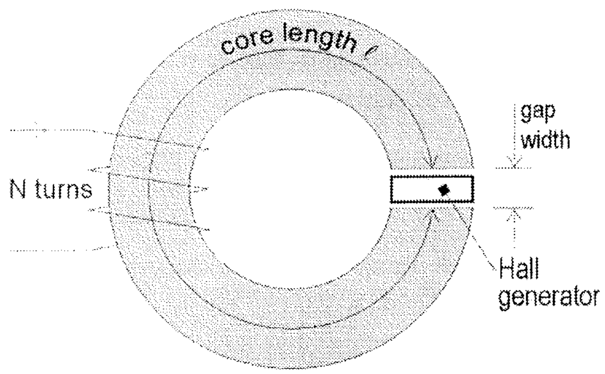

Fig. 1: Principle of current measurement using the Hall sensor

It is a known fact that around the current conductor the magnetic field is formed. If the magnetic field is concentrated in the magnetic core, then the Hall sensor can be put into the core gap, as shown in the Fig. 1.

Voltage on the output connection of the Hall sensor is defined by (1),

$$U(I_m, I_v) = k_h \cdot I_v \cdot I_m \quad (1)$$

where I_m is the measured current, I_v is the excitation current and k_h is the constant. The factor $k_h\, I_v$ can be used as the changeable gain of the sensor, (2) and (3):

$$A(I_v) = k_h \cdot I_v \quad (2)$$

and

$$U(I_m, I_v) = A(I_v) \cdot I_m \quad (3)$$

$A(I_v)$ is the slope of the straight line on which the output voltage of the Hall sensor moves in relation to the measured current I_m. That is the basis of the how the proposed current sensor works. The value of the measured current I_m is determined by the division of the Hall sensor output voltage with the chosen gain. Statical characteristics of the Hall sensor voltage U in relation to the gain $A(I_v)$ and dependence of the gain $A(I_v)$ on the excitation current I_v are shown in the Fig.2. Fig.2 illustrates the ideal course of the characteristics. In the real Hall sensor, the offset voltage must be considered. The offset voltage depends on the sensor temperature and the amplitude of the excitation current.

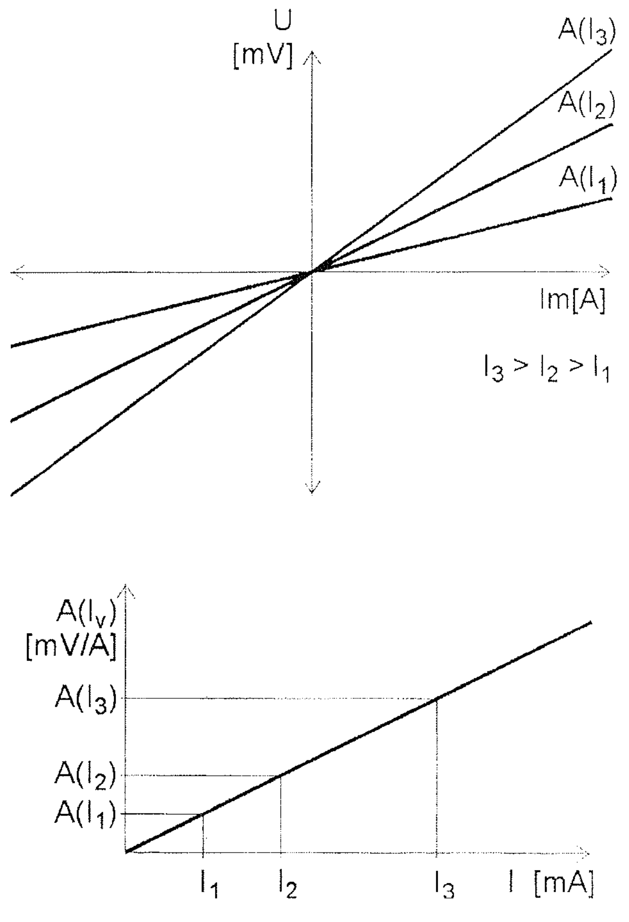

Fig. 2: Static characteristics of the Hall

3.2 Design of the measuring circuit

The project block scheme of the proposed measuring circuit is shown in Fig. 3.

