IMPLEMENTATION OF THE VECTOR CONTROL SYSTEM FOR TRACTION ASYNCHRONOUS MOTORS

Iurie RÎMBU, Vitalie EŞANU, Vitalie MIHALACHI, Andrei RÎNCĂU, Ilie NUCA[*], Segiu IVANOV[**]

ITŞ "Informbusiness", SRL *[*]Technical University of Moldova* *[**]University of Craiova*

rimbui@mdl.net, nuca_ilie@yahoo.com, SIvanov@em.ucv.ro

Abstract **– The paper describes the InBus-103 electronic equipment for the trolleybus traction system with vector controlled asynchronous motor. Based on the experience acquired during more years and hundreds of equipment installed and operational on urban vehicles from different cities, the equipment was developed using of the IGBT transistor technology, 32 bits Fujitsu micro-processors control systems, informational systems with optic fibers and CAN protocols. Due to the modular structure of the power electronics equipment and software implementation which has been developed within multifunction electronic control equipment, the whole system can be used both for trams and trolleybuses traction, using either AC or DC motors. It has also been developed a modern, user friendly graphic board panel which indicates all the functionality of the system. Laboratory tests were performed by using the facility of the company. They were followed by open field tests on a trolley prototype, also the property of the company. The trolley was loaded more than the rated value and the requirements higher than the specifications. All the tests have proven the good functionality of the equipment. According to the technical parameters, the exploitation facilities, the control algorithms and the performed functions, the InBus-103 proved to be a competitive product on the market of electric traction dedicated to the passenger urban units.**

Keywords: *electronic traction equipment, vector control, asynchronous motor, trolley, tram.*

1. INTRODUCTION

Nowadays the development of the propulsion systems for electric vehicles is marked by the development and implementation of control electronic equipment and by traction motors without mechanical contact [1, 2]. This direction is due the necessity of: increasing the reliability and energetic efficiency of the traction systems, decreasing of exploitation costs, increasing of comfort etc. The place of the traditional DC motors is taken by the brushless DC (BLDC), synchronous motors with permanent magnets PMSM, switched reluctance motors SRM and asynchronous motors (AM) [3-7]. Each type of the electric drives based on these motors has advantages as well as disadvantages. Nevertheless, nowadays, the asynchronous motor preferred for applications in the traction area.

There are reported developments and implementations of the traction electronic equipment with asynchronous motors for urban vehicles in neighboring countries such as Czech Republic [8, 9], Poland [12], Romania [10, 11], Russia [13, 14]. The differences of the equipment lie in architecture and compound, control of the power electronics elements, control algorithms, applied technologies, implemented functions, dimensions, weight and price.

The InBus-103 (Fig. 1) electronic equipment was developed [15] in accordance to the specifications of the passenger urban vehicles market requests. It is able to supply and control the traction motors of tramcars and trolleys. Improved technical parameters, multifunction, guaranteed reliability, decreased weight and size for accessible price have been the goals of the developers in order to ensure competitiveness of the product.

The aim of the paper consists in presenting the structure, technical and functional characteristics, as well as the results of the implementation of vector control for the trolley's traction asynchronous motor within the InBus-103 system.

Figure 1. General view of the InBus-103 equipment mounted on the trolley's roof .

2. GENERAL STRUCTURE OF THE SYSTEM

The main target of the InBus-103 electronic equipment consists in supplying and controlling the traction asynchronous motors with powers up to 250 kW depending on the trolley's movement diagram, appliance of breaking and electrical energy recovering regimes. The equipment has many other bonus functions: system's diagnostics, data base processing and error statistics, driver and passengers notifications etc. Taking into account all the requirements, the system was developed as a modular structure with CAN network internal communication (Fig. 2).

Figure 2. Modular structure of the control system.

The main module 1 contains the power converter for the motor's supply and the control system which ensures the motor's control algorithm and control of the peripheral units of the trolley. The module 3 is placed close by the trolley's peripheral units and is used for necessary signals acquisition and procreation for the functioning of the entire system. The InBus-103G type board panel (4) with TFT display is placed in the drivers' cabin (Fig. 3). It is used for displaying: the information on the system's state (speed, board and contact line voltages), the video cameras' images, the connection of speakers (6) etc.

Figure 3. InBus-103G graphic board panel.

