Instructional Laboratory for Practical Investigation of Electric Drive Control

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Abstract: The study discusses the design principles of instructional laboratory equipment applied for practical investigations of electric drive control. The laboratory workstations comprise of two-motor hardware systems where each motor is controlled by a real-time DSP board. A control structure under test is assembled at the software level using a number of control elements, which is then compiled into a control algorithm for the microcontroller. In order to provide safe test execution, the control algorithm operates under the supervision of a real-time core software ensuring protection of the motors and the power converters. Due to the improvement in the reliability of hardware operation, the rated power of the motors and converters is increased to >1 kW to provide a proper characterisation of electric drives similar to industrial installations. The study also describes the laboratory hardware and software details using an example of the control system for an induction motor based on flux-vector control strategy. The example demonstrates configuring the control systems, compiling it into the execution code, the test procedure and result analysis.

1. Introduction

Practical activity is an essential component of higher education in the area of engineering. The main objective of practical activity is to reinforce the students understanding of theory learnt from lectures, tutorial and self-studies. The core of practical activity comprises of a series of controlled assignments usually referred to as laboratory works where students conduct tests and experiments under academic staff supervision [1].

The study of electrical machines and drives is application-driven requiring a practical demonstration. This suggests that practical laboratory work has great value in the curriculum of the subject [2], [3]. As the modern electric drive is a very complex system integrating the latest developments in electrical and electronic engineering technologies, the curriculum on motor drive systems should reflect the recent advances in electric motors, power electronics and control engineering. Today, electric motion systems is a major technology in industrial and domestic applications consuming almost half of the energy produced in the world with a prediction of 13,000TWh per year by 2030 [4].

The modern control of electric drives is based on digital technology. It utilises complex control strategies and algorithms embedded into DSP to provide desired operation of power converters and electric motors. In the context of education, to provide the students with knowledge and skills in the area of electric drive control the curriculum should cover principles of operation of DSP control systems, real-time software

execution and the influence of the control structure tuning on motor performance. These objectives require appropriate equipment to be integrated into instructional laboratories on electric drive control. However, the industrial equipment produced by major manufactures is not really appropriate for educational purposes. Although practical activity, focused on tests of embedded control structures, can be conducted using standard industrial power converters, these devices are black boxes in terms of investigation and understanding of control processes and algorithms. Therefore, the industrial equipment without any adjustments or modifications is only applicable for basic training or vocational education.

In the last two decades, laboratory work execution has been completely reshaped due to the introduction of digital computerised systems. Data acquisition systems and automated instrumentation have replaced conventional laboratory instruments to provide better accuracy of results and rapid data processing. Computer based simulation has converted laboratory investigations on electric drives into hardware-in-the-loop experiments where computer or DSP boards provide real-time control of hardware [5]-[8].

The laboratory works based on power converters controlled by DSP kits can perform very detailed analysis of tested control structures [9]. However, these sophisticated systems require students to learn the principles of real-time programming and significantly increase time spent in the laboratory preparing an experiment. Another drawback is that DSP based laboratory works usually use low power converters and machines (up to 1 kW) [10] performing differently from industrial installations. The increase in rated power of the converter and motor controlled by a real-time DSP based system may cause an unrecoverable fault due to a software error or a mistake made in its operation.

In practice, a motor control system comprises of a number of standard control elements. These include PI-controllers, adding elements, filters, gains, hysteresis elements, Clark and Park transforms, observers of the motor state etc. The list of elements to be compiled into a control algorithm depends on the tested systems and could be limited to the investigation of common and relatively simple control structures. For example, scalar, flux-vector and direct torque control can be built in the same drive using just a few control elements. Therefore, instead of complicated real-time programming, a control structure can be easily designed by a limited number of control elements. However, these elements must operate under control of the fixed real-time system core ensuring the protection of the motor and power converter. This approach provides a comprehensive and safe execution of laboratory work and ensures that the students can focus on the achievement of the curriculum learning outcomes.

This paper discusses the design of an instructional laboratory workstation developed to investigate electric drive control principles and algorithms. The workstation consists of an induction machine and a dc machine coupled together and controlled by real-time DSP boards via power converters. Due to the

integrated core software ensuring protection of the machines and power converters their rated power is increased to an industrial size. The software accessible for students contains a number of control elements used to build the control algorithm to be investigated. A variety of algorithms for both induction motor and dc motor control can be studied, tested and analysed using the same workstation. An instructional laboratory comprising several workstations allows the investigation of a vast majority of possible control strategies used in various motor drive systems. The workstation can provide an energy saving mode of operation, recuperating power from the "load" machine converter to the "drive" machine converter.

