A test bench to study propulsion drives of electric vehicles

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A Test Bench to Study Propulsion Drives of Electric Vehicles

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***Abstract*- This paper describes the composition and performance of a test bench developed for research and monitoring of the propulsion drives of electric vehicles. Testing possibilities and benefits of the new bench are explained and the results obtained are discussed. In addition, the testing conditions are drawn that correspond to the standard ECE speed cycles.**

I. INTRODUCTION

An electric vehicle (EV) represents a transport facility, such as a bicycle, a car, or a train propelled by an electric motor. Motor drives are the main components of EVs that define their energy efficiency, distance, speed and acceleration performances, and cost. Therefore the focus in this paper is on the propulsion drive of an EV.

The EV is a rather complex system for accurate mathematical description, monitoring, and validation. However, today much attention is paid to the studies of EVs and their test platforms. The test bench, combining advantages of software models and real equipment, contributes to the reduction of the number of vehicle test runs and safe maintenance. Reports of the test benches developed in different research centres cover energy management [1], [2], optimal configuration [3], [4], [5], and combination of different energy sources of EVs [6], like the batteries [7], supercapacitor packs [8], [9], [10], [8], flywheels [6], and fuel cells [11].

Research problems solved for the EV using the test benches are derived from the peculiarities of their performance, in particular from frequent accelerations and decelerations, multiple stops, and stochastic velocity changes, mechanical vibrations, and elastic deformations [12], [13]. All these features require proper drive characteristics, like fast torque response, fault tolerance, and high efficiency at low maintenance and cost. These considerations imply that the design of the platform intended to study and monitor the EV propulsion drive should be verified by forcing it to follow the test cycles that reproduce the actual operating conditions.

As the investigations are focused on the motors, power converters, supply chains, transmissions, transfer cases used in EVs, the main objectives of the test bench developed and described here are as follows:

• to provide the research environment for analysis, investigation, and simulation of marketable EV drive systems

• to establish assessment and verification procedures for different motor, gear, and power converter types used for propulsion

• to support commercial consulting, research and testing for enterprises

• to promote students' participation in research topics associated with electromobility

Below, the configuration and the composition of the new test bench are covered. The tests with the bench are described and the results are discussed in the following sections of the paper. In addition, the testing conditions corresponding to the standard ECE speed cycles are explained. Finally, conclusions are drawn.

Results from the test bench application could affect both the choice of the propulsion drive components and the assessment of the particular drive manufacturing technologies. They suit for comparison of the different models of the propulsion drives in terms of their dynamic performance at start-up and braking, static stability on the road, energy consumption, reliability, and control suitability. It may help researchers to select car models and companies to support and provide customers with many hidden data of the marketable electric cars.

II. TEST BENCH CONFIGURATION

The sketch of the test bench developed in the Electrical Drives Laboratory of Tallinn University of Technology is presented in Fig. 1.

Following [7], the test bench is based on the induction machines. Induction machines, especially squirrel cage motors, have high reliability and low manufacturing cost, but their efficiency and torque density are not adequate. As these demerits are unimportant for the test bench, this type of a machine was used in the test platform. Unlike the synchronous and the dc motor, an induction motor has simple design and suits both for the open ended and the close loop exploration.

The test bench incorporates two motor drives. The testing system based on the ABB ACS800 electric drive consists of a squirrel cage induction motor, an active AC/DC power converter, a remote console, control, measurement, and cabling equipment. The testing drive is furnished with a foot pedal to imitate the real driver's habits in vehicle management. The testing motor M3AA 112m 3GAA 112022-ADC has the following parameters: rated speed of the

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motor - 1455 rpm, rated voltage - 400 V, frequency - 50 Hz, and rated power - 4 kW.

ABB ACS800 power converter is a middle-power class device with broad control possibilities. There are two main control modes of the drive, namely the direct torque control (DTC) [14] and the scalar control supporting the constant voltage-frequency ratio. The converter possesses several predefined macros with factory settings allowing flexible drive tuning for a user. Additionally, ABB ACS800 is equipped with the model-based measurement tools allowing the real-time parameter tracing. It includes the built-in logical controller for programming the converter outputs and inputs to fulfil the basic operations. In the developed test bench, this drive is employed in the scalar control mode to imitate the real driving needs of the EV driver.