3. POWER ELECTRONIC MODULE

The main module 1 (Fig. 2) of the traction system contains a capacitor C, ON/OFF VT7 and VT9 breaking transistors, VT1-VT6 transistors of the DC/AC reversible power electronic converter (Fig. 4). For the power part, Intelligent IGBT Power modules FZ600R17KE3 from Infineon Technologies AG [17] were chosen. The converter's structure is influenced by the supply source, operating regimes of the traction asynchronous motor and technological conditions of fabrication. The module is connected to the 550-900 V DC contact line by line contactors SW1 and SW2. The output supplies the three-phase asynchronous motor 220 kW rated power and 350 A rated current.

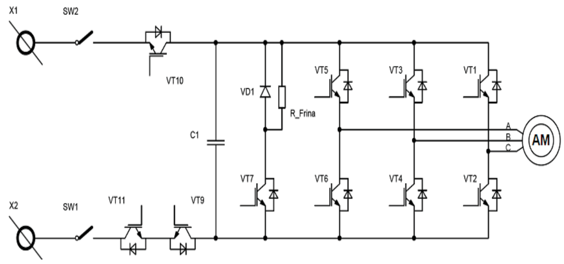

Figure 4. Electric diagram of the power module.

In order to simplify the installation and maintenance technology, reduce the manufacturing costs, increase the reliability, uniform placing of the power transistors on the whole surface of the radiator and to minimize the inductance of the switching circuits, it has been decided to make a mixed topology and a converter's common supply bus [15, 16]. Elements were unified for allowing modularization of the converter (Fig. 5).

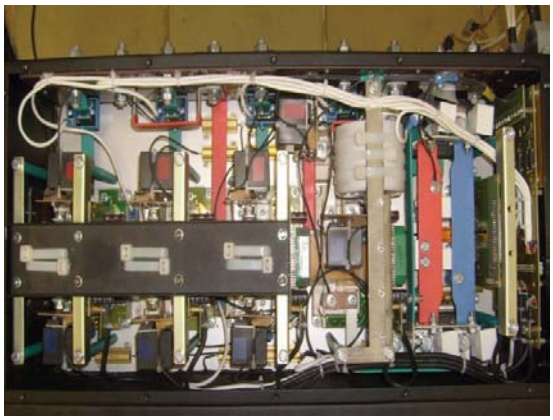

Figure 5. General view of the power module.

The structure of the power module allows the operation of the traction asynchronous motor in a normal regime, as well as other regimes: dynamical breaking, counter-connection with energy recovery into the network. On the other hand, the module is capable to supply DC motors traction systems irrespective of the excitation type.

4. CONTROL MODULE

The InBus-103 equipment's control module, basically is a card with imprinted cable-work (Fig. 6), mounted on the left lateral side of the main module 1 (Fig. 2). The control module's structure (Fig. 7) consists of two

CPU1 MB91F467CA and CPU2 MB91F267 [18] Fujitsu microprocessors. The CPU1 processor, through the CAN network and module 3, communicates with all the peripheral units and ensures the general control of the whole system. The traction CPU2 is used for separate control of the converter through **Power module.**

Figure 6. General view of the control module.

Power module consist of the **IGBT Drivers** and of the current, voltage and temperature sensors. After filtering the noise and limiting at the maximum imposed level, the signals are sent to the CPU1 and CPU2 processors, error processing block **Error module**. The **Energy meter** block represents a microcircuit specialized in calculating the consumed energy.

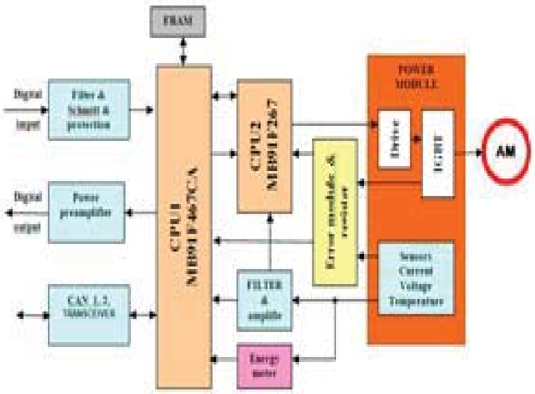

Figure 7. General structure of the control system.

