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Remote Wireless Monitoring of an Electric Drive System

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Abstract—**An application of wireless standards for remote monitoring of a DC electric drive is discussed in this paper. An appropriate wireless system has been developed and described. The structure presented allows measurement of all necessary parameters namely power converter voltage, armature current, angular speed, motor torque, temperature and vibrations. It uses ZigBee standard for remote data transmission combined with Internet connectivity for assessment of the Global network-collected information. Detailed experimental study confirms the good performance of this wireless monitoring system. The research carried out as well as the results obtained can be used in design and set up of such types of remote wireless systems.**

Keywords-Intelligent sensors; Measurement system; ZigBee network; Remote monitoring; DC electric drive system

I. INTRODUCTION

Modern wireless technologies and devices develop very quickly and find ever expanding practical applications. Compared to the wired systems they offer much more flexibility and convenience [1], [2], [3]. Wireless devices using standards like ZigBee are widely applied in remote measurement equipments because of their capabilities to provide very low energy consumption, easy maintenance, data encryption, diverse network topologies, etc. Another benefit of the ZigBee networks is that they allow monitoring parameters of different devices. They are also characterized by much faster installation in comparison with the wired systems. ZigBee networks require only the end points to be installed saving users much time. Wireless sensing and control are especially useful in cases where the monitored objects are situated in remote and hardly accessible places.

Currently wireless systems are often applied for remote monitoring and control in many areas such as robotics, manufacturing processes, building automation, environmental research, etc. Some implementations of wireless control in industry for robots and manipulation systems are descried in [4], [5]. An industrial real-time measurement and monitoring system based on ZigBee standard is presented in [6]. An increased interest in this standard for building automation has been registered recently [7].

For monitoring of electric drive systems, measurement of a variety of parameters is often required, such as voltage, current, torque, speed, position, distance, temperature, energy consumption, battery charge and vibrations. Some implementations of appropriate devices for wireless data transfer are described in [8], [9], [10], [11].

This paper presents a modular wireless sensing system for remote monitoring of a DC electric driving system. It uses ZigBee standard for data transmission combined with Internet connectivity for assessment of the Global network-collected information. The ZigBee standard provides high reliability and immunity against any narrow-band interferences. A coordinator device realizes data acquisition and the network management. It also expands the low-range ZigBee network to a widespread range.

II. FEATURES OF THE MONITORED DRIVE SYSTEM

A simplified block diagram of the monitored electric drive system is shown in Fig. 1. The notations used are as follows: CD – control device; SC – speed controller; CL – current limitation block; CC – current controller; FC – firing control block; RF - thyristor rectifier; PC – power convertor; M – permanent magnet DC motor; SS – speed sensors; G – gear; L – load applied to the motor shaft; P – potentiometer for power converter voltage; CS – armature current sensor; CF – current feedback block; SS – motor speed sensor; SF – speed feedback block; LC – current limitation correction; L – load applied to the motor shaft; TS – temperature sensor, VS – vibration sensor; MS – measurement device block; V_{sr} – speed reference signal; V_{cr} – current reference signal; V_{vr} – voltage reference signal; V_{cf} – current feedback signal; V_{sf} – speed feedback signal; V_a – power converter output voltage; I_a – armature current; ω – angular speed of the motor. The power converter includes a reversive thyristor rectifier and a firing circuit for phase-angle control.

The main parameters of the monitored electric drive system are presented in Table 1.

The electric drive system under consideration is of dual-loop type, with subordinated regulation of the contolled coordinates of motor speed and armature

