ENERGETICAL ASPECTS OF TROLLEYBUS TRACTION WITH CHOPPER AND COMPOUND DIRECT CURRENT MOTOR

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Abstract **– The main aim of the paper consists in estimating the energy efficiency of the electric traction of a trolleybus driven by a Compound Direct Current Motor (CDCM) and controlled rheostat or DC/DC converter (Chopper). That is why the Simulink model of the traction system was elaborated taking in consideration the particularities of the electronic converter, of the motor and the mechanical load. The global and instantaneous efficiency were used as indexes.**

Keywords: *trolleybus, electric traction, chopper, compound direct current motor, mathematical model, computer simulation*

1. INTRODUCTION

The necessity of this project was imposed by the reequipment of the trolleybuses of the pastsovietic production in the frame of the Electric Transport Administration in Chisinau and the production of new trolleybuses with electronic supply and control system elaborated by the technical-scientific enterprise „Informmbusiness" [1].
The main aim of the paper consists in estimating the energy efficiency of the electric traction of a trolleybus driven by a Compound Direct Current Motor (CDCM) and controlled rheostat or DC/DC converter (Chopper).

The electric drive of the trolleybus represents a complex system that includes the supply-control system, Compound DC Motor , the mechanical part (tires-mechanical transmission) depends on the load, speed and the state of the rolling path. For the Compound DC Motor typical is the magnetic flux dependence on the armature current and on the shunt field circuit current.

The Simulink model of the traction of the trolleybus was elaborated taking in consideration the particularities of the electronic converter, of the motor and the mechanical load. The estimation of the energetic indexes was accomplished with the utilization of the instantaneous efficiency (local) notion that corresponds to the current time moment t_i and the global efficiency notion that corresponds to the time interval $[t_0 , t_f]$.

2. MATHEMATICAL MODEL OF THE SYSTEM

Comparing to other types this trolleybus driven by a Compound DC Motor, of which electric scheme with the respective notations is represented in the fig.1. For this type of main motor is the dependence of the flux as of the current of the rotor circuit as of the current shunt field circuit, but preponderant is the influence of the series field winding.

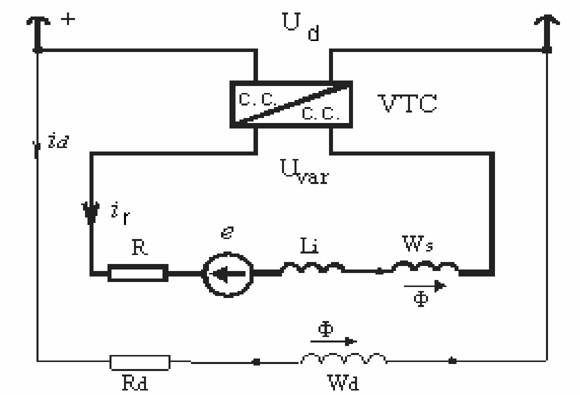

Figure 1. Electric scheme of CDCM

$$U_d = i_d R_d + W_d \frac{d\Phi}{dt}; \qquad (1)$$

$$U_{var} = i_r R + L_i \frac{di_r}{dt} + k\Phi\,\omega + W_s \frac{d\Phi}{dt}; \qquad (2)$$

$$\frac{J}{p}\frac{d\omega}{dt} = k\Phi\, i_r - M(v); \qquad (3)$$

The transient regimes of CDCM is described by the following differential equations:

where U_d , U_{var} – contact web voltage and exit of chopper voltage; i_d, i_r – shunt field and armature currents; W_d, Ws – number of turns of the shunt and series field windings; L_i – the inductance of the rotor winding, inclusively the auxiliary poles; Φ – useful magnetic flux; ω – the rotor's angular speed; $M = k\Phi i_r$ – electromagnetic torque; *M(v)* – load torque as the function of trolleybus's speed; *p* - number of pole pairs; *k* – machine constant; *J* – moment of inertia.