As distinct from [7] where the driven motor is connected to the utility supply through a voltage adjustment variator, in the proposed solution the loading machine is supplied with the DTC DC link converter. In this way, the testing drive operates in speed control mode to follow the test cycles whereas the loading drive performs in the torque control mode to follow the torque references. Both systems are power reversible.

The loading system built on the ABB ACS611 electric drive consists of an induction motor M3AA132SB 3GAA 138110-ADC, AC/DC power converter with the diode front end, remote console, and measuring and cabling equipment. ABB ACS611 represents a variant of ABB ACS800 drive with a different firmware version and similar functionality. The DTC mode of the drive operation is suitable for simulation of different loads of the real EV. The loading motor has the following parameters: the rated speed of the motor - 2820 rpm, rated voltage - 400 V, frequency - 50 Hz, and power - 4.7 kW.

To imitate a mechanical chain of an EV, the belts with electromagnetic clutches were used in [5] that join the motor with the transmission shaft. In [7] the traction motor was connected to the wheels via a step-down gear stage. On the contrary, in the proposed solution, a direct coupling through the long metal shaft is implemented, as recommended in [15]. The transmission has a possibility to change the slope angle, thus simulating the cardan with alternating transmission rigidity and moment of inertia. The testing and loading motors are placed on the uniform base to provide their joint operation.

Remaining installation equipment is mounted within a specially manufactured cabinet where interconnections are provided through the cabling equipment. The remote control buttons and measurement devices are located on the front panel of the cabinet. Two power meters Merlin Gerlin Power Logic PM500 acquire full information about the input power variables of each drive, such as voltage and current values, active, reactive and apparent powers, power factor, and total harmonic distortion. For speed measurements, the Leine&Linde 861007455 encoder of 9–30 VDC supply voltage and 2048 pulses per revolution is fitted on the motor shaft. To measure device connection the 4 mm laboratory plugs are available. For quick shutdown of the laboratory setup, the emergency shutdown button is placed on the front panel of the cabinet.

Both drives are connected to the computer through a set of optical wires.

The ABB toolbox DriveWindow provides the remote control of the tested and the loading drives, their tuning, monitoring, graphical trending, and registration of the drive parameters. The output data from the DriveWindow software can be presented and saved in graphical and numerical forms for the following analysis.

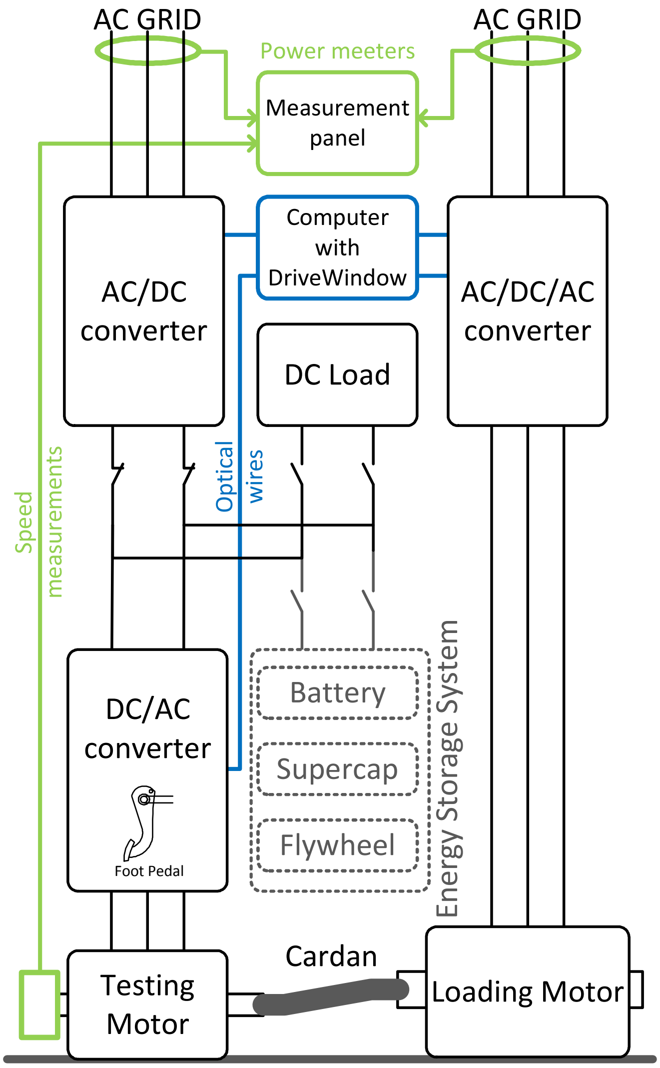

Fig. 1. Basic circuit of the laboratory setup

To provide motor testing in regenerative braking mode, to recover kinetic energy and to capture the excess energy from the vehicle [16], an additional DC electronic load is connected to the DC link of the tested machine. High power DC electronic load Chroma 63200 can be operated independently at constant current, voltage, resistance and power modes. The DC electronic load allows to register the