The developed microprocessor software ensures: diagnostics of the system's component elements, operating in different regimes of the electric vehicle's traction, vector control of the asynchronous motor, displaying messages and images of the video cameras on the board panel, error statistics, calculus of the consumed energy and set-up of optimal consumption mode according to real movement conditions. The adequate developed software responds to the type and model of the traction electric motor of the trolley.

4. VECTOR CONTROL ALGORITHM

The vector control algorithm is based on the two-phased mathematical model of the asynchronous motor [18, 19]. The principle of vector control uses a reference system attached to the controlled flux vector which determines the electromagnetic torque of the asynchronous machine. Finally the vector control is reduced to supplying the stator winding with a system of three-phased currents which will ensure the permanent perpendicular position of the controlled flux and the active stator current of the two-phased model of the asynchronous machine.

The choosing of the rotor flux as control flux is beneficial for implementation, as well as for ensuring more advanced control parameters. The phase regulator of the rotor flux $\underline{\Psi}_r = \Psi_{rx} = |\underline{\Psi}_r|$ is fixed after the *x* axis of the common reference system *x-y*, rotating with the angular speed $\omega_\rho = d\rho / dt$, where ρ is the angle between the axis α and *x* (Fig. 8).

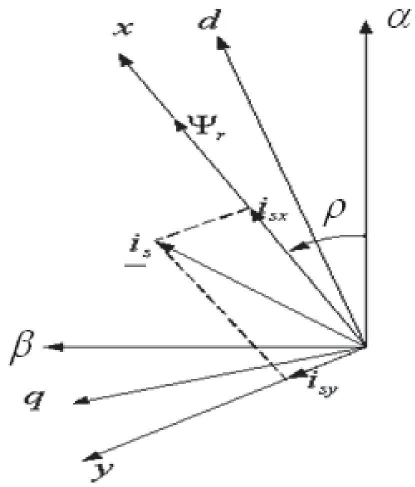

Figure 8 Control vectors in the rotor flux reference frame.

Considering the component $\Psi_{ry} = 0$ of the rotor flux, the expression of the electromagnetic torque becomes

$$t_e = \frac{3}{2}\frac{L_m}{L_r}\Psi_{rx} i_{sy}$$

and the stator voltage equations of the two-phased model necessary for the realization of the asynchronous motor's vector control [18]

$$u_{sx} = R_s i_{sx}\left(1 + sT_s^{'}\right) - \omega_\rho \sigma L_s i_{sy}$$

$$u_{sy} = R_s i_{sy}\left(1 + sT_s^{'}\right) + \omega_\rho \sigma L_s i_{sx} + \omega_\rho \frac{L_m}{L_r}\Psi_r .$$

The vector control system of the traction asynchronous motor (Fig. 9) is formed of sensors (stator currents and voltages, rotor angular speed), state observer **Model MA**, **FOC** controller, **PWM** generator and **Inverter**. The observer serves for estimation of the position ρ of the rotor flux module $|\underline{\Psi}_r|$, of the electromagnetic torque t_e and of the rotor speed ω (when needed). The **FOC** controller calculates the stator voltages necessary for the realization of motor's orientation principle depending on the rotor flux $|\underline{\Psi}_r|$. The control flux regulator $R\Psi_r$ and the electromagnetic torque regulator Rm_e are used for control (the first generates the reference reactive current i^*_{sx}, while the second generates the active current i^*_{sy} respectively.

The algorithm of vector control of the traction asynchronous motor is realized by the micro-controller CPU2 MB91F267 with the technical recourses repartition according to Fig. 9. The **ADC** converts analogical signals into digital signals. The **MFT** unit is a multifunctional timer for a fast creation of the **PWM** signals. The **PWC** unit serves for calculating the motor's speed. The PI controllers of the control system are realized in parallel with the ale **uDSP** module**.** The **CPU** unit ensures the functions of: the state observer's **Model MA** and the **FOC** controller.

