Automatic Train Control Systems on Sustainable Urban Metro

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Abstract: - Our correct activities must be referred into the frame of Sustainable Development that encompass three general policy areas, concerning the economical development, the environmental issues and the social problems. A priority of engineering researchers should be the improvement of public transportation systems. The merit of an electric transportation system is based on technical performance, safety, energy and exergy efficiencies, societal and economic acceptance and small environmental impact. This paper aimed to emphasize that more and more the train control systems are building upon traditional control to meet the growing demands. There are presented structures of urban train control systems, there are analyzed structural schemes and it is presented a study case concerning the operation control on an urban underground metro trains produced by Craiova Electroputere Factory for Bucharest Underground Transportation System. The research is made into the frame of a scientific project regarding the realization of an intelligent railway vehicle, Project Number 126 CEEX II 03.

Key-Words: - Control system, Electric train, Sustainable transportation, Underground metro

1 Introduction

Operating in the majority of capital cities for over a century, the metro has completely transformed to meet the modern needs of major cities and their inhabitants. Fast, economical and non-polluting, metro systems can transport up to 50,000 people an hour, in total safety and comfort [1]. Today's rail industry is rapidly transforming. More and more Train Control Systems are building upon traditional control to meet the growing demands. These systems need to guarantee safety and higher performance today, and be adaptable to more demanding needs well into the future. The automatic operation, which are important techniques in metro railways, are required to increase safety, reliability, and transport capacity. To satisfy such demands, we must have a system design and testing technique for the railway system operation [2]. These techniques are related to the onboard train control and communication systems which include TCMS (train control and monitoring system), ATO (automatic train operation), ATC (automatic train control), and TWC (train to wayside communication) [3]. These sub-systems must be interfacing with not only each other but also the system on the ground. Consequently, the electronic and electrotechnical products supplied to the Rail Industry must be reliable and safe, ensuring the sustainability of the transportation system.

2 Urban Railway Transportation

The urban electric railway systems by metro types had been developed on basis of d.c. line supply, according the IEC Recommendation no.38. The electric energy for supplying the d.c. network it is taken from the industrial three-phase network and it is transformed in d.c. energy by the electric traction substations (SSTE) [3]. The main advantage of the d.d. contact lines it is represented by the possibility of direct link of the traction sub-stations to the industrial three-phase network, without producing some major unbalanced regimes. In Fig.1 it is represented a d.c. sub-station with a direct link to the a.c. three-phase network and in Fig.2 it is shown a d.c. sub-station with an indirect link, through a traction three-phase line, to the industrial three-phase network [4].
are represented by the a.c. – d.c. conversion groups, mainly realized by a three-phase electric transformer, a three-phase rectifier and a three-phase inverter (in case of reversible traction substations) Sections.

3 Urban Train Control Structure

Defining a computerized control system for an urban electric train that is composed by two elastic coupled wagons it means to take into account the vehicle traction electric scheme [5]. Thus, for a such electric train (MW+MW), the computerized control system will be distributed and will work in real time, similar with that used in the case of industrial automatic lines. The main characteristic of a such computerized control system is the data thoroughfare integrated network, which is necessary to be realized with optical fibers (in the goal of minimum reduction of cables volume). That is ensuring the synchronized operation of the electric frames which compose the urban train, it is including a diagnosing system and a passengers informations service system [6]. The entire system must guarantee safety and higher performance operation. For instance, for an urban train realized by 3 electric frames, each frame composed by 2 motor wagons, the proposal for an computerized control system is presented in Fig.3 and Fig.4.
The commands specific to traction and brake regimes are made from the drive cabin or by the automatic train control equipments (ATC), so that the vehicle movement is safe and continuous during the train acceleration or deceleration [7].

The control system is distributed on 4 levels:
- urban electric train operation level;
- urban electric train control level;
- motor wagons electric frame control level;
- equipments control level.

4 Structural Schemes

Further on, will be presented different structural schemes for the vectorial control. Hence, in case of electric drive applications with static converters and traction induction motors it can be applied the direct control method (Direct Field Orientation – DFO) and consequently, the structural diagram of Fig.5 had resulted.

- for Reg \( R_1 \): input quantities \( \psi'_r \) and \( \psi_r \) output quantities \( i_{sx} \);
- for Reg \( R_2 \): input quantities \( i_{sx} \) and \( i_{sx} \) output quantities \( u_{sx} \);
- for Reg \( R_3 \): input quantities \( i_{sy} \) and \( i_{sy} \) output quantities \( u_{sy} \).

On basis of rotor flux components, the angle \( \epsilon \) between the two used referentials can be calculated by the formula:

\[
\epsilon = \arctg \left( \frac{\Psi'_r}{\Psi'_r} \right) + \left( 1 - \frac{\pi}{2} \right)
\]  

(1)

In electric drives with static converters and traction induction motors it is used also the indirect vectorial control (Indirect Field Orientation – IFO). On basis of a speed transducer that allow to provide the quantity \( \omega_{mr} \), it can be determine the angle between the two used referentials [8], [9]. Consequently, in Fig 6 it is presented the indirect vectorial control structual diagram.

![Fig6 Indirect vectorial control structural diagram (IFO)](image.png)

On the urban electric trains by metro type it seems that a solution that could be adopted is that which combines the two previous variants. In this case, the control scheme (Fig.7) is based on direct vectorial control scheme, adjusted with elements of indirect vectorial control scheme and with some specific blocks.