2. Hardware design

Most hardware in electric engineering instructional laboratories is limited as educational equipment. It is designed and manufactured to provide protection for both the student and the equipment. This principle has been applied for the design and development of the proposed instructional laboratory workstation.
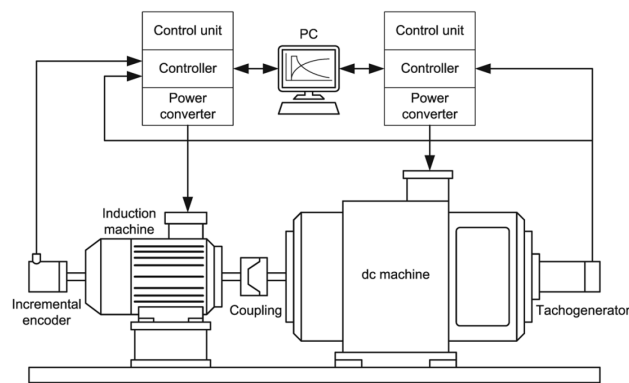

Fig. 1. *Structure of the instructional laboratory workstation.*

The hardware structure of the workstation is shown in Fig. 1. The workstation has two electrical machines: an induction machine of 1.5 kW and a dc machine of 1.9 kW. Both machines are coupled together and installed at the base of the workbench. Because the induction motor is the most popular type of electric machine used in industry worldwide, it was selected for control and investigation in the workstation. The area of industrial dc motor drives has significantly reduced in the past decades. However, this type of motor is still widely used for educational purposes due to simplicity of its operation and control principles. The rated power of 1.5kW and 1.9kW are selected being very close values to the average power of the commonly used industrial drives.

Most of manufactures of electrical engineering equipment for education and training such as Feedback-Instruments [11], Terco [12], Leybold [13], Lucas-Nuelle [14] use the motors rated at lower power (typically 300W) in commercially available laboratory workstations mainly due to safety reasons. However,

the low power motors demonstrate different performance characteristics compared to electrical machines installed in industrial applications. For example, a typical 300W motor widely used in instructional laboratories has a very low efficiency, extremely small stiffness of the speed-torque characteristic and high damping factor. The control of an object having a large integral component is stable within a wide range of parameters and requires a very rough adjustment or tuning. High damping factor makes difficult observation and analysis of back e.m.f. compensation and its influence on motor control operation. Mistakes in motor control design produced by a student during a laboratory work exercise might not have a noticeable effect on motor performance. Thus, the results obtained from practical investigations of low power motors can not always be extrapolated to bigger size machines (more than 1.5 kW). Therefore, in order to obtain the realistic characteristics of industrial size electrical machines the rated power of the motor under test should exceed 1.5 kW.

Manufacturers of educational electrical engineering equipment recognise the fact that 250-300W motors are performing differently compared to the industrial size machines. This is why Terco [12], Leybold [13], and Lucas-Nuelle [14] offers another range of educational electric drive workstations where the motors have the rating power of 1kW. However, these workstations utilise a very basic motor control (start, stop, braking etc.) and are mainly applied for the investigation of electrical machine parameters and characteristics rather than for electric drive control performance.

The workstation is equipped by two power converters installed on the left and right side to energise the induction and dc motors. The Mitsubishi Intelligent Power Modules (IPM) have been used as converters due to their excellent protection from short circuit current. The structures of the converter for the dc machine and the frequency converter for the induction machine are shown in Fig. 2 and Fig. 3 respectively. The converters are controlled by the embedded controller collecting the feedback signals and executing both hardware protection software and configurable control algorithm. The control system is based on the TMS320LF2406A microcontroller, a member of C2000 family of DSPs designed for power electronics, motion and industrial control applications [15]. The system has a 4-channel DAC and can transmit any internal variable to the computer for the further processing and display. The control unit is connected to the controller via CAN interface. The signals from the tachogenerator and incremental encoder are used for speed and position feedback. Both structures contain a voltage sensor in the dc-link and a number of current sensors to measure armature current of the dc motor and stator current of the induction motor. The frequency converter for the induction motor is additionally equipped with the brake circuit for the dc-link voltage control
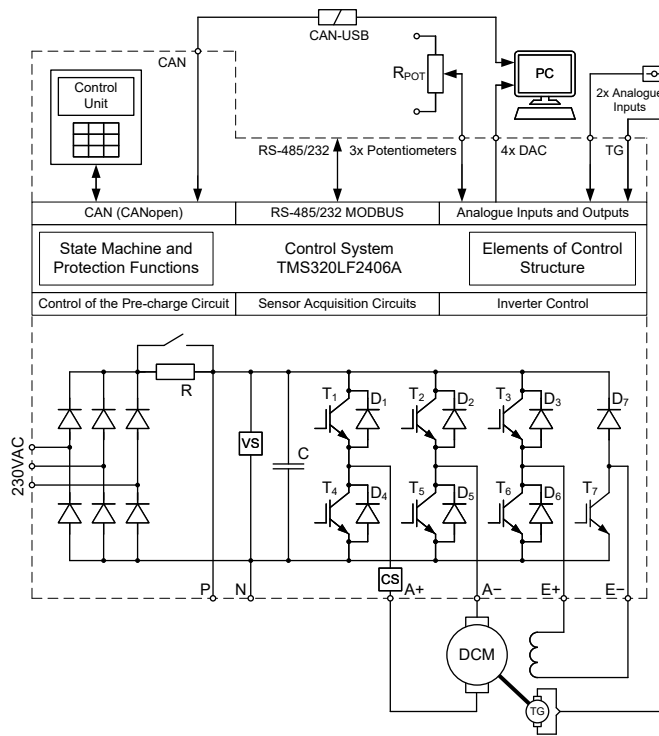
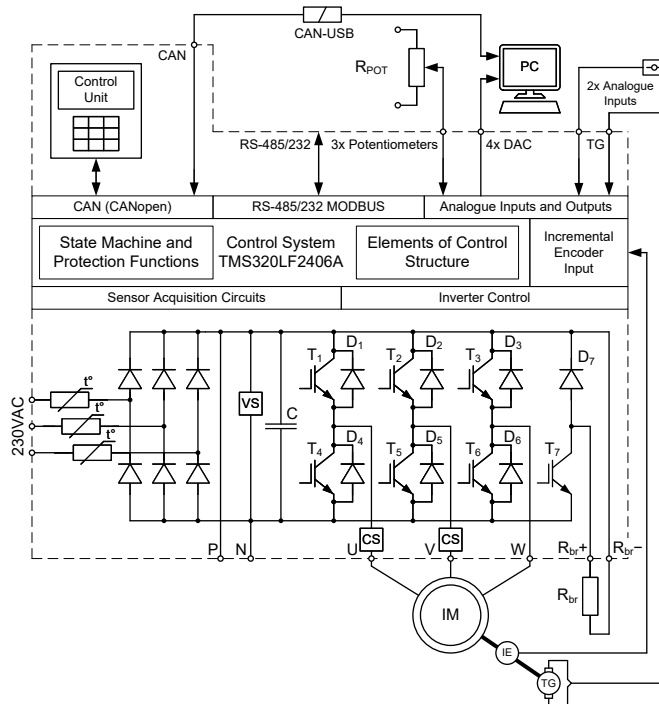***Fig. 2.*** *Structure of the converter for dc machine.*