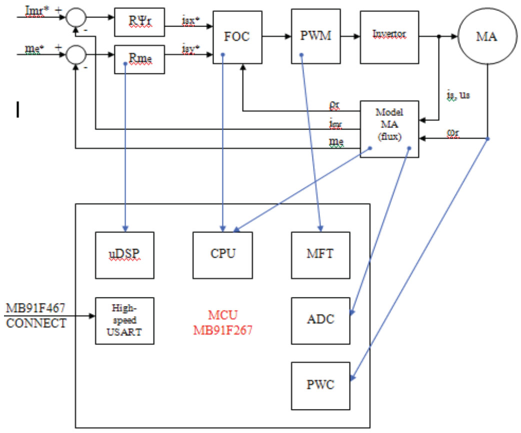

Figure 9. Allocation of the CPU's technical resources

The realization program of the motor's vector control is saved in a **FLASH** memory and uses the parameters of the motor and the present variables from the **RAM** memory of the processor.

5. TESTING OF THE TRACTION SYSTEM

The testing of the vector control system of the traction asynchronous motor were realized in the laboratory of the INFORMBUSINESS Company [20], formed of measurement (Fig. 10) and electric machines (Fig. 11) rooms. The aim of the lab testing was the checking the functionality of the power electronic converter, the verification and the adjusting of the command and control algorithms, dynamic act of the traction system in whole, heating and ventilation of the power module.

During testing a few problems of the system were found and solved.

Figure 10. Measurement room.

Figure 11. Electric machines room.

When increasing the control characteristic (Fig. 12) of the PWM converter, the presence of a non-linear zone for the modulation index (PWM%) less than 7 % has been discovered, caused by the dead time and non-linearity of the transistors. Because dead time can not be eliminated, a certain improvement of this curve has been obtained by varying the gate resistance of the IGBT transistors.

At start or reversing of the asynchronous motor at low rotation, the real output voltage of the inverter deviates from the calculated value, causing a slower movement and exceeding the imposed values of stator currents (Fig. 13). The solution of the stator current's value was brought by placing a compensation block of the voltage drop on the stator resistance (Fig. 14).

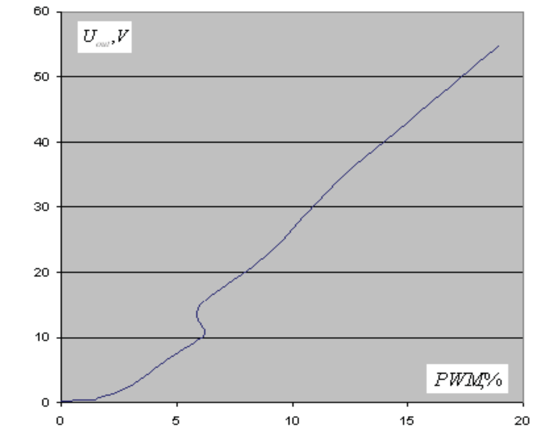

Figure 12. Adjustment feature of the converter.

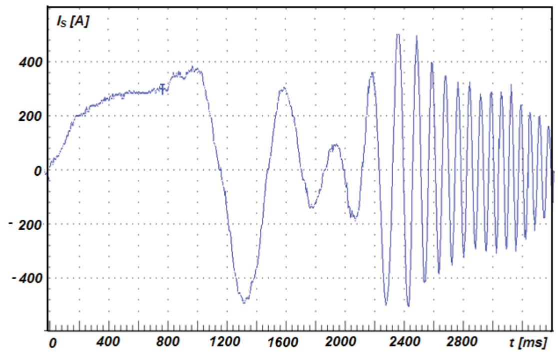

Figure 13. Stator current without compensation block.

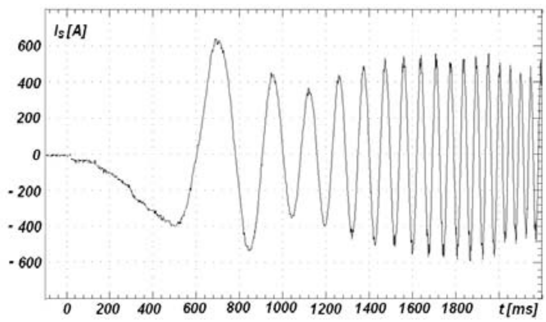

Figure 14. Stator current with compensation block.