The traction induction motor behavior is described by the equations:

\[
u_{st} = R_s i_{st} + \frac{d\psi'_r}{dt} + j\omega_s \psi'_r
\]  

(2)

\[0 = R_r i_{rs} + \frac{d\psi'_r}{dt} + j\omega_r \psi'_r
\]  

(3)

\[
\Psi'_r = \frac{L_u \psi'_r}{L_r} \quad ; \quad i'_{rs} = \frac{\psi'_r - \frac{L_i}{L_s} \psi_{sr}}{\sigma L_r}
\]  

(4)

Further on, after intermediary calculus there will result:

\[
\psi'_r = \psi'_r + j0
\]  

(6)

\[
\psi'_{rs} = \psi'_r + j0 \quad \text{and} \quad \psi'_{ry} = 0
\]  

(7)

\[
u_{st} = R_s i_{st} + \frac{d\psi'_{sx}}{dt} - \omega_s \psi_{sy}
\]  

(8)

\[
u_{sy} = R_s i_{sy} + \frac{d\psi'_{sy}}{dt} + \omega_s \psi_{sx}
\]  

(9)
For an efficient control of traction induction motor it must be realized the flux and torque control. In this aim, the two components of the stator current will be controlled [10], [11], [12]. Consequently, the equations presented as before will have the following form that express the conversion block CONVE (Fig. 7):

\[
\begin{align*}
\psi'_r &= \frac{u'_r L_s}{\sigma L'_r} \psi'_r, \\
i'_x &= \frac{L_u}{L_s} \psi'_y, \\
i'_y &= \frac{L_u}{\sigma L_r} \psi'_r, \\
M &= \frac{3}{2} p \frac{L_u}{L_r} i_{sy} \psi'_r
\end{align*}
\]

(10) (11)

Fig. 7 Mixt vectorial control structural diagram (MFO)

5 Study Case of Underground Metro

The electric urban underground trains supplied from a d.c. contact line are equipped with three-phase induction motors (having squirrel cage rotors) and variable voltage and frequency inverters [13]. An electric traction scheme with the power supply from the d.c. network (Fig. 8) must have the following elements [14]:

- a current connector to third rail;
- a loading contactor + a loading resistor;
- a rapid automatic circuit breaker;
- an input circuit (known as a LC filter);
- a voltage and frequency converter;
- the electric traction motors;
- a braking chopper + a braking resistor + a shunt; wagons electric couplings.

In the paper an electric vehicle VM+VM (MW+MW) it is taken into account, meaning two motor wagons which are elastic coupled. The scheme is defined by the coefficient \( k = 2/2 \), meaning that on the vehicle two static converters are installed, each of them supplying two traction induction bi-motors [10].

Briefly, the train operation will be presented. After the connectors coupling and the circuit breakers and contactors switching, the control of the units inverters is made. Therefore, the traction induction bi-motors groups are supplied from the three-phase voltage inverters with variable voltage and frequency. Consequently, the urban electric train is prepared to running. At the minimum adjusted frequency \( f_{\text{min}} = s f_n \), the traction motors \( M_1 \) and \( M_2 \) placed on first unit VM \( A \) (respectively \( M_3 \) and \( M_4 \) placed on the second unit VM \( B \)) are immobile. When the frequency exceeds that value, the motors get in motion, the operation having been on the frequency mechanical characteristic corresponding to the minimum supply frequency. The electric train is accelerating at constant traction torque, the operation having been on the mechanical characteristics at \( U_1/ f_1 \), up to \( f_{\text{sn}} \), when \( U_1 = U_{1n} \) and then, over \( f_{\text{sn}} \), at constant power.

The three-phase traction induction motors are reversing the rotation sense by a simple supply commutation, by the stator phases succession switching. Moreover, the motors have identical characteristics for both rotation senses. Hence, the non-autonomous electric vehicles are with bidirection and the mechanical characteristics for the two movement senses are symmetrically in the axes coordinates (speed \( v \) and force \( F \)), having been placed in the quadrants I or III of the frame VOI.

Since the electric driving systems with static converters and traction induction motors are used, by an appropriate control, with the same motors it can be realized the electric braking regime of the electric traction vehicles [5], [13].

For a certain running direction, the passing from the traction regime to the electric brake regime will correspond to the active force \( F \) sign change. It is obviously that, in traction regime \( v \) and \( F \) have the same sign, while in braking regime \( v \) and \( F \) have opposite signs.

With a view to electric train braking, the traction induction motors are passing into the electric generator regime, by the decreasing control of the supply voltage frequency. The electric traction
machines will operate in the generator regime on the mechanical characteristics in the quadrants II and IV, respectively. In that situation, which is complex from the viewpoint of the powers circulation, the inverter provides the reactive energy for the traction machine in generator regime by the capacitors battery from the LC circuit and through the recovery diodes group, the electrical machine supplies as an induction generator into the voltage intermediary circuit. This recovered energy it is taken by other running underground trains or, if the intermediary circuit voltage exceeds 1,2U_d (meaning, over 1,2*750=900 V), it is automatically controlled the operation of the braking choppers of train units, realizing an electric rheostatic brake.

6 Conclusion
Today's rail industry is rapidly transforming. The train control systems need to guarantee safety and higher performance today, and be adaptable to more demanding needs well into the future. The automatic operation, which are important techniques in metro railways, are required to increase safety, reliability, and transport capacity. To satisfy such demands, we must have a system design and testing technique for the railway system operation. The study case presented in the paper emphasized the operation control of the static converters and the traction induction motors as an assembly, on an urban underground metro trains produced by Craiova Electricputere Factory for Bucharest Underground Transportation System. In traction and electric brake regimes, the train case study accomplishes remarkable results. Using the structural diagrams and high techniques converters, an appropriate vehicle control can be achieved. The electric traction scheme analyzed in the paper, meets the criteria both of the vehicle running behavior safety and of the traction scheme reliability.

References:


