Laboratory DC Machine Test Bench with Siemens DCM Drive

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Abstract: *This paper gives educational aspect of a laboratory setup with DC machine dedicated to students who follow the courses of electric machines and drives. The main idea is to present possibilities of new Siemens DCM drive in different operation modes with DC machine in laboratory environment. Laboratory test bench allows students to load DC machine and observes characteristic parameters, tune the motor current and speed control loops, implement different braking and regenerative operation regimes of DC machine. Basic setup of DCM drive and laboratory exercises are described as well as some experimental results. Proper discussion of the obtained results is given at the end of a paper.*

Keywords: *DCM drive; laboratory setup; DC machine; Starter.*

1. INTRODUCTION

Electric motor drives are unavoidable part in modern industrial processes. Nowadays, in the industry, the majority of all drives makes drives with AC machines. Substantial increase in urbanization along with growing rate of industrialization are the major factors driving the AC drives market trends. Urbanization would increase consumer demand, which results in to increase in the manufacturing sector, propelling the demand for AC drives during the forecast period [1]. Installation of new electrical drives in solving industry operation demands and retrofit or repairing existing industrial drive usually imply installation of (or replacement) with the AC drive. This is mainly justified after a simple economic analysis as well as the extraordinary control capabilities of the AC drives and induction machine characteristic.

However, the installation of drives with AC machines is not always justified in economic and technical terms. Depending on the power of the drive, the existing technical conditions and the operational range of the drive, there are situations where the installation of a drive with DC machines has an economic advantage over an AC drive with the same power [2]. From this reason, the principles of operation and control of DC drives are still studied in courses of electrical machines and drives at universities.

Modern power converters for DC drives used in industry rely on very simple operational principle that students are get familiar during the course of electric drives and laboratory exercises. However, the software capabilities of modern converters and

drives with the development of IT are becoming advances and more complex, so students, although knowing the principle of operation of the drive, are not able to quickly and easily perform commissioning the DC drive. Modern industrial communications, higher control levels, the Industrial Internet of Things (IIoT), etc. represent a special aspect of drives nowadays that further enhance their possibilities.

For this reason, in the EMPA laboratory [3] of Faculty of Technical Sciences Čačak, a laboratory setup for 4-quadrant (4Q) operation of DC and AC drive is developed where students can get familiar with different operation principles of modern electrical drives. This is particularly important nowadays where the use and exploitation of DC drives is almost neglected and rarely applied. In this paper modern Siemens DCM converter is described and its educational and operational possibilities are presented through experimental setup.

2. LABORATORY SETUP AND THEORETICAL BACKGROUND OF DC DRIVE CONTROL

DC machine is an unavoidable part of the industry, and it is used in electric drives that require a wide range of power and speed as well as high accuracy in terms of torque, speed and position control [4].

Laboratory setup with AC and DC machine drives and with a control joystick is developed and shown in Fig. 1. In this laboratory setup students can perform different operation regimes of DC machine where AC machine can be used for emulation of different load characteristics. Parameters of DC machine are given in the Appendix. The theoretical

principles of DC drive control are much simpler compared to the AC drive. DC drive control is based on armature and field circuit voltage / current control as it is shown in Fig. 2.
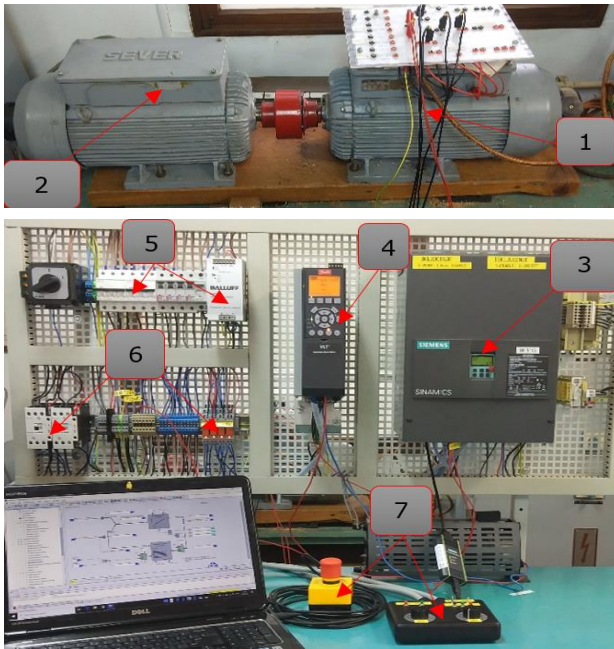