At the separation of the derivate $d\Phi / dt$ from (1) and substituting it in relation (2) are obtained equation of the CDCM mathematical model:

$$\left.\begin{array}{l} \dfrac{di_r}{dt} = \dfrac{1}{L_r}\left[U_{\text{var}} - k\Phi\omega - i_r R - \dfrac{W_s}{W_d}(U_d - i_d R_d)\right] \\ \Phi = f(i_d, i_r) \\ \dfrac{d\omega}{dt} = \dfrac{p}{J}\left[k\Phi i_r - M_s\right] \end{array}\right\} \cdot (4)$$

The expression $\Phi = f(i_d, i_r)$ from (4) represents magnetization curve of the Compound DC motor. The magnetic flux depends as on the armature current (of load) as on the shunt field circuit current. For the CDCM the magnetization curve was experimentally obtineded [4].

Proceeding from the relationships (4) was elaborated the Simulink model of the electric traction of the trolleybus (fig.2). Block **CDCM** represents the model of Compound DC Motor that uses at the voltage ***Ud*** and the current of the shunt field circuit, the controlled voltage ***Uvar*** of the rotor circuit and the mechanical load ***Ms.*** The **Load** subsystem uses for the calculation proceeding from [5] of the load torque ***Ms*** of the trolleybus depending on the mass of the vehicle ***Mv*** and the angular speed of the rotor ***w***. **Speed** subsystem is used for the transmission of the electromagnetic torque M_e, load torque M_s and the angular speed *w* of the rotor for posting and calculating the linear speed and trolleybuse's acceleration.

*S*tandard bloc **Switch** allows to supply the armature circuit with constant voltage or adjustable voltage from the **Chopper**. Using the constant voltage the model permits studying the system's energetic for rheostat control or at the dynamic brake. Electronic control system ensures programmed control of the current and of the speed without using the feedback back reactions. For this reason the **Chopper**'s model is considered by making the imposed supply voltage and the loses of real powers.

Subsystem **CDCM** consists from **Derivatie, Rotor,** and **EcMotion** blocks (fig.3). The block **Derivatie** is the model of the shunt field circuit – of the $\dfrac{W_s}{W_d}(U_d - i_d R_d)$ term of the first equations from (4).

The block **EcMotion** simulates the motion equation – last equation from (4) - of electric drive (fig.5). The **Rotor** block (fig.6) represents the model of the rotor circuit (the first equation of the system (4)). The **PowerEffic** block (fig.6) permits the estimation of the traction system's energetic by utilization

