ADVANTAGES WHEN TESTING WITH pHIL E-MOTOR EMULATOR

pHIL E-Motor Emulator allows simplified, full power E-Drive inverter testing with extended features even without E-Motor, measurement shafts and load dynamometers.

Extensive functionality
• Low speed (0..10 rpm) and very high speed tests available
• No thermic E-Motor drift for full reproducible test cycles
• Production tolerance simulation
• Fault simulation (rotor sensor offset, over temperature, signal noise, short circuit, open wire, mechanical fault …), non-destructive to the UUT
• E-Motor model exchange with a mouse-click
• Easy exchange of a virtual E-Motor model in one mouse click
• Change E-Motor parameters during runtime

UUT protection
• Current limitation by parameter for easy stepwise approach

INTRODUCTION AND BASIC INFORMATION


GAME CHANGING TEST METHODOLOGY FOR INVERTERS

pHIL – Technology (Power-Hardware-in-the-Loop) Simulated mechanics, correct electrical power flow

The “mechanical world” for inverter tests can be avoided in a smart way with the aid of an electronic emulation of the E-Motor, so-called E-Motor Emulator (E-ME). Wherever the electric motor is only present to test the drive inverter, the new technology of E-Motor Emulator can be employed with convincing advantages.

This technology eliminates the need for all rotating parts and, on the phase level, it can reproduce exactly the behavior of a rotating E-Motor over all 4 quadrants.

The E-Motor Emulator emulates not just the electric motor itself, but also the mechanical drive train components with its torsional behavior.

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The implementation of an E-Motor Emulator for inverter testing offers many advantages, in addition to a simplified inverter operation without motor, measurement shafts and dynamometer:

**Original E-Motor Linked to Dynamometer**
- Extension of mechanical setup (high stiffness frame, high-speed shaft) and handling with different E-Motor types.
- Rotating parts (safety issue) - compliancy with machinery directive 2006/42/EC and EN ISO13849-1 standard.
- Operating, maintenance & lifetime costs (dynamic bearings, drive shafts, isolation, cooling systems).
- Reduced handling effort with a virtual E-Motor (adjustable and changeable by SW model).
- Low hazardous potential - simplified automation / safety system.
- Rotating parts (safety issue) - compliancy with machinery directive 2006/42/EC and EN ISO13849-1 standard.

**Electric Motor Emulation (E-ME)**
- Full performance test with minimum energy consumption.
- Original E-Motor linked to Dynamometer Electric Motor Emulation (E-ME).
- Extensive mechanical setup (high stiffness frame, high-speed shaft) and handling with different E-Motor types.
- Reduced handling effort with a virtual E-Motor (adjustable and changeable by SW model).
- Low hazardous potential - simplified automation / safety system.
- Rotating parts (safety issue) - compliancy with machinery directive 2006/42/EC and EN ISO13849-1 standard.
- Reduced handling effort with a virtual E-Motor (adjustable and changeable by SW model).
- Low hazardous potential - simplified automation / safety system.

**E-Motor Emulator Availability Limitation for Different Motor Types**
- As well as encoder/encoder types.
- Switch between different model types by SW.
- Inertas and dynamc of test rig drivetrain might be different from real vehicle drivetrain depending on dynamometer control dynamics and drivetrain simulation idealization.

**E-Motor Emulators from AVL**
- Autonomous devices that can be run completely stand-alone.
- Emulators are usually employed for the operation of drive inverters in a test environment that emulates not only the electric motor, but also the drive-train battery.
- The topology enables a bi-directional energy flow, whereby only the power loss of individual components is taken from the mains.

**TYPICAL SET-UP FOR THE EMULATION OF AN ELECTRICAL DRIVETRAIN WITH E-ME**
- The topology of such a set-up can be adapted to diverse requirements and conditions.
- All components for a completely integrated testbed can be provided out of AVL's product portfolio and supplied as a turnkey solution including a state-of-the-art automation system.
An E-Motor Emulator represents the electrical schematic of an E-Motor as three-terminals (typically) that portray the three phase connections. The integral components of an E-ME include, apart from phase emulation, the emulated motor position sensors which act identically to a real motor - forms a closed loop system. In this configuration, an E-Motor Emulator can be directly connected to a drive inverter and operated like a real motor.

The characteristics of the original motor to be emulated are embedded in the E-ME as a software model (which the user can influence). This model controls behavior of the motor phases and the rotor sensor in a virtual way. Software models are available that correspond to various basic motor types that can be emulated, for example, synchronous or asynchronous motors. These motor models can be changed by software, so that one single emulator can be used to represent different motor types. The phase emulation permits a smooth transition of bi-directional power flow that represents both operating modes “motor feeding” and “generating”. The high dynamic behavior modeling together with the emulated rotor sensor. This enables the cabling and the commutation logic to be tested simultaneously at an early stage.

APPLICATIONS

The E-Motor Emulators from AVL have a variety of fields of use, from the development of system tests to end-of-line tests and lifetime investigations of drive inverters. An E-ME can be of valuable service during the development or the installation of an inverter, whereby the setting of current limits in the E-ME protects the unit under test during the initial first steps. The test inverter can be brought into full operation one step at a time thanks to the closed loop configuration together with the emulated motor sensor. This enables the cabling and the commutation logic to be tested simultaneously at an early stage.

