AC Current Transducer as an Element of the Electrical Energy Consumption Control System

Viša Tasić[1], Marijana Pavlov-Kagadejev[2], Radoš Jeremijić[3], Vladimir Despotović[4], Olivera Tasić[5], Ivana Stojković[6]

Abstract – **A paper presents the elements of the realized AC current transducer which solves the problem of converting the input signal (AC current) into a DC voltage signal suitable for further processing in the distributed control system. Such devices are heavily applied in distributed control systems for controlling the electricity consumption, for monitoring of industrial processes, as feedback elements, in telemetry and etc. The proposed AC current transducer is further connected to Arduino microcontroller to form a basic unit of the distributed control system for the control of electrical energy consumption in households.**

Keywords – **AC current, transducer, electricity, consumption**

I. INTRODUCTION

The principle of measuring electrical current by digital instruments is based on voltage measurement. The measured current passes through a resistor of known electrical resistance. By measuring the voltage at the ends of the resistors, the measured current is indirectly determined [1].

AC current converters and transducers are necessary elements in the realization of the Distributed Control System (DCS) because the control and management of the electrical energy consumption requires continuous measurement of electricity/energy in real time [2]. DCS systems accept standard current and voltage signals (4-20 mA, 0-5 V DC) at their input. For this reason, it is necessary to adjust/convert all input signals to a format suitable for further processing in DCS system.

AC current transducers have wide application in DCS systems for controlling electrical energy consumption, for monitoring of technical processes, as feedback elements, in telemetry and etc. The choice of the appropriate transducer depends on a number of factors, such as: measuring range, accuracy of the measurement, commercial and other conditions. AC current transducers mainly represent a combination of current transformer, precision rectifier, and stage for adapting the output signal level (0-20 mA, 4-20 mA, 0-5 V DC or 0-10 V DC). The following examples indicate that there is a need for this type of device on the market.

The CRT4100AC [3] is designed to measure AC currents in the range 0-150 A, with galvanic isolation of the primary circuit. These devices can be ordered with the desired current or voltage output: 4-20 mA, 0-5V DC or 0-10V DC.

The Swiss company, LEM manufactures, produces AC Current Transducer AP-B10 for measuring AC currents in the range 0-400 A, with galvanic isolation of the primary circuit [4]. The output range can be selected either 0-5V DC or 0-10V DC. YHDC Company manufactures AC current transducers (ACT series) that contain a current transformer and electronics for conditioning of signals in one device [5]. The ACT devices can be made for input AC currents in the range 0-2 A up to the range 0-2000 A. Output signal can be DC current 4-20 mA or DC voltage 0-10 V. The Indian company, Adept Fluidyne, has developed Adept AC Current Transducer 2010 [6]. The output DC signal is proportional to the input AC current and is calibrated to the RMS value.

In the Republic of Serbia, the Company MINEL AUTOMATIKA A.D. Belgrade has developed MPI/L device for measuring the AC current (AC input 0-1 A or 0-5 A, output 0-20 mA or 0-10V) [7].

II. AC CURRENT TRANSDUCER HARDWARE

A. General Characteristics of AC Current Transducer

The realized AC current transducer is primarily intended for measuring AC current in the range 0-10 A, at the frequency 50-60 Hz. If necessary the range of the input AC current can be expanded to 0-50 A, with the appropriate transformer installed in transducer. The input AC current inside the transducer is transformed into a DC voltage 0-5 V signal, which is galvanically separated from the input signal. The wiring diagram of the proposed AC current transducer is shown in Fig 1.

[1] Viša Tasić is with the Mining and Metallurgy Institute Bor, Department of Science, Zeleni bulevar 35, 19210 Bor, Serbia, e-mail: visa.tasic@irmbor.co.rs,

[2] Marijana Pavlov-Kagadejev is with the Mining and Metallurgy Institute Bor, Department of Industrial Informatics, Zeleni bulevar 35, 19210 Bor, Serbia, e-mail: marijana.pavlov@irmbor.co.rs,

[3] Radoš Jeremijić is with the Dielectric DOO, Dr Milovanovića 15, 19210 Bor, Serbia, e-mail: radosh2009@gmail.com,

[4] Vladimir Despotović is with the University of Belgrade, Technical Faculty in Bor, Vojske Jugoslavije 12, 19210 Bor, Serbia, e-mail: vdespotovic@tf.bor.ac.rs,

[5] Olivera Tasić is with the Mechanical and Electrical High School Bor, Zeleni bulevar 24, 19210 Bor, Serbia, e-mail: oliverina.posta@gmail.com,

[6] Ivana Stojković is with the University of Niš, Faculty of Electronic Engineering, Aleksandra Medvedeva 14, 18000 Niš, Serbia, e-mail: ivana.stojkovic@elfak.ni.ac.rs