Figure 1. *4Q laboratory setup with DCM drive*

Where:

1. DC machine
2. AC (induction) machine
3. DCM converter – Siemens DCM
4. AC converter – Danfoss
5. Logic power supply and safety
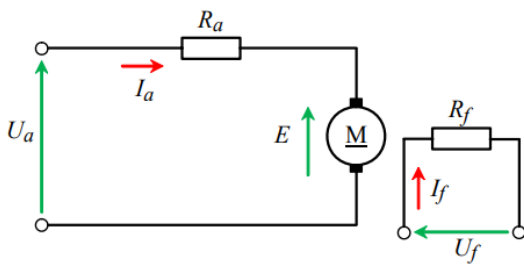6. Relays and contactors
7. Control joystick and emergency stop

Figure 2. *DC machine armature and field circuits*

By controlling the parameters of the motor armature and field circuits, it is possible to achieve different mechanical (torque vs. speed) characteristics of the DC drive in order to adapt it to the load system. With the additional load system control, it is possible to realize and record characteristics for different operating regimes of the 4Q DC drive such as:

- Recording of mechanical characteristics at different values of armature voltage, Fig. 3
- Recording of mechanical characteristics at different values of field current, Fig. 4
- Recording of mechanical characteristics with added resistance in armature circuit
- Generator (recuperative) braking

- Reverse current braking (plugging)
- Electrodynamic braking
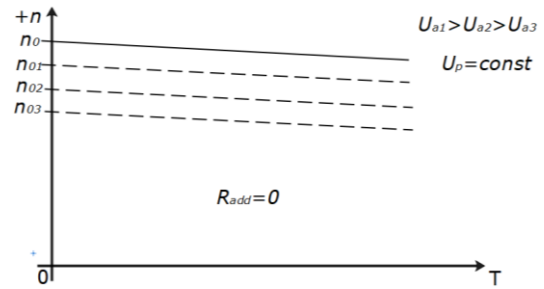- Characteristics of DC machine as a generator, etc.

Figure 3. *Mechanical (torque vs. speed) characteristics of DC machine obtained by changing the armature voltage*

The principles of DC drive control, although very simple, require different control loops implemented and tuned in order to achieve satisfactory drive characteristics [5-6]. The control loops of the current, speed and position of the DC drive require careful tuning so the drive can keep higher possible bandwidth characteristics.
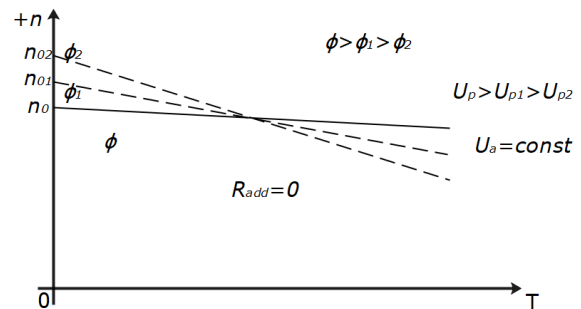

Figure 4. *Mechanical (torque vs. speed) characteristics of DC machine obtained by changing the field voltage (field weakening)*

The realized laboratory setup enables 4Q drive operation with DC motor and closed speed loop control where the speed is measured with tachogenerator located on the motor shaft. The control structure loops of the armature current, field current as well as speed/position is realized within the DCM converter. Parameterization of entire drive is performed via the software package STARTER. Commissioning and reference control are performed by using the joystick shown in Fig. 5.

Figure 5. *Control joystick*

3. SIEMENS DCM DRIVE AND STARTER SOFTWARE

SINAMICS DC MASTER converter units are compact units containing both the power unit for the armature supply and the power unit for the field supply, as well as the control electronics and possible additional modules, Fig. 6. SINAMICS DCM converter can operate in all four quadrants (4Q), can control the speed of the motor in both directions and return the energy directly to the power network during the generator regime. The armature is supplied via two fully-controlled three-phase bridges connected in a circulating-current-free inverse-parallel configuration.

