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POWER FLOW MONITOR OF MOTOR DRIVES IN HYBRID-ELECTRIC CAR EXPERIMENTAL SYSTEM

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Abstract: *This paper presents the power flow monitor of motor drives of the supervisory control and data acquisition system (SCADA) for the hybrid-electric vehicle (HEV) experimental working stand. This system part of operational laboratory structure for testing the newly developed technological solution of the HEV. Energy and power transformation is essential in determination of performance and efficiency of complex electrical drives such as HEV systems.*

Key Words: ***Power Electronics/SCADA/Data aqisition/Hybrid-electric drive/ Power control***

1. INTRODUCTION

Commercial hybrid electric cars (Toyota Prius), for splitting energy from internal combustion engine (ICE) are using mechanical planetary changing gear and separate electrical generator (EG) for electrical power supply of traction motor (TM) and charging the traction battery (TB). In the hybrid electric system developed on the CTU Prague (defined as HEV-CVUT), the power splitting is performed entirely electrically by using the electric power splitter (EPS). That directly will influence the reduction of the fuel consumption of the vehicle. Elimination of one energy transformation means that significant energy transformation losses will be avoided. Also, instead of chemical battery for accumulation of the breaking kinetic energy, in this drive concept, it is used the super-capacitor as new technological element for electrical energy storage. That gives opportunity to store energy without transformation from electrical to chemical and back.

In this HEV concept, Internal combustion engine is main and only power source of the vehicle that produces the mechanical power P_{ice}. EPS is special type of synchronous generator with two rotating parts: classic permanent magnet rotor and rotating stator (Figure 1). The rotor is firmly coupled to the drive-shaft of ICE. The stator of the EPS is firmly coupled to the TM and to the transmission that leads to the car wheels and rotates with the speed proportional to the vehicle velocity. This technical solution enables engine to operate on most optimal revolutions.

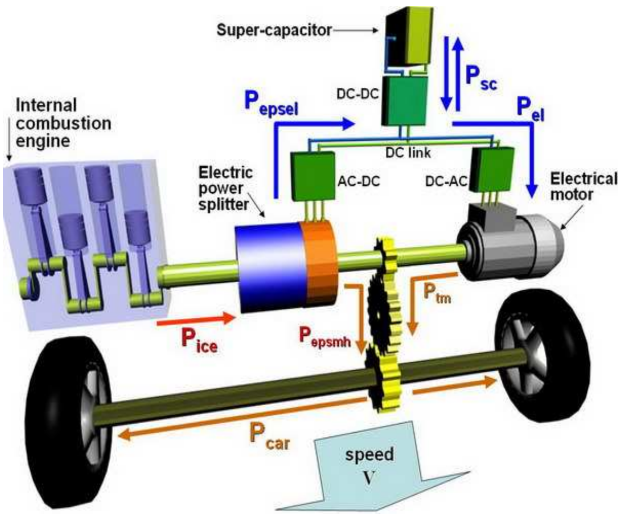

Fig.1. *Illustration of the HEV drive concept*

2. LABORATORY EXPERIMENTAL SET FOR NEW HYBRID-ELECRIC DRIVE

Proving the eligibility of this new technological solution has been obtained thought the creation of the mathematical model and computer simulation. The results show that this new concept of the vehicle enables standard passenger cars to consume almost 50% less fuel in urban driving and less than 20% in highway. As a part of the real data acquisition of the new concept, the experimental working stand has been created in laboratory at Department of electric drives and traction. The aim of this stand is testing the performance of each functional component of this new HEV concept. The scheme of this laboratory stand is shown on Figure 2. The main functional units of the stand are the same as the working components of the HEV-CVUT (Figure 1).

As a part of the research project, the experimental working stand has been created in laboratory at Department of electric drives and traction. The aim of this stand is testing the performance of each functional component of this new HEV concept.

On this HEV laboratory model, ICE and the car wheels has been substituted with two regulated induction motors. Produced power P_{ice} and rotations n_{ice} of ICE drive-shaft are simulated by an AC induction motor controlled with frequency converter (FC). This converter regulates power and rotations according to demanded ICE working performance. Traction load (brake) is simulated with another controlled AC induction motor. It produces braking torque M_{brake} on the shaft proportional to the expected braking resistance of the traction load. By this means, it is created laboratory test stand for testing of the hybrid-electric car components and technology, without using actual vehicle.