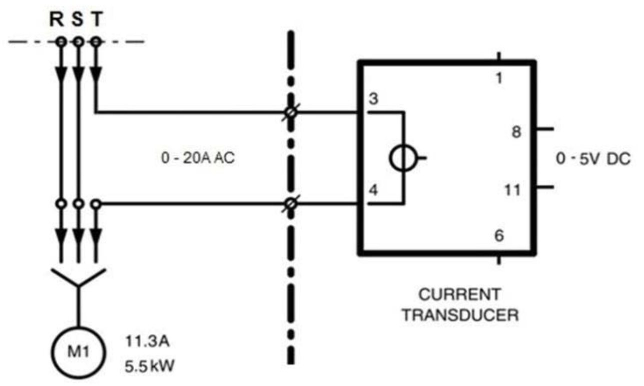

Fig. 1. The wiring diagram of the proposed AC current transducer

The realized AC current transducer is placed in a standard plastic housing with the dimension 50x78x108 mm for installation on a standard 35 mm wide rail (according to EN 60715 standard) with IP20 protection degree. On the front of the transducer housing, there are 12 terminal clamps arranged in two rows of 6 terminals, as shown in Fig 2. Terminals 1 and 6 are intended for connecting the supply voltage of the transducer, 220 V AC. Terminals 3 and 4 are intended for connection to the electric grid (AC input, 0-10 A).

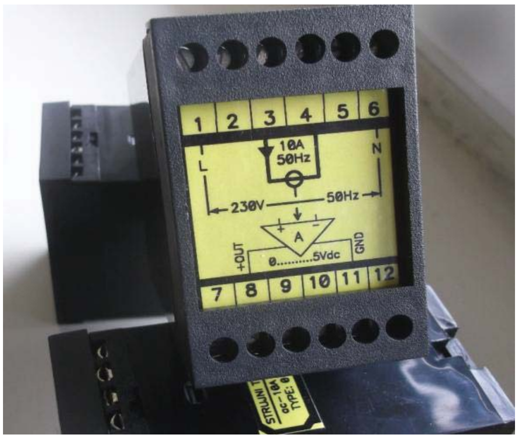

Fig. 2. The transducer's front panel and housing

All transducer's components are located on a single-sided printed circuit board shown in Fig 3. The electrical scheme of the transducer (shown in Fig 5.) consists of the following components: power supply, current transformer/sensor, inverting amplifier, precision two-sided rectifier and output stage.

B. Power Supply

The transducer's power supply supplies electronic components with ±12 V DC. It consists of voltage transformer TR1 (220 V AC, 2x12 V AC, 2 VA), Graetz bridge 1.5A, voltage regulators IC1 (78L12) and IC2 (79L12), and electrolytic capacitors for filtering the supply voltage referred as CF1-CF6 as shown in Fig 5.

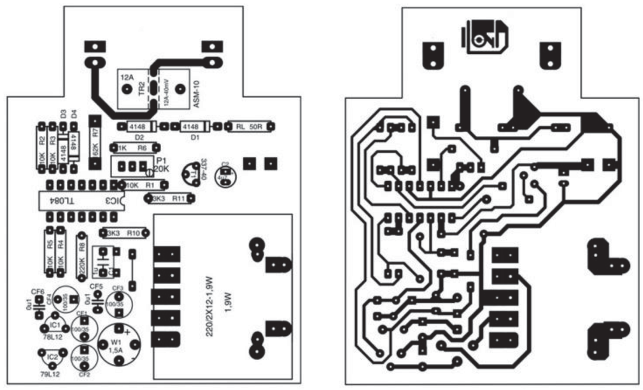

Fig. 3. The transducer's PCB layout

C. Current Transformer/Sensor

A current transformer is an instrument transformer in which the secondary current is substantially proportional to the primary current. Current transformers are switched on to the primary circuit regularly because they need to reduce the current being measured; they work in the short circuit regime. The transducer uses a miniature current sensor type: ASM-010/TALEMA. A typical characteristic of ASM current sensor is shown in Fig 4 [8].

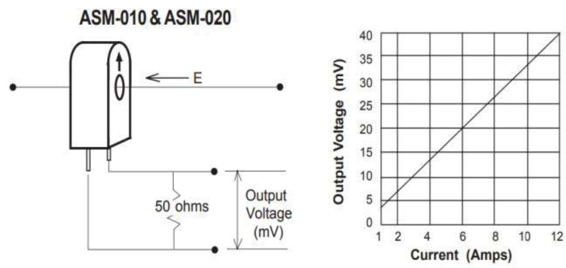

Fig. 4. The ASM-010 current sensor characteristics [8]

D. Inverting Amplifier

Operational amplifier (OP) IC3:A with resistors R6, R7 and potentiometer P1 forms inverting amplifier arrangement as shown in Fig 5. No inverting input of the IC3:A is bound to ground (zero potential). Since the input voltage of an ideal OP is zero, the inverting input of the OP IC3:A is virtually on the potential of the ground. Since the input current of OP is zero, all input current is closed over R7 and P1. The amplification A of this amplifier is negative and equal to:

$$A = -\frac{R7+P1}{R6} \tag{1}$$

E. Precise Double-sided Rectifier

OP amplifiers IC3:B and IC3:C, diodes D3-D4 and resistors R1-R5 form a precise double-sided rectifier as shown in Fig 5.