Figure 6. *Sinamics DCM drive*

Applications where a logic operation connecting several states (e.g. access control, system status) to a control signal (e.g. ON command) is required to control the drive system also can be implemented in DCM drive with Free Function Blocks (FFB) where vast of logic and mathematics operation and latching elements can be implemented. Moreover, for applications requiring a more complex method of controlling the drive system which cannot be accomplished using the FFB option of Drive Control Charts (DCC) can be used. DCC makes it possible for one of the interconnected elementary function blocks to generate a graphical depiction of an existing function diagram and load it to the converter [7].

The drive can be parametrised and controlled via board operator panel (BOP – in this case) or advanced operator panel (AOP). However, easiest way of parametrisation of the drive is through STARTER software where with graphical representation of drive control structures user can easily access to all parameters (form digital and analogue IO to the output gating unit of the armature and field voltage control structures).

After properly wired the converter and motor and established profibuss industrial communication with the PC (Starter), it is necessary to configure the drive and enter the basic information about the drive. This means entering the motor rated values, definition of the motor current and speed limits as well as additional drive elements such as encoder / tachogenerator, motor brake, etc. (Fig. 7).
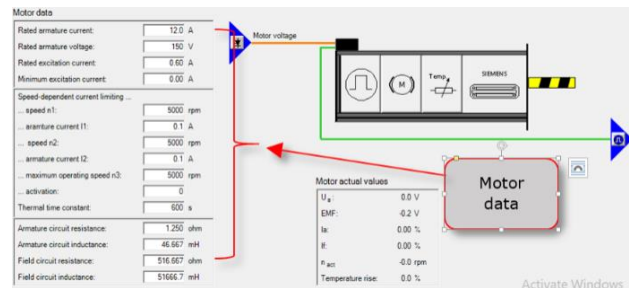

Figure 7. *Motor data*

Before commissioning, it is necessary to assign the main digital IO functions and connect them to the buttons, switches and potentiometer on the control joystick shown at Fig. 5. Then the user can define the drive control type – torque or speed control.

Definition of digital and analogue IO drive functions can be done by connecting them to wide range of other drive variables, as it is shown in Fig. 8. In this way, the necessary requirements and procedures for switching on, switching off the drive, emergency stop function, alarms and other faults acknowledgements and reset can be defined and set.
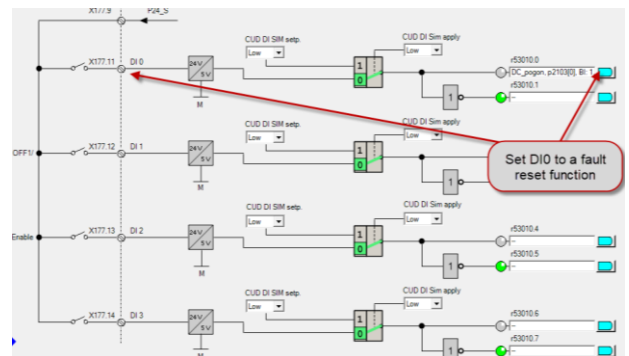

Figure 8. *Definition of D/A inputs and outputs*

In order to have a drive with fast and quality response, the motor data (resistances and inductances of all motor windings) must be properly entered. Moreover, the optimisation procedure of the drive control structures must be performed. Optimisation procedures (self-tuning) include the start of the drive under certain conditions where the drive itself determines the necessary and optimal parameters of the current and speed control structures, friction coefficients, shaft torsion, etc. (Fig. 9.)
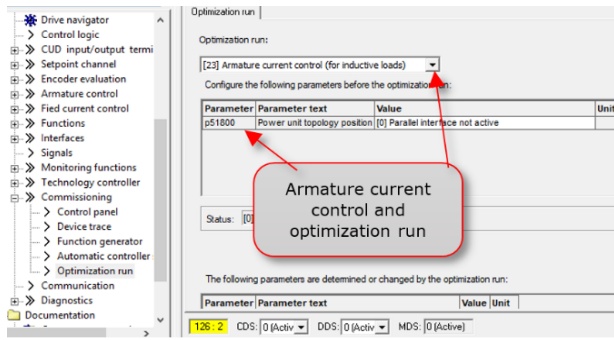
Figure 9. *Drive optimisation runs procedures*