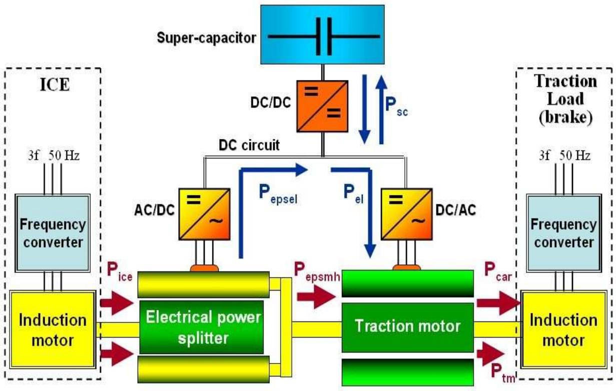

Fig.2. *Laboratory concept of HEV motor drives*

There are two rotating shafts. First is ICE shaft on which are connected the ICE (controlled induction motor) and rotor of the EPS. Second shaft is traction shaft, on which are connected rotating stator of EPS, traction motor and induction motor (brake). During operation, these two shafts are mechanically independent and only EPS magnetic field is connection between them. For testing purposes, working stand provides firm connection of these shafts with electromagnetic clutch, enabling acting as one shaft (Figure 2).

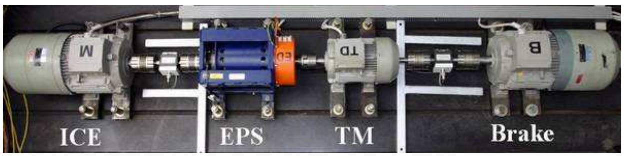

Fig.3. *Electrical machines of the laboratory stand*

HEV working stand is consisted of four electrical machines, five semiconductor power control units, super-capacitor and all the necessary instrumentation, control, power supply and protection equipment. The electrical machines (two induction motors, electric power splitter and traction motor) are shown on Figure 3. Rest of the working stand, two Danfoss frequency converters, power control units (traction AC-DC, DC-DC and DC-AC converters), control and power switches, electrical quantity transducers, instrumentation, condition indicators e.g. are functionally interconnected and placed into the equipment and instrumentation cabinet of the laboratory working stand (Figure 4).

HEV laboratory stand is consisted of electric drives, power electronics and associate electrical equipment. On the working stand, there are not included traditional automotive components like real internal combustion engine, changing gear, car wheels etc. Entire experimental approach is based on traditional power electrical engineering using electrical drives.

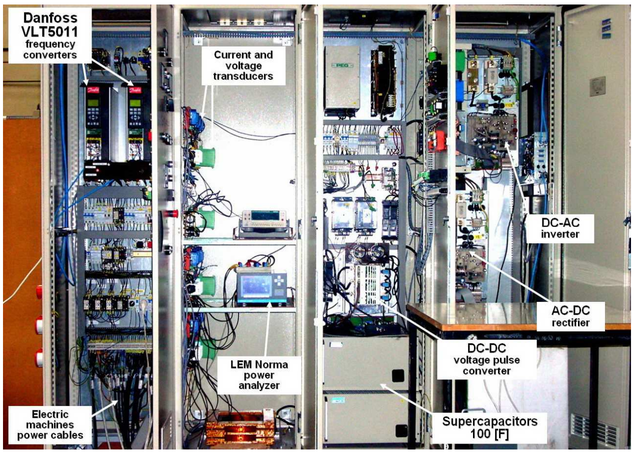

Fig.4. *Equipment and instrumentation cabinet of the laboratory working stand*

3. SCADA SYSTEM FOR HEV EXPERIMENTAL SYSTEM

The HEV working stand can be efficiently used only if there is supervisory system that gives real-time information of all essential parameters of the stand. In addition, real-time control is necessary for synergetic use of all functional entities of the stand. Therefore, supervisory control and data acquisition system is created for HEV stand (HEV-SCADA).

The real-time measurement of all necessary electrical quantities of the system is achieved by emplacing the voltage and current transducers. The mechanical quantities of two shafts (ICE and TM shaft) are measured with two speed and torque transducers.

The main intelligent part of the SCADA is a supervisory computer system that gathers, acquires data of the stand, and sends control commands to the process. This subsystem is consisted of PC based platform with Windows XP/Vista operating system. Using standardized computer structure enables versatility of this SCADA system to be used in any PC based platform and gives options for further development and flexible upgrade according to the needs.

Significant contribution of creating this SCADA for the HEV working stand is enabling user-friendly human-machine interface (HMI) for the operating personnel. A HMI is the apparatus that presents process data to a human operator and through this the human operator monitors and controls the process.