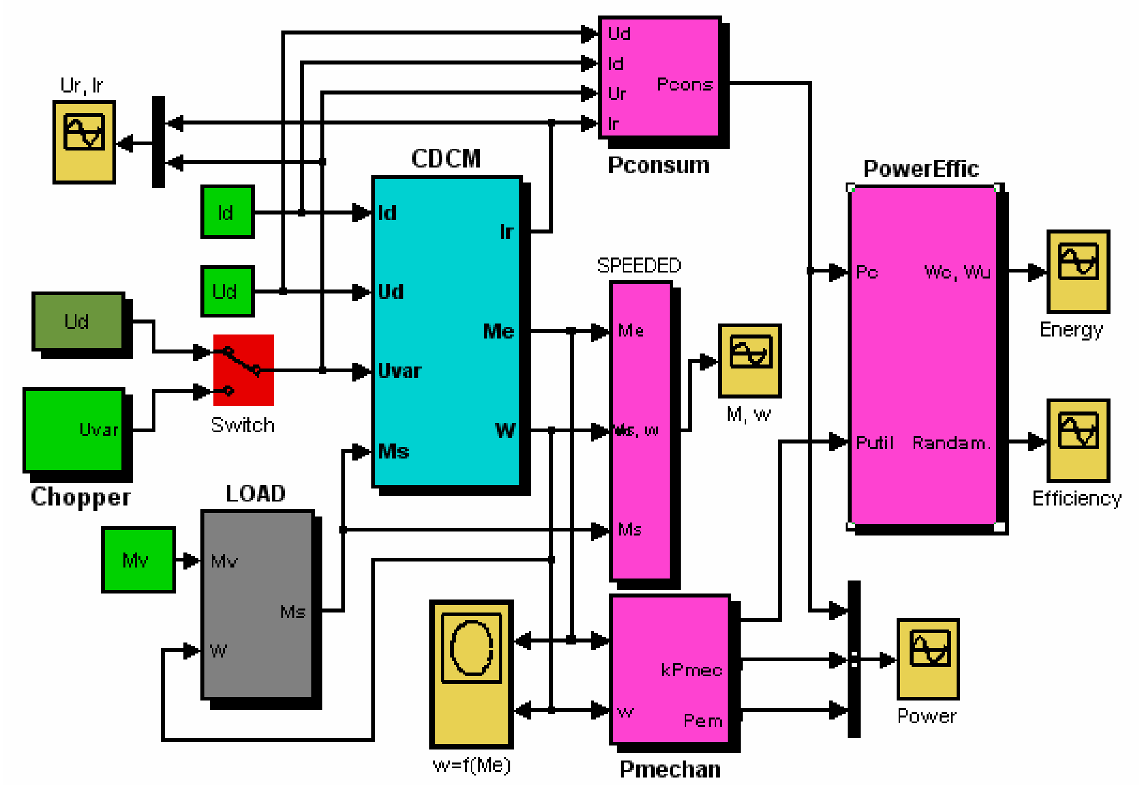

Figure 2. Mathematical model of trolleybus traction

instantaneous efficiency η_i and of the global efficiency η_{gi} in the time moment t_i:

$$\eta_i = \frac{Pu}{Pc} \cdot 100\%$$

and

$$\eta_{gi} = \frac{Wu}{Wc} \cdot 100\%, \qquad (5)$$

where P_u and P_c – are the useful mechanical and consumption power, respectively.

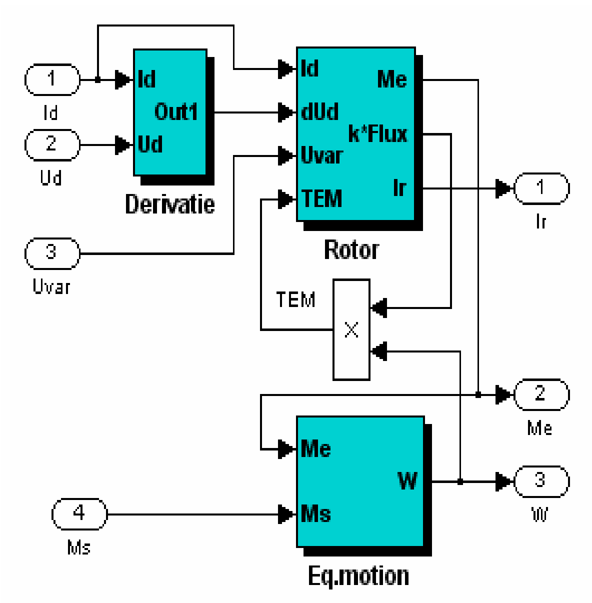

Figure 3. Model of Compound DC Motor

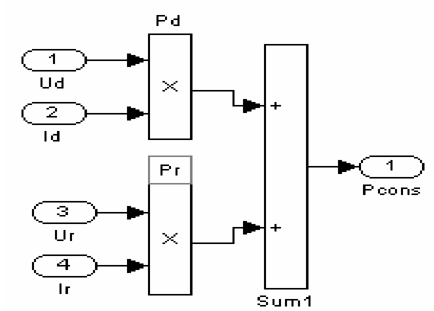

Figure 4. Model of power consumption

In (5) W_u and W_c represent the useful energy and the consumed energy in the time interval [0, t_i]:

$$W_u = \int_{t_0}^{t_i} P_u(t)dt$$

and

$$W_c = \int_{t_0}^{t_i} P_c(t)dt \cdot \qquad (6)$$

The global efficiency notion is universal and can serve for the energetic efficiency's estimation as for a time interval as for the for whole transient process.