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voltage, current and power values applied to the load input. The test bench permits simulation of the different loads to study the steady-state and dynamic modes of the EV operation or to keep them constant for making static measurements. In addition, energy flows generated during the regenerative braking of the testing motor are registered.

Along with the AC/DC converter, the battery supply can also be provided for the test bench, as in [6], [7]. To this aim, the LiFePO4 battery pack HE4921 from Harju Elekter was installed the components of which are arranged in series to give 460 to 470 VDC in full charge and the overall energy of 18 kWh traction battery. As the battery has a limited specific power (W/kg) regarding to absorption and delivery of energy, such built-in components of the institutional smart grid, like a flywheel energy storage T3-15, a supercapacitor bank Maxwell BMOD0165P48B, a fuel cell Capstone C30, an UPS EDP90 can also be included into the test bench configuration. This composition is suitable for using advantages of different power supplies depending on a vehicle operating mode.

The following research problems can be solved with the help of the platform described:

- comparative analysis of the tools to identify and test the propulsion drive components
- experimentation on the static and dynamic operation modes using the developed physical prototypes
- application of the library of the motor drive models that support the EV experimental study and identification procedures
- combination of both the marketable simulation instruments and the author's original software in the propulsion drive exploration
- load-dependent and speed-dependent study of EV drives for the search of optimal equipment configurations
- evaluation of the most economical performances to choose the best EVs for the particular application regions

III. Study of EV Drive Performance in Statics

First, equipment installation and tuning for the validation of measurements were performed. The testing drive can be calibrated to obtain the speed-torque characteristics similar to those shown in Fig. 2. The test bench enables smooth load variation of the testing drive in four quadrants. It means that all the possible running and braking modes can be explored here. The traces of Fig. 2 display both the high-speed and the low-speed vehicle motion at uphill and downhill roads.

By adjusting the torque, a wide range of tire/road conditions can be simulated on the test bench at different slip values including the vehicle locking. This is analogous to the braking process of a vehicle whose wheel can rotate freely or be locked. Because induction machine characteristics are asymmetrical, different voltages and frequencies for motor exciting can be studied. Thus, a variety of driving conditions on the dry, wet, and icy surfaces that the EV should overcome can be studied.

The diagram in Fig. 3 represents an active power dependence on the load within a broad speed range. The measurements can be taken in the first and third quadrants of the power-torque plane. To study the testing drive at different speeds, it is supplied with variable voltages and frequencies in the scalar mode. To explore the motor performance at different loads, the loading drive operates in the DTC mode with smooth transition between the forward and the reverse torque values. The speed of the motor rotation is measured with the speed sensor from the measurement panel of the test bench. This study enables us to register the energy flow in the motoring and regenerative braking modes for all four quadrants where the testing motor could be operated. An active DC load allows the active energy flow to be registered during the regenerative braking.

Many studies concentrate on propulsion efficiency. The main goal is to reduce the losses of the drive resulting in efficiency maximization. The test bench enables us to plot efficiency diagrams for all four quadrants of the drive performance and conduct their full-scale analysis. Fig. 4 represents an efficiency diagram of the testing drive resulted from the analysis of the measurements. The efficiency traces in the first quadrant were derived as a ratio of the shaft power and the active power consumed by the testing drive. The loading drive output power is taken as a shaft power, whereas the testing drive input power measured by the input power meters is considered as the consumed value. For the second quadrant of the diagram in Fig. 4, an active power consumed by the DC load is taken as an output power, whereas the loading drive output power is considered as an input power of the drive.

IV. Study of EV Drive Performance in Dynamics

The test bench suits for the investigation of the dynamic loads and processes in the propulsion drive.

