# POWER ELECTRONICS LABORATORY WITH HARDWARE IN THE LOOP ASSISTED BY *MATLAB AND SIMULINK*

# DL PEL-HIL 4.0

***MATLAB & SIMULINK for model-based control algorithm design, simulation, and real-time testing***

## *INTRODUCTION*

The Power Electronics Laboratory with Hardware-in-the-Loop support provides a complete and flexible platform for studying, designing, testing, and validating advanced control strategies for power converters and electric drive systems. The laboratory combines a real hardware environment with the modelling and simulation capabilities of **MATLAB and Simulink**, allowing users to move efficiently from theoretical analysis to practical implementation.

The system is specifically designed to support hands-on experimentation on key power electronics topics, including DC choppers, inverters, DC motor drives, permanent-magnet servo motor drives, and asynchronous motor drives. Through its integrated measurement and control architecture, users can acquire electrical and mechanical variables, analyse system behaviour, and implement sophisticated control algorithms in a structured and reliable way.

By integrating **Hardware-In-the-Loop (HIL)** and **Rapid Control Prototyping (RCP)** techniques, the laboratory enables real-time testing of control models before and during hardware implementation.

This approach allows users to evaluate dynamic performance, tune control parameters, verify converter operation, and validate motor drive strategies under realistic operating conditions while reducing development time and improving system reliability.

The modular configuration of the laboratory makes it suitable for a wide range of educational, research, and industrial training activities. Different experimental setups can be easily configured according to the required application, enabling users to investigate both basic and advanced concepts in power electronics, control engineering, and electric drives. To reproduce different load conditions for both DC and AC machines, the system includes a brushless motor servo drive operating in speed and torque control modes. This configuration supports bidirectional operation and enables four-quadrant testing, making the platform particularly effective for analysing motor behaviour under motoring and regenerative braking conditions.

Overall, the laboratory offers a comprehensive environment for developing practical skills in model-based design, real-time control, converter control, and motor drive applications, while also supporting the validation of academic research and advanced engineering studies.

**MATLAB and Simulink**

***Note: Licenses are not included with the trainer and must be managed independently by the users***

## *TRAINING OBJECTIVES*

The system enables users to study and develop control strategies for power converters and electric drives.

They will be able to:

- Conduct hardware-in-the-loop testing in real-time,
- Model the complete system in offline simulation,
- Study Park and Clarke transformations in control design,
- Study space vector modulation to optimize control of IGBT-based inverters,
- Perform model-based design for control of DC choppers, inverters, DC motors, servo motors, and asynchronous motors in open-loop, single closed-loop, and cascade closed-loop configurations using a speed sensor,
- Convert control models in Simulink into discrete compiled code for real-time execution in the control system,
- Study and develop automatic current and speed controllers,
- Compare actual test results with offline simulations.

## *EXPERIMENTAL TOPICS*

The users can cover the following topics:

- DC chopper,
- Inverter,
- DC Drives with Cascade Control,
- Variable-Speed Permanent-Magnet Servo Drives,
- Field-Oriented Control of Asynchronous Motors.

# POWER ELECTRONICS

## *LABORATORY'S COMPOSITION*

The laboratory is composed of different modules, components, and motors as in the following list:

| CODE | DESCRIPTION | QTY |
|---|---|---|
| **DL RCPCORE** | Rapid Control Prototyping Core module | 1 |
| **DL 2106SPS-EXCT** | AC and DC Power supply module | 1 |
| **DL 2106T06** | Frequency converter module | 1 |
| **DL 2106LPF** | Low-pass filter module | 1 |
| **DL 2106T21-ADP** | Fuses protection module | 1 |
| **DL 2106RLC** | RLC load module | 1 |
| **DL 10400** | Base for machines coupling | 1 |
| **DL 10200A1** | Shunt excitation DC motor | 1 |
| **DL 10115A1** | Three-phase squirrel cage motor | 1 |
| **MOTBRA1.3NM** | 1.3Nm brushless motor | 1 |
| **DL 2108T26-LP** | Brushless motor controller module | 1 |
| **DL 2108T26BR** | Braking resistance module | 1 |
| **DL 9026N** | Three-phase waveform acquisition module | 1 |
| **DL 2600TTI** | Isolated transformer | 1 |
| **DL PCGRID** | All-in-One Computer | 1 |
| **DL T12090_SK** | 120x90 workbench | 1 |
| **DL T06090** | 60x90 workbench | 1 |
| **DL A120-3M** | Frame with 3 levels, basic version | 1 |
| **DL SP-A120-LED** | Upper base with LED strip, for DL A120-3M | 1 |
| **TLRCP** | Kit of connecting leads | 1 |
| **DL 1196** | Holder for leads | 1 |