Fig. 3. *Structure of the converter for induction machine.*

The workstation is equipped with a computer to collect, process and display the test results obtained from the experiments. The computer has a 16-channel ADC converter with maximum sampling rate of 400

kHz for a single channel to collect data. If more than one channel is used for an experiment, then the maximum sampling rate is divided by a number of active channels. The computer runs PowerGraph software providing data storage, signal processing and display of the results. It can plot the graphs in various scales, generate a Fourier transform and plot XY-graphs. The computer can be also used for configuring of control structure in Matlab/Simulink environment with a graphical programming interface.

Any electrical machine contained within the workstation can operate as a "drive" in motoring mode or as a "load" in generating mode. It means that if one machine is tested as a "drive" then another machine creates the load torque on the motor shaft working as a "load". For example, in order to investigate the speed-torque characteristic of dc motor drive under nested loop control the induction machine produces the load on the motor shaft operating under the flux-vector control with the torque reference as a source of torque or under the v/f open loop control with the frequency reference as a source of speed. On the other hand, if the induction motor is tested to investigate the speed-torque curve under the open loop control, then the dc motor drive generates the load torque on the shaft. This approach provides investigation and analysis of performance of any motor drive control of the workstation.

3. Control System Design

The syllabus on the subject of motor drive control has to cover different types of the control strategies such as:

- closed-loop PI-control with nested loops;
- open-loop control;
- hysteresis control;
- field weakening control and other types.

The number of control strategies is significant and it is difficult to predict that all connections, switches and settings have been implemented into the control software. This can be solved using a configurable control structure having a number of the standard control elements. These elements can be combined by a student into a control system for further investigation and analysis. There are two options to configure the control system: (1) using the control unit having input pad and display or (2) a computer running Matlab/Simulink software environment. The first option requires the student to list the elements of the control system and the appropriate connections manipulating the input pad. The second option provides the student with a graphical programming interface to build up the system using conventional Simulink blocks and links. However, at the final stage of the configuration procedure, the file representing the Simulink project will be converted into the list of elements and connections, similar to the outcome of the first option.

After completion of the configuration, the control system must be compiled in a programme control core where all connections are replaced with data copy instructions. Also the execution of elements are replaced by function call instructions.

This approach provides a compilation of a control system core to be executed inside the PWM interrupt routine. The core interacts with the hardware via input and output variables without the involvement of low-level methods. It means that the protection functions can be implemented directly in the real-time PWM interrupt routine outside the core.

Every element of the control core can have four data types:

- **data sources or the output variables** which have read-only access and can be connected to the inputs of other elements (for example, the output of the PI-controller unit);
- **settings** for tuning of the elements (for example, gains of the proportional and integral channels of the PI-controller);
- **data consumers or input variables** which can be linked with the data sources (for example, the reference or feedback of the PI-controller);
- **data consumers/settings.** If the input is not linked with the source then it works as the settings. However, if the input is linked then it works as the data consumers. (for example, the saturation of the PI-controller can be defined by setting or by another variable if it has to be changed during the operation).

The links between the elements are defined on the consumer side where the data sources can be linked to various data consumers if necessary. The following control elements have been created in the software for the design of dc motor control:

- converter control subsystem (gains voltage references for armature and excitation windings);
- DAC control element (gains data from any sources);
- subsystem of internal microcontroller ADC (provides information about current, speed from tachogenerator, references signals from potentiometers and auxiliary analogue inputs);
- 8 programmable variables;
- 5 PI-controllers having adjustable gains and output limits;
- 5 adding elements with three inputs of programmable polarity;
- 5 amplification elements having adjustable gain and offset;
- 3 hysteresis elements;
- 5 filters;

- 4 multiplexers for signal switching;
- ramp generator.