HEV experimental stand is exceedingly complex laboratory system. It has numerous different electrical and mechanical values that must been controlled and regulated. As it is explained, all the measuring equipment works as individual and independent sets. Also, the microcontrollers of the power converters are regulated independently by separate PCs without any possibility of common interaction. The Danfoss frequency converters are also individually regulated. Significant problem for creation of integrated measurement and control system is lack of data-exchange interlink among the regulated devices. Therefore, supervisory control and data acquisition system SCADA is created for HEV experimental stand (HEV-SCADA). The communication infrastructure and functional subsystems of this SCADA system are shown on Figure 5.

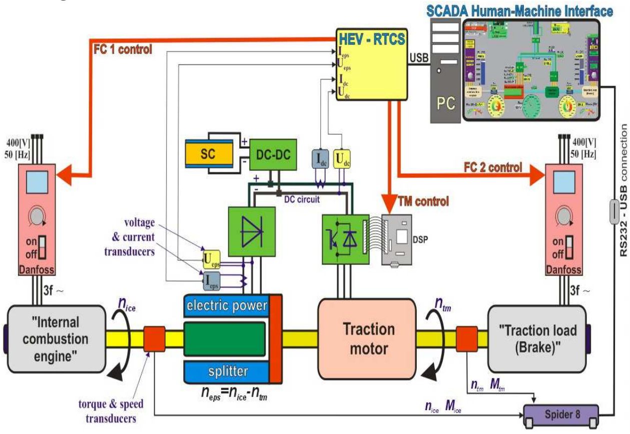

Fig.5. *HEV-SCADA measure, communication and control infrastructure*

For creation of the HEV-SCADA is used the software package LabVIEW. It provides a graphical programming environment for developing sophisticated measurement, test, and control systems. Human-machine interface for HEV is created within this software system. The main control and visualization panel which functionally is active graphic user interface (GUI) is shown on Figure 6. For HEV-SCADA are created many GUI panels for detail visualization, monitoring and control of specific processes of HEV stand.

LabVIEW is used as a platform because it enables intuitive graphical programming for advanced analysis and data visualization. It offers universal and versatile equipment integration with hardware devices and provides built-in libraries. This characteristics enables integration of the specially customized remote terminal unites (RTU) for these purposes.

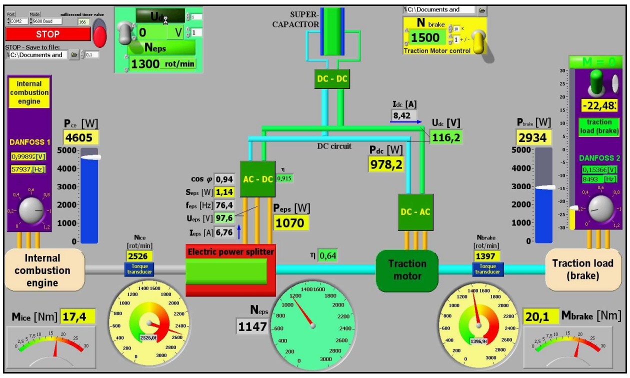

Fig.6. *Main visualization GUI of HEV-SCADA*

4. POWER FLOW MONITOR OF HEV-SCADA

This essential part of HEV-SCADA system utilizes input values such as input values are intermediate power P_{dc}, electric power P_{epsel} output of EPS, ICE output torque M_{ice}, traction torque M_{brake}, ICE revolutions n_{ice} and traction speed n_{brake}. All this are output signals acquired by SCADA using LabView Sub-VI (Figure 7).

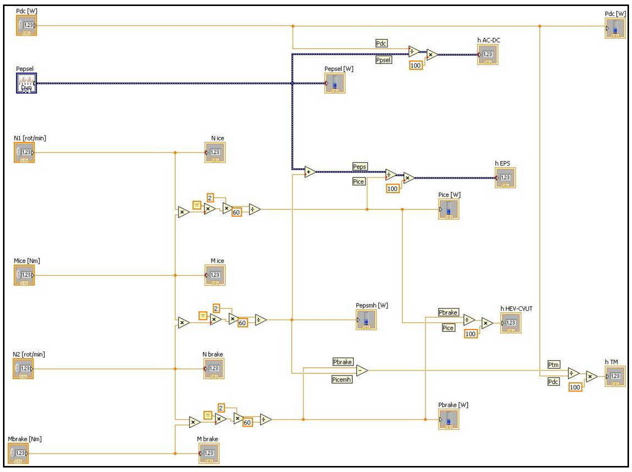

Fig.7. *Power flow Sub-VI block diagram*

Internal combustion engine power P_{ice} and braking power P_{brake} are calculated with expressions (1) and (2):

$$P_{ice}(t) = \frac{2\cdot\pi}{60}\cdot M_{ice}(t)\cdot n_{ice}(t) \tag{1}$$

$$P_{brake}(t) = \frac{2\cdot\pi}{60}\cdot M_{brake}(t)\cdot n_{brake}(t) \tag{2}$$