| ENVIRONMENT | DESCRIPTION |
|---|---|
| **MATLAB and Simulink** | This environment allows users to first perform offline simulations of the complete system. Subsequently, they can extract the control component and execute the compiled code on the **DL RCPCORE** for real-time control validation and performance evaluation. |

**MATLAB and Simulink**

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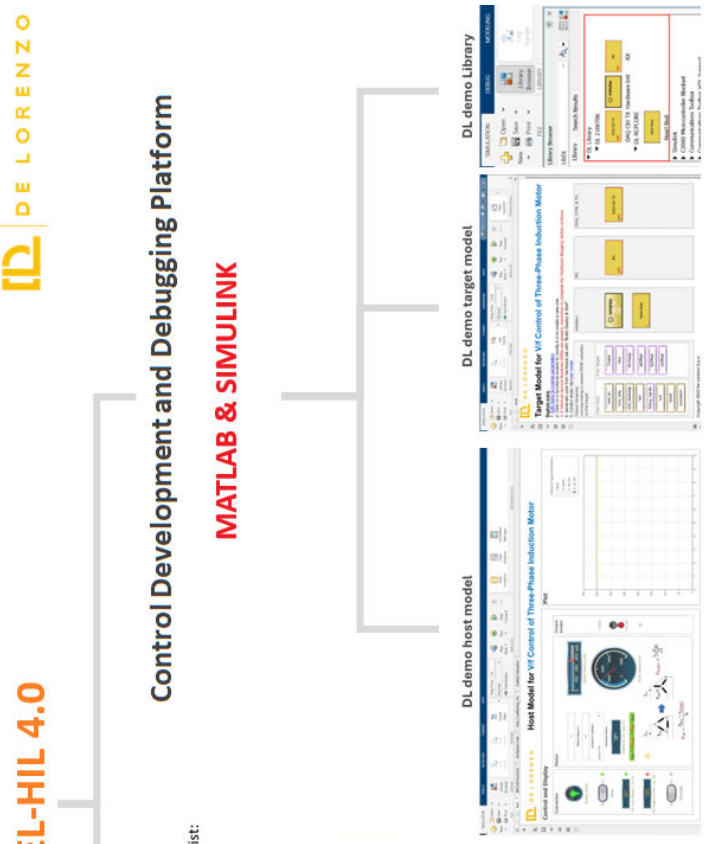
## *DEMO MODELS AND LIBARARY*

Although we do not directly provide the development platform (**MathWorks**), we do offer for each experiment (see image below):

- a **target demo model** (control algorithm),
- a **host demo model** (interface for real-time debugging),
- and a **library** developed by DL, to be installed in Simulink, designed to facilitate further development by the user.

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## *LABORATORY'S MODULES*

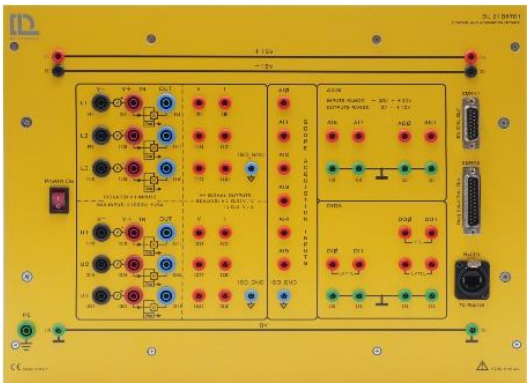
### ***DL RCPCORE***

This is the rapid control prototyping core, a real-time controller designed to execute code generated from **MATLAB and Simulink**. It seamlessly connects **Simulink** users to real hardware implementations, minimizing effort and eliminating the need for C programming skills typically required for embedded systems.