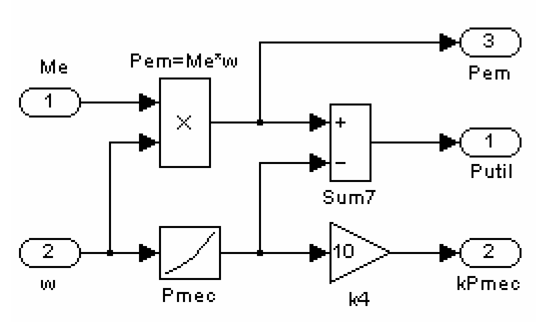

Figure 5. Model of output power

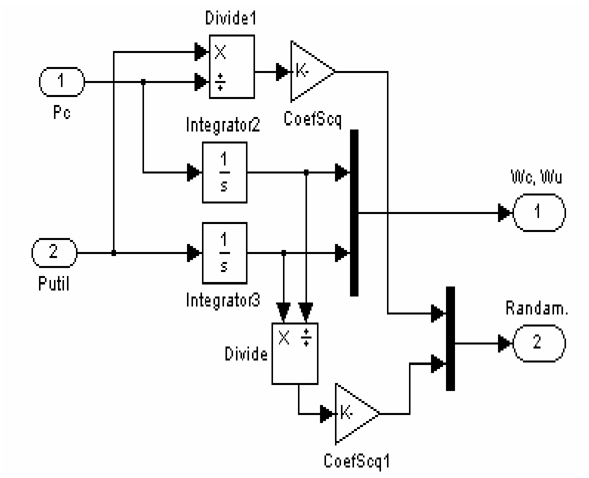

Figure 6. Model of output power

The Simulink model's validation „Chopper-CDCM – Load" was realized proceeding from experimental dates and results. The relative error of the measured and simulated currents does not exceed 3.9%, and the one of the speeds is less the 1%.

3. COMPUTER SIMULATION

Following there are presented results of a computer simulation of the compound direct current motor type DK-210A with the nominal power 110 kW, voltage 550V, 2p=4 (parameters tab. 1) trolleybus's traction system and the characteristics of which were determined proceeding from laboratory stand experiments [4] .

For comparison the transient processes were simulated at rheostat control-regulate and control system with chopper and microcontroller. Of the trolleybus's traction's transient regimes [6] the ones that can be assured by both regulation methods at the start of CDCM considerate are evidence.

Another imposed study problem was the examination of the energetic regulation methods depending on the load: from 0.5 (the trolleybus without passengers) to 1.25 M_{nom}.

Index	u.m.	Value
Rotor summary resistance R	Ohm	0,181
Summary rotor inductivity, L	mH	2,6
Număr spire înfaşurare excitaţie serie , w_s	-	24
Circuit resistance derivation, R_d	Ohm	125
Număr spire înfaşurare excitaţie serie, w_d	-	930
Reported inertness moment , J	kg m^2	41,61

Table 1. Parameters of CDCM

3.1. Rheostat control

At the rheostat control the CDCM start with compound was considered in 11 resistance steps [6] with equal commutation time for every step (tab.2).

t, sec	R_i, Ohm	t, sec	R_i, Ohm
0	*3.31*	6	*0.924*
1	*3.31*	7	*0.71*
2	*2.988*	8	*0.532*
3	*1.848*	9	*0.37*
4	*1.54*	10	*0.231*
5	*1.232*	11	*0.136*

Table 2. The rheostat steps

At the supply with constant voltage for nominal load (M_n=700 Nm) the commutation of the start resistance steps causes rotor current beats (fig.7).

Fig.8 illustrates the dependence of the consumed and useful energy, and the fig.9 – of the instantaneous efficiency (5) and the global efficiency (6) depending on the time at the CDCM's rheostat start. In 7 sec after the start the instantaneous efficiency states at the value of 92% and the global efficiency states at only 52%. At the end of the transient process (t=9 sec) the global efficiency states 57%. The difference between the instantaneous efficiency and the global is about 35%. In the same time, at the rheostat control on the detachment of the consumed energy and utile energy curbs can be observed (fig.7), as well as the detachment of the global and instantaneous efficiency curbs (fig.9). The global efficiency curb is closer to the exponent, and the instantaneous efficiency – closer to the ramp.