The control system for the induction machine has some extra control elements related to ac processing:

- 3-phase inverter control subsystem (gains voltage references in stationary frame and support four different types of PWM such as sinusoidal and space vector modulation);
- v(f) function;
- frequency to angle integrator;
- Clarke transform;
- inverse Park transform
- 3 Park transforms;
- transform from stationary frames to magnitude and angle;
- state observer of rotor flux for flux-vector control (using speed and currents);
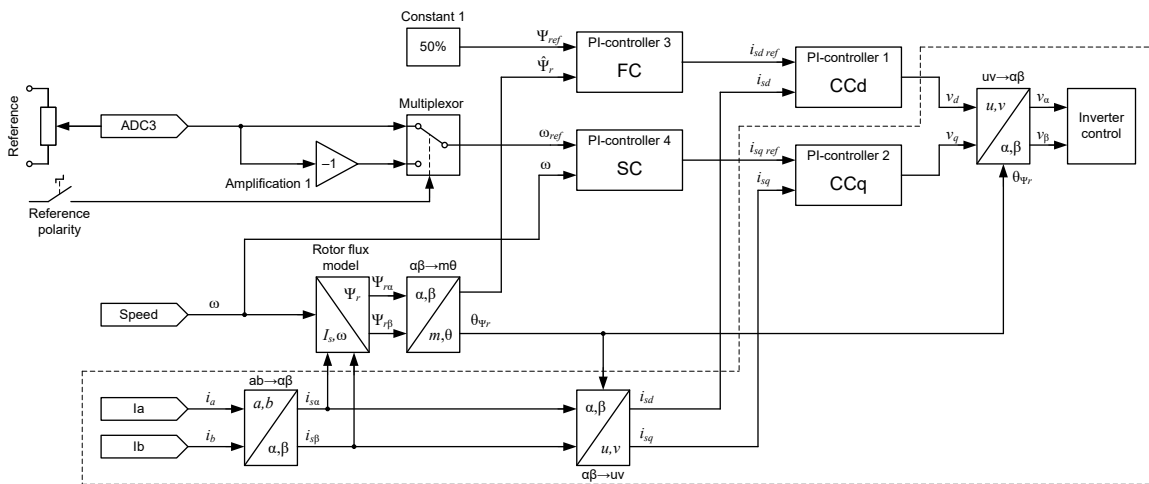- state observer of stator flux for direct torque control.

Fig. 4. *An example of the control system for induction motor comprising flux-vector control strategy.*

An example of the control system for induction motor operating under flux-vector control strategy is shown in Fig. 4. The control structure has been designed using the above described set of control elements. The structure transforms the measured currents from 3-phase into a 2-phase system and contains the flux observer, the transform from stationary reference frame to amplitude and angle, the transform from stationary to rotary reference frame of the stator current values, four controllers for the flux, speed and two current components, the transform from rotary to stationary reference frame and some minor elements to obtain torque current reference from the potentiometer.

4. Configuring the Control System

The structure of the control systems is configured using the control unit or a computer. The configuration starts with the setup of all necessary links between the elements and then the parameters of the elements should be tuned. The example of control strategy shown in Fig.4 illustrates the configuration process.

This control strategy is too complex to be implemented in a single step without an error, thus, it is advised to select a small part of the structure to implement and test separately. After each step completion, more elements can be added to the system, until the final structure is built up. The part of the structure selected to be implemented at the first step is outlined with the dashed line in Fig. 4. In fact, it presents a fully functional, simplified control system for an induction motor.

Following the simplified control system in Fig. 4 the topology of the control structure is described by a set of links between control elements presented in Table I. It can be seen that the current feedback signals I_a and I_b from the current sensors are linked to the input of the Clarke transform element "ab→αβ". Therefore, these links are described in the lines 1 and 2 of Table I. The output of the Clarke transform is connected to the transform from the stationary to rotary reference frames (lines 3 and 4 in Table I). The rotor flux angle is assumed to be zero (line 5 in Table I). The q-axis output is connected to the q-axis feedback input of the PI-controller (PI-controller 2) and the current reference signal for the control system obtained from an external potentiometer is transmitted through the ADC3 channel (lines 6 and 7 in Table I). The output of q-axis PI-controller is referred to the rotary frame and should be converted to the stationary frame. The d-axis is not included in the simplified structure, therefore, the zero value is applied as shown in the lines 8, 9 and 10 in Table I. The α- and β-axis control signals are connected to the converter control as represented in the lines 11 and 12 in Table I.

Investigated control structure should provide the observation of the internal variables of the system. For example, it may be interesting to observe the output of the q-axis PI-controller. The built-in DAC of the frequency converter can be used for this purpose. Therefore, the connection between the DAC and PI-controller output is set in the line 13 in Table I. This line completes the topology building of the simplified control structure.

The next configuring action is setting up the element parameters. The power converter used to energise the motor can have various configurations of PWM – sine-PWM, space vector PWM, space vector PWM with a clamp to a positive or negative DC-link bus bar. The compensation of the DC-link voltage variations can be switched on or off. The selection of these converter settings is given in the lines 14 and 15 in Table I.

