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An Investigation and Simulation of Frequency Controlled Electric Drive System

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***Abstract*—Paper presents experimental and simulation results with 4 kW induction motor drive. Experiments are done using hardware in the loop real time simulation which allows implementing of motor control directly from the personal computer. This technique enables to replace part of the system with computer model running software. Regulator model was simulated in Matlab/Simulink. PI and PID regulators were tested. Experimental and simulation results starting and loading the motor are elaborated.**

***Index Terms*— Induction motors, hardware in the loop, regulators, Pi control.**

I. INTRODUCTION

Induction motors (IM) are the most common motors used in industrial motion control systems as well as in main powered home appliances. Simple and rugged design, low-cost, low maintenance and direct connection to an AC power source, reliability are the main advantages of AC induction motors.

Usually, speed of an IM must be controlled in order to save energy and control technological process. The synchronous speed of the motor is proportional to supply frequency and is inversely proportional to the number of stator poles. The number of poles cannot be changed once the motor is constructed for one speed operation.

The variable frequency drive (VFD) is a system made up of active/passive power electronics devices (IGBT, MOSFET, etc.), a high speed central controlling unit (a microcontroller) and optional sensing devices, depending upon the application requirements [1].

So, by changing the supply frequency, the motor speed can be changed. For control of induction motor speed usually frequency converters are used.

Digital signal processing (DSP) controllers enables cost-effective design of intelligent controllers for motors which can yield enhanced operation, fewer system components, lower system cost and increased efficiency [2].

In this paper, hardware in the loop (HIL) control technology for the investigation of 4 kW IM is used.

HIL simulation allows for system and component test scenarios that would be impossible to implement. The test of a hardware component, i.e., speed regulator, with an extended system (simulated) becomes possible.

The HIL technology is used to control the rotation speed of IM. This method allows controlling of IM directly from personal computer.

In this work, the induction motor speed control model was developed using Simulink. The performance time domain characteristics of investigation system with HIL simulation in Matlab is presented. Experimental and simulation results are presented and discussed.

II. HARDWARE IN THE LOOP CONTROL TECHNIQUE

The HIL simulation is a recognized simulation method in different engineering areas, e.g. control of induction motor drive.

HIL applications are used by design and test engineers to evaluate and validate components during development of new systems. Rather than testing these components in complete system simulations, HIL allows the testing of new components and prototypes while communicating with software models that simulate the remainder of the system. Replacing the remainder of the system with computer models running software simulations greatly reduces the size and complexity of applications and increases the flexibility and rate of running many different tests and test scenarios. The physical components being tested respond to the simulated signals as though they were operating in the real hardware application [3].

As the name implies, in HIL simulation, a part of the system is modeled and simulated in real time, while the remainder is the actual hardware, connected in closed loop by various I/O interfaces such as analog-to-digital (A/D) and digital-to analog converters, and signal conditioning equipment. The simulation can be controlled by user-defined external inputs, e.g., closing and opening of switches to connect the components in the modeled system. HIL simulation can be of two kinds: controller HIL (C-HIL) simulation or signal HIL and power HIL (P-HIL) simulation. In C-HIL simulation, the power system, including the power electronic converters, is represented by a real-time model, while the digital controller is the device under test connected in closed loop with that model. This method is also known as rapid controller prototyping. There is no real power transfer in this method. The controller takes the sampled voltages and currents from the simulator and provides control inputs in the form of switching signals. In contrast, in P-HIL

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simulation, a part of the power system is external to the simulator, thus requiring a transfer of real power to the external hardware [4]–[6].

An embedded system (ES) is any electronic device that incorporates a computer in its implementation. The user of an embedded device is often not even aware that a computer is present in the device. The computer is used primarily to provide flexibility and to simplify the system design. Unlike a PC, program code is usually stored in ROM and not on hard disk drive. Typically, the end user does not develop new software for the embedded device. With advances in very-large-scale integration (VLSI) technology, ES have become so inexpensive that they are found in most of today's electronic devices [7].

Simple block diagram of ES connected to a hardware-in-the-loop simulator (HILS) is shown in Fig. 1.