Test Case 1
Static Test of the Phase Current

The E-ME is connected, as the original motor would be, to the test inverter. The rotor position is set numerically to 0° by a software command to the E-ME and kept at that value. In order to safely limit the phase current, the E-ME is commanded to activate a suitable phase current limit. The unit under test is then set to a desired current value and the resulting d/q currents can be read on the E-ME (for example, via the graphical user interface). The test is repeated with various rotor positions, so that any fundamental fault in the cabling or commutation logic can be quickly found.

The possibility to virtually place the rotor sensor on the shaft helps to determine the correct configuration and, if necessary, to recognize complex fault combinations.

Test Case 2
360° Test of the Phase Current

Once Test 1 has been successfully completed, the E-ME is commanded to keep the rotor speed constant within a few rpm and the resulting d/q currents can be viewed as a pilot diagram on the graphical user interface. The plots provide very accurate information on the commutation behavior of the test inverter. By virtually moving the rotor sensor angle, the commutation angle can be influenced on a test-by-test basis.

Test Case 3
Torque Control Check

The E-ME is configured in such a way, that increasing speed generates increasing load torque. This is simply achieved by programming the correspond- ing friction coefficients. If the unit under test is now commanded to generate a torque, the virtual motor begins to turn in accordance with the previously defined mass of inertia. The speed increases until a balance is achieved between the commanded torque and the resulting frictional torque. Several tests can be run using this procedure, for example, to optimize d/q current or torque checks.

Test Case 4
Speed Control Check

To test the speed control, the friction coefficients in the E-ME are set back to the original system values. The friction ratios and mass of inertia on the take-off side of the motor shaft can be included in the original system settings. In this way, a simplified, complete drivetrain can be represented using very simple means.

Soped values of the drive inverter can be comman- ded to this set-up and the settling behavior of the speed controller under different load torques or changed motor characteristics can be verified. Step responses of all relevant parameters during a reverse of rotational direction, or operation in the field-weakening area, can be simply investigated.

Extended Tests

Depending on the project phase, the E-ME as a virtual test motor for the drive inverter can be used to:

• Optimize the commutation algorithms
• Check the reaction to safety-relevant motor faults or noise minimization
• Run loading and aging tests
• Test special functions such as active short circuit or field weakening
• Investigate active damping compensation or noise minimization
• Run end-of-line tests
• Test motor optimizations in real-time
HIGHLIGHTS

Technological Highlights

VARIETY OF MOTOR MODELS

The basic type of motor to be emulated is determined by a variety of pre-defined motor types.

ENTERING THE MACHINE DATA

Depending upon the availability of machine data, the user can choose between a simple and a comprehensive approach with the emulation of boundary effects. The user can enter the data via the E-ME interfaces using parameters or tables, which can then be successively fine-tuned and immediately tested.

VARIETY OF VIRTUAL ROTOR SENSORS

All market standard rotor sensor types are available as emulation modules for the E-ME. This also includes, apart from encoders and Hall sensors, resolvers from manufacturers such as Tyco, Tamagawa and Vogt.

Two or more rotor sensors can be installed in one emulator for special applications such as position control, or for redundant drive systems. All sensor modules strictly emulate the corresponding replacement electrical circuit diagram, including the galvanic conditions, according to the original. This also includes the inductive coupling and decoupling of the signals. This permits the emulated rotor sensors to be connected to the control unit, just as the originals would be, without creating changed galvanic conditions or earth loops.

MODEL PARAMETER SYSTEM

The E-ME employs a powerful parameter system to control the various motor models. The basic motor type is adapted to the specific attributes of the client’s motor by configuring the parameters via one of the bus interfaces. Motors that physically do not yet exist can also be created virtually and run as simulations via the parameters.

The parameter system has the specific ability to make changes to the virtual motor in runtime and in real-time. Specific fault situations and motor tolerances can be emulated and investigated in this way. A further speciality of the parameter system is the “freeze” function. This function permits the motor model to be cut at an arbitrary point and subsequently modified with other data. This results in the following, wide-ranging, possibilities:

1. Validation of the motor model (crucial for safety-critical applications)
2. Fault stimulation
3. Investigation of the control ability of the control unit (current, torque, speed,…)

USER INTERFACES

The emulator has bus and analog interfaces that permit the problem-free integration of the device in every environment:

1. CAN2.0B
2. TCP/IP
3. EtherCAT
4. Analog signal outputs

MODEL PARAMETER SYSTEM

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GRAPHICAL USER-INTERFACE

This GUI is for installation on an external PC and eases the E-ME operation via TCP/IP. All basic motor parameters are visualized in their physical measures. In addition to this, the GUI informs the user about the E-ME hardware (voltage, warnings, status) and allows the user to plot up to four parameters versus time.