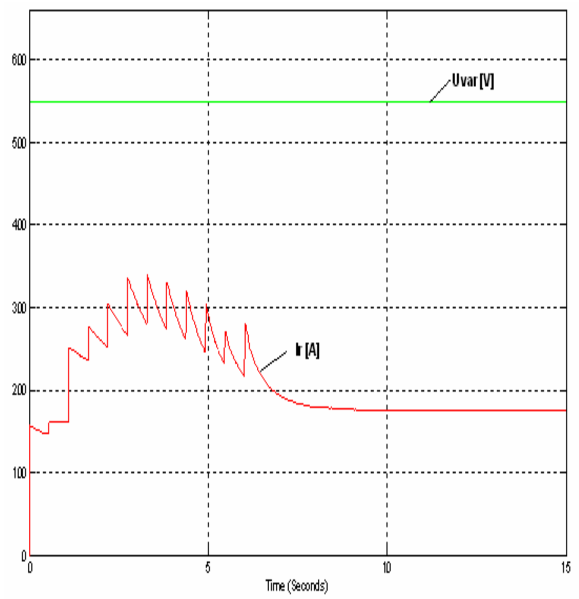

Figure 7. Armature voltage and current

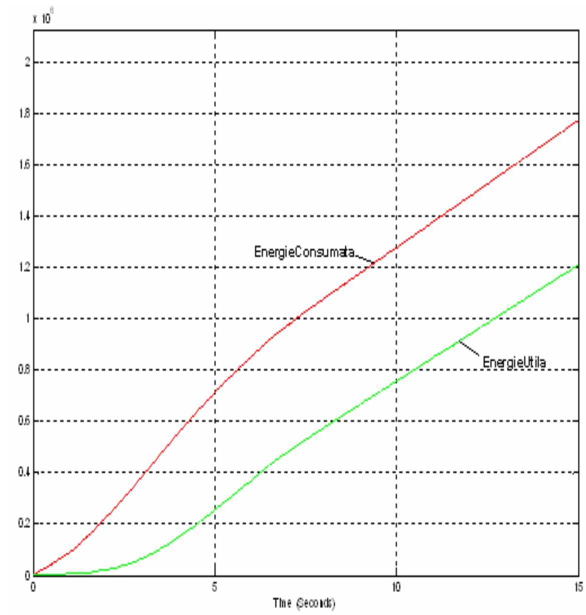

Figure .8 Consumption and useful energy

At the increase in the start resistances steps commutation length (of speed) from 2 to 10 sec the transient process duration increases for more then tow times, and the efficiency – decreases for about 4 % (fig.10). At the load increase from 350 to 700 Nm the transient process decreases with about 5 sec, and the difference between the global and instantaneous efficiencies increases from 4% to 11% depending on the start resistances commutation length (of speed).