To explore dynamics, the standard urban driving cycle ECE-R15 is commonly taken, which represents an alternating speed of the EV in the predefined time intervals. To set the required speed set-points, an adaptive programming of the built-in controller is executed. The sample speed set-point diagram adopted for the test bench is shown by the dashed lines in Fig. 5. The ABB ACS800 controller has 15 functional blocks that can be programed with 25 different arithmetical and logical functions. Each block has three inputs and one output. To prepare the separate ECE-R15 driving cycle, all the functional blocks are to be used, hence for more complex driving cycles of other analogue or digital inputs of ABB ACS800 could be employed. The diagram in Fig. 5 was plotted by the DriveWindow toolbox by applying different constant loads, from 0 to 21 Nm, to the same speed reference cycle.

The set of speed timing traces in Fig. 5 shows that the measured values of speed correspond to the speed set-point values. Some inaccuracies in the corners could be explained by the normal open loop system operation. Inaccuracy during the constant-speed motion could be explained by the sliding of the induction motor. Both errors can be restricted by transition to the close loop operation.

The timing diagram in Fig. 6 shows the active power distribution during the driving cycle at different loads. The power peak values at acceleration could be reduced by using the fast operated storage systems such as supercapacitors.

The timing diagram in Fig. 7 displays the motor torque alternation during the driving cycle at changing loads. The highest torque spikes are observed in the initial points of the drive acceleration. Also, as the test bench can operate in regenerative braking mode, the definite level of spikes occurs in this mode because severe part of energy cannot be regenerated during breaking.

The data from the tests illustrated in Fig. 6 and 7 can be used effectively for calculating the proper values of the energy storage devices.

V. Conclusions

The platform described in this paper provides durability and functional tests to the customers and helps to solve many other propulsion problems. Depending on the respective prototype phase of the specimen, multiple examinations can be performed in the form of acceleration block programs, multi-step tests (speed control, torque control), load collectives or close-to-reality driving trials (driving simulation). Functional testing focuses on the measurements of power and energy efficiency and investigations in the driving simulation mode used for application purposes. For highly accurate power measurements, a pool of different torque measuring procedures is proposed that adapt the experimental setup and the measurement range to the tested physical values. In order to enable the examination of the drive trains beyond the standard modes of operation, different parameters, like wheel slip, multiple wheel speed left/right, front/rear, and uphill/downhill grades can also be studied.

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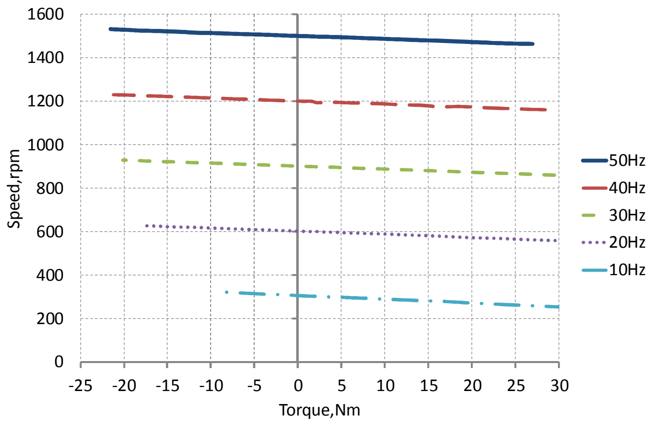

Fig. 2. Speed-torque characteristics of the testing induction motor obtained from the test bench

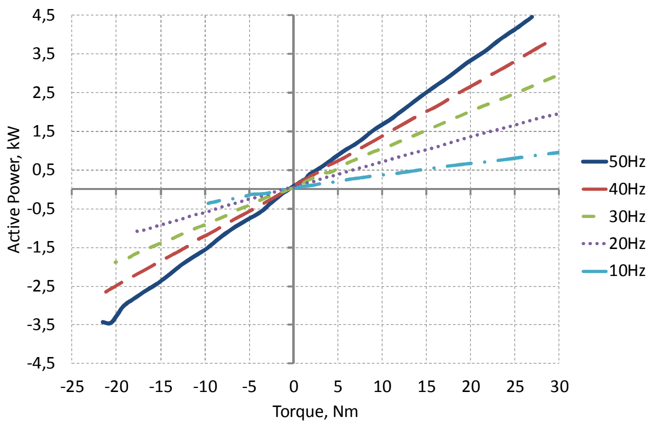

Fig. 3. Active power diagram of the testing induction motor obtained from the test bench