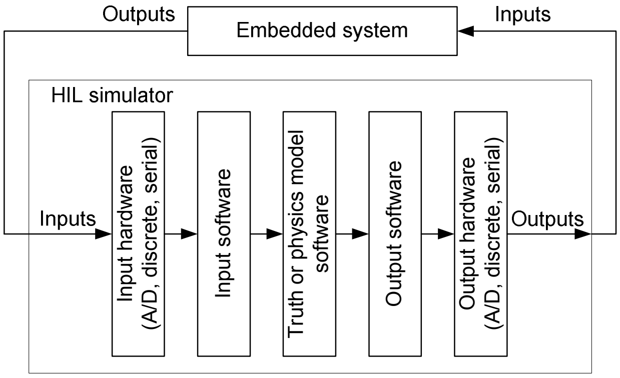

Fig. 1. Hardware in the loop structure.

A powerful tool often used in this situation is HILS. HILS is a device that fools embedded system into thinking that it is operating with real-world inputs and outputs, in real-time. Fig. 1 shows a simple block diagram of an embedded system being tested using a HILS.

It could be assumed that the simulator simply measures the signals, e.g. analog, that the computer sends to the actuator.

III. EXPERIMENTAL STAND

The HIL controlled stand of 4 kW electric drive system with generator load is shown in Fig. 2.

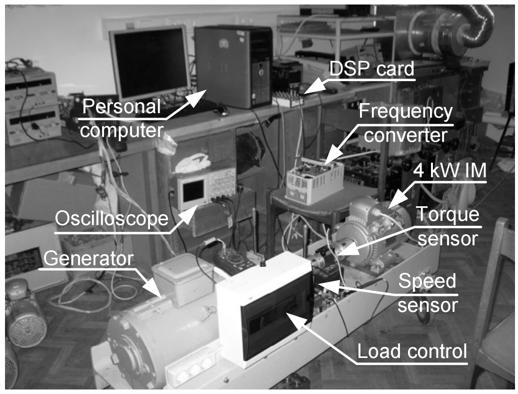

Fig. 2. View of the experimental stand.

Analog reference signal can be changed from -10 to 10 V. 10 V corresponds to nominal drive speed which is 2890 rpm. Analog reference signal is sent to frequency converter where 10 V corresponds to 50 Hz. In order the Simulink and frequency converter could communicate the digital signal processing (DSP) NI (National instruments) 6024E card is used. Also this analog to digital conversion card needs to read the feedback signal. DSP NI 6024E card has 15 analog inputs and 2 analog outputs. The power of used frequency converter is 7.5 kW. Torque is measured using Lorens Messsetecknik GMBH DR-2212-R type contactless rotary torque sensor. To load the generator is used 6x1 kW lamps. All measurements are recorded using Tektronix TDS 2024B oscilloscope.

Controlled system includes speed and torque reference signals, both those can be changed.

IV. SIMULATION MODEL

The model of frequency controlled electric drive system with speed feedback signal is shown in Fig. 3. Elaborated computer model is created according to the real 4 kW IM. Motor type 112M-2, whose parameters are presented in Table I.

Required speed value is maintained by PI and PID controllers. Elaborated model includes speed and torque reference signals, both those can be changed.