It is equipped with six channels for high-voltage and high-current measurements, functioning like six volt-ammeters.

These channels support measurements of up to ±1000 V and ±25 A, featuring protective bushings and built-in galvanic isolation for enhanced safety and reliability. This simplifies closed-loop control, enabling users to seamlessly integrate it into their control algorithms without worrying about missing hardware setups for distributed measurements.

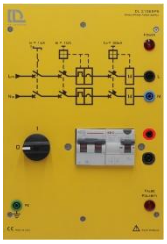
It also features digital and analog inputs and outputs, allowing users to customize the hardware setup to suit their needs.



### ***DL 2106SPS-EXCT***

This is a single-phase AC power supply for power converters and electric drives, featuring an integrated MCB (Miniature Circuit Breaker) and RCCB (Residual Current Circuit Breaker) for local protection.

It also provides excitation voltage to the DC shunt motor **DL 10200A1**.

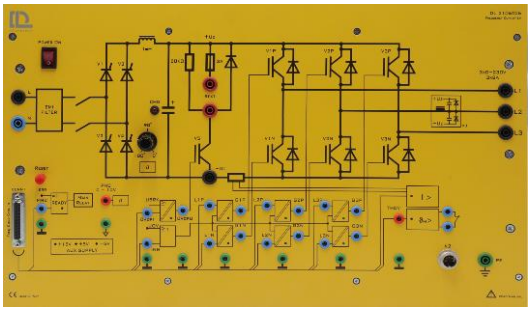


### ***DL 2106T06***

Intrinsically, this is a frequency converter consisting of a single-phase controlled rectifier, a DC link with regenerative braking, and a three-phase inverter.

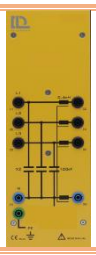
Thanks to the independent drive of the inverter IGBTs, it can also be configured to create various converters, such as DC choppers and single-phase inverter.

It will be controlled by the **DL RCPCORE**, acting as the actuator for the control algorithm to supply a passive load **DL 2106RLC** or motor loads like DC shunt motor **DL 10200A1**, three-phase asynchronous motor **DL 10115A1**, and permanent-magnet motor **MOTBRA1.3NM**.



### ***DL 2106LPF***

This low-pass filter is applied to the output of the **DL 2106T06** to filter AC or DC output voltage and current.



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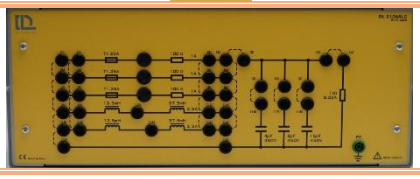
| ***DL 2106T21-ADP***<br>Fuse box for hardware protection, suitable to various needs with different sets of fuses for varying protective currents. | |
| ***DL 2106RLC***<br>This module consists of a set of resistors, inductors, and capacitors, which can be used as passive loads or power filters. |  |
| ***DL 10400***<br>This is a metallic base designed for mounting DL motors. It includes an optical transducer for detecting rotational speed and features anti-vibration rubber feet, making it suitable for cases where two machines are coupled together. | |
| ***DL 10200A1***<br>This is a shunt excitation DC motor with open excitation and armature windings, with thermal protection.<br>*Technical features:*<br>• Power: 200 W,<br>• Voltage: 220 V,<br>• Current: 1.2 A,<br>• Excitation: 150 V/0.06 A,<br>• Speed: 3000 rpm. | |
| ***DL 10115A1***<br>This is a squirrel cage three-phase asynchronous motor, with armature windings suitable for delta or star connection, with thermal protection.<br>*Technical features:*<br>• Power: 370 W,<br>• Voltage: 230/400 V - Δ/Y,<br>• Current: 1.9/1.1 A - Δ/Y,<br>• Frequency: 50 Hz,<br>• CosØ: 0.7,<br>• Speed: 2870 rpm. | |
| ***MOTBRA1.3NM***<br>This is a permanent-magnet servo brushless motor with an embedded encoder, used with the controller **DL 2108T26-LP** or with the frequency converter **DL 2106T06**.<br>*Technical features:*<br>• Nominal power: 400 W,<br>• Nominal torque: 1.3 Nm,<br>• Nominal speed: 3000 rpm. | |