In addition to the listed options, the DCM converter enables detailed adjustment of armature and field circuit parameters, definition of reference values, encoder evaluation, brake control function, motor monitoring, control panel, device trace, function generator, etc., as can be seen in Fig. 10.
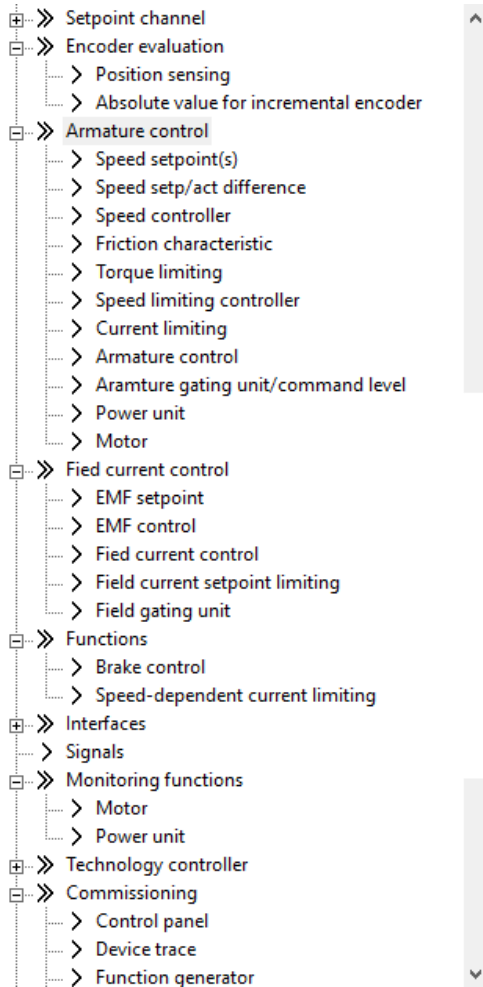

Figure 10. *Converter properties menu*

One of the blocks for the armature circuit control parameters setting is shown in Fig. 11. In addition to the parameters of the PI controller, it is possible to correct the influence of the motor back EMF on the current controller parameters (armature current pre-control - Fig. 11).
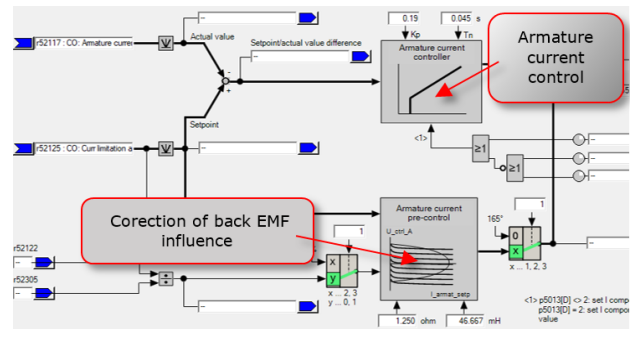
Figure 11. *Armature control block*

In the case of armature and field circuits, where the converter regulates the currents by changing the converter's output voltage, it is also possible to make an influence on the ignition angles of the corresponding thyristor switches as can be seen in Fig. 12.
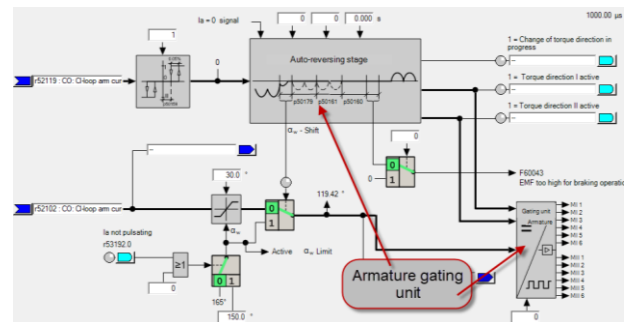

Figure 12. *Armature gating unit block*

Beside previously mentioned BOP and AOP the STARTER software allows the user to create an operator panel with all necessary control functions. Moreover, it is possible to create a repeating motor operation sequence with changing the control type during the sequence execution.