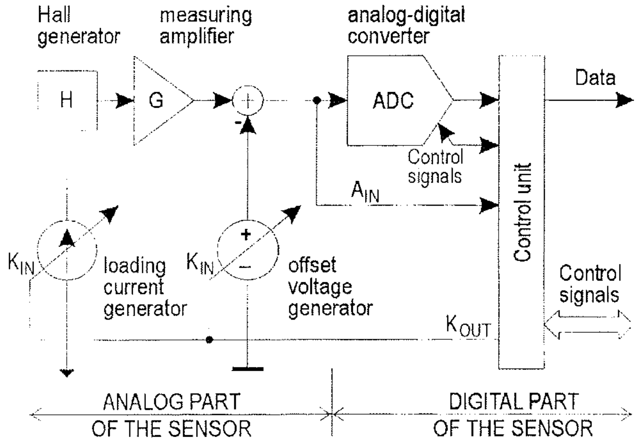

Fig. 3: Block scheme of the adaptive current measuring circuit with the Hall sensor

The temperature compensated current generator, driven by the voltage, excites the Hall sensor. Using the current, the gain of the Hall sensor is set. The output of the Hall sensor is connected to the measuring amplifier, and the offset voltage is subtracted from the amplifier. The resulting signal is then converted with an AD converter. The measured data is then corrected in the control unit to remove the influence of the changeable gain of the Hall sensor. Therefore the measured data is multiplied by the gain of the Hall sensor. If the gain is set in steps by a factor of 2^n, then the multiplication is simplified into a simple bit shift of the measuring result by *n* bits in the direction of the most significant bit. That way the building of the control unit is simplified a lot and is suitable for integration into the programmable unit. The control unit also takes care of settings of the Hall sensor's gain with appended hysteresis, so that uncontrollable switching between the measuring ranges is prevented. The resulting static characteristics are shown in Fig. 4.

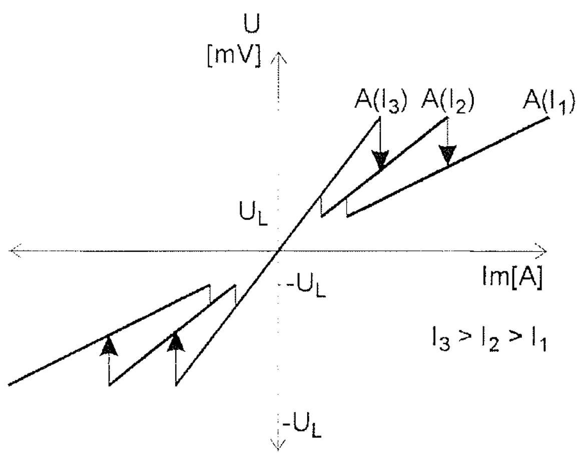

Fig. 4: Results of the static characteristics of the adaptive current measuring circuit with the Hall sensor

4 Measurements and testing

Measurements were made on the analog part of the sensor, as shown in Fig. 5.

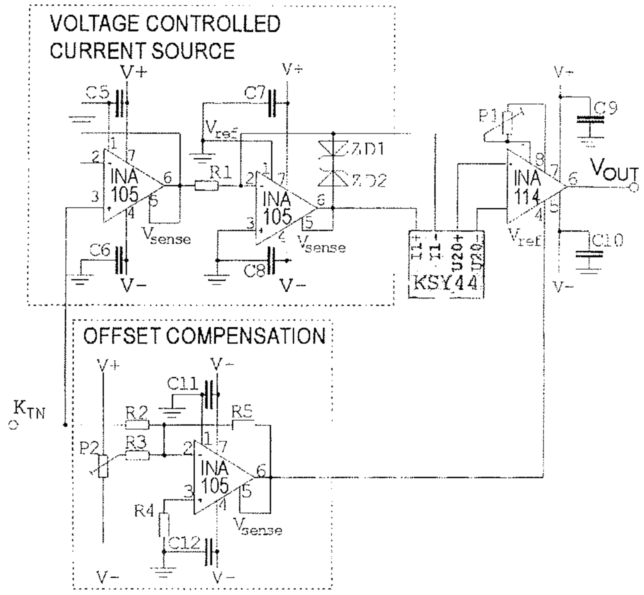

Fig. 5: Analog part of the sensor

The Siemens KSY44 Hall sensor was used. In Fig. 6 the static characteristics of the differential Hall voltages for different gains of the Hall sensor are shown. The gain was set for excitation currents from 4 to 9 mA.

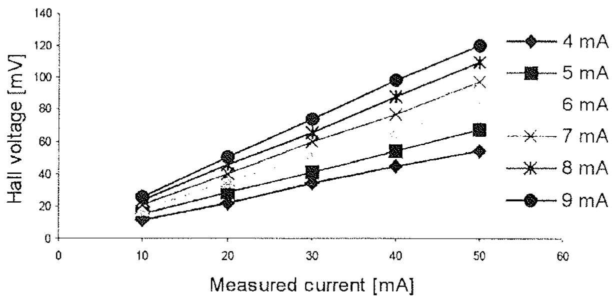

Fig. 6: The static characteristics of the differential Hall voltages for different gains of the Hall sensor

Compensation of the offset voltage can be done with an electronic circuit, however it is better to record the course of the offset voltage in relation to the excitation current of the sensor and the temperature of the sensor, and then store it into the memory. The measured course of the offset voltage at a constant temperature is shown in Fig. 7.

