Experimental investigation of variable speed drive

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Abstract
The paper discusses the model of variable speed drive, controlled by scalar algorithm. Results of simulation are compared with experimental results of the wide control possibility experimental stand. Description of experimental stand is presented. Means to improve experimental stand are proposed.

Keywords
Induction motor, AC drive, control algorithm, simulation, experiment

Introduction
Different types of motor control algorithms are widely used in high-performance drives, providing precise and responsive speed control, and guaranteeing optimized efficiency during transient operations [1]. The needs for speed and torque control are usually fairly obvious. Modern electrical variable speed drives (VSD) can be used to accurately maintain the speed of a driven machine to within ±0.1%, independent of load, compared to the speed regulation possible with a conventional fixed speed squirrel cage induction motor, where the speed can vary by as much as 3% from no load to full load.

Experimental stand of DI-4000
Experimental results of induction motor drive dynamic transients are elaborated with the experimental stand DI-4000. This stand is created for safe, informative and reliable data reading of variable speed drive. It is easy to start up the stand and try different type of induction motor control algorithms. The block diagram of experimental stand DI-4000 of induction motor drive is presented in the Fig. 1.

Experimental stand consist of these parts:
- Siemens “MICROMASTER 440” AC drive with a CPU for mathematical calculations;
- 2 analogue to digital inputs for connecting different equipment for example: programmable logic controllers;
- 6 optically isolated inputs DI1-DI6. They are used for Starting/Stopping/Reversing the motor, also others inputs can be programmed for fault conditions;
- 2 digital to analogue outputs for connecting the oscilloscopes for data reading of the motor working conditions;
- 2 relay outputs RL1 and RL2;
- RS485 communication interface for connecting the drive to the different types of networks: Modbus, Profibus;
- Additionally three phase induction motor is equipped with electromagnetic brake used for loading of the main motor;
- Control panel with numerical LCD and buttons used for control of the motor and set parameters of the drive;
- Experimental stand is provided with potentiometer for adjusting a speed of the motor;
- RS232 communication interface is used to connect the personal computer for easy access to all system parameters with Siemens “Drive Monitor” software.

Motor control algorithms which can be tested experimentally with the DI-4000 are listed below [2]:
- V/f with linear characteristic;
- V/f with flux current control (FCC);
- V/f with parabolic characteristic;
- V/f with programmable characteristic;
- V/f for textile applications;
- V/f control with independent voltage setpoint;
- Sensorless vector control;
- Vector control with sensor;
- Sensorless vector torque-control;
- Vector torque-control with sensor.

Sensorless vector control (SLVC) can provide excellent performance for the following types of application where open loop control is used:
- Applications which require high torque performance;
- Applications which require fast respond to shock loading;
- Applications which require torque holding while passing through 0 Hz;
- Applications which require very accurate speed holding;
- Applications which require motor pull out protection.

Simulink model of variable speed drive
On the base of mathematical model of induction motor in stationary reference frame the motor model is developed with Matlab/Simulink software package [4]. Model of variable speed drive is presented in Fig. 2.
Fig. 1. The block diagram of experimental stand DI-4000 of induction motor drive

Fig. 2. The Simulink model of the inverter controlled induction motor drive

The model consists of blocks of power supply, coordinates transformation, PWM inverter, induction motor drive in the stationary reference frame. The inverter in this figure is simplified and shown without the rectifier. Simulation results of dynamic torque transient characteristics can be observed in figures 3, 4, 5. One division of the time axis corresponds to 0.05 seconds.

An experiment and simulation of induction motor drive is made with the following AC motor parameters listed in the Table 1.

Setpoints and actual values and control signals inside the drive inverter are read-out via the D/A converter using analog inputs. The digital signal is converted into analog signal. All of the signals can be output via the D/A which contain the "CO" abbreviation in the parameter text (refer to list of all of the parameters in the parameter list) [3]. FLUKE oscilloscope connected to the stand analog output was used to display the actual transient process of the motor.

Fig. 3. Simulation of torque of the motor with 1 N·m load on the shaft at frequency \( f = 50 \text{ Hz} \)
Table 1. Parameters of induction motor drive

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>Value</th>
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<tr>
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<tr>
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</table>

Experimental results

The purpose of experiment is to get the real torque transients of induction motor drive with different loads on the shaft. To access the actual torque parameter r0080, Siemens “Drive Monitor” software was used. The smoothed actual torque output, via the analog output, corresponds to parameter P0771[0] = 80. Reference frequency was set equal to 50 Hz. Three experiments were made with a different load on the shaft (1 N-m, 2 N-m, 3 N-m). Experimental results of dynamic torque transients are presented in figures 7, 8, 9.

Features of analog output of experimental stand:
- Sampling time: 4 ms;
- resolution: 10 bit;
- accuracy: 1 % referred to 20 mA.

Fig. 4. Simulation of torque of the motor with 2 N⋅m load on the shaft at frequency f = 50 Hz

Fig. 5. Simulation of torque of the motor with 3 N⋅m load on the shaft at frequency f = 50 Hz

Fig. 6. View of experimental stand DI-4000

Fig. 7. Experimental results of torque of the motor with 1 N⋅m load on the shaft at frequency f = 50 Hz

Fig. 8. Experimental results of torque of the motor with 2 N⋅m load on the shaft at frequency f = 50 Hz
Representation of experimental results is not smooth because the experimental stand gives the motor torque results over the analog output which has only 10 bit resolution and 4 ms sampling time. Still the experimental results conform to the simulation results of the dynamic torque transients. For adequate dynamic response of the drive, the model calculations need to be done at least more than 2000 times per second, which gives an update time of less than 0.5 ms. To improve the presentation of experimental results it is requested to use different types of DSP (digital signal processing) circuits with advanced software [5].

Conclusions
1. In the scalar control method maximum dynamic torque value is two times greater than nominal motor torque value.
2. D/A converter has low resolution of analogue output to get precise results.
3. A mathematical model of induction motor in stationary reference frame is developed. Motor model provided additional blocks to develop scalar control model of the variable speed drive.
4. The most important requirements for tests and measurements performed on both static (transformers) and rotating electric machines must be organized to realize a PC compatible Data Management System: automatic or semi-automatic Data Acquisition and Processing System (DAPS), with necessary interface – personal computer- software and other accessories.

References