The user has the option to observe and modify all drive parameters in the *Expert list* section as it is shown in Fig. 13. The option of *field weakening* activation which allows the drive to reduce motor field and operate at speeds higher than rated speed is shown in Fig. 13. The *Expert list* enables the overview and modification of more than 52,000 drive parameters, which allows students great opportunities for learning and practicing with this laboratory setup.

Figure 13. *Activation of Field weakening option in parameters Expert list*

4. LABORATORY EXERCISES AND OBTAINED RESULT

Working on this laboratory setup students can get familiar and perform:

- Proper identification and wiring of the drive elements;
- Establishing appropriate industrial communication protocol between the converter and the computer;
- Entering the basic parameters of the motor and defining the overall operating limits of the drive;
- Drive optimisation process and control structures tuning;
- Recording and graphical presentation and analysis of characteristic drive quantities obtained at different operating drive regimes;
- Control parameters modification of the motor current and speed loops and analysis of its influence on the obtained response quality.

The obtained results of the motor speed response to a set reference in the form of a step function are shown in this chapter. The following drive quantities were recorded using the *Device trace* option:

- *Speed actual value,*
- *Armature current actual value,*
- *Feld current controller actual value,*
- *Armature voltage actual value* – voltage measured on machine armature terminals
- *Fixed setpoint output after selection* – speed reference.

Selection of recorded quantities and definition of the recording parameters are shown in Fig. 14.
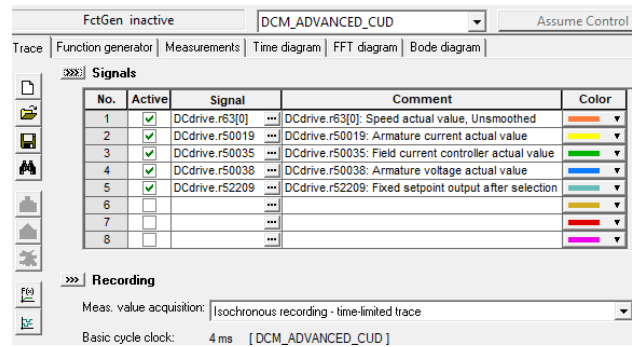

Figure 14. *Recording drive quantities*

The obtained results during the motor start with set speed reference change from zero to rated speed value are shown in Fig. 15. The acceleration and deceleration ramp parameters are set to a minimum value (0s) while the armature current limits are set to ± 100%. Current and speed loop parameters are set to optimal values determined during the optimisation runs (Fig. 9). In this way, the experiment of recording the motor speed response time (time necessary to motor reaches rated speed from zero speed) with armature current limits of 1 p.u. is performed. Having in mind the acceleration time, the speed change range and the motor rotor inertia the accelerating torque as well as motor torque constant can be calculated.

Fig. 15 shows that motor field is turned on approximately 2s before the motor speed reference is set. The filed current response exhibits a small overshoot (around 15%) at the rated reference value of 0.6A. Thanks to the armature current limits (±100%) motor reaches the reference speed in 850ms with 5% overshoot. Other information regarding the quality of the motor current and speed control loops can be seen in Fig. 16. Zoomed part of Fig. 15 during the acceleration and deacceleration (braking) are shown in Fig. 16.
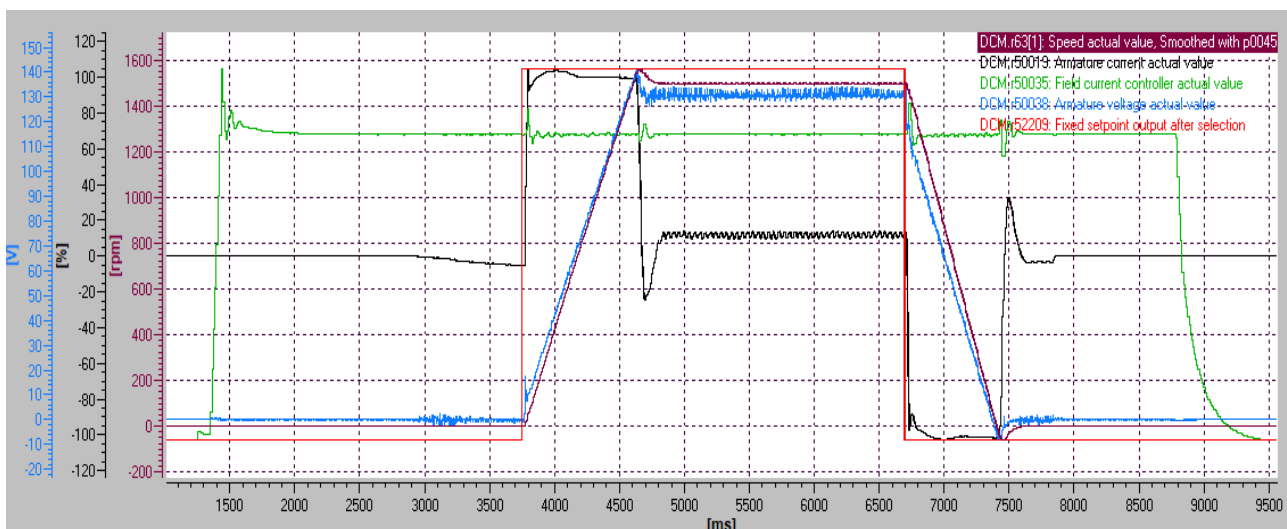