Power of the combustion engine P_{ice} is input power to electric power splitter. Into this machine this power is divided into two parts – electrical P_{epsel} and mechanical P_{epsmh}. Torque M_{ice} is transferred with electromagnetic force onto the EPS rotating stator, which rotates with revolutions n_{brake}. This transmitted power from ICE shaft to traction shaft is P_{epsmh} and it is calculated with (3):

$$P_{epsmh}(t) = \frac{2\cdot\pi}{60}\cdot M_{ice}(t)\cdot n_{brake}(t) \tag{3}$$

Remaining power in EPS is induced by magnetic field into the electric winding arranged on the rotating stator. On the three phase electrical output EPS generates electric power P_{epsel}. Total EPS output power is:

$$P_{eps}(t) = P_{epsmh}(t) + P_{epsel}(t) \tag{4}$$

Correlation between input EPS power P_{ice} and output power P_{eps} defines energy efficiency of electric power splitter:

$$\eta_{eps}(t) = \frac{P_{eps}(t)}{P_{ice}(t)} = \frac{P_{epsmh}(t) + P_{epsel}(t)}{P_{ice}(t)} \tag{5}$$

Real-time monitoring of electrical power P_{epsel} and rectified power P_{dc} in intermediate DC circuit provides information for AC-DC rectifier efficiency:

$$\eta_{ac-dc}(t) = \frac{P_{dc}(t)}{P_{epsel}(t)} \tag{6}$$

Traction braking power P_{brake} is sum of produced power from traction motor P_{tm} and mechanical power P_{epsmh} from EPS:

$$P_{brake}(t) = P_{tm}(t) + P_{epsmh}(t) \tag{7}$$

Total efficacy of energy transformation from DC link to traction shaft thought DC-AC inverter and traction motor is:

$$\eta_{tm}(t) = \frac{P_{dc}(t)}{P_{tm}(t)} = \frac{P_{dc}(t)}{P_{brake}(t) - P_{epsmh}(t)} \qquad (8)$$

All these powers and energy efficiencies are displayed and monitored in real-time during HEV working stand operation. Graphic monitor of SCADA system (Figure 8) provides overview of entire HEV system power flow and energy efficiency transformations:

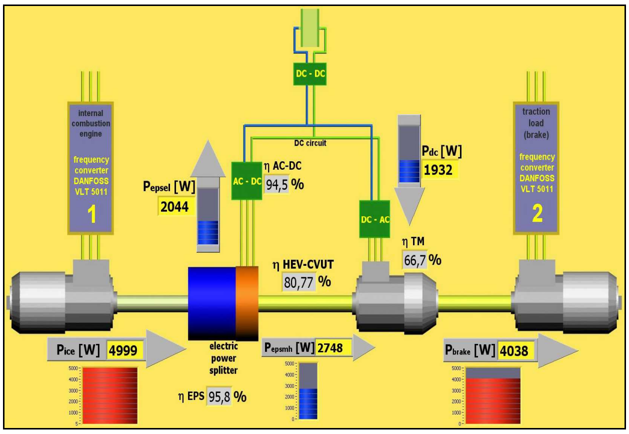

Fig.8. Real-time p*ower flow and energy transformation graphic monitor of SCADA system*

4. CONCLUSIONS

Power flow monitor of this SCADA system has considerably increased the operational performance of the HEV laboratory working stand. Supervising the real-time information of all essential parameters of the stand enables control for synergetic use of all functional entities of the system. To the operators enables intuitive graphical programming for advanced analysis and data visualization. This characteristics enables integration of more remote terminal unites and further development of the SCADA structure.

HEV-SCADA system has provided better operational performance of the HEV laboratory working stand. Choosing the LabVIEW as a software platform for SCADA offers universal and versatile equipment integration. To the operators it enables intuitive graphical programming for advanced analysis and data visualization. These characteristics enable integration of more remote terminal unites and further development of the SCADA structure.

HEV-SCADA is operational and numerous tests are performing on the HEV working stand. The results obtained from the experiments are used for data analysis and providing working characteristics of each component of the HEV system. That leads to further development of this new technological solution for hybrid-electric vehicle.

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