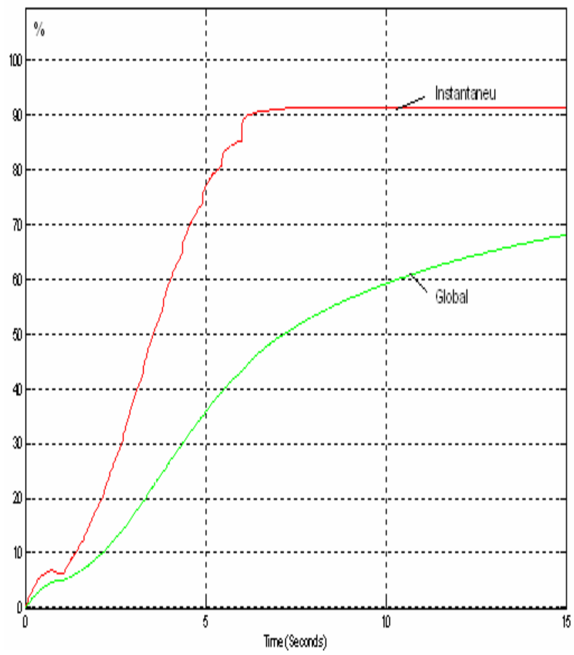

Fig.9 Instantaneous and global efficiency

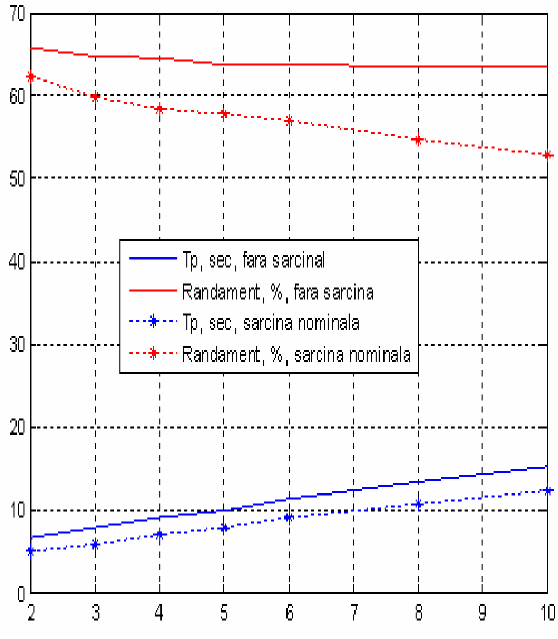

Fig.10 Dependens Tp, Randament=f(t_{comuat})

3.2. Chopper control

The traction chopper control in cause is realized by a programmable microcontroller and can assure the rotor circuit supply voltage necessary form. Following it will be considered the control in exponential voltage that will assure and the rotor current also in exponential form in the absence of the oscillations or mechanical beats (fig.11).

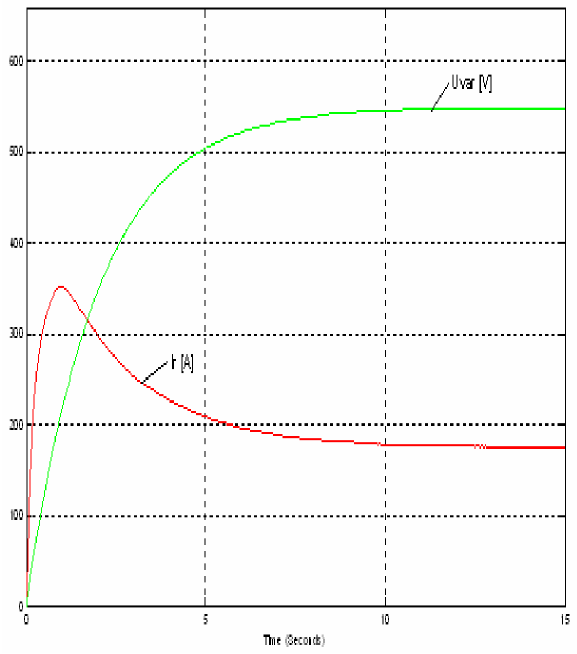

Fig.11 Armature voltage and current

At the command in exponential voltage the consumed energy and useful energy curbs in 2 sec after start become practically linear and have a slow deviation in growing (fig. 12). The global efficiency and instant-

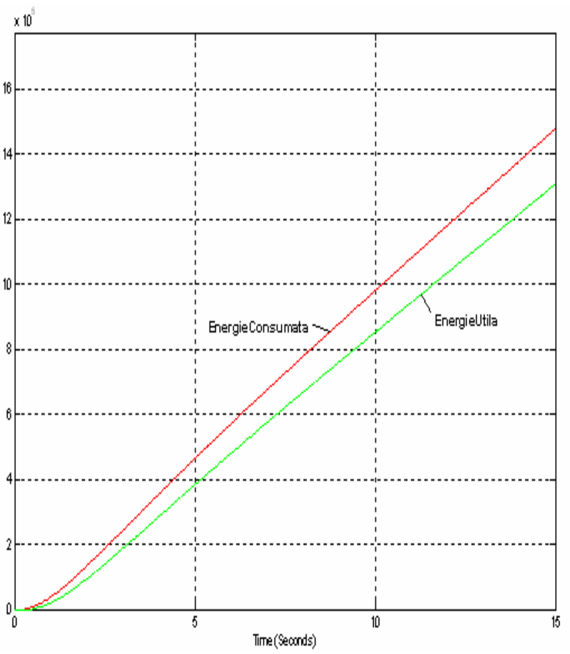

Fig.12 Consumption and useful energy

taneous efficiency curves (fig.13) have an exponential form. At the ending of the transient process (t=9 sec) the global efficiency states 87% compared to 92 % of the instantaneous efficiency, it means that the difference is only about 5%