The most important error was in the domain of the inverter's control at stop and resupply after a short time of the motor, having the moving rotor. Thanks to the influence of the residual flux and induction of the fem voltage into the stator winding, the restart of the motor lasted long or was impossible. For solving this problem changes were introduced into the command algorithm. New facts were foreseen: measurement of the stator voltage induced by the lasting flux and the formation of the initial output voltage of the inverter, after which the motor is resupplied. This solution allows a soft and fast restart of the motor in the needed regime. The current and torque shocks do not go over 10% of the necessary values. At the start of the motor, the current shock is much higher without the presence of the lasting flux (Fig. 15) then when it is present (Fig. 16), which is thanks to a complete demagnetization of the machine.

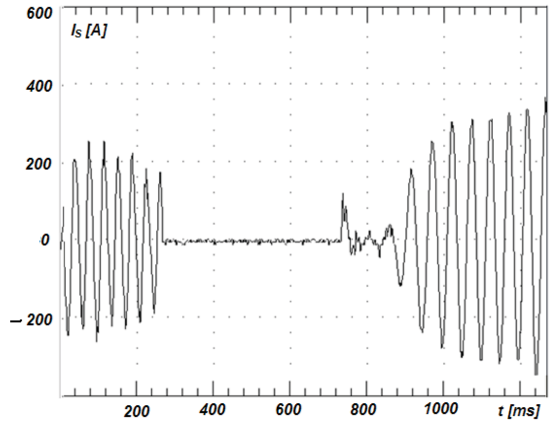

Figure 15. Restarting with residual magnetic flux

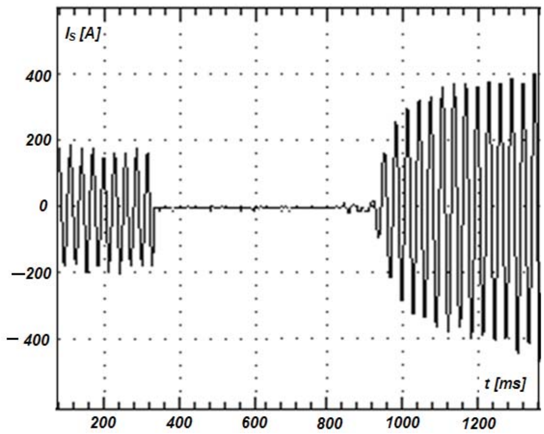

Figure 16. Restarting without residual magnetic flux

The preliminary tries in real conditions on the trolley have prove, that the developed vector control system of the asynchronous motor ensures the necessary traction characteristics.

6. MAIN TECHNICAL CHARACTERISTICS

The usage of the top elements from the power and micro electronic domains, from the modern informational technologies and from the know-how technologies has allowed the realization of the vector control of the traction asynchronous motor of passenger urban vehicle InBus-103 high performance equipment, with technical characteristic presented in Table 1. Compared to other prototypes, the developed equipment has very compact construction, extended functionality, high reliability, adaptation only by software to different types of electric vehicles for vector control asynchronous motors, as well as direct current motors.
The modular structure with separate and CAN interconnected control micro-processors simplify the

fabrication and maintenance, allows the extension of functions according to new conditions. Each module's micro-processor performs its base function, as well as a continuous diagnosis. Based on the Fujitsu graphical micro-processors board panels have been developed, which displays numerical information, as well as graphical images from the video cameras, contains USB, CAN, RS232, I^2C communication ports.

Parameter	Unit	Value
Rated power	kW	220
Maximal power	kW	300
Input rated voltage	V DC	660
Input voltage limits	V DC	50÷900
Rated current	A	350
Maximal current	A	425
Command voltage	V DC	28
PWM frequency	kHz	2.5
Frequency control limits	Hz	0÷130
Allowed temperature of the environment	^{0}C	-40…+40
Protection level	-	IP54
Size	mm	750*325*560
Weight	kg	84

Table 1. Parameters of the InBus-103 equipment

A complex program of testing is required for finding all the technical characteristics and the economical parameters.

7. CONCLUSIONS

In this paper the structure and implementation of the vector control of the traction asynchronous motor for passenger urban vehicles, InBus-103 type electronic equipment is presented. The usage of top elements from the power and micro electronic domains, from the modern informational technologies and from the know-how technologies has permitted the realization of multifunction high-performance equipment, which can be used in different types of urban vehicles (trolleys, trams) with vector control traction asynchronous motors or direct current motors.

The lab tests and real conditions on a trolley have proven the functionality of the developed system. For certification of all the technical characteristics and economical parameters it is necessary to continue the testing program.

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