Table 1 Links and Settings of the Control Structure

#	Variable name	Value	Units
1	ab→αβ.a	Ia	link
2	ab→αβ.b	Ib	link
3	αβ→uv1.α	αβ.α	link
4	αβ→uv1.β	αβ.β	link
5	αβ→uv1.θ	Const1	link
6	PIC2.ref	ADC3	link
7	PIC2.fbk	αβ→uv1.v	link
8	uv→αβ.u	Const1	link
9	uv→αβ.v	PIC2.out	link
10	uv→αβ.θ	Const1	link
11	PWM.α	uv→αβ.α	link
12	PWM.β	uv→αβ.β	link
13	DAC1	PIC2.out	link
14	PWM type	SVPWM	enum
15	Vdc corr.	Yes	enum
16	PIC2.Kp	1.00	-
17	PIC2.Ki	0.0	%/s
18	PIC2.Max	100.0	%
19	PIC2.Min	-100.0	%
20	Const1	0.0	%

The parameter settings of the PI-controller for *q*-axis are shown in the lines 16-20 in Table I. It gives numeric parameter values, the range of possible deviation and their units. For example, the proportional gain is set to 1 whereas the integral gain is set to zero for the initial test. Minimum and maximum saturation points are set according to the limits of the inverter.

All these links and settings can be selected, edited and implemented using the control unit or a PC. It has been observed that the control structure building requires the students to work relatively longer for the first time. However, the following experiments are conducted much faster due to the gained experience. The advantage of this approach is that the students compose and build the control system understanding the links between elements and behaviour of the complete system.

5. Compilation of the Control System Core

Upon successful completion of the control system configuration the list of links and settings is used to compile the software core for the controller using the built-in compiler. Initially the compiler determines the sources having data available for processing and creates the data copies from these sources. At the next step the compiler inserts the calls for the elements having the full set of the input data. For example, the Clarke transform has all input data available and its function can be executed. But the next transform from stationary to rotary frames uses the data from the Clarke transform. Therefore, these transforms should be consequently executed in the compiled programme.

All the elements described in the data area "elements" are shown in Table 2. Each element has the execution address in the program memory and a ready flag. If the compiler generates the execution code of the particular element in the control core then the flag is set.

Table 2 Description of the Elements

# of the element	Address in the program memory	Ready flag
0	doNothing	0
1	piController1	0
2	piController2	0
…	…	…
16	hysteresis1	0
…	…	…
24	filter5	0
…	…	…

Table 3 Description of the Data Sources

# of the source	Address in the data memory	# of parent element	Ready flag
0	main_null	0	1
1	constant1	0	1
…	…	…	…
9	main_speed	0	1
…	…	…	…
13	PIcontroller1_out	1	0
…	…	…	…
26	hysteresis1_out	16	0
…	…	…	…
35	main_ADC3	0	1
…	…	…	…

Table 4 Description of the Links

# of the link	Destination address in the data memory	# of the data source	# of the element	Optional flag	Ready flag
…					
5	PIcontroller2_xSet	52 (αβ→uv1.v)	1	0	0
6	PIcontroller2_xFdb	64 (Ia)	1	0	0
7	PIcontroller2_max	0 (disconnected)	1	1	0
…	…	…	…	…	…
10	PIcontroller3_xSet	0 (disconnected)	3	0	0
…	…	…	…	…	…

Table 3 shows all data sources described in the data area "sources". The first column is the number of sources used to define the link from the link table (Table 4). The second column contains information about the physical address of this variable in the data memory of the microcontroller. The next column contains the information about the corresponding element to be executed to produce the data. The last column is the

ready flag set by the compiler when the element execution function is generated and placed into the control core code. Some sources are always available such as speed, constants, currents etc. and contain "1" in the flag field.

The connections between elements are defined in the "links" data area (Table 4). Every link can be set to a data source or disconnected if the input is optional or the corresponding element is not used. If the link is defined then the data is taken from the data source and if the link is undefined then the data is taken from the parameter.
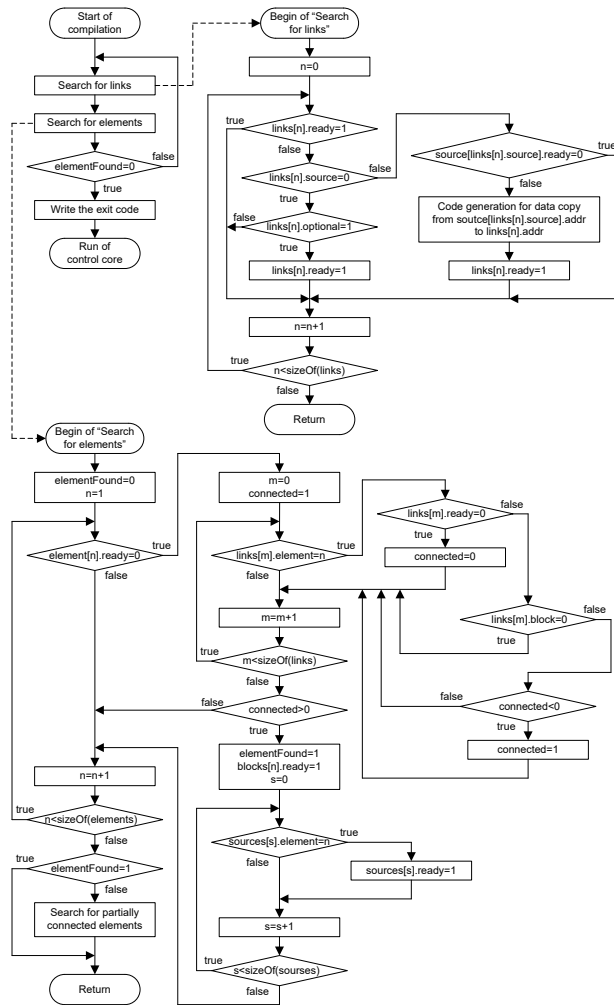