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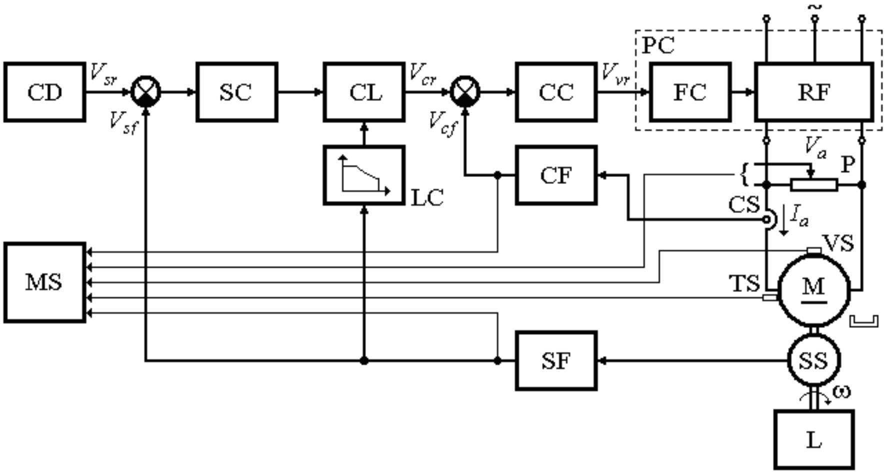

Figure 1. Block diagram of the monitored electric drive system.

current. To improve the drive performance an adaptive speed controller is applied. Control loops opitimization is carried out following the resepctive criteria, providing for the necessary drive performnce. Tuning of controllers is done sequentially, starting from the inner loop.

TABLE I. MAIN PARAMETERS OF THE MONITORED DRIVE.

Parameter	**Value**
Rated speed	78.5 rad/s
Maximum speed	157 rad/s
Rated armature current	35 A
Rated motor torque	21 Nm
Voltage reference signal	- 10 V ÷ + 10 V
Gain of the speed feedback	5.236 rad/s.V
Torque coefficient	0.6 Nm/A

The armature current limitation is done by means of the respective reference signal V_{cr}. Automatic speed dependent correction is introduced through block LC.

III. WIRELESS MONITORING SYSTEM

A simplified block diagram of the developed wireless system is shown in Fig. 2. A ZigBee coordinator device collects all the measured data from the measuring devices (or end-devices). The presented system measures voltage and temperature. Measured values are transmitted via Internet to a database server where they are stored for further processing. Remote users can read the stored data in the data server through Internet and with a valid permission from a remote PC.

The structure of a measuring device is presented in Fig. 3. This device was designed to work with power supply from a 12V lead-acid accumulator battery chosen for its lower cost in comparison with Lithium batteries. A main component of the constructed device is the microcontroller (MCU). It facilitates measuring of analog quantities through an external 12 bit analog to digital converter (ADC). This ADC converts analog data from the temperature sensors (RTD – Pt100) and from the voltage inputs into a suitable form for the microcontroller. MCU transmits the measured data through radio channel via a serial controlled ZigBee module. As an option the device has RS232 converter for direct PC-Link.

Figure 2. Block diagram of the wireless monitoring system.

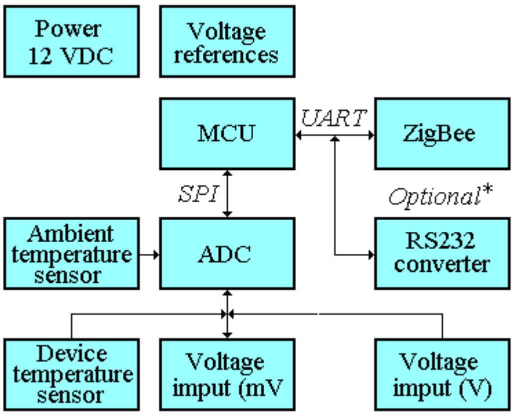

Figure 3. Structure of a proposed measuring device.

Fig. 4 presents the diagram of an input Pt100 temperature channel. In order to reduce errors caused by the connecting wires resistance, the platinum sensors are connected in bridge circuit using 3-wire connections [12]. Each wire is represented as a resulting resistance Rw1, Rw2 and Rw3. Given that Rw1 and Rw2 are equal, as well as the currents flowing through them, the respective voltage drops compensate each other. The sensing analog channel consists of one instrumentation amplifier and a 12 bit analog to digital converter. The input channel can be used with a thermistor and depending on the sensor only the bridge values must be recalculated. The microcontroller software must also be changed.