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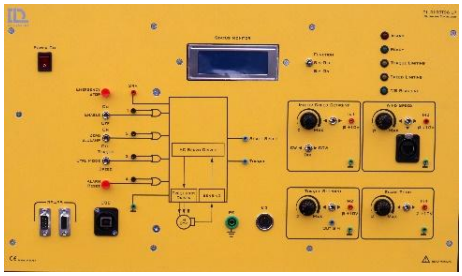
## DL 2108T26-LP

This is the application-level controller module for the brushless motor **MOTBRA1.3NM**, enabling the operation of a servo motor in a generator application or in the braking of the motor.

*Technical features:*

- Motor speed setpoint,
- Torque setpoint with torque limiting Led,
- Torque analog output: 0…10V,
- T/S (Torque/Speed) reaching Led,
- Rated power: 300 W,
- Rated speed: 3000 rpm,
- Ports: 1 USB and 2 RS485,
- 5 pins connector: for speed reading.



## DL 2108T26BR

This is the external brake resistor for the **DL 2108T26-LP**, used during regeneration to protect its internal DC link.

## DL 9026N

Advanced module used in three-phase systems laboratories to visualize and measure waveforms.

*Technical features:*

- Selectable AC single-phase to measure V, I, P, Q, and S,
- An embedded data acquisition board, with a full-speed USB interface, to observe the voltage and current waveforms of the three-phases simultaneously with isolated input, and with RS485 communnication port,
- Complete with data acquisition SW developed in Labview for waveforms visualization. It shows the most importand electrical parameters (RMS for voltage and current for all phases, single and total, P, Q, S, and power factor) and performs the FFT transformation to show the voltage and current spectrum.

## DL 2600TTI

Isolation transformer to be placed between the three phase mains and the laboratories providing a three phase secondary voltage with isolated neutral suitable for the modules operation.

*Technical features:*

- Three-phase mains input with +10%/-10% adjustment.
- Output: 400V with +5%/-5% adjustment.
    - ♦ 3 x three phase CEE sockets (3P+N+E)

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| ♦ 2 x single phase CEE sockets (2P+E)<br>♦ 2 x single phase type F socket<br>• 10 A, 30 mA differential magneto-thermal protection.<br>• Motor-protection circuit-breaker: 4 to 6.3 A.<br>• Mushroom emergency stop push-button.<br>• Maximum output power: 3 KVA. | |
| ***DL PCGRID***<br>PC All-in-One.<br>*Technical features:*<br>• Display: 21.5", Full HD,<br>• Resolution: 1920 x 1080 Pixel,<br>• Processor: Intel® Core™ i3, 1,2 GHz ,<br>• RAM: 8 GB,<br>• SSD: 256 GB,<br>• OS: Windows 11. | |
| ***DL T12090_SK***<br>Workbench with melamine flatbed. Two holes are present on the flatbed to allow the assembly of a three level frame **DL A120-3M**.<br>*Technical features:*<br>• Dimensions (HxLxW): 80x120x90 cm,<br>• With locking wheels,<br>• Supplied with 15 sockets protected by a thermal magnetic circuit breaker. | |
| ***DL T06090***<br>Multifunctional bench used in laboratories as support for modules and electrical machines.<br>*Technical features:*<br>• Dimensions (HxLxW): 80x60x90 cm,<br>• With locking wheels. | |
| ***DL A120-3M***<br>Frame with 3 levels, basic version, for assembling the modules of the laboratory. To be fixed on the workbench **DL T12090_SK**. | |
| ***DL SP-A120-LED***<br>Base with LED strip, to be fixed on the upper side of the frame **DL A120-3M**. | |

| | |
|---|---|
| ***TLRCP***<br>Set of wiring cables of different diameters and lengths. | |
| ***DL 1196***<br>A sturdy structure used to store and organize the various connection cables in the laboratory, with wheels. | |