Figure 15. *Motor speed response: Speed reference (red), actual motor speed (purple), field current (green), armature current (black), armature actual voltage (blue).*
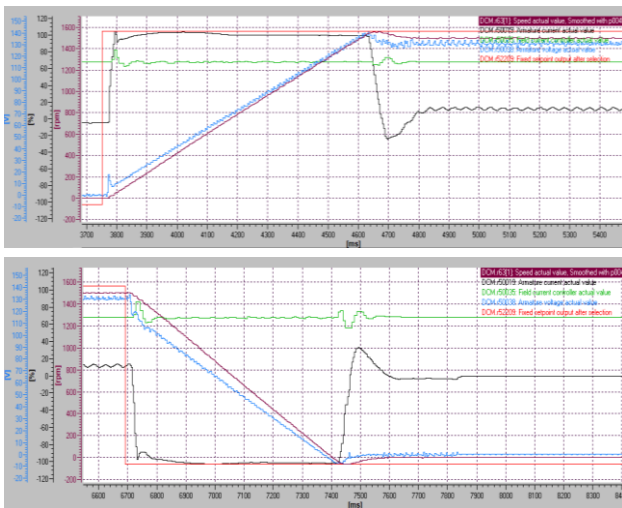
Figure 16. *Zoomed part of Fig. 15 – acceleration (top) and deacceleration (bottom)*

During the deacceleration motor operates in reverse current braking also known as plugging regime. In such case, *Armature voltage actual value* showed in Fig. 16. (bottom – blue line) represents back EMF of the machine, while armature voltage U_a has negative values in order to keep armature current at 1 p.u. The user can achieve desired acceleration and deacceleration time values by defining higher armature current limits or corresponding rump-up and rump-down time values for slower speed response.

By changing parameters in motor current and speed loop the user can observe and learn how each of the control parameters affects the current and speed response quality or compare it to the simulation results. This knowledge is very useful in situations where user have to tune controller manually on a base of experience.

5. CONCLUSION

The paper presents a laboratory setup with a DCM converter for DC drive. The setup allows students who follow the course of electric machines and drives to get familiar with the principles and possibilities of modern industrial controllers in DC drive. The commissioning of the DCM converter, parameters setting, drive optimisation and other laboratory activities that the student can perform with the described setup are presented throughout the work. The obtained results and responses of the DC drive at the optimally set current and speed control loop are presented and analysed at the end of the paper. Working on this setup, the student can try out and examine different operating regimes of the DC machine that exist in nowadays industrial exploitation.

APPENDIX

Table 1. *DC machine SEVER ZIN.112N.S parameters*

I_{an} [A]	12	n_n [min^{-1}]	1540	P_n [W]	1500
U_{an} [V]	150	R_a [Ω]	0.504	L_a [H]	16.56
U_{fn} [V]	200	R_f [Ω]	276.1	L_f [mH]	37.832

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