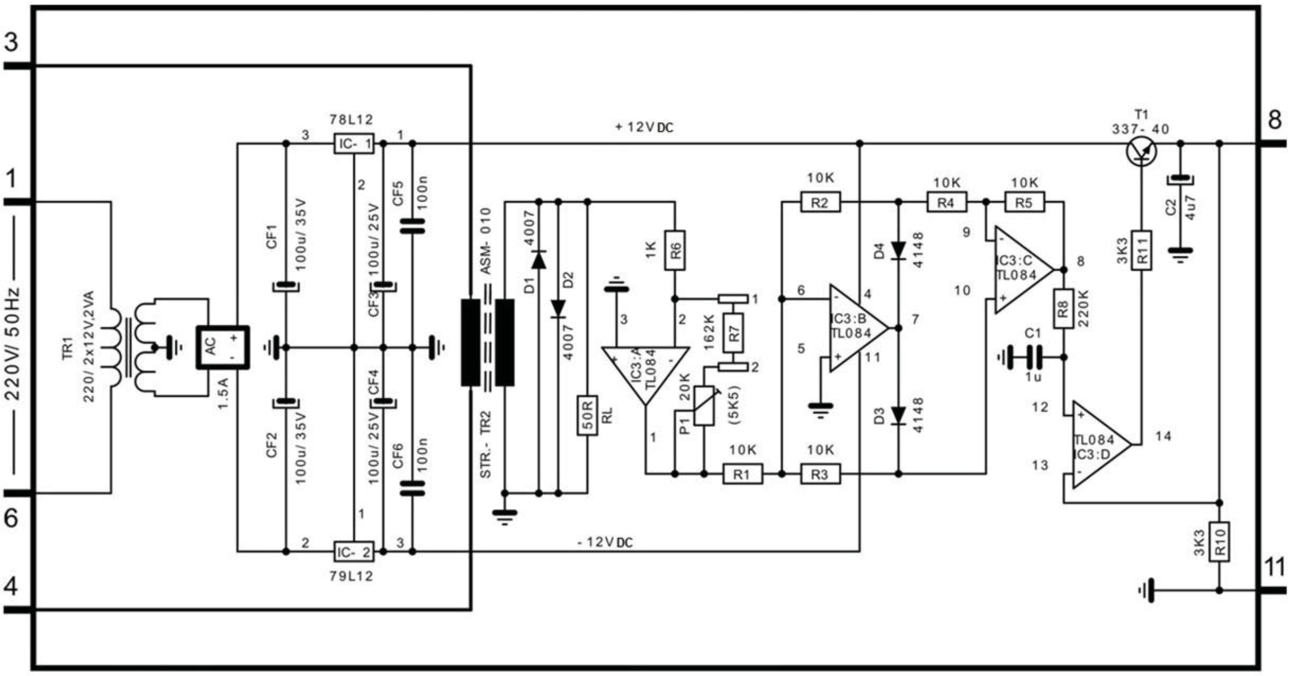

Fig. 5. The electric scheme of the AC current transducer

When the input voltage is positive, the diode D4 leads. On its anode, the voltage is equal to the input one, but with the opposite polarity. In the second OP (IC3:C), this voltage is only inverted and a positive voltage with a single amplification is obtained at the output of the rectifier. Both OP amplifiers work as inverting amplifiers with unity gain. When the input voltage is negative the feedback circuit of the first OP (IC3:B) is realized via diode D3. The input current is negative and it is divided in the ratio of 1:2, with one third going upstream, and over R2 and R4 entering the second OP, and two-thirds closing via D3. The gain is, therefore, ±1 depending on the polarity. The output voltage is not affected by voltage drops on the diode; hence, the circuit acts as a precision rectifier (absolute value detector). The circuit is simple because resistors of equal resistance are used. The disadvantages of the circuit are a unit gain and a small input resistance [9].

F. Output Stage

OP amplifier IC3:D, transistor T1 (BC337), resistors R8, R10, R11 and capacitors C1 and C2 form the voltage controlled current source, as shown in Fig 5. The OP amplifier IC3:D acts as a voltage comparator. No inverting input of OP IC3:D is connected to the output of precise double-sided rectifier through the integrator, formed by the R8 resistor and the capacitor C2. The output stage provides greater current availability due to the use of transistor at the output instead of using the direct output from OP. The OP IC3:D and transistor T1 ensure that the voltage over resistor R10 is kept equal to the one at the non-inverting input of OP IC3:D. The voltage on the resistor R10 is proportional to the AC current at the transducer input. Adjustment of the transmission characteristics of the transducer is done using the potentiometer P1.