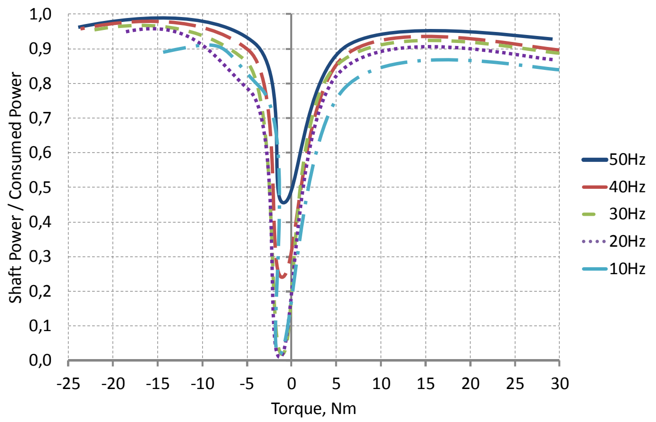

Fig. 4. Diagram of the shaft power to consumed power ratio of the testing induction motor obtained from the test bench

What does this graph mean?

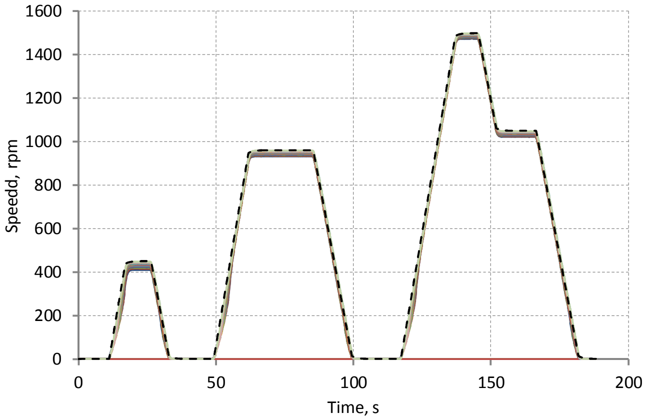

Fig. 5. Sample speed timing diagram of the testing drive

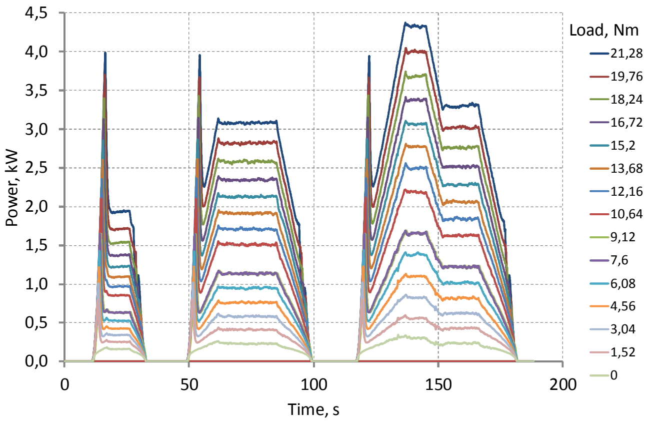

Fig. 6. Active power timing diagram of the testing drive obtained from the test bench

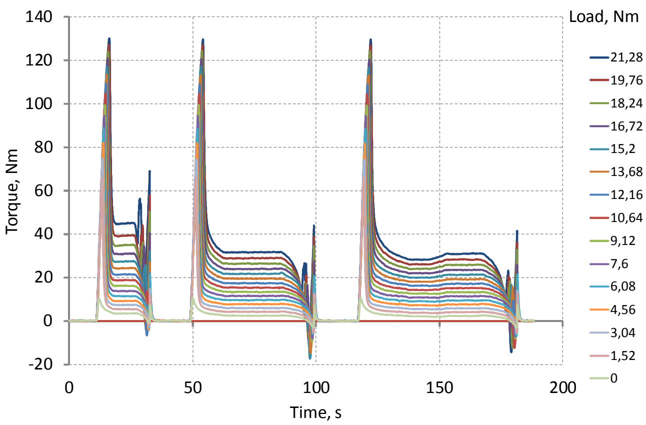

Fig. 7. Motor torque timing diagram of the testing drive obtained from the test bench

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