Fig. 8 shows the measured statical characteristic of the sensor with the adaptation of the gain.

For example, there are 5 measuring ranges shown for currents measured from 1 mA to 64 mA. The output voltage of the analog part of the measuring circuit moves in the range from 1 to 7 V. In the case of the ordinary

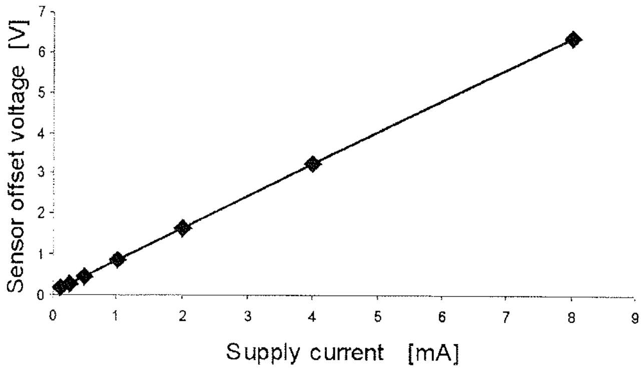

Fig. 7: Measured course of the offset voltage at a constant temperature

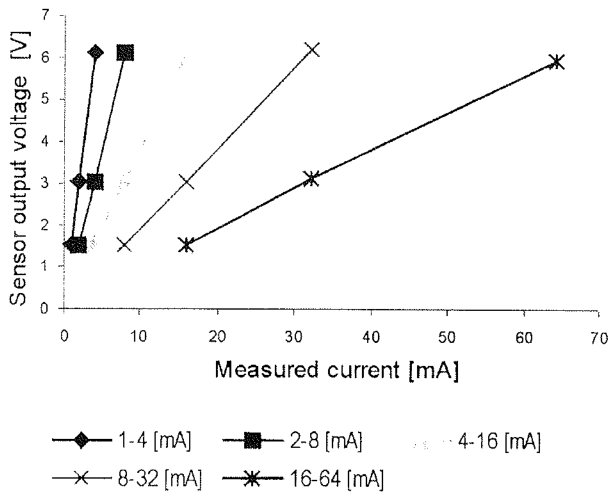

Fig. 8: The measured statical characteristic of the sensor with the adaptation of the gain}

sensor, to achieve the measuring class 0.2, defined by the standard IEC687, a 15 bit AD converter must be used for the range measuring from 1 mA to 64 mA. In the case of the proposed adaptive sensor, only a 12 bit AD converter is required to achieve the measuring class 0.2 by the standard IEC687. The input measuring range of the AD converter is 1 to 7 V. 5 measuring ranges of the sensor are described with 3 bits of the DA converter. Thus there are still 3 additional measuring ranges that can be used to widen the measuring range of the measuring circuit without any change in its measuring class or that of the AD converter. Together there are 15 bits required to describe the measured signal inside the margin of error allowed for a class 0.2 measuring circuit.

5 Conclusion

In this article the current measuring circuit for the use in electric power meters is represented. The current measuring circuit uses a Hall sensor and exploits its properties to dynamically engage the measuring range. With this, it is possible to replace the high resolution and expensive AD converter with the standard, and therefore cheaper, AD and DA converter. In the case of the ordinary sensor, the AD converter must provide enough bits to satisfy the accuracy demands in the entire range of the measured signal. This means that at higher amplitudes of the measured signal there are less significant bits that are not necessary for that measuring range, and at low amplitudes we find the most significant bits which are not used for the measurement. In the case of the proposed adaptive current measuring circuit, this is avoided by the use of the changeable gain of the Hall sensor, so that AD converter must provide enough bits to satisfy the accuracy demands only inside the output range of the measuring circuit. By doing so, the needed bits for the AD converter are reduced. Measurements on the completed prototype of the measuring circuit have shown that the circuit is capable of satisfying all demands for accuracy in a wider current range, as the standard IEC687 requires.

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Dr. žarko Čučej,
Tomaž Romih, univ. dipl. ing.,
Mag. Jože Mohorko,
University of Maribor,
Faculty of electrical engineering
and computer science,
Smetanova 17,
Slovenia,
tel.: (02) 220 71 20
fax.: (02) 25 11 178
zarko.cucej@uni-mb.si
tomaz.romih@uni-mb.si,
mohorko@uni-mb.si

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