MODEL MONITOR

The graphical user interface of the E-ME includes an online plot function, which can be extended to a three-channel software oscilloscope “model monitor”. This permits the switching behavior of the test inverter to be investigated with high time resolution. Very short commutation faults can also be visualized using the extensive trigger possibilities.

MAGNETIC FLUX MODELLING

The exact modeling of magnetic flux effects in electric motors is one of the outstanding advantages to our customers. Saturation effects as well as native flux characteristics can be emulated allowing flux non-linearities and harmonics and the correct operation in field-weakening mode.

DQ HARMONIC DESIGNER TOOL

Nonlinearities of the magnetic flux can easily be implemented into the motor model by use of the “DQ Harmonic Designer” tool. The user can simply define harmonics on the back EMF which are automatically transformed into the dq-System.
## Technical Data

### System Data

<table>
<thead>
<tr>
<th>Emulator Type</th>
<th>S-ME 400-400</th>
<th>S-ME 600-300</th>
<th>S-ME 600-600</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of Motor Phases</td>
<td>3 Phases</td>
<td>3 Phases</td>
<td>3 Phases</td>
</tr>
<tr>
<td>Cooling</td>
<td>Liquid cooling</td>
<td>Liquid cooling</td>
<td>Liquid cooling</td>
</tr>
<tr>
<td>Dimensions HxDxW [mm]</td>
<td>2,400x800x1,600</td>
<td>2,400x800x1,600</td>
<td>2,400x800x2,400</td>
</tr>
<tr>
<td>Weight [kg]</td>
<td>850</td>
<td>1,880</td>
<td>2,600</td>
</tr>
<tr>
<td>System documentation</td>
<td>Manual (Installation and Operation)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Electrical Specification

<table>
<thead>
<tr>
<th>Emulator Type</th>
<th>S-ME 400-400</th>
<th>S-ME 600-300</th>
<th>S-ME 600-600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emulator DC-link voltage</td>
<td>450 V</td>
<td>850 V</td>
<td>850 V</td>
</tr>
<tr>
<td>Motor phase current [max]</td>
<td>&lt; 400 Arms</td>
<td>&lt; 300 Arms</td>
<td>&lt; 600 Arms</td>
</tr>
<tr>
<td>PA current dynamic</td>
<td>10,000 Arms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enclosed electrical field</td>
<td>0 … 5 kHz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjustable number of pole pairs</td>
<td>1 … 32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enclosed Phase Impedance</td>
<td>adjustable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Enclosed Phase Resistance</td>
<td>adjustable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor speed dynamic</td>
<td>4πu/s &gt; 10x10^6 rpm/sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internal instrumentation sampling rate</td>
<td>U: 25 Ms, I: 10 Ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mode of operation rate</td>
<td>3 MHz / 520 ms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching frequency</td>
<td>800 kHz</td>
<td></td>
<td></td>
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</table>

### Motor Model Specification

<table>
<thead>
<tr>
<th>Emulator Type</th>
<th>S-ME 400-400</th>
<th>S-ME 600-300</th>
<th>S-ME 600-600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real Time Machine Models</td>
<td>Permanent M�ted Synchronous Motor</td>
<td>Separately excited Synchronous Motor</td>
<td>Brushless Machine</td>
</tr>
<tr>
<td>Modeling algorithms</td>
<td>Linear and non-linear via magnetic flux model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model variation</td>
<td>Via powerful parameter system at turbine and in machine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Error simulation</td>
<td>Error Simulation and Manipulation of virtual Motor via Real Time and real-time via operator interface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emulated rotor position sensors</td>
<td>Tamagawa Resolver</td>
<td>Tyco Resolver</td>
<td>Vogt sine/cos sensor Hall Sensors</td>
</tr>
<tr>
<td>Emulated temperature sensors</td>
<td>PT 100</td>
<td>PT 100</td>
<td>NTC</td>
</tr>
</tbody>
</table>

### Operation Modes and Interfaces

<table>
<thead>
<tr>
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<th>S-ME 400-400</th>
<th>S-ME 600-300</th>
<th>S-ME 600-600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand alone</td>
<td>Control with standard PC and graphical user interface</td>
<td>Control by any automation system via any of the serial interfaces</td>
<td></td>
</tr>
<tr>
<td>Inside automation environment</td>
<td></td>
<td>Control via any automation system via any of the serial interfaces</td>
<td></td>
</tr>
<tr>
<td>Interfaces</td>
<td>VCAN 2.0B</td>
<td>TCP/IP 10/100Mbit</td>
<td>EtherCAT</td>
</tr>
<tr>
<td></td>
<td>Configurable analog outputs</td>
<td></td>
<td>Digital-to-analog output and feedback</td>
</tr>
<tr>
<td>Parameter source</td>
<td>Direct from motor specification</td>
<td></td>
<td>Direct from measurement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simulation output (ANSYS or ANSYS)</td>
<td></td>
</tr>
<tr>
<td>Load Simulation</td>
<td>Internal, external and combined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td>Current limits adjustable (for UUT protection)</td>
<td>Temperature supervision</td>
<td>Integration into Emergency Shut Down Environment</td>
</tr>
</tbody>
</table>

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Custom specific solutions on demand.