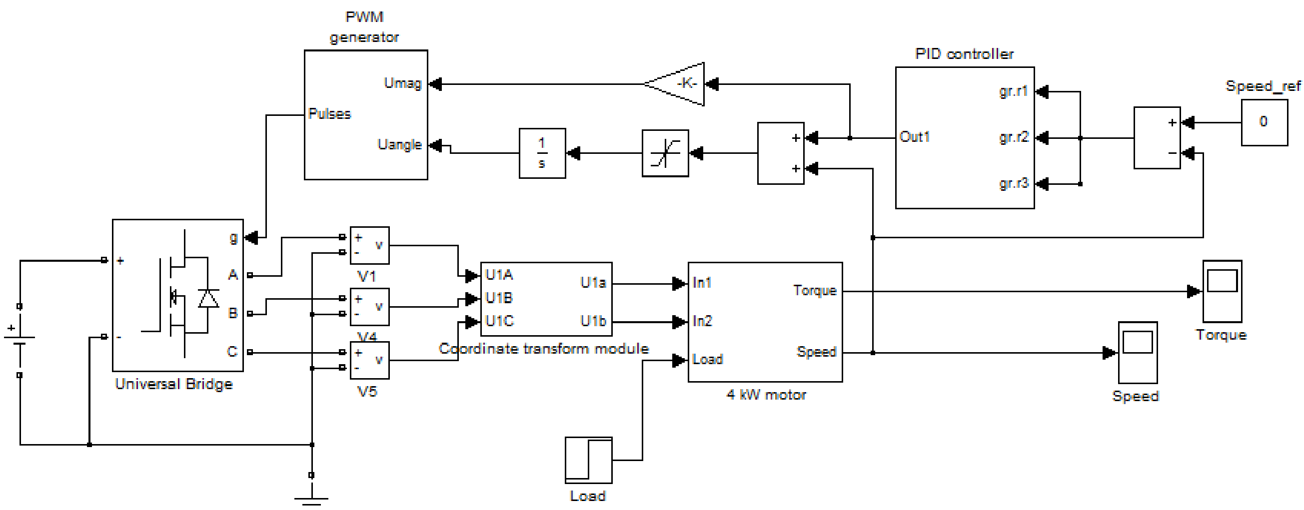

Fig. 3. Simulink model of frequency controlled electric drive system.

TABLE I. PARAMETERS OF THE MOTOR.

Parameter	Value
Motor power, kW	4
Number of pole pairs	1
Nominal speed, rpm	2890
Phase voltage, V	230
Power factor	0,88
Rated torque, N·m	13,22
Rated current, A	7,7
Inertia, kg·m^2	0,0055

Fig. 4 shows reference, speed and torque transients when speed reference is half of the nominal motor speed – 1455 rpm. Motor was loaded by 5.3 N·m after settling time, when speed reached steady state value. The PID regulator was used.

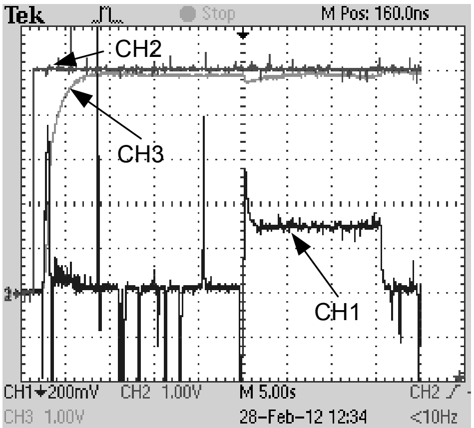

Fig. 4. Motor speed and torque transients (CH1 – torque, CH2 – speed reference, CH3 – speed feedback).

Fig. 5 shows the same transients as in the Fig. 4, the difference is that load is turned on and off twice. From the figure it is evident, that motor speed comes back to the reference signal despite the load.

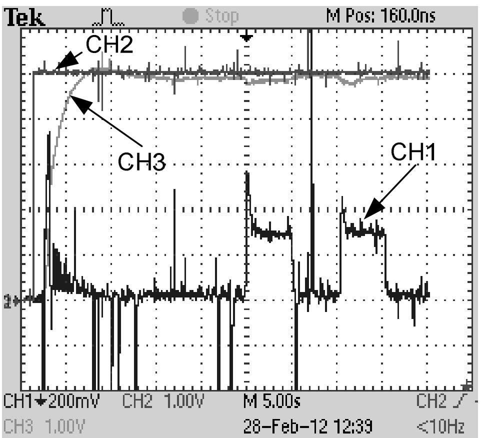

Fig. 5. Motor speed and torque transients (CH1 – torque, CH2 – speed reference, CH3 – speed feedback).

Fig. 6 shows motor speed and torque transients at speed reference 8.561 V or 2500 rpm and load is 0.4 mV or 3.1 N·m. The PID regulator was used. Comparing Fig. 5 it is seen, that when motor speed ir greater and close to the nominal the speed transient doesn't show instants when load is on.

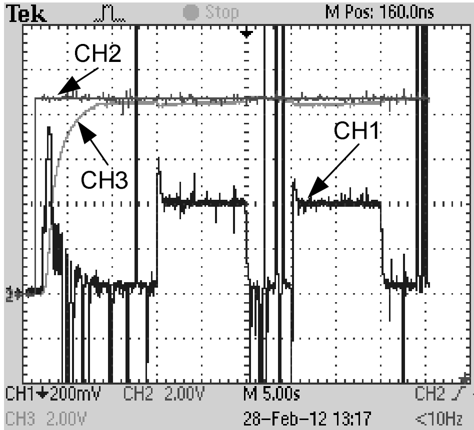

Fig. 6. Speed and torque transients (CH1 – torque, CH2 – speed reference signal, CH3 – speed feedback signal).