At the command parameter τ (it can be treated as the time constant) variation of the exponential voltage is

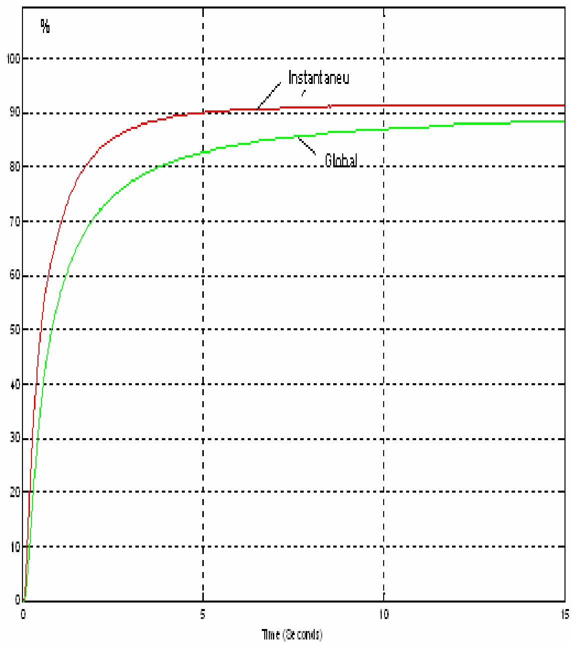

Fig.13 Instantaneous and global efficiency

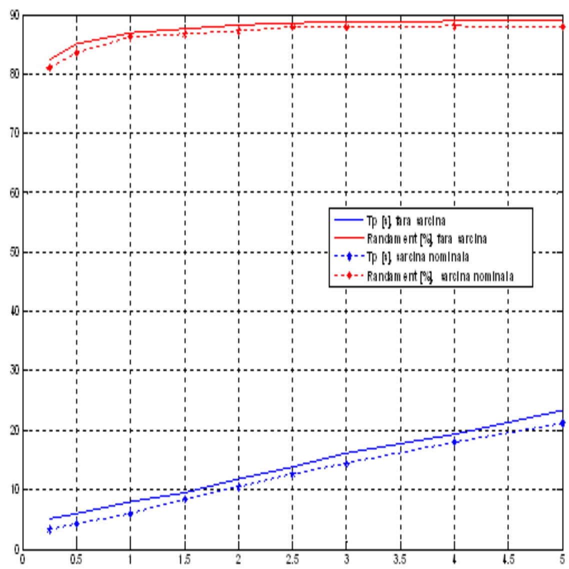

Fig.14. Dependens Tp, Randament=f(t_{comuat})

from 0,25 to 5, the duration of the transistor process increases practically 5 times. In the same time the efficiency of the system grows with about 6% after which it stabilizes. At the load increase from 350 to 700 Nm the duration of the transistor process decreases with about 1 sec, and the global efficiency practically everywhere decreases with about 1 % (fig.14).

4. CONCLUSIONS

The energetic efficiency of the electric traction of the tested in transient regimes trolleybus can be estimated by using the global and instantaneous curves as well as using the consumed and useful energy curves. The smaller the difference between the curb pairs the lesser are energy losses and the bigger is the energetic efficiency. Based on the Simulink model it was established that for the same transient process duration and rated load the global efficiency at exponential voltage control (chopper) is with about 30% bigger comparing to the compound direct current motor trolleybus traction system rheostat start method. It is important the facts that at the voltage control the global efficiency is less dependent on the load comparing to resistance regulation method.

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