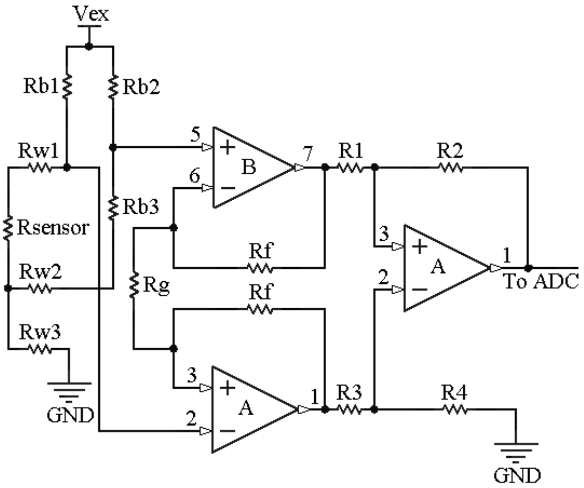

Figure 4. Diagram of Pt100 input channel.

Fig. 5 presents a diagram of the voltage input. This input is configured to measure voltage in the range 0 – 30 V for input from the motor speed sensor and 0 – 400 mV for input from the armature current sensor. The difference between the two inputs is in the input voltage divider coefficient and in the amplifier gain.

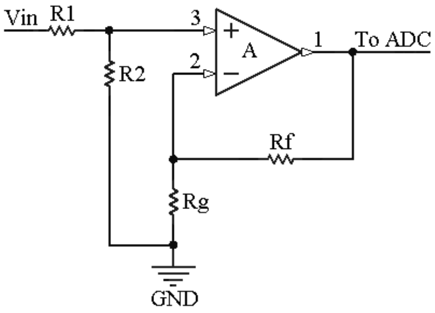

Figure 5. Digram of the voltage intput.

IV. EXPERIMENTAL RESULTS AND ANALYSIS

The monitoring system allows measurement of all necessary parameters namely power converter output voltage, armature current, angular speed, motor torque, temperature and vibrations.

The motor speed is monitored by measuring the respective speed feedback signal V_{sf} . Its value is determined as follows:

$$\omega = K_{sf} V_{sf} \,, \tag{1}$$

where K_{sf} is the speed feedback gain.

Because the DC motor excitation is done by permanent magnets, the magnetic flux does not change. This feature allows calculating the motor torque through measurement of the respective armature current:

$$T = K_t I_a \,, \tag{2}$$

where: $K_t = c\Phi$ is the torque coefficient; c – the DC motor coefficient; $\Phi = \text{const}$ – the magnetic flux.

Fig. 6 shows feedback voltage V_{sf} and armature current I_a . At t_g the current sign becomes negative, because the DC motor passes into generator regime of operation.

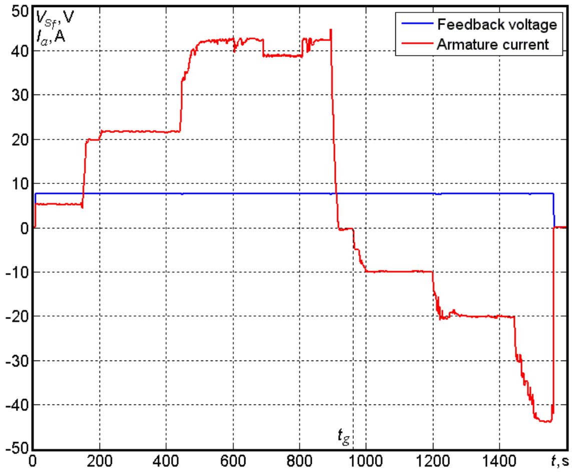

Figure 6. Time-diagrams of speed feedback voltage and armature current for close-loop control.

The controlled coordinates of speed and torque are calculated by (1) and (2) respectively. Their time-diagrams obtained experimentally are presented in Fig. 7. In this test the reference motor speed is $\omega_r = 40$ rad/s .

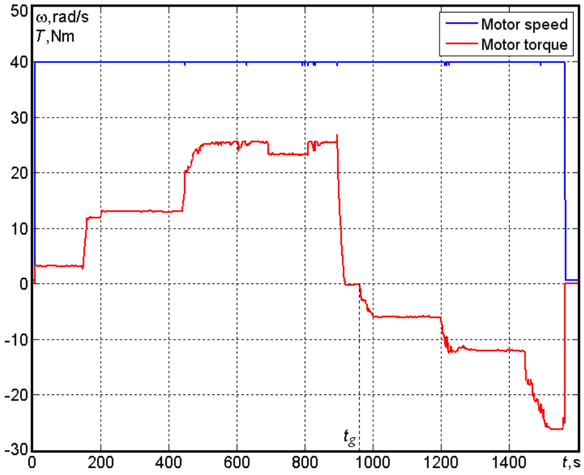

Figure 7. Time-diagrams illustrating the motor speed and torque monitoring for close-loop control.