Fig. 5. *Algorithm of the control core compiler.*

The algorithm of the control core compiler is shown in Fig. 5. The compiler executes the search of the links with the ready data to produce the data copy code and then the search of the elements with ready inputs to produce the execution code of the elements. These operations are repeated until the search of the elements returns a zero result. This means that the compilation of the control core is completed. The compiler produces

relatively good code, which contains the data copy operations and the element function execution code. The example of the generated code for the simplified control system is shown in Table 5. It can be seen that the compiler initially forms data copy code using "ldp" and "bldd" instructions for all currently available data sources. When the ready data sources are completed, the compiler produces the code for the execution of the element functions using "call" instruction for the elements having the full set of data at the inputs. The compiler forms the data copy code and the execution code until the control structure is fully compiled.

Table 5 Example of the control core code for the simplified control structure

```
prog:
        ldp       #main_ai3
        bldd      main_ADC3, #PIcontroller2_ref
        ldp       #main_iA
        bldd      main_iA, #ab2alphaBeta_a
        ldp       #main_iB
        bldd      main_iB, #ab2alphaBeta_b
        ldp       #const_1
        bldd      const_1, #alphaBeta2uv1_teta
        ldp       #const_1
        bldd      const_1, #uv2alphaBeta_teta
        ldp       #const_1
        bldd      const_1, #uv2alphaBeta_u
        call      ab2alphaBeta
        ldp       #ab2alphaBeta_alpha
        bldd      ab2alphaBeta_alpha, #alphaBeta2uv1_alpha
        ldp       #ab2alphaBeta_beta
        bldd      ab2alphaBeta_beta, #alphaBeta2uv1_beta
        call      alphaBeta2uv1
        ldp       #alphaBeta2uv1_v
        bldd      alphaBeta2uv1_v, #PIController2_fbk
        call      PIcontroller2
        ldp       #PIcontroller2_out
        bldd      PIcontroller2_out, uv2alphaBeta_v
        call      uv2alphaBeta
        ldp       #uv2alphaBeta_alpha
        bldd      uv2alphaBeta_alpha, Inverter_alpha
        ldp       #uv2alphaBeta_beta
        bldd      uv2alphaBeta_beta, Inverter_beta
        call      Inverter
        b         returnToT1Int
```

6. Experiment Execution Results

6.1. Test of the Simplified Control System

The result of the operation of the simplified control system is shown in Fig. 6. Every graph represents currents in three phases of the motor and the voltage reference for q-axis obtained from the q-axis PI-controller.