III. TESTING THE CHARACTERISTICS OF THE AC CURRENT TRANSDUCER

Adjusting the I/O characteristics of the transducer (slope of the working curve) was done using the potentiometer P1 (shown in Fig 5.). Recording of the I/O characteristics was done by using the PHILIPS FLUKE PM2525 [10]. The measurement of DC voltage in the range 0-20 V with these instruments has an accuracy class of 0.02. The I/O characteristic of the transducer when it uses the current transformer CT010P-A/B/C [11] is shown in Fig 6.

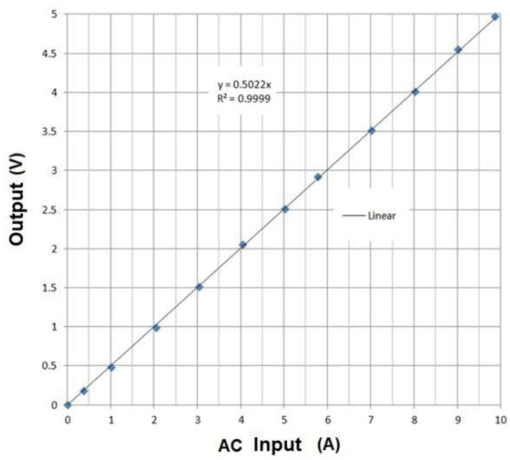

Fig. 6. The I/O characteristic of the transducer

Simulation of DC, AC and transient working regime of the transducer was carried out using the TINA-TI V9 program [12]. The response time of the transducer is approximately 1s, as shown in Fig 7. The transducer's response time can be adjusted as needed by choosing the appropriate value of capacitor C1 (shown in Fig 5.).

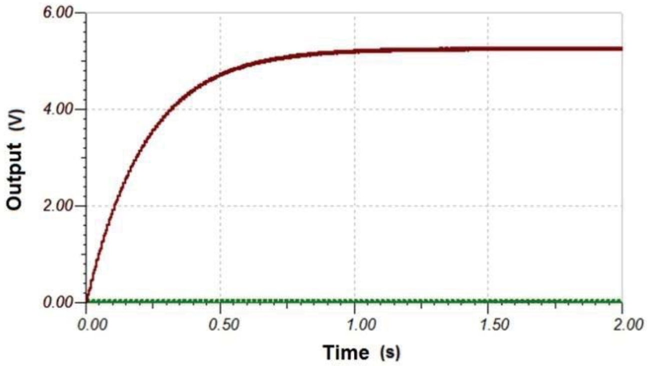

Fig. 7. Transducer response time for the maximum current on the input

IV. The Example of Application

A circuit diagram of the electric motor overcurrent load protection system is shown in Fig 8. The protective element compares the preset maximal current load with the actual current load measured by the transducer. When the actual current exceeds the preset maximum, the protection system activates the sound and the visual alarm. Hence, the information about the actual electrical energy consumption of the electric motor is forwarded from the Arduino board [13], that serves as DCS node, via the wireless network to a DCS control level (PC workstation).

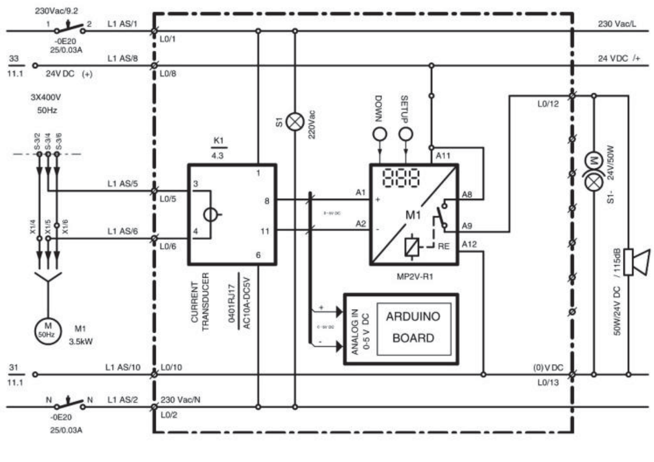

Fig. 8. The electric motor overcurrent load protection system [14]

V. Conclusions

In this paper, the main characteristics of the recently realized AC current transducer are presented. The application of such devices enables measurement of the electricity consumption of a wide variety of electrical consumers in the industrial facilities, as well as in the households. The realized device is easy to manufacture, install, calibrate and maintain. In the practical application in overcurrent protection systems, it has shown good stability and reliability. We expect that, in the near future, it will be extensively applied in the electrical energy consumption control systems.

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