Fig. 7 shows motor speed and torque transients when speed reference 8.561 V or 2500 rpm and load is 6.1 N·m. The PI regulator was used. Comparing to Fig. 6 it is seen, that with PID regulator torque oscillates more than with PI regulator.

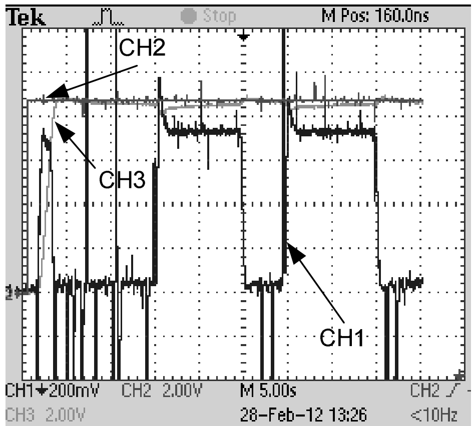

Fig. 7. Motor speed and torque transients (CH1 – torque, CH2 – speed reference, CH3 – speed feedback).

Fig. 8–Fig. 10 present simulation results. In Fig. 8 speed reference is 151 rad/s and in Fig. 9, 10 it is 262 rad/s. Simulations are done with 5,3 N·m and 10 N·m load.

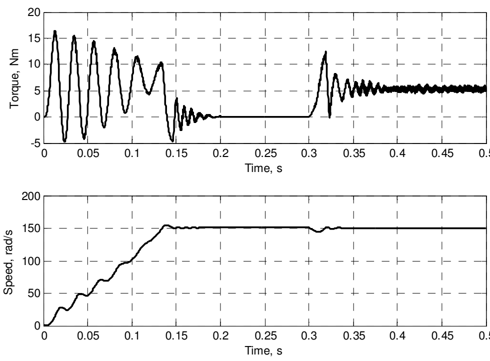

Fig. 8. Simulated motor speed and torque transients with PID regulator and 5,3 N·m load.

Fig. 8 and Fig. 9 show torque and speed transients when PID regulator was used. Small oscillations are seen on speed curve and greater on the torque.

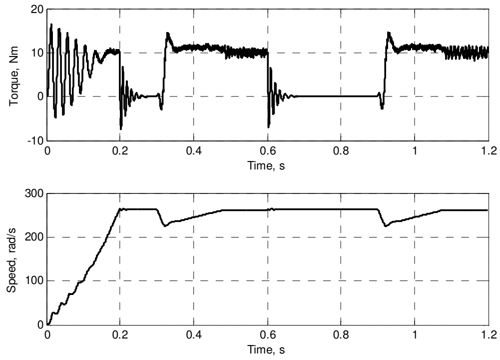

Fig. 9. Simulated motor speed and torque transients with PID regulator and 10 N·m load.

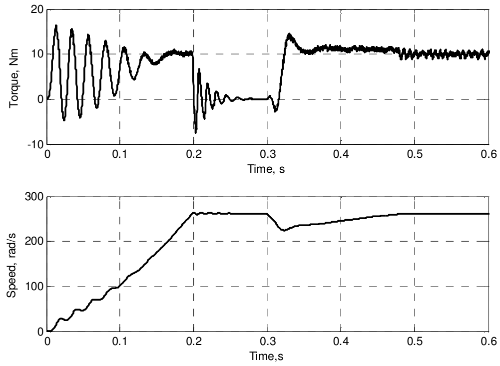

Fig. 10. Simulated motor speed and torque transients with PI and 10 N·m load.

Presented in Fig. 10 simulation is done with PI regulator. It is seen, that speed reaches steady state value after 0,2 s. After loading it took less than 0,2 s to adjust system to the reference speed.

V. Conclusions

1) Motor speed reaches steady state value without overshoot. It shows that HIL control simulation is reliable.
2) Experimental and simulation results of proposed system with PI and PID regulators were presented.
3) Motor torque oscillates because of coupling clearance. Oscillations are smaller when motor is loaded.
4) After loading the motor speed returns to reference signal or returns with small 1–3% error.
5) The higher speed of the motor the smaller oscillations are obtained at loading moment.

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