As evident, with an appropriate tuning of the speed controller, static speed error does not appear when the load applied to the motor shaft changes.

In an open-loop control drive system (i.e. without speed feedback) if the motor load is changed, speed stabilization is lacking. Such a case is illustrated in Fig. 8, where experimentally measured motor speed and armature current for open-loop control are shown.

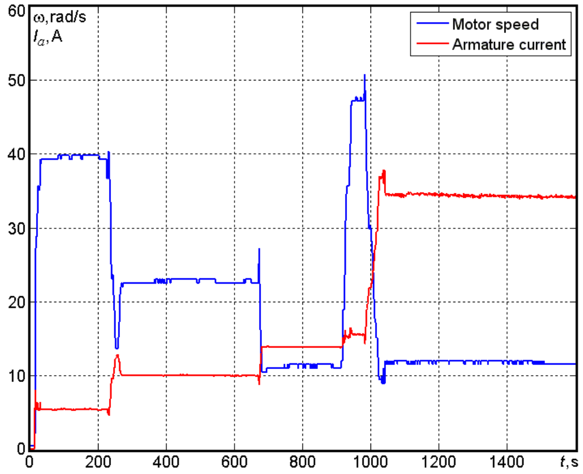

Figure 8. Time-diagrams of experimentally obtained motor speed and armature current for open-loop control.

Fig. 9 shows the experimentally measured both motor and ambient temperatures.

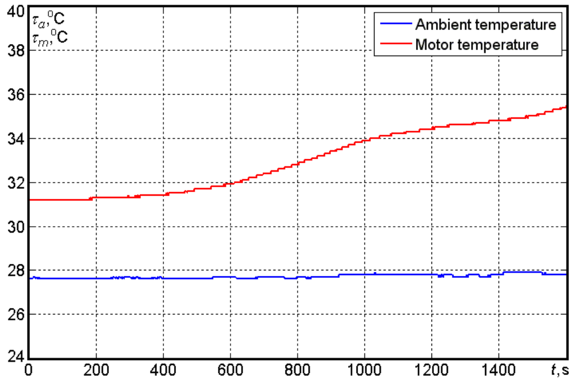

Figure 9. Time-diagrames of the ambient and motor temperatures.

Fig. 10 presents experimentally obtained motor vibrations. The vibration measurement allows remote monitoring of the electrical motor fixing to the respective fundament, as well as the condition of its bearings.

V. CONCLUSIONS

A system for remote wireless monitoring of a DC electric drive has been developed and described. The structure presented is flexible due to the utilized wireless standards and allows measurement of all necessary parameters namely output power converter voltage, armature current, speed, motor torque, temperature and vibrations.

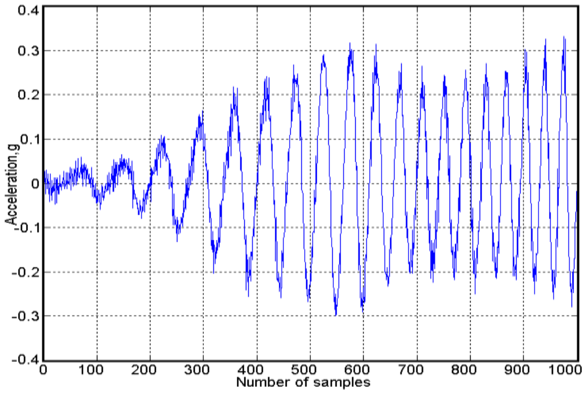

Figure 10. Experimentally obtained motor vibrations.

Detailed experimental studies confirm the good performance of the described wireless monitoring system.

The research carried out as well as the results obtained can be used in design and set up of such types of remote monitoring systems for various electric drives.

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