The current reference set to 5.7 A is received from the potentiometer. The simplified control strategy produces q-axis current which only appears in the phases B and C whereas the current in the phase A should be close to zero. The transient in Fig. 6a shows that the tuning of the current controller is very relaxed. There is no oscillation and the steady state value is smaller than the references due to absence of the integral component of the PI-controller.
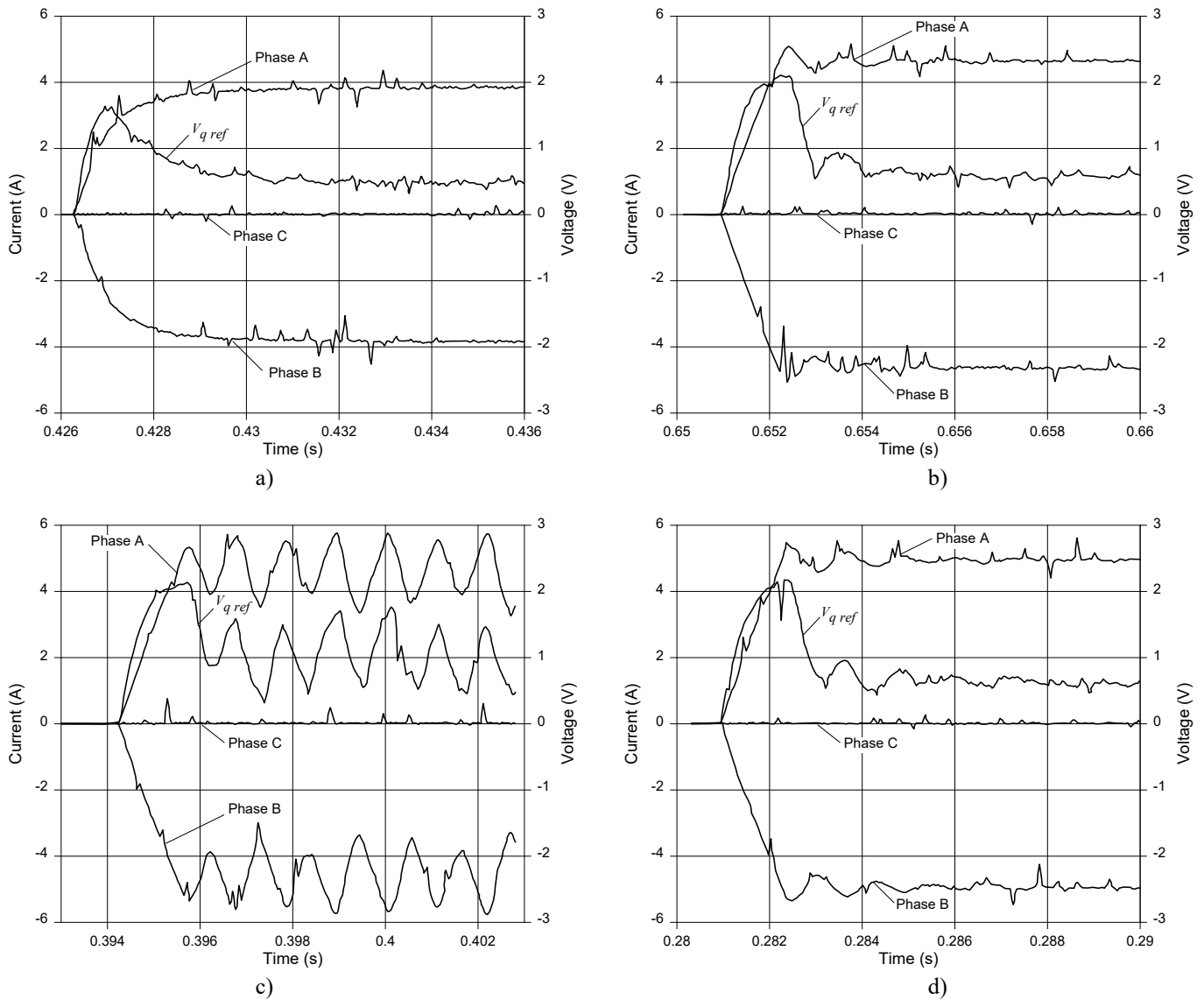
Fig. 6. *Transients of currents in each phase of the induction motor operating under the simplified control system algorithm.*
a Proportional gain of PI controller is 1; no integral component
b Proportional gain of PI controller is 4; no integral component
c Proportional gain of PI controller is 8; no integral component
d Proportional gain of PI controller is 4; gain of integral component is tuned

The tuning of the PI-controller is set as a practical student experiment. The students are expected to increase the proportional gain of the current controller and run the step response test a few times. Fig. 6b shows the transient for the proportional gain of 4 and Fig. 6c shows the transients for the proportional gain of 8. It can be seen that there is an oscillation under the higher proportional gain, therefore the value of 4 should be selected for the integral gain tuning. The integral gain of the current controller should be increased until the steady state error is eliminated. Also, the stability of the system should be on the acceptable level as shown in Fig. 6d.

6.2. Tuning the Flux Controller

When the *q*-axis current controller is tuned, its settings can be copied to the *d*-axis current controller. The axes have approximately the same parameters and it is assumed that any difference due to saturation effect is neglected.

At the next stage the flux controller and rotor flux observer should be added into the system. It is expected that the motor parameters are already known and the students use it to conduct the tuning of the rotor flux observer.
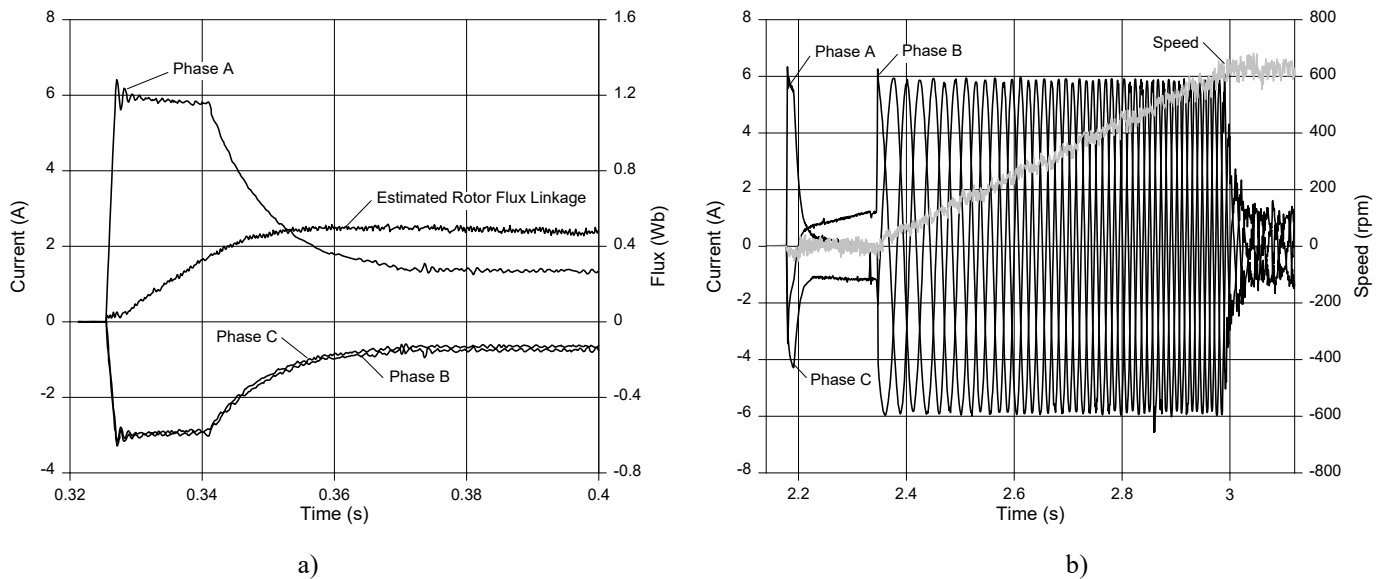

a)   b)

Fig. 7. *Transients of currents in each phase at start-up of the induction motor*
a Flux controller in operation at step response
b Magnetisation and start-up of the motor

The rotor flux estimation can be observed using the DAC. The limits of the flux controller are set to 100% of the rated current of the motor. The reference *q*-axis current is set to zero. The transients for the step response are shown in Fig. 7a. On start-up the flux controller is saturated and, therefore, the maximum current reference is applied to the *d*-axis current controller. While the *d*-axis current is limited at the maximum value, the estimated rotor flux linkage is growing until the reference value. Then the *d*-axis current i_{sd} is decreased to the steady state value to support the rated flux linkage. The flux controller remains stable at relatively high gains in the proportional and integral channels. The *d*-axis current is equal to the current in phase A until the motor starts rotating.

The inclusion of the speed controller into the control system provides the induction motor operation at the reference speed. However, the motor start-up under the speed control should be conducted in two steps: (1) the motor magnetisation where the rotor flux linkage reaches the referenced value; (2) the normal operating mode. The start-up transient of the motor is shown in Fig. 7b.

7. Energy Saving Operation

It is expected that the electrical power consumption of the laboratory workbench is significantly increased due to the higher power rating of the electrical machines involved in the tests. In order to reduce the amount of electrical power required for the test execution, the laboratory workstation operates under an energy saving mode where electrical energy generated by a "load" machine is recuperated to supply a "drive" motor. Under this approach, the power consumption is minimised to cover only electrical and mechanical power losses occurring in the workstation. The energy saving operation requires a parallel connection of dc-links of the power converters for both machines to ensure power recuperation. Fig. 8 shows an example of the workstation scheme connected to operate under energy saving mode where dc machine is a "load" generating electric power to be sent back through dc link to supply an induction motor running as a "drive".
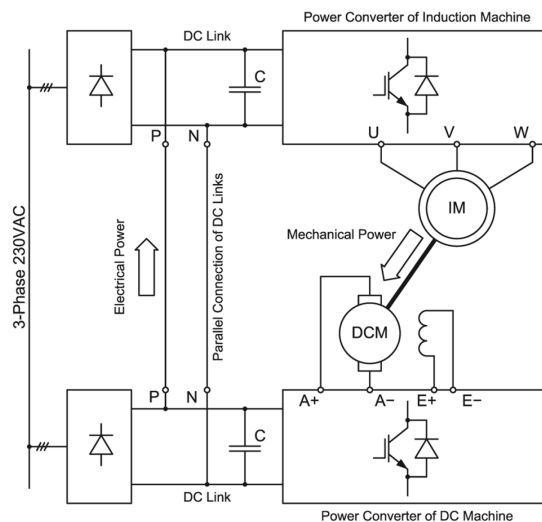

Fig. 8. *Energy saving operation of the workstation where dc links of both converters are connected in parallel; the dc machine is operating as a "load" and the induction machine (motor under test) is operating as a "drive"*

8. Conclusion

The instructional laboratory equipment discussed in this paper was designed and manufactured to provide the practical investigations of electric drive control principles and algorithms. The laboratory

equipment is based on two-machine workstations controlled using a 7.5 kW power converter and embedded microcontroller. The workstations are applicable for the investigation of a vast majority of control strategies for the induction and dc motors. The hardware of the workstations are equipped with the electrical machines of industrial size ensuring proper characterisation of the motor control. The software integrated into the microcontroller provides the protection of the hardware and suggests a number of control elements used by the students to build up an appropriate control structure for the further investigation. This approach ensures safe laboratory work execution and underpins the students' understanding of the subjects learnt during lectures and tutorials.

Fig. 9. *The instructional laboratory on electric drive control at Moscow Power Engineering Institute.*

A 5-workstation instructional laboratory has been implemented at the Department of Electric Drives of Moscow Power Engineering Institute. The laboratory is currently used to support the delivery of the practical component of the subject "Motor Control Systems" at the masters level. In order to extend the portfolio of experiments on various types of electric drives, two workstations in the laboratory have been recently equipped with Switched Reluctance Motors [16]. The future work suggests the expansion of the laboratory to include practical experiments on Synchronous Reluctance